LONG-TERM EFFECTS OF CONFIRMATION LIGHTS AND FACTORS THAT LEAD TO RED LIGHT RUNNING

By

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LONG-TERM EFFECTS OF THE RED-SIGNAL INDICATION LIGHT AND FACTORS THAT LEAD TO RED LIGHT RUNNING

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ABSTRACT

Red Light Running (RLR) is a safety concern for communities nationwide. The Federal Highway Administration (FHWA) reported a total of 676 fatalities in 2009 were due to RLR. The Insurance Institute for Highway Safety (IIHS) reported that more than half of RLR crash fatalities are other than the driver (pedestrians, occupants, etc.). There are many strategies to mitigate RLR violations that fall in the category of engineering, enforcement, or education. This dissertation focused on confirmation lights which are a low-cost countermeasure that enhance enforcement at four-approach intersections. Confirmation lights were deployed at two intersections in Overland Park, Kansas. Traffic was observed at the treatment sites, nearby signalized intersections (spillover), and control sites. Traffic was recorded before deployment, one-month after, and three-months after deployment. A total of 14 intersections were recorded during the morning peak hours (7 a.m. to 9 a.m.) and the afternoon peak hours (4 p.m. to 6 p.m.) for a total of 583 hours of traffic video. A test of proportions showed that overall the confirmation lights did not significantly reduce RLR violations. A violation analysis showed that there was a global increase in RLR violations after deployment, showing that other factors were involved in the increase of violations observed. Time into the red analysis showed that the majority of RLR violations occurred within one second into the red. The negative binomial regression model re-affirmed that the confirmation lights were not a significant factor in the RLR violations observed. The model showed that lane volume, presence of a right turn lane, and traffic movement (left or through movement) were significant factors.

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CHAPTER 1: INTRODUCTION AND MAGNITUDE OF THE PROBLEM

1.1 Background

Red light running (RLR) crashes at signalized intersection continue to be a serious safety concern in the United States. The most recent national crash data indicates that 676 fatalities occurred due to RLR in 2009, which represents 10 percent of all intersection crashes and two percent of all roadway fatalities (FHWA, 2011). According to the Insurance Institute for Highway Safety (IIHS) in addition to the 676 fatalities in 2009, there were 113,000 injuries caused by people running a red light in 2009 (IIHS 2011). In the state of Kansas running a red light accounted for 2.2 percent of reported crashes in 2010 (KSDOT, 2010). The IIHS reported that two-thirds of the fatalities were people other than the driver who was running a red light. Overall, the driver running a red light accounted for 36 percent of the total deaths, pedestrians and bicyclists for 6 percent, occupants of the RLR vehicle were 12 percent and 46 percent of the total fatalities were occupants in vehicles that did not run the red light (IIHS 2011). Vehicles running a red light also have significant economic impacts associated with every serious injury or fatality crash. The Federal Highway Administration (FHWA) reported in 2005 that the societal cost relating to RLR was approximately $14 billion annually (FHWA, 2005). Communities across the US have responded to RLR through such countermeasures as targeted enforcement campaigns, intersection geometric and signal timing improvements, low-cost countermeasures and automated enforcement.

These countermeasures have been implemented across the country and their effectiveness has been reported by previous research studies (McGee et al., 2003; Bonneson et al., 2004; Hallmark et al., 2012). The literature reviewed the effectiveness of these countermeasures found by researchers. Also stated in the literature search, many communities have turned to automated enforcement to monitor and ticket red light runners at signalized intersections. Automated enforcement, although found by many research studies to be effective at reducing RLR violations and related crashes, have become a target of driver privacy. The State of Kansas currently has legislation that prohibits the use of automated enforcement (State of Kansas, Article 61, subsection 6(a)), unless deemed essential to safety by a community and all other options have been exhausted. However, automated enforcement can be found in the neighboring state of Missouri. Traditionally, when signalized intersections have been identified as a location with a high number of RLR violations, traditional targeted enforcement is used to reduce the number of violations.

In the case of targeted enforcement, multiple police officers are needed to verify a vehicle has run a red light to correctly ticket the driver. Many times, this requires at least one officer watching the signal and stop line while another is waiting downstream of the targeted approach and/or movement. In some instances, an officer observing a RLR violation will chase an offending driver through the intersection, thus exposing him or her to crossing vehicular traffic.

1.2 Research Objectives

The objective of this study was to investigate the effectiveness of a low-cost signalized intersection treatment to reduce RLR at signalized intersections, determine if any potential effects the confirmation lights may have on drivers, and develop a statistical model to assess the effectiveness of the confirmation lights as well as identify other factors that may contribute to the behavior of drivers running a red light. Confirmation lights were chosen because of their low installation and maintenance costs. Confirmation lights are a way to aid police officers in enforcing RLR violations when positioned downstream from the intersection. Confirmation lights have been deployed in many communities across the United States. However, limited effectiveness data have been published that can support the effectiveness of this device.

The following hypotheses were tested:

- Ho: No difference in RLR violations at onset of red
- Ha: There is a difference in RLR violations at onset of red

- Ho: No difference in RLR violations at end of red
- Ha: There is a difference in RLR violations at end of red

A performance measure is used are the changes in RLR violations observed at the treatment sites. A secondary performance measure that is used included the changes of violation time into red which is an indicator of how far after the red signal did a vehicle run the red light. To monitor the effects of the confirmation lights on drivers, time into the red of violations is measured.

1.3 Organization of Dissertation

This dissertation is divided into seven chapters. Chapter 1, Introduction, presents the background and research objectives of the research. Chapter 2 is the literature review where different definitions for RLR, attitudes and frequency of RLR incidents, characteristics of red light runners, factors that contribute to RLR, and the effectiveness of RLR countermeasures found by researchers is presented. Chapter 3, Research Approach, presents how intersections were chosen and a summary of the intersections that were part of the study. Chapter 4, Data Collection and Methodology, describes how traffic data were collected and reduced.

CHAPTER 2: LITERATURE REVIEW

The following sections provide current literature on RLR. It cites information from articles, informational and technical reports, research journals and other relevant publications pertaining to RLR. Currently, a wide range of countermeasures exists to mitigate RLR violations and crashes. These include traffic signal timing adjustments, physical improvements, advance warning for drivers, automated enforcement, targeted enforcement, and public awareness campaigns. It also covers different definitions for RLR, attitudes and frequency of RLR incidents, characteristics of red light runners, and factors that contribute to RLR.

2.1 Definition of Red Light Running

The definition of RLR differs from state to state based on whether “permissive yellow” or “restrictive yellow” laws are in effect. According to the FHWA (2013), under the “permissive yellow” rule as stated in the Manual on Uniform Traffic Control Device (MUTCD) and Uniform Vehicle Code (UVC); “Driver can legally enter intersection during the entire yellow interval and violation occurs if driver enters intersection after onset of red.” Under the “restrictive yellow” rule; a “driver can neither enter nor be in intersection on red and violation occurs if driver has not cleared the intersection after onset of red.”

In most states, vehicles that are within the intersection waiting to make a left turn when the signal changes from yellow to red are not considered to be running a red light, and are encouraged to clear the intersection. At intersections where a right turn on red is permitted, a vehicle must come to a complete stop; failure to do so is also considered a violation (IIHS, 2013). For this study only vehicles that were behind the stop line when the light turned red and then proceeded to traverse through the intersection were considered as a red light runner. When a stop line was not clearly outlined then the pedestrian crosswalk was used.

2.2 Frequency of Red Light Running

A research study was conducted in 1994 and 1995 to analyze RLR violation data at two busy intersections equipped with red light cameras in Arlington, Virginia. The study found a total of 8,121 RLR violations over a period of 2,694 hours, representing an average of 3.0 red light runners per hour (Retting et al. 1998). In 2003 a study was performed to develop models to predict RLR violation rates at four-leg intersections based on their traffic operational and geometry characteristics. They collected RLR violation data at 19 study intersections in four states (Alabama, California, Iowa, and Texas) for a period of 6 hours on weekdays (2 p.m. to 8 p.m.). They observed 1,775 violations in 554 hours representing a rate of 3.2 violations per hour per intersection (Hill et al., 2003).

McCartt and Eichelberge (2011) conducted a study to evaluate the attitudes of drivers towards red light camera programs in 15 cities in the United States. A sample size of 3,411 drivers participated in the telephone survey study. Results of the study indicated that 82 percent of the drivers said running red lights was a serious threat to their personal safety, and 93 percent said it was unacceptable to society.

The AAA Foundation for Traffic Safety conducted a national survey from September through October 2013 to assess the degree to which Americans value and pursue traffic safety. A sample size of 3,103 U.S. residents aged 16 years and older was asked to complete a web-based survey for this study. It was found that approximately 93 percent of drivers considered RLR as an aggressive and unacceptable way of driving. However, 35 percent of the same drivers admitted to running the red light least once in the previous month (AAA Foundation for Traffic Safety, 2014). Drivers' attitudes toward RLR and the frequency of violations have not changed over the years. Drivers are aware of the risks implied by running a red light, and view the behavior as unacceptable. However, drivers still admit to running a red light on occasion. This shows that RLR is an ever-present danger faced by drivers at intersections.

2.3 Characteristics of Red Light Runners

Porter et al. (1999) conducted a telephone survey study to identify red light runners and their characteristics. Out of the 5,024 respondents who completed the survey, 4,007 were concentrated in ten target states and 1,017 in the remaining 40 states. Based on national data, the authors concluded that a driver running a red light was more likely to be:

- A younger driver;
- A driver without a child or children (less than 20 years old);
- Driving alone;
- In a rush to school or work in the morning on weekdays;
- Unemployed or employed in jobs requiring less education;
- Driving more than two miles from home; and
- Previously ticketed for RLR.

Retting and Williams (1996) also conducted a similar study to investigate the behavior of red light runners in Arlington, Virginia. They asked trained observers to collect RLR violation data at an intersection equipped with red light enforcement cameras. During each cycle length, the observers recorded the characteristics of the drivers that ran the red lights and the type of vehicles they were driving. Out of 1,373 observations, the observers recorded 462 RLR violations at the study location. Findings from their study indicated that red light runners generally were drivers below 30 years of age, who drove small cars and had multiple convictions for speeding and moving violations. They also found out that violations were common to drivers with car models manufactured after 1991 and the drivers were less likely to be wearing seat belts.

Retting et al. (1999c) extracted data from the Fatality Analysis Reporting System (FARS, 1992 to 1996) and the General Estimates System (GES) to review the characteristics of red light runners. They found that red light runners involved in fatal crashes were more likely to be a male driver under 30 years of age, more likely to have been ticketed for moving violations and more likely to have been convicted for driving while intoxicated. The authors also found that the violators were more likely to run red lights in the nighttime than in the daytime, and 53 percent of such drivers were believed to have a high blood alcohol concentration.

2.3.1 Factors Contributing to Red Light Running

In the previous section, it was found that a majority of the RLR violations and crashes were human related. However, many studies have identified other contributing factors that lead to the frequency of RLR.

Traffic operation characteristics such as approach volume and speed and intersection features such as signal timing, approach grade, and sight distance affect drivers' behavior as they approach an intersection. Additionally, environmental factors such as time of day and weather conditions may also influence driving behavior (Yang and Najm, 2006). Table 1 explains how intersection, traffic and environmental factors contribute to the frequency of RLR.

Table 1. Intersection, Traffic and Environmental Factors Relating to RLR (Yang and Najm, 2006)

Element	Variable	Key Findings	Reference
Intersection	Signal Timing	The frequency of RLR increases when the yellow interval is less than 3.5 seconds.	*Brewer et al., 2002*
		Longer yellow intervals will cause drivers to enter intersection later and lengthening the all-red intervals caters to red light violators.	*Eccles and McGee, 2000*
	Stopping Distance	Probability of a vehicle stopping for traffic signal decreases as its distance from the intersection decreases.	*Chang et al., 1985*
	Approach Speed	Probability of a driver stopping for traffic signal decreases as the approach speed to the intersection increases.	*Chang et al., 1985*
	Grade	Probability of a driver stopping for traffic signal increases as the approach grade to the intersection increases.	*Chang et al., 1985*
	Intersection Width	Drivers tend to stop for traffic signals more at wider intersections than at narrower intersections.	*Chang et al., 1985*
Traffic & Environment	Approach Volume	Higher RLR rates are observed in cities with wider intersections and higher traffic volumes.	*Porter and England, 2000*
		The RLR frequency increases as the approach traffic volume at intersection increases.	*Brewer et al., 2002*
	Time of Day	Higher red light violations occur during the time period of 3:00 p.m. to 5:00 p.m.	*Kamyab et al.,2002;* *Kamyab et al.,2000*
		The average number red light violations are higher during a.m. and p.m. peak hours compared to other times of the day.	*Retting et al.,1998*
	Day of the week	There are more red light violations on weekdays compared to weekends.	*Lum and Wong,2003;* *Kamyab et al., 2002;* *Kamyab et al., 2000;* *Retting et al., 1998*
	Weather	The influence of rainfall on RLR behavior is not significant.	*Retting et al.,1998*

In addition to human factors, geometric and operational aspects, volume, time of day, and day of the week can contribute to the rate of violations. Researchers noted that with increasing volume there is an increase in violations. There is also an increase in violations during the traffic peak hours of the day.

2.4 Red Light Running Countermeasures

RLR countermeasures fall into three categories: engineering, education and enforcement. Studies have been conducted to investigate the effectiveness of these countermeasures and sometimes results showed a positive effect in reducing RLR violations and associated crashes. Prior to implementation of any of the countermeasures, studies investigating possible causes of RLR should be carried out and then appropriate countermeasures are selected to mitigate the problem (Bonneson et al.,2004). Table 2 shows why a driver might want to run a red light and correlates the appropriate countermeasures that are likely or could address the cause (Hallmark et al., 2012).

Table 2. Possible Causes and Appropriate Countermeasures for RLR (Hallmark et al. 2012)

Possible Causes of RLR	Engineering Countermeasures			Enforcement
	Signal Operation	Driver Information	Physical Improvement	
Congestion or excessive delay	●		●	
Disregard for red				●
Judged safe due to low conflicting volume				●
Judged safe due to narrow cross street				●
Judged safe due to following < 2 sec behind vehicle in front				●
Expectation of green when in platoon	●			
Downgrade steeper than expected	●			
Speed higher than posted limit	●			
Unable to stop (excessive deceleration)	●			
Pressured by closely following vehicle	●			
Tall vehicle ahead blocked view		●		
Unexpected, first signal encountered		●		
Not distracted, just did not see signal		●		
Distracted and did not see traffic signal		●		
Restricted view of signal		●	●	
Confusing signal display		●		

Driver education, improvements to traffic operations and geometric improvements can address most possible causes for drivers running a red light. Enforcement should be considered when drivers disregard the red light and use their judgment when crossing the intersection. The following section shows examples of engineering, education, and enforcement countermeasures.

2.5 Engineering Countermeasures

Engineering countermeasures are generally categorized into three groups, namely: signal operation countermeasures, driver information countermeasures, and physical improvement countermeasures. Signal operation countermeasures involve the modifications or adjustments of the timing of the signal phases, and change in cycle interval. With driver information countermeasures, drivers are provided with advance information about existing traffic signals ahead for drivers to respond appropriately as they approach an intersection. Physical improvement countermeasures involve the redesign of intersections to increase vehicle operational characteristics. Table 3 shows the three countermeasure categories with specific engineering countermeasure to reduce RLR.

Table 3. Engineering Countermeasures to Reduce RLR

Countermeasure Category	RLR Countermeasure	
Signal Operation	Yellow change interval	
	Green extension	
	Signal operation and coordination	
	All-red clearance interval	
Driver Information	Improve sight distance	
	Improve signal visibility	Placement and number of signal heads
		Size of signal display
		Line of sight
	Improve signal Conspicuity	Redundancy
		LEDs signal lenses
		Backplates
		Lighted Stop line Systems and LED outlined backplates
	Advance warning signs	Signal ahead signs
		Advance warning flashers
		Rumble strips
Physical Improvements	Remove unwanted signals	
	Add capacity with additional traffic lanes	
	Improve the geometry (vertical and horizontal curves)	
	Convert signalized intersection to roundabout intersection	

The countermeasures listed in Table 3 have a range of cost from very low to high. Physical improvements to an intersection could be too expensive or not feasible for a community. Signal timing and signal conspicuity are among the lower cost and more rapid means to address the problem of RLR at signalized intersections. Outcomes of research studies performed for each countermeasure category are reported herein.

2.5.1 Traffic Signal Timing

Adjusting the traffic signal timing may include the changing of the yellow interval, including an all-red interval, coordination of signals, and extending the green phase. The results of a literature search including research studies and current guidance are included in the following sections.

2.5.2 Yellow Change Interval

The Manual on Uniform Traffic Control Devices (MUTCD) provides guidance with regards to minimum and maximum yellow intervals. It recommends that "A yellow change interval should have a minimum duration of three seconds and a maximum duration of six seconds. The longer intervals should be reserved for use on approaches with higher speeds" (MUTCD, 2009). In the Institute of Transportation Engineers (ITE) Traffic Engineering Handbook, 6th Edition (2009), it is recommended that Equation 1 be used to calculate the appropriate yellow time for any signalized intersection approach. However, it cautions that maximum care should be used when the time interval chosen is more than five seconds. McGee et al. (2012) in their research study did not find any reason to suggest a minimum or maximum yellow interval.

$$Y = t + \left[\frac{v}{2a + 2Gg}\right] \quad \textbf{Eq. 1}$$

Where: Y = yellow clearance interval (sec.);

t = reaction time (typically 1 sec.);

v = design speed (ft./sec.^{2});

a = deceleration rate (typically 10 ft./sec.^{2});

g= acceleration due to gravity (32 ft./sec.^{2}); and

G = grade of approach (percent/100, downhill is negative).

Most RLR violations occur less than two seconds after the onset of the red light (Washburn, 2004). This means that increasing the yellow signal time could aid drivers in safely clearing the intersection prior to the onset of red signal. Retting et al. (2007) conducted a before and after comparison study to determine the effects of lengthening the yellow change time interval at two study intersections in Philadelphia, Pennsylvania. The yellow time was increased by one second, followed by red light camera enforcement several months later. They conducted a similar study at comparison intersections without any treatment. Results of their study showed a 36 percent reduction in violations when the yellow change interval was increased by one second. With the addition of red light enforcement, they observed a further reduction in RLR violations by 96 percent beyond the implemented yellow time change.

2.5.3 All-Red Clearance Interval

An all-red phase is defined as when all the approaches at an intersection have a red-signal display for a very short period of time. If a vehicle enters an intersection without an all-red interval at the end of the yellow phase, it is more likely to result in a crash if vehicles in conflicting approaches receive a green light (McGee et al., 2003).

According to the MUTCD (2009), "Except when clearing a one-lane, two-way facility or when clearing an exceptionally wide intersection, a red clearance interval should have a duration not exceeding 6 seconds." However, in the ITE Traffic Engineering Handbook, 6th Edition (2009), it is recommended that Equation 2 should be used to calculate the appropriate all-red clearance interval. McGee et al. (2012) also recommended a minimum of one second time to be used for all-red clearance intervals. They suggested that providing additional time for vehicles that are legally in an intersection at the onset of red light allows drivers to clear the intersection in order to avoid conflicts with adjacent traffic stream with a given green light.

$$R = (w/L)/v \qquad \textbf{Eq. 2}$$

Where: R = all-read interval (sec);

w = width of stop line to far side no conflict point (ft.);

v = design speed (ft. /sec.); and

L = length of vehicle (ft.).

Schattler et al. (2003) conducted a study at three signalized intersections in Oakland County, Michigan. The purpose of the study was to evaluate the impact of all-red clearance intervals on RLR violations and late exit of vehicles within the intersections when the red light was indicated. They used video cameras to collect data before and after the implementation of the clearance intervals. They found that the implementation of all-red clearance intervals that ranged from two to three seconds significantly reduced the risk of late exiting of vehicles being struck by opposing traffic streams that have a green signal.

2.5.4 Green Extension

Green Extension Systems (GES) extend the green phase of traffic signals before the yellow aspect of the signal is shown. This allows a vehicle or platoon of vehicles to clear the intersection before the yellow indication is shown. With this technology, advance detectors are deployed on the major road approaches at an actuated-signalized intersection to change the signal phase or increase the green time when a vehicle passes over them. Approaches are cleared of vehicles that might have been in the dilemma zone until the green phase is maxed-out.

Zegeer and Deen (1978) conducted a study to evaluate how GES could reduce RLR crashes at three signalized intersections in Kentucky. They used about nine years of before crash data and about four years of crash data after the installation of the GES at the three study sites. Results of their study showed 54 percent reduction in total crashes.

2.5.5 Signal Operation and Coordination

Two or more adjacent signalized intersections in a signalized corridor are sometimes coordinated to move platoons of vehicles along a corridor in order to minimize delays and increase traffic flow. At isolated locations where signalized intersections are not in coordination, it may result in excessive delays and impatient drivers may violate a red light when they arrive at an intersection near the end of the green interval (Bonneson et al., 2002). For this reason, adjacent intersections should be coordinated so that the likelihood of drivers running a red light is minimized. Changes in signal phasing or cycle length can also reduce delays which potentially may reduce the frequency of RLR (Bonneson et al., 2002).

2.5.6 Driver Information

One common reason drivers give for frequently running a red light is that “I did not see the signal” (McGee et al., 2003). Poor signal visibility and conspicuity, lack of advance warning signs and inadequate sight distance at signalized intersections influence driving behavior (Fitzsimmons et al., 2007).

2.5.7 Improve Signal Visibility

The positioning of signals either overhead or pole-mounted impacts driving behavior. An overhead signal display provides a clear meaning, good visibility, and eliminates the blockage of drivers' line-of-sight to the signal head when tall vehicles, such as trucks, are present in the traffic stream.

Schattler et al. (2011) investigated how different signal mounting configuration affects RLR at urban signalized intersections in Illinois and Michigan. The researchers focused on three types of signal mounting configurations: mast arm, diagonal span wire and near-side/far-side post mount. They collected data at 12 study intersections looking for RLR and yellow light running using video cameras. Data collection was for three hours (noon to 3 p.m.) on weekdays in the spring and summer of 2007. A comparative parallel analysis of their data showed significantly fewer RLR and yellow light running incidents at the intersections with mast arm configurations than the intersections with span wire configurations. At the near-side/far-side post mounted signalized intersections, the authors found a higher rate of RLR and yellow light running. Their study showed that post-mounted configurations reduced the visibility of signal heads, which may result in the increase in the frequency of RLR.

When considering the location to mount a signal head at an intersection, a driver's line-of-sight is a critical factor that should not be overlooked. The closer the signal heads are installed as practical to a driver's line of sight, the more visible the signal head becomes.

2.5.8 Improve Signal Conspicuity

Another technique of making signal head conspicuous is to use retroreflective materials on the borders of backplates as shown in Figure 1.

Figure 1. Retroreflective backplate border (FDOT, 2014)

The MUTCD (Section 4D.18) requires the front surface of the backplate to have a dull black finish "to minimize light reflection and to increase contrast between the signal indication and its background." Research has shown that signal head backplates have the effect of reducing the frequency of crashes at intersections by 32 percent (Bonneson et al., 2002). In 2010, the FHWA reported a before and after study at three intersections in Columbia, South Carolina, on the effectiveness of retroreflective borders on the backplates. The study found a 28.6 percent reduction in total crashes, a 36.7 percent reduction in injury crashes and a 49.6 percent reduction in late-night/early-morning crashes. (FHWA, 2010)

For intersections where visibility is a problem, using redundant signal heads is a means of improving the conspicuity of the signals. The MUTCD (2009) illustrates various configurations of redundant signal heads that have shown to be effective at signalized intersections. Figure 2 illustrates different configurations of two red signal heads from the MUTCD. A study in Winston-Salem, North Carolina, found a statistically significant 33.1 percent reduction in RLR right-angle crashes when nine study intersections were equipped with redundant signal heads (Polanis, 2002).

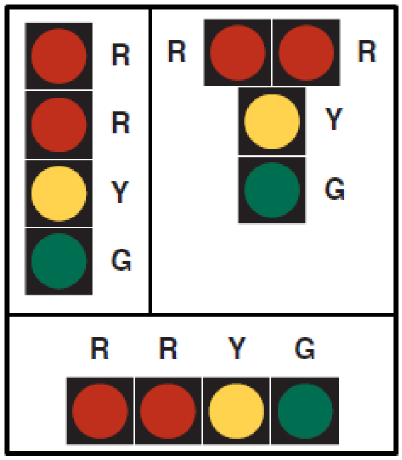


Figure 2. Redundant red light signal configurations (MUTCD, 2009)

Lighted Stop Bar Systems (LSBS) and Light Emitting Diode (LED) outlined backplates have shown to be effective in reducing RLR at signalized intersections. LSBS consists of markers installed into the pavement along the stop line of an intersection. The markers contain LED lights which activates during the red signal indication of the traffic light. LED outlined backplate also consists of LEDs placed around the perimeter of a signal backplate. The LEDs emit light during the red signal indication of the traffic light to gain the attention of drivers approaching the intersection. Active operation of the LSBS and LED outlined backplates are shown in Figure 3 and Figure 4, respectively.

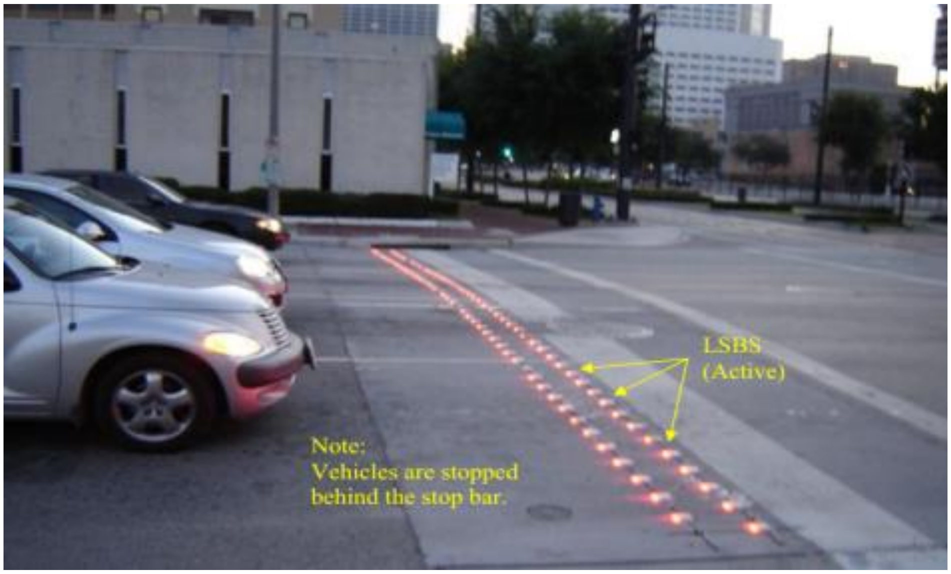


Figure 3. Lighted stop bar system (active) in Houston, Texas (Tydlacka et al., 2011)

Figure 4. LED backplate in Houston, Texas (Tydlacka et al. 2011)

Tydlacka et al. (2011) conducted a study at two signalized intersections in Houston, Texas to evaluate the effectiveness of these supplemental traffic control devices. They collected data using video cameras three days before and three days after the installation of the LED backplates and LSBS separately at the two study intersections. They found a statistically significant reduction of RLR violations from 21.8 to 11.2 violations per day per 10,000 vehicles at the site where the LED backplates were installed. At the intersection with LSBS, they found reductions in RLR violations from 12.9 to 11.3 violations per day per 10,000 vehicles which was not statistically significant.

2.5.9 Advance Warning Signs

Advance warning signs gain the attention of road users to unexpected roadway conditions that might be not readily apparent to them. According to the MUTCD (2009), the "Signal Ahead" sign (W3-3) shown in Figure 5 can be used to alert derivers of the presence of a signalized intersection ahead.

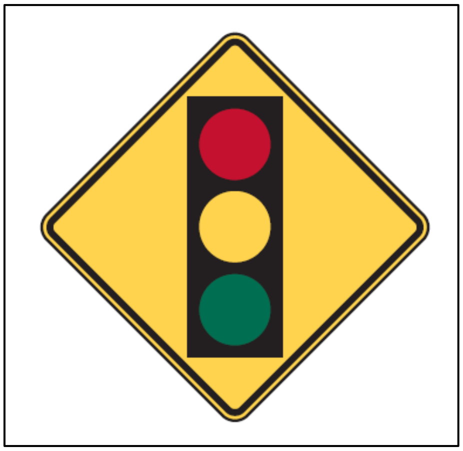


Figure 5. W3-3 Signal Ahead sign (MUTCD, 2009)

Polanis (2002) analyzed a before and after crash data (36 to 48 months) from collision diagrams prepared by police department in the city of Winston–Salem, North Carolina to evaluate the effectiveness of eight engineering countermeasures to reduce RLR. A before and after study of "Signal Ahead" signs was one of the strategies evaluated. It was found that installation of the "Signal Ahead" sign at 11 study locations showed a 44 percent reduction in right angle crashes.

Another type of advance warning sign is the "Be Prepared To Stop" sign (W3-4) as shown in Figure 6.

Figure 6. W3-4 Be Prepared to Stop sign (MUTCD, 2009)

Flashing beacons and "When flashing" plaques (W16-13P) shown in Figure 7 can be added to this sign to alert drivers that the green light is about to change to red in few seconds (MUTCD 2009).

Figure 7 Be Prepared to Stop sign supplemented with flashing beacons (MUTCD, 2009)

Messer et al. (2004) performed a two-year study to evaluate how the Advance Warning for End-of-Green Systems (AWEGS), could reduce RLR violations at two high speed intersections in Texas. Red light runners were detected at their study sites by using "video imaging vehicle detection systems" (VIVDS). Prior to the installation of the systems, they collected data for two weeks. After installation of AWEGS, they collected data for 35 days for the first phase of their study followed by the second phase where data were collected for 21 days. Results of their field evaluations showed that AWEGS reduced RLR violations within the first five seconds by 40 to 45 percent.

2.5.10 Physical Improvements

At low-volume intersections where traffic signals are unwarranted, removing the signals can be an effective measure to reducing crashes at such locations provided the safety and the operational characteristics of the intersections are not compromised. Before traffic signals are installed at any intersection, warrant studies should be conducted based on pedestrian volumes, traffic volumes and safety measures at the intersection. A study in Philadelphia showed that the removal of unwarranted signals at 199 low-volume intersections contributed to a crash reduction of 24 percent at those intersections (Retting et al., 1998).

Additional traffic lanes for maneuvering through or making right or left turns at signalized intersections is an effective measure of reducing congestions. Most traffic delays occur at intersections and when drivers stay in queues for longer periods, they might run the red light to avoid waiting for the next cycle. When additional lanes are added to intersections to increase their capacity, the problem of congestion will be reduced.

A modern roundabout is another alternative to reduce the severity of crashes that are common at signalized intersections. Converting a signalized intersection into a roundabout has shown to increase safety. In NCHRP Report 572: Roundabouts in the United States, Rodegerdts et al. (2007) found a 48 percent reduction in all crash types and a 77.7 percent reduction in injury and fatal crashes when nine signalized intersections were converted to a roundabout. Persaud et al. (2001) performed a study to evaluate the change in vehicle crashes when 23 signalized or stop-controlled intersections were converted to roundabouts at urban, suburban and rural locations in the United States. They performed a before and after Empirical Bayes analysis of the data they gathered. Results of their study showed a 40 percent reduction of all crash types and an 80 percent reduction of all injury crashes at the 23 intersections combined.

2.6 Enforcement Countermeasures

Enforcement countermeasures are those that include the use of a police officer, or a device which acts as a surrogate to a police officer. Several studies have been conducted to investigate the effectiveness of these three countermeasures or combination of the countermeasures in reducing RLR at signalized intersections. Listed in the following section are research results for enforcement countermeasures.

2.6.1 Automated Enforcement

Automated enforcement is a highly effective way of using cameras to enforce RLR at signalized intersections. As of March 2014, 508 communities in the United States had red light camera programs (IIHS, 2014). Several studies have shown that using automated enforcement is an effective tool in reducing RLR violations and associated crashes at signalized intersections.

Fitzsimmons et al. (2007) found 44 percent, 90 percent and 40 percent reductions in total, right-angle and rear-end crashes, respectively in a study they conducted in Council Bluffs, Iowa.

Similarly, a study conducted in North Carolina at red light camera equipped intersections showed a 17 percent reduction in total crashes, 22 percent reduction in RLR related crashes, 42 percent reduction in angle crashes and 25 percent reduction in rear-end crashes (Cunningham and Hummer, 2004). Studies in Oxnard, California and Fairfax, Virginia found enforcement cameras reduced RLR violations by approximately 40 percent (Retting et al., 1999a, Retting et al., 1999b).

In addition to the studies that assess the effectiveness of enforcement cameras, researchers from the IIHS state that red-light cameras saved 159 lives from 2004 to 2008 (IIHS 2011). Hu et al. attempted to assess the impact of RLR cameras by comparing RLR rates in large U.S. cities. In this study large cities were defined as cities with a population larger than 200,000 residents according to the 2008 census. There were 99 cities that fit the population criteria and had a camera enforcement program in place. Researchers gathered information about each city's red light camera program by reading news reports, and contacting city police departments and public works departments. The study used fatal crash data from 1992 to 1996 as the "before" period of the study since few communities had camera programs during that period. Crash data from 2005 to 2008 were used as the "after" period of the study. Cities were divided into two groups, camera group or comparison group, according to whether cities did not have camera programs during the before period, and had a camera program during all the years of the after period. Out of the 99 cities, 14 cities comprised the camera group, 48 cities composed the comparison group, and 37 cities were excluded. Crash data were extracted from the Fatality Analysis Reporting System (FARS) for both periods of the study. The research study determined that there was a decline in RLR fatalities in both groups, however, the decline was larger in the camera group with RLR cameras (35 percent) than the comparison group without RLR cameras (14 percent) (Hu et al., 2011). These results lead to the estimation that if all cities with more than 200,000 residents would use camera enforcement, a total of 815 fewer fatalities would have occurred during the time periods mentioned in the study (IIHS 2011).

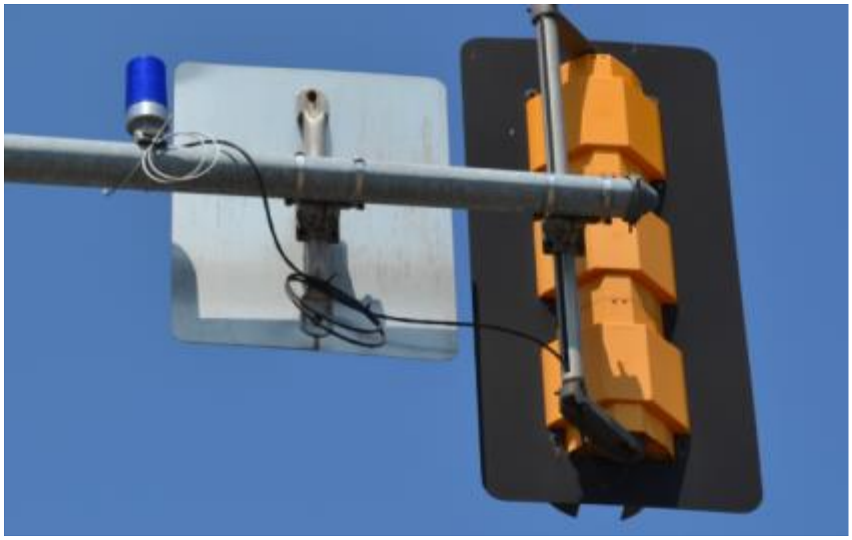
Not all communities embrace automated enforcement. Kansas state statutes do not allow the use of red-light running cameras (State of Kansas, Article 61, subsection 6(a)). In Missouri and Kansas City there is debate about whether the cost of the system is worth the benefits. In Columbia, it was reported that the city collected $158,515 and about $18,000 was net revenue after paying all expenses (41 Action News, 2010). In Kansas City, it was reported that the camera system used in 17 intersections cost $76,000 monthly (41 Action News, 2012). In 2011, lawmakers in Missouri tried to ban red-light cameras (Peterson, 2011), and in 2013 the Missouri court of Appeals stalled the enforcement of RLR cameras because "… a red-light camera ordinance in the town of Ellisville conflicts with state statutes because it treats running a red light as a non-moving violation, when the state considers the offense a moving violation" (Cho, 2013).

2.6.2 Targeted Enforcement

Targeted enforcement is designed to target an identified signalized intersection or corridor where RLR has recently become a problem, or has been identified as a problem through a crash and/or violation study. Law enforcement agencies will increase the number of officers at a particular location and enforce RLR. The goal of targeted enforcement is to make the public more aware of RLR through an increase in ticketed violations or presence of law enforcement at the intersection.

2.6.3 Confirmation Lights

Confirmation lights are a relatively small, low-cost light mounted on the top or the bottom of a traffic signal head or mast arm. This light is sometimes referred to as "Red-Signal Enforcement Lights" or "Red Indication Lights" or "Rat Boxes" or "Tattletale Lights" (Hsu et al., 2009). The confirmation light activates simultaneously during the red signal phase to aid a police officer located downstream of the intersection in observing a RLR violation. After the confirmation light turns on, it is visible 360 degrees from any intersection approach. The confirmation light is wired directly into the red signal aspect and only activates when the red light is indicated as shown in Figure 8 a, b and c which shows confirmation lights in operation during the day and night times respectively.



(a)

(b) (c)

Figure 8. Blue confirmation light wiring (a), daytime operations (b), and nighttime operations (c)

This system eliminates the need for a team of officers to monitor red light violators at a single intersection, thereby reducing the police staff required to effectively enforce RLR at the intersection. Additionally, the low-cost of confirmation lights (approximately $50 to $100) potentially allows more installation at other problematic intersections, hence, increasing enforcement resources efficiently (Hsu et al., 2009).

Although confirmation lights have been largely deployed through the United States including communities in Florida, Texas, Minnesota, Kentucky and California, limited data or research studies have been published to determine effectiveness of the countermeasure in reducing RLR violations or crashes.

Reddy et al. (2008) investigated white enforcement lights at 17 intersections on the state highway system in Hillsborough County, Florida. The researchers evaluated effectiveness by a violation and crash analysis. Five months prior to installation, violation data were collected at 24 intersections on weekdays during morning and evening peaks hours. A similar study was conducted in the three months after installation at the 17 intersections in which the lights were installed. Considering all intersections, a total of 759 violations were recorded in the before period while 567 violations were recorded in the after period. It was noted that some intersections saw an increase in violations. A matched-pair t-test was performed and it was determined the reduction in violations were statistically significant. The authors further reduced the data and found the reduction in violations during the morning peak hour were not statistically significant while the evening peak violations were significant at the 95 percent level of confidence.

Crash data were obtained from the Florida Department of Transportation for a period of six years (2000-2005). Data from 2000-2002 were considered the before period in which 828 crashes per year occurred at the study intersections of which 56 crashes per year were due to RLR. Data from January 2004 to December 2004 were considered the after period with 2003 being considered the installation period. An average of 860 crashes per year at the study intersection was recorded with 52 crashes per year due to RLR. The authors further broke down the crash analysis and investigated approaches with white enforcement lights and found crashes were reduced from approximately 40 crashes per year to 28 crashes per year.

The Minnesota Local Technical Assistance Program (2009) summarized a completed study conducted by the University of Minnesota and City of Burnsville, Minnesota in which blue confirmation lights were installed at two signalized intersections on County Roads 5 and 11. An investigation assisted by the University of Minnesota saw the daily violation rate reduced by 41 percent. Research also found that violations increased in heavy traffic and most violations occurred during peak hours.

2.7 Public Awareness Campaigns

Reaching out and educating the public is an effective way to communicate the seriousness of a driver running a red light at a signalized intersection. Public education could include media campaigns, grants for targeted enforcement, commercials, further instruction during drivers' education classes, and/or television newscast segments on high crash intersection locations. Usually public awareness campaigns are used in conjunction with other traffic safety strategies, such as targeted police enforcement. A study by Tarawneh et al. evaluated the effectiveness of a public awareness campaign coupled with a targeted police enforcement effort. Researchers monitored RLR behavior at six signalized intersections in Lincoln, Nebraska. The sites were chosen according to crash data, intersection classification, and geometry. Traffic was recorded using video equipment during weekdays from 7 a.m. to 9 a.m., 11 a.m. to 1 p.m., and 4 p.m. to 6 p.m. Targeted enforcement occurred during those hours during the after period of the study. For the awareness campaign various materials were used such as billboards, signs, and posters. Public service announcements were made for TV, and radio. The TV ads were shown 265 times during the one month campaign. Researchers measured vehicles' entry time during yellow, speed, vehicles' distance from stop line during the yellow phase, volume of vehicles traversing the intersection during the yellow phase per cycle, proportion of vehicles upstream and proportion of vehicles downstream from the dilemma zone, and RLR violations per cycle. An analysis of variance (ANOVA) test was performed for the before and after analysis. The analysis showed that the public campaign and targeted enforcement had a significant effect on drivers (Tarawneh et al., 1999).

2.8 Literature Review Summary

As reported in the literature search, RLR continues to be a serious safety concern and many communities and researchers have investigated countermeasures ranging from low-cost signal timing adjustments to expensive intersection geometric improvements or automated enforcement. To fully address RLR, it takes all aspects of the three E's (Engineering, Enforcement, and Education). Public awareness campaigns coupled with a countermeasure can have an effect on RLR behavior. As stated previously, this research project is intended to investigate a low-cost countermeasure to aid police officers. There was very limited research on the effects of confirmation lights on RLR violations. This research will provide additional information into the effectiveness of the confirmation light system.

CHAPTER 3: RESEARCH APPROACH

The research study was conducted in Overland Park, Kansas. The City of Overland Park has a population of over 178,000 residents and one of its major centers of activity is Johnson County Community College. The city has a significant number of signalized intersections along major arterials such as Metcalf Avenue, Quivira Road, Antioch Road, 119th Street, 135th Street, and College Boulevard. Figure 9 shows the city limits of Overland Park. Prior to meeting with city officials, it was specified to the city that the study required study intersections be located within the city limits, similar in operations (e.g. traffic signal timing and lane configurations), and have no current or planned construction at any of the intersections during the study period. Since the project was limited to 12 months, it was decided to utilize a violation study in place of a crash study which would require at least three years of before and after crash data.

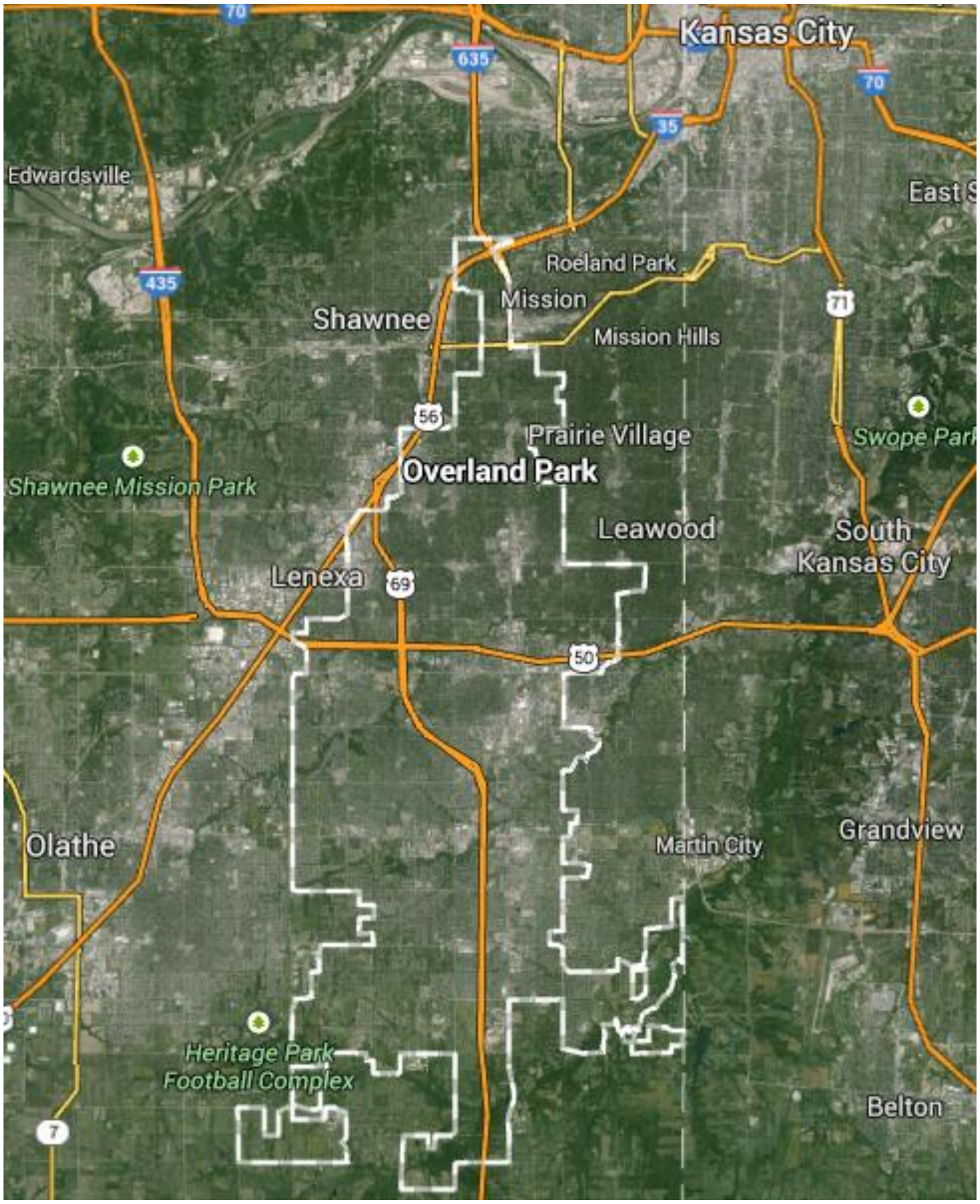


Figure 9. Map of Overland Park

3.1 Site Selection

Before approaching the city to seek permission to investigate the confirmation light system, possible intersections were identified for confirmation light installation. A set of variables were investigated at each of the intersections including: approach geometry (e.g. number of lanes, pavement markings, taper, and right-turning lane), whether the posted speed limited was between 30 and 50 mph, the presence of protected left-turning lanes, a safe location where a police car could monitor the intersection approaches, and moderate to high peak hour volumes. A police ride-along was conducted on December 7th, and December 15th, 2012. During the ride-along the following intersections and highway interchanges were observed:

1. 119th Street and Blue Valley Parkway;
2. 75th Street and Metcalf Avenue;
3. College Boulevard and Metcalf Avenue;
4. College Boulevard and Quivira Road;
5. 95th Street and Antioch Road;
6. 103rd Street and Metcalf Avenue;
7. Interstate-435 ramp and Metcalf Avenue;
8. 75th Street and Interstate-35 ramp; and
9. Antioch Road and Indian Creek Parkway.

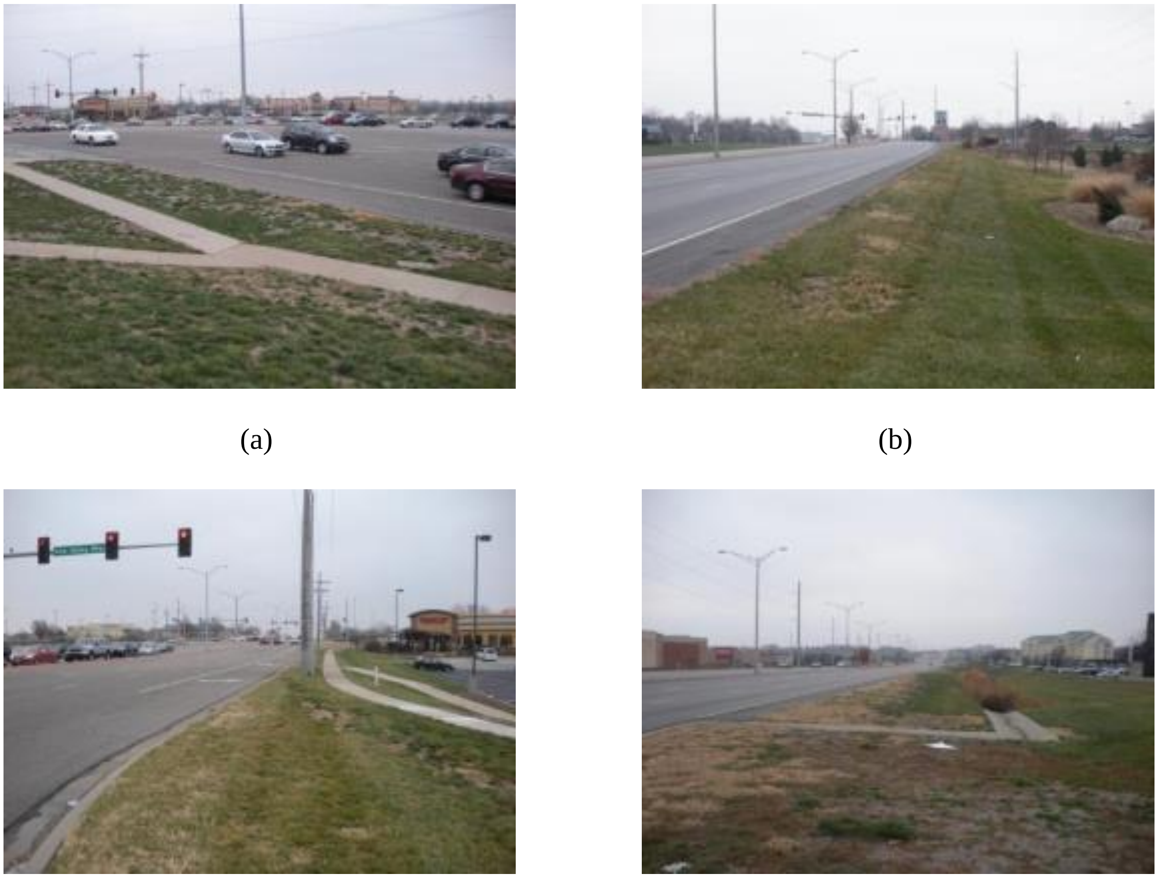
The following sections present observations made during the ride-along by the officer. Some of the following intersections were eventually decided as treatment sites and some were decided as control sites. Descriptions of the intersections not found in this section are found in later sections in the report. This section contains descriptions of intersection that were considered but not used in the study.

119th and Blue Valley Parkway

The intersection at Blue Valley Parkway and West 119th Street accommodated heavy volumes of traffic during peak hours. For the northbound and southbound approach there were two left-turning lanes, three lanes for thru-traffic, and one right turn lane. For eastbound and westbound approaches there were two left-turn lanes, three through-traffic lanes and one right-turn lane. The intersection is shown in Figure 10.

Figure 10. 119th and Blue Valley Parkway (aerial image, Google Earth, 2013)

For northbound and southbound approaches there was a two-foot shoulder, some turf, and then a ditch. For the eastbound approach there were no shoulders or driveways. The street became a four lane road, with the right lane designated as a right turn only for people turning onto Metcalf Avenue. For westbound traffic, there was a driveway, however it was too narrow for a patrol car to sit, therefore blocking the entrance to the bank and a restaurant. The shoulders of each approach are shown in Figure 11.



(a) (b)

(c) (d)

Figure 11. Shoulder for (a) westbound (b) northbound (c) eastbound (d) southbound approach at 119th Street and Blue Valley Parkway

Figure 11 (a) shows an area recommended by the police officer to monitor traffic if the confirmation lights were to be installed. The police car would be located exactly where the mast arm for westbound approach is located. This means that the officer could only enforce left-turning traffic, since the northbound mast arm is visible through the rear-view mirror, but not the westbound traffic. What could make enforcement more complicated is that the intersection stop line was not visible, and the left-turning traffic was located approximately 10 feet behind the stop line for through movement traffic. Even if a delineator outlining the location of the stop line was to be placed on the street, the officer would have to multi-task and view three different locations in order to view a RLR violation. Figures 11 (b) and (d) show the shoulder for northbound and southbound traffic, respectively. There was approximately two feet of paved shoulder and then a slope. A concern raised by the officer was that most police officers are reluctant to sit on shoulders for enforcement. Figure 11 (c) shows the stretch of roadway for eastbound traffic, where there was no spot for the officer to sit far enough to watch the light, and watch traffic. Because of the limited areas for an officer to pull over and watch for violators this site was not chosen as a deployment site.

College Boulevard and Metcalf Avenue

At College Boulevard and Metcalf Avenue the northbound and southbound were identified in the field as the approaches with the most RLR violations. The police officer pointed out that this was because of the long queues that form during rush hours. At rush hour, the southbound approach could be backed up all the way to 105th Street. There was also another traffic signal less than a quarter mile away, which made enforcement difficult because of the short proximity between signals. According to the police officer the westbound and eastbound approaches were a problem in the evening rush hour. Also, the proximity of adjacent traffic signals may affect driver behavior and promote RLR.

Figure 12. College Boulevard and Metcalf Avenue aerial view (Google images, 2013)

As was the case at 119th Street and Blue Valley Parkway, there were no convenient spots for a police officer to pull-over and enforce RLR with the use of confirmation lights. The lack of shoulders and the long queues during peak hours would also make it hard for officers to make violators safely pull over.

Interchanges on Interstate Highways

Signalized intersections at highway ramps were among the top locations for RLR violations and crashes according to both officers and city officials. It can take up to three police officers and a representative at the traffic operations center for targeted enforcement at underpasses such as I-435 and Metcalf Avenue. An officer sits on the shoulder of the overpass bridge and watches the traffic signal and the traffic turning left. When the light turns red that officer signals to the two other officers waiting on the on-ramp, and those two officers flag down drivers that ran the red light. Only one movement can be enforced at a time. With confirmation lights installed, officers believed that signalized intersections at highway ramps can be enforced more frequently and more on than one approach at a time.

Overpasses also present issues when conducting targeted RLR enforcement. Because of poor sight distance, the City of Overland Park has installed a "no right turn on red" policy, which drivers are known to ignore. Officers observed that such spots are common for "piggy-back" violations. Piggy-back violations occur when one vehicle proceeds and the queue follows the first vehicle without checking for conflicting traffic. There are also occasions where the first vehicle begins turning right, notices the regulation, then stops, and proceeds to be involved in a rear-end crash with the vehicle that were following because they were checking for on-coming traffic. Officers say that they use right-turning signals as tattle tale lights because they are synchronized with permitted left turn lights. This research study focuses on the effectiveness of confirmation lights at four-legged intersections. Factors relating violations at highway ramps may call for low-cost countermeasures that may or may not include confirmation lights.

After consideration of all intersections, a meeting was set up with City of Overland Park officials including the city traffic engineer, traffic signal technician, and traffic police officer. City officials agreed on the two treatment sites where the confirmation lights would be installed and also other intersections to be investigated for possible spillover effects of the treatment, and global changes in RLR will be investigated using control intersections located in different areas of the city. Section 3.2 explains the selected intersections used in the study.

3.2 Site Category

3.2.1 Treatment Sites

As stated previously, two signalized intersections in Overland Park were determined to be optimal locations for the confirmation lights to be installed which included:

- 75th Street and Metcalf Avenue; and
- College Boulevard and Quivira Road.

Detailed information on each intersection can be found in Section 3.3.1 of this chapter. The intersection at 75th Street and Metcalf Avenue was appropriate for this type of enforcement system because there are many driveways where the police officer could sit and monitor the intersections for all approaches. College Boulevard and Quivira Road was also an appropriate location for a police officer to pull-over when compared to the other sites described in Section 3.1. During the police officer ride-along, it was determined that an officer could pull-over at the right turn lane for an access driveway that leads into Johnson County Community College for the southbound approach.

3.2.2 Spillover Sites

Spillover sites are signalized intersections located adjacent to the two treatment intersections in Overland Park and included the following locations:

- 71st Street and Metcalf Avenue;
- 75th Street and Conser Street;
- 79th Street and Metcalf Avenue;
- 119th Street and Quivira Road;
- College Boulevard and Nieman Road; and
- College Boulevard and Pflumm Road.

Previous research studies relating to automated enforcement have indicated that if an intersection was treated with an enforcement device (e.g. automated RLR camera), similar effects to improving safety can occur at nearby intersections (Retting and Kyrychenko, 2002, McGee and Eccles, 2003) thus terming the phrase "spillover effect" or "halo effect." It was a goal to observe if a reduction in red light violations occurred at the treatment intersections, would a reduction in RLR violations also occur at these six intersections. A map indicating where the treatment and spillover intersections are located is shown in Figure 13.

Figure 13. Location of treatment and spillover intersections in Overland Park Kansas (Google, 2013)

3.2.3 Control Sites

Six control sites were selected for the study that were located outside of the study corridor around the City of Overland Park which included the following:

- 95th Street and Metcalf Avenue;
- College Boulevard and Nall Avenue;

- College Boulevard and Antioch Road;
- 95th Street and Antioch Road;
- 103rd Street and Antioch Road; and
- 103rd Street and Metcalf Avenue.

The purpose of the control sites were to determine if any global changes in RLR violations occurred in Overland Park for the duration of the study. For example, if a reduction in RLR violations at both the control and treatment sites was observed, other factors that could not have been quantified may have contributed in the reduction in RLR violations (e.g. public awareness campaign, severe weather events, or targeted enforcement). It was expected that a reduction in violations at the treatment site and a constant or increase in the number of violations at the control site would also be a strong indicator of the confirmation light effectiveness. Figure 14 shows the location of the treatment sites as well as the control sites.

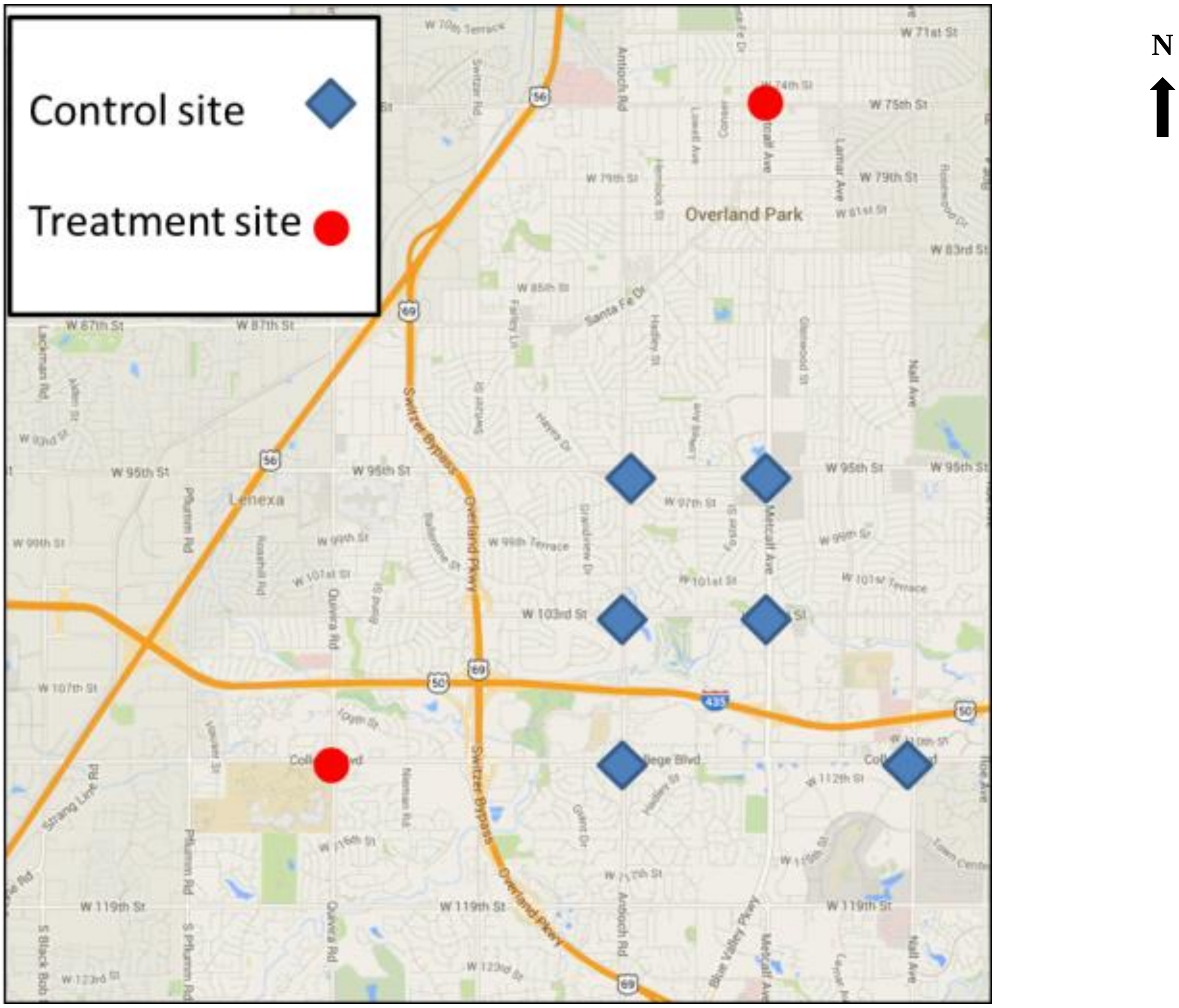


Figure 14. Location of treatment and control intersections in Overland Park, Kansas (Google, 2013)

3.3 Site Description

As stated in the previous section, 14 intersections were utilized for this study. This section provides additional information for each intersection. Each description provides information about land use, posted speed limit, lane configuration, number of lanes, clearance path length, turning movements, and peak hour volumes. Clearance path refers to the distance between the stop line of one approach to the stop line of the opposite approach. This distance was approximated through Google Earth, and it serves as an approximate distance that vehicles have to travel to clear the intersection. The morning and evening peak hours were determined to be 7 a.m. to 9 a.m. and 4 p.m. to 6 p.m. Traffic was observed on a Tuesday, Wednesday, or Thursday.

3.3.1 Treatment Sites

Video data of RLR violations for the intersection of 75th Street and Metcalf Avenue were collected using vehicle detection cameras. The video data were provided by the City of Overland Park. This intersection was filmed between January 16th and January 24th for the before study, and between October 29th and October 30th, 2013 for the three-month after period of the study. There were no data provided for the one-month after period of the study. RLR violation video data were collected by students at the treatment intersection of College Boulevard and Quivira Road using multiple cameras setup at the intersection. The intersection was recorded on March 13th for the before period, August 27th for the one-month after, and November 14th, 2013 for the three-month after period. More details about data collection and reduction are found in a later section.

75th Street and Metcalf Avenue

Metcalf Avenue is the north/south approach, and there was a designated left turn lane, a right turn lane, and two through lanes for both approaches. The speed limit at the south corridor of the intersection was 35 mph. The north end of Metcalf Avenue had a posted speed limit of 40 mph. The clearance path for traffic along Metcalf Avenue was 106 feet. Along 75th Street the posted speed limit was 35 mph, and the clearance path was 110 feet. For the approaches along 75th Street there was one left turn lane, a through lane, and a shared through/right turn lane for each approach. Figure 15 shows an aerial view of 75th Street and Metcalf Avenue.

Figure 15. 75th Street and Metcalf Avenue (aerial image, Google Earth, 2013)

As shown in Figure 15, this intersection was located in a dense commercial district. There were convenience stores at the south end of the intersection, a gas station on the northeast corner, and a restaurant in the northwest corner. Left turns were protected on all approaches and right turns were protected for the northbound and southbound approaches. No U-turns were allowed for eastbound and westbound traffic. Figure 16 shows the signal heads on all approaches at the intersection.

(a) (b)

(c) (d)

Figure 16. Signal mounting for 75th Street and Metcalf Avenue for (a) northbound (b) southbound (c) eastbound and (d) westbound approaches

All overhead signals had backplates installed and there was one signal head per lane for all approaches. There were also pedestrian countdown signals for all pedestrian crosswalks. Only the North and South phases were coordinated. The peak morning and evening cycle length was 140 seconds. Table 4 shows the yellow and all-red phase length in seconds.

Table 4. 75th Street and Metcalf Avenue Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	4.2	3
Northbound Left Turn	3.3	1.9
Southbound	4.2	2
Southbound Left Turn	3.3	2
Eastbound	3.7	2
Eastbound Left Turn	3.3	2.1
Westbound	3.7	2
Westbound Left Turn	3.1	2.1

Manuals and literature suggests that yellow phase time should be between three and six seconds and that caution should be used when using more than five seconds. At this intersection, all movements had a yellow timing between 3 and 4.2 seconds. All through movements had a yellow time of around four seconds, while left-turning movements had a yellow time around three seconds. The literature search also showed that researchers (Schattler et al. 2003) recommend an all-red time between two and three seconds. The northbound through movement traffic had the highest all-red interval time of three seconds. All other approaches and movements had around two seconds of all-red interval time. Traffic data were provided for only the before and three-month after period of the study. Figure 17 shows the volume for all approaches during both periods of the study. Figure 17 shows the combined morning and evening peak hour volumes for all approaches during the before and three-month after periods of the study.

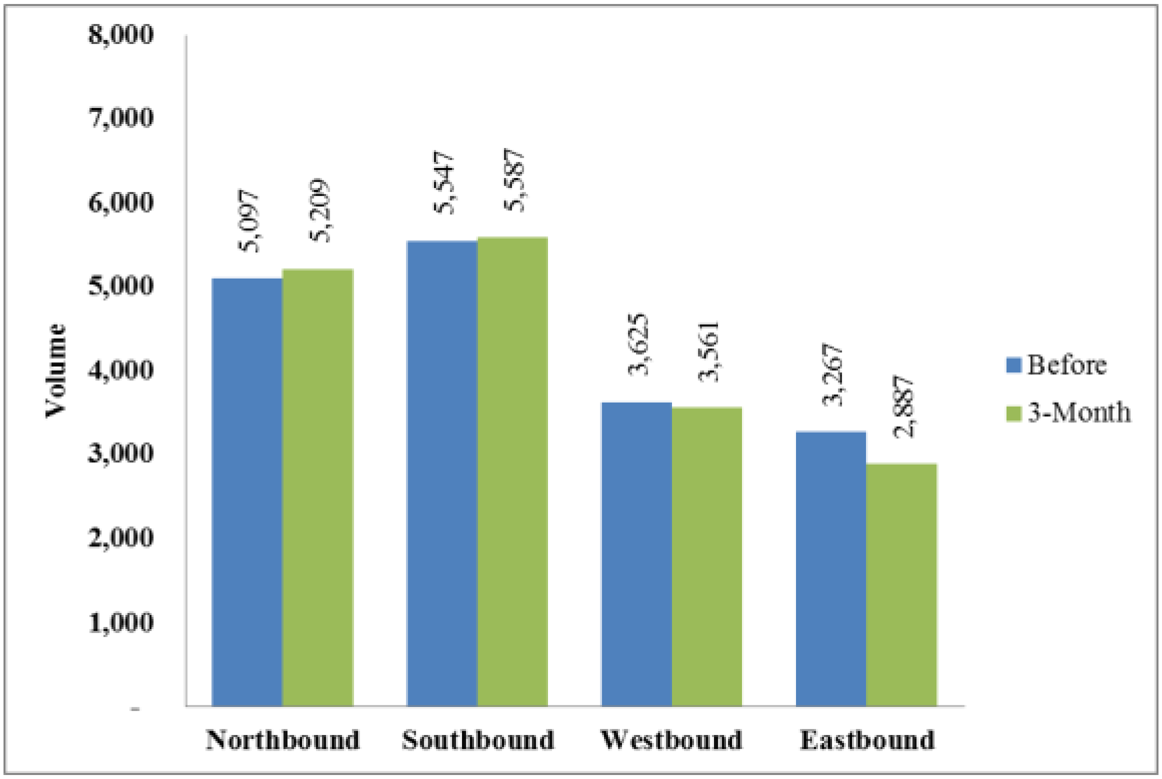


Figure 17. Total volumes for 75th Street and Metcalf Avenue

As shown in Figure 17, the southbound approach had the highest recorded volumes at the intersection. The eastbound approach had the fewest vehicles out of all four approaches. Traffic volumes were higher during the evening peak. From the total count, 54 percent of vehicles were observed during the evening peak hours. Figure 18 shows the turning movements in terms of percentage observed during the peak hours.

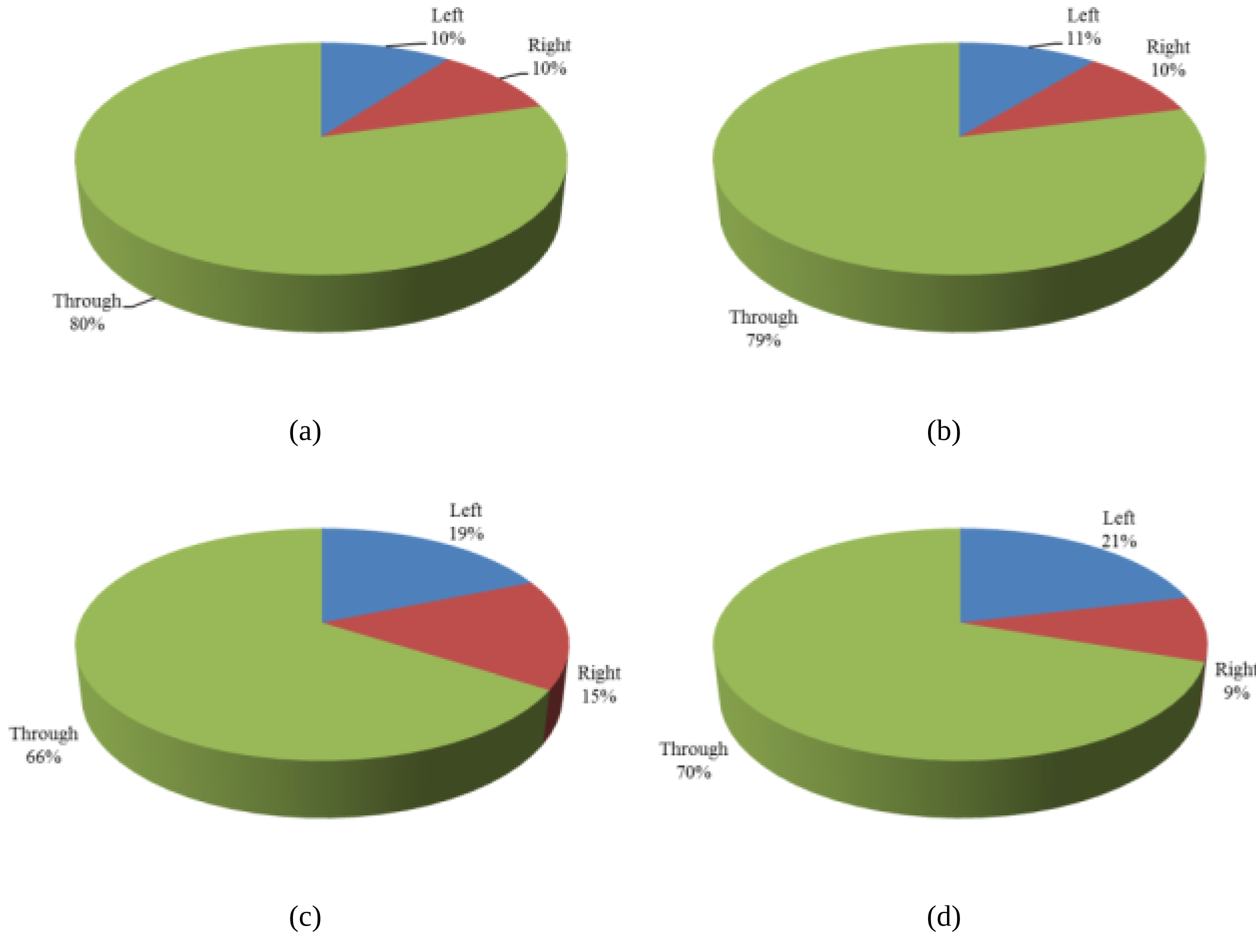


Figure 18. Turning movements at 75th Street and Metcalf Avenue for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

Most of the entering traffic traversed through the intersection at all approaches rather than turning left or right. The eastbound and westbound approaches had the most left-turning vehicles. The westbound approach also had the highest volume of right-turning vehicles. There were a total of 34,780 vehicles counted with right turns representing 11 percent of volume counts, left turns 14 percent, and 75 percent of vehicles moved straight through the intersection.

College Boulevard and Quivira Road

The posted speed limit on College Boulevard and Quivira Road was 45 mph. On the northbound and southbound approaches of the intersection, there were three through lanes, two left turn lanes, and one right turn lane. This intersection was located in a commercial area.

The northbound approach had a restriction on U-turns, while in the southbound direction U-turns were allowed. In the eastbound and westbound approaches there were three through lanes, two left turn lanes, and one right turn lane. The intersection is shown in Figure 19.

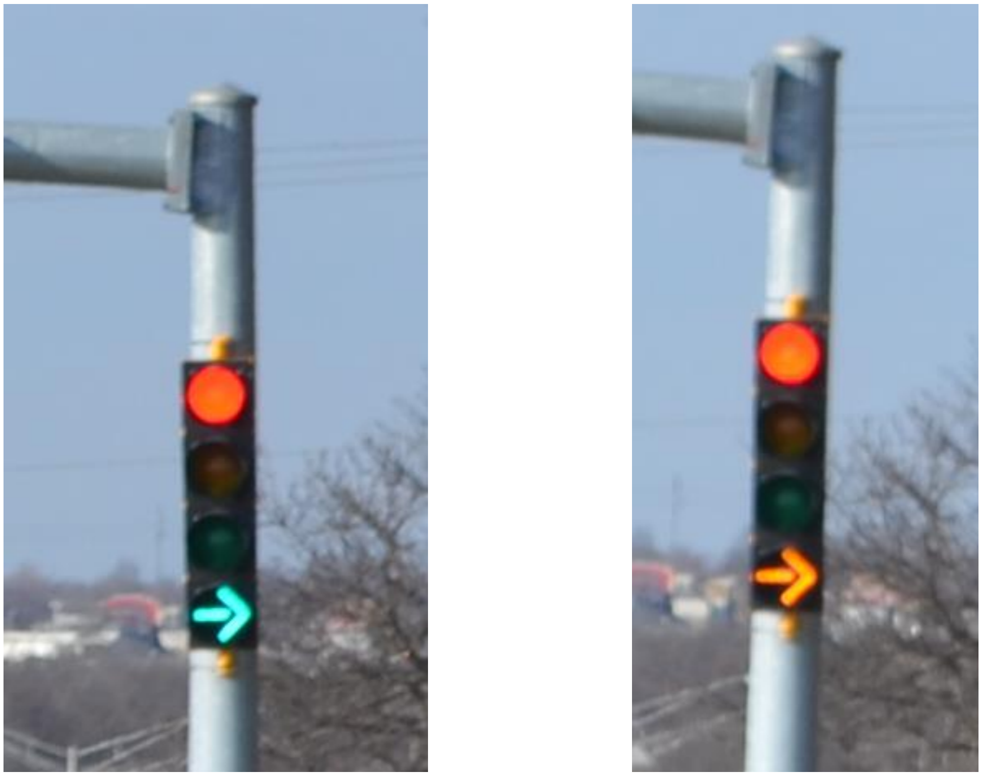
Figure 19. College and Quivira aerial view (Google images, 2013)

As shown in Figure 19, downstream of the northbound and southbound approaches there were three through lanes. For the northbound and southbound movements vehicles had to travel approximately 182 feet. The clearance distance for westbound and eastbound approaches was 183 feet. Johnson County Community College is located at the southwest corner of the intersection. There was a bank on the northwest corner, an office building on the northeast corner, and restaurants in the southeast corner of the intersection. Figure 20 shows the traffic signal set-up at the intersection.

(a) (b) (c) (d)

Figure 20. College and Quivira signal system for (a) northbound approach (b) southbound approach (c) eastbound approach and (d) westbound approach

The westbound, northbound, and southbound approaches all had a protected right turn signal. Left turn movements were protected on all approaches. For all left-turning movements there were two signal heads, one per lane, indicating to drivers when to go and stop. As shown in Figure 21, the fourth bulb on the signal head facing the right turn lane had the arrow signaling to drivers that they can turn right. The same aspect had green and yellow colors.



(a) (b)

Figure 21. (a) green indication for permitted right-turn (b) yellow indication for permitted right turns

For the eastbound approach, there was a sign board indicating to the driver that turning right was not allowed at that time as shown in Figure 22. The sign activated when southbound left-turning traffic were traversing the intersection. Since southbound drivers were allowed to make U-turns, and since a right-turning vehicle and a U-turning vehicle might conflict if they were performing these maneuvers at the same time, the City of Overland Park installed this secondary notification device.

(a) (b)

Figure 22. Westbound College and Quivira (a) right turns are allowed (b) no right turns are allowed

With the presence of the sign board shown in Figure 22, only the right turn violations were monitored when the board was illuminated as shown in Figure 22 (b). This was the only approach at all the study sites where right-turning violations were written down. The signal at the intersection was an eight phase system and the North and South directions were coordinated. The morning peak cycle length was 120 seconds, and the evening peak cycle length was 140 seconds. Table 5 shows the existing signal timing plan.

Table 5. College Boulevard and Quivira Road Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	4.3	2.6
Northbound Left Turn	3.2	3.3
Southbound	4.3	2.6
Southbound Left Turn	3.2	3.3
Eastbound	4.3	2.4
Eastbound Left Turn	3.2	3.5
Westbound	4.3	2.4
Westbound Left Turn	3.2	3.5

As shown in Table 5, all through movements had a yellow time slightly more than four seconds. The left turn movements had slightly more than three seconds. All-red clearance intervals for through movements were almost three seconds, while for the protected left turn phase all intervals were more than two seconds. All times shown in Table 5 are within the requirements of the MUTCD and the recommendations made by previous research studies as mentioned previously. Volumes and turning movements for all three study periods are shown in Figures 23 and 24.

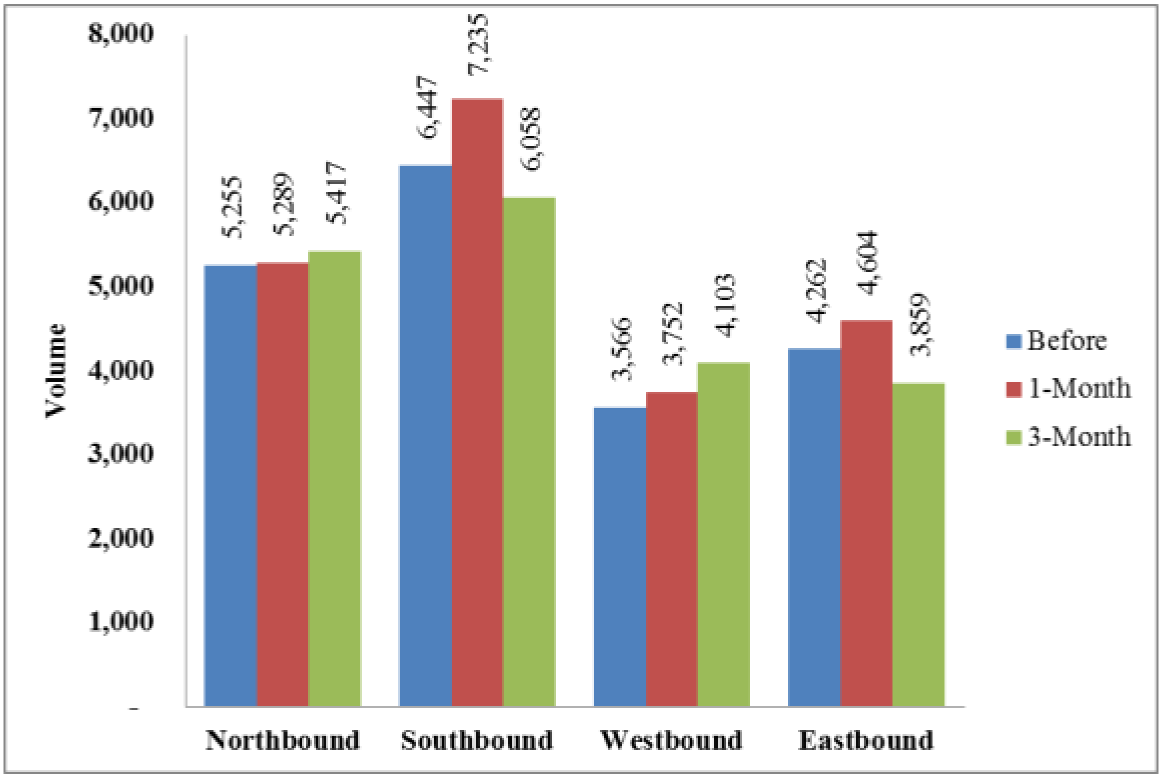


Figure 23. Total volumes for College Boulevard and Quivira Road

Shown in Figure 23 are the combined morning and evening peak volumes. The northbound and southbound approaches represent 60 percent of the total volume recorded for all study periods. The one-month after period had the highest volume count out of all periods of the study with 20,880 vehicles observed during both peak periods. The southbound and eastbound approaches experienced the highest volume increase during the one-month after period. The westbound approach saw an increase in volume with each continuing phase of the study. The northbound volumes remained relatively constant throughout the study. From the total volume observed, 55 percent of drivers were observed in the evening peak hour. Shown in Figure 24 are the percentages of turning movement volumes.

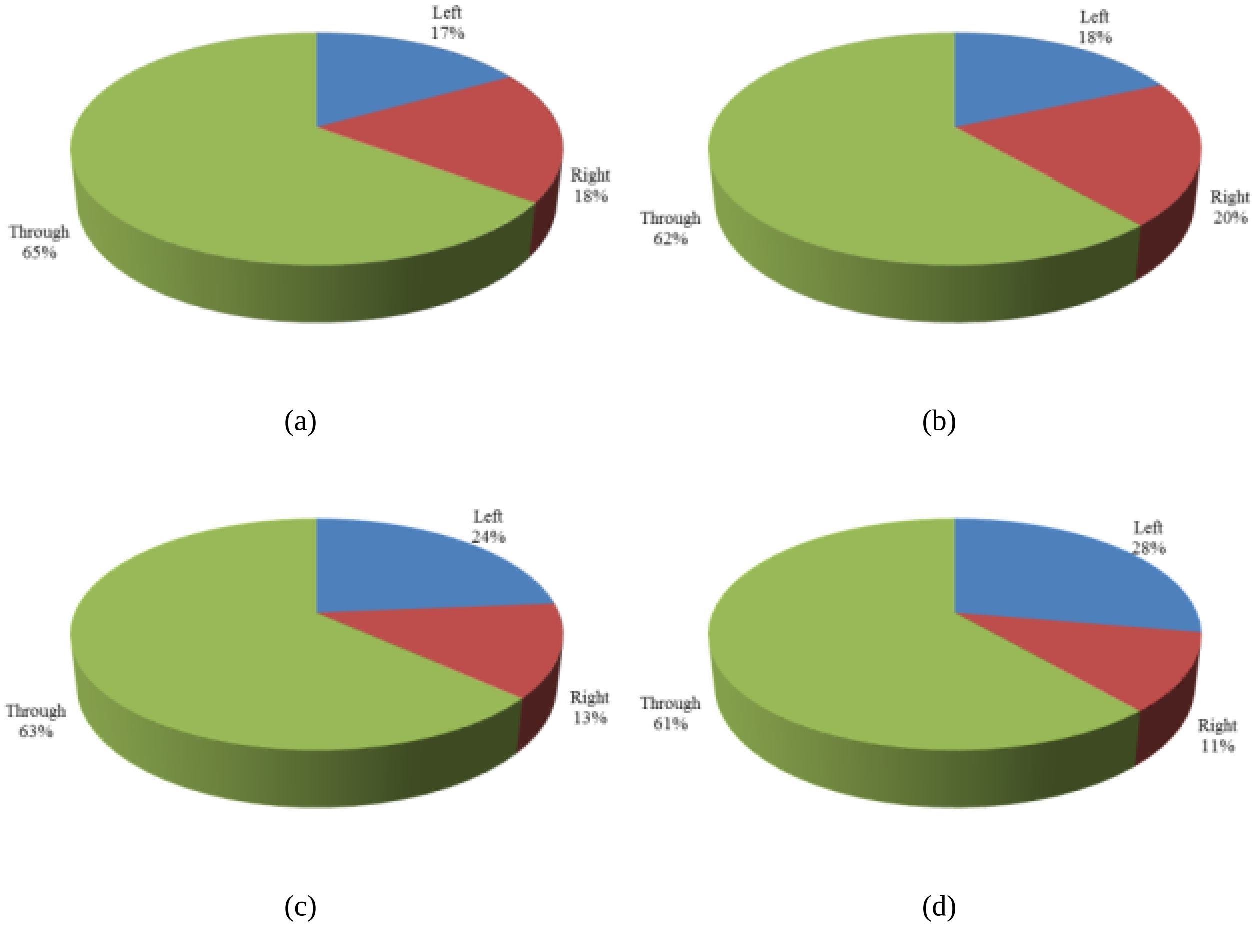


Figure 24. Turning movements at College Boulevard and Quivira Road for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 24, the northbound and southbound approaches had the highest volume counts and percentages of right-turning vehicles. Between both of these approaches, a total of 6,902 right-turning vehicles were observed and this represents 71 percent of all right-turning vehicles. More than a quarter of traffic traveling eastbound turned left to travel northbound on Quivira Road. Although the eastbound approach had the highest percentage of left-turning traffic (Figure 24 (d)), it was also found to have the second highest count of 3,526 vehicles. The southbound approach was found to have the highest volume count of 3,626 vehicles turning left, which represents 18 percent of the total traffic observed at that approach. The total volume observed at this intersection for both morning and evening peak hours was approximately 59,847 vehicles. In total, 63 percent of vehicles went straight through the intersection, 36 percent turned left, and 28 percent were turning right.

3.3.2 Spillover Sites

The video data for the spillover sites were recorded using vehicle detector cameras by the City Overland Park. The intersection of 75th Street and Conser Street was recorded by a student researcher for the one-month and three-month after periods; the before period was recorded by the City of Overland Park. Traffic volumes for the intersection of 79th Street and Metcalf Avenue were recorded for the before and three-month after periods of the study only.

71st Street and Metcalf Avenue

The intersection of 71st Street and Metcalf Avenue was chosen as a spillover site for the treatment intersection for 75th Street and Metcalf Avenue. This intersection was located in a residential area. There were private residencies at all corners of the intersection, except for the southeast corner where there was a church. The posted speed limit for northbound and southbound traffic was 40 mph, for eastbound it was 30 mph, and westbound was 25 mph. The clearance path for cars traversing the intersection in the northbound or southbound direction was approximately 100 feet, and 114 feet for westbound and eastbound traffic. Figure 25 shows an aerial view of the intersection.

Figure 25. 71st Street and Metcalf Avenue (aerial image, Google Earth, 2013)

For traffic along Metcalf Avenue (North/South) there was a left turn lane, a through lane and a shared through/right turn lane. There was no protected right turn signal, the left turn signal was protected/permitted, and there were no restrictions on left turns. There were three signal heads per approach, two on the mast and one on the post. For traffic along 71st Street, there was a left turn lane and a shared through/right turn lane. The left turn movements were protected/permitted, and there were two signal heads per approach. There was one signal head on the mast and one on the post. All approaches had pedestrian countdown signals, backplates for overhanging signal heads, and the posts and masts arms were decorative black. The north and southbound approach phases were coordinated along the corridor, Table 6 shows the yellow and all-red phasing.

Table 6. 71st Street and Metcalf Avenue Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	4	1.5
Northbound Left Turn	3.1	2.1
Southbound	4	1.5
Southbound Left Turn	3.3	2.1
Eastbound	3.3	2.3
Eastbound Left Turn	3.3	1.8
Westbound	3.3	2.3
Westbound Left Turn	3.2	1.8

The morning and the evening peak hour cycles were 140 seconds for the intersection. The through and right-turning movements traffic on the northbound and southbound approaches had a yellow phase time of 4 seconds and an all-red interval of 1.5 seconds. Eastbound and westbound approaches had a yellow time of 3.3 seconds and an all-red interval of 2 seconds. All of these times were within the recommendations found in the literature review and MUTCD. Figure 26 shows the volumes recorded during all periods of the study for both morning and evening peak hour periods.

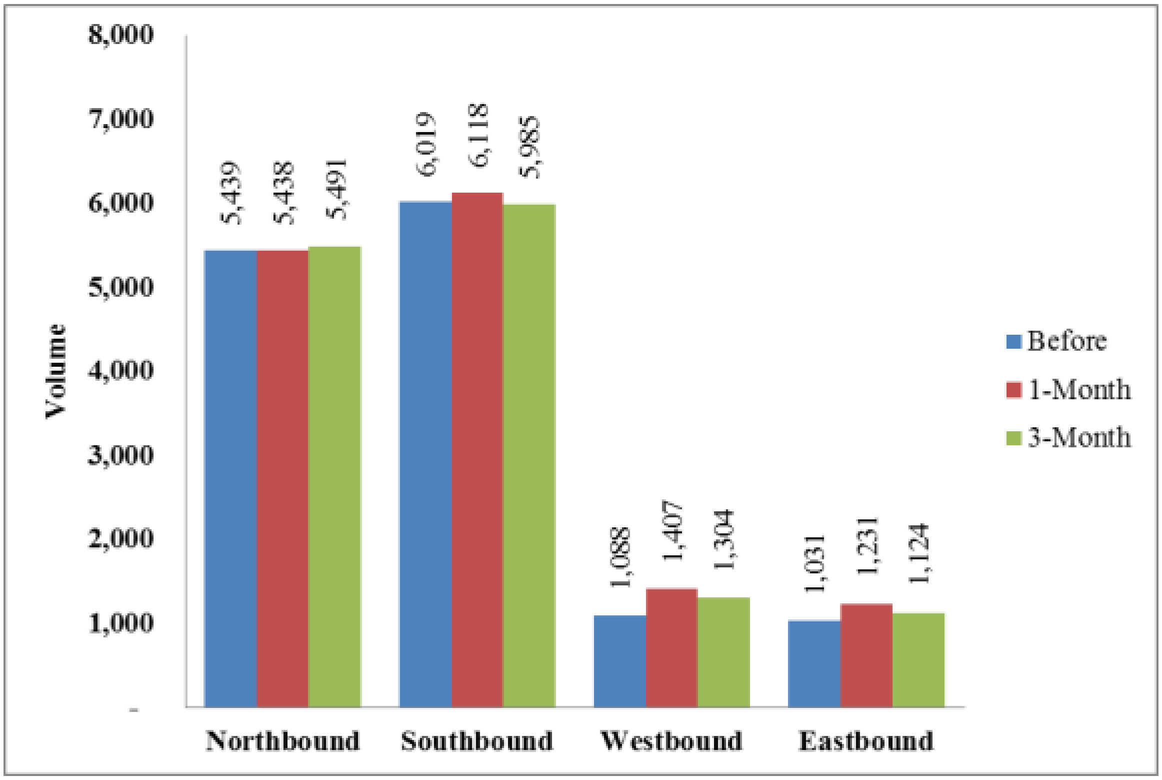


Figure 26. Total volumes for 71st Street and Metcalf Avenue

As shown in Figure 26, vehicular volumes remained constant throughout all periods of the study. The southbound approach had the highest combined volume out of all approaches. Traffic counts were found to be higher during the evening peak hour as compared to the morning peak hour. The increase in traffic volume from morning to evening peak hours was found to be approximately 1,000 vehicles. It's important to note that for the before and one-month after periods, all approaches were recorded on different days during the week. During the three-month after period all approaches on 71st Street (eastbound and westbound) were recorded on the same day, and traffic along Metcalf Avenue were recorded during the same day.

Figure 27 shows how traffic moved through the intersection.

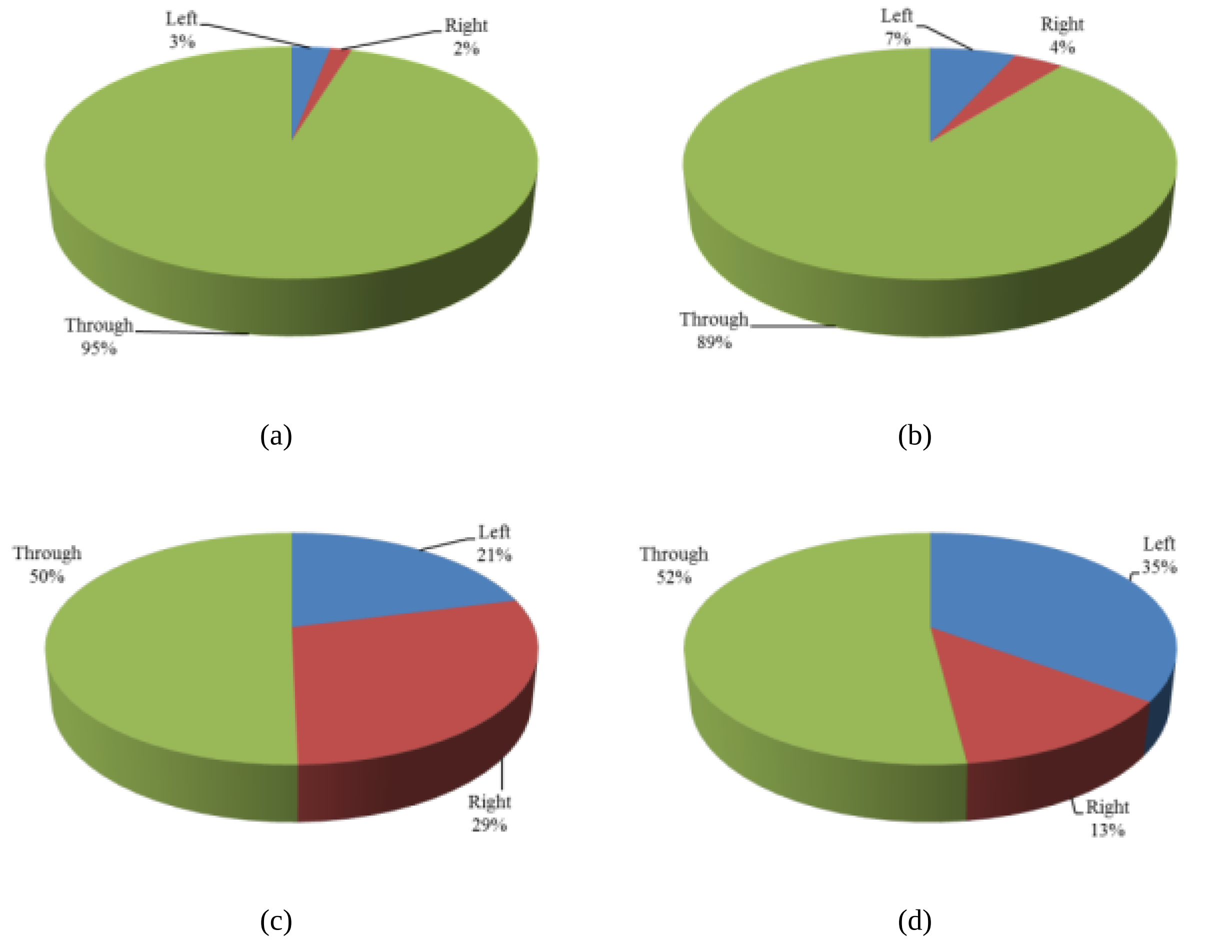


Figure 27. Turning movements at 71st Street and Metcalf Avenue for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

A majority of traffic along Metcalf Avenue traversed through the intersection and approximately one-half of traffic turned westbound onto 71st Street. The westbound approach had the highest percentage (29%) and total volume count (1,089) of right turns for this intersection. The eastbound approach had more than 33 percent of traffic turn left onto Metcalf Avenue, which was the second highest recorded volume of left turns at this intersection. The seven percent of left-turning traffic translates to a total volume of 1,228 vehicles, which was the highest volume of left-turning vehicles. In summary, there were a total of 41,675 vehicles counted at this intersection for all three periods combined. Approximately nine percent of vehicles observed turned left, six percent turned right, and 85 percent went straight through the intersection.

75th Street and Conser Street

The intersection of 75th Street and Conser Street was also selected as a spill-over effect because its proximity to the signalized intersection of 75th Street and Metcalf Avenue. This intersection was located on a residential area. The posted speed limit along 75th Street (eastbound and westbound) was 35 mph, and the speed limit for Conser Street (northbound and southbound) was 25 mph. The clearance path for vehicles along 75th Street was 70 feet, while for traffic along Conser Street it was 73 feet. Figure 28 shows an aerial view of the intersection.

Figure 28. 75th Street and Conser Street (aerial image, Google Earth, 2013)

In the northeast corner of the intersection there was a city fire station. To avoid westbound traffic from blocking the entrance and exit of the station, an emergency traffic signal was placed approximately 129 feet downstream from the stop line and cars were required to stop at this location when the signal shows red. Along 75th Street, there were two lanes that share turning movement traffic. Conser Street gives access to the residential neighborhoods adjacent to the intersection and there was one lane per approach. There were two signals for the southbound traffic, one overhead and one on a pole, and only one signal on a pole for northbound movement traffic. Left turn movements were permitted only and along the eastbound approach there were two overhead signals and one on the pole. This configuration was the same for the westbound signals at the intersection and prior to the fire station driveway. There were pedestrian countdown signals at each corner, and backplates installed on all overhead signal lights. There were no protected turning movements at this intersection. The traffic signal timing along 75th Street was coordinated, and the morning and evening peak hour cycles were approximately 70 seconds. Table 7 shows the yellow and all-red phasing in seconds.

Table 7. 75th Street and Conser Street Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	3	2.2
Northbound Left Turn	NA	NA
Southbound	3	2.2
Southbound Left Turn	3	2.2
Eastbound	3.7	1.4
Eastbound Left Turn	NA	NA
Westbound	3.7	1.4
Westbound Left Turn	NA	NA

Traffic along 75th Street had a yellow time of almost four seconds and for traffic along Conser Street it was three seconds. The all-red phase was slightly over one second. The all-red phases along with the yellow time were within the guidelines and recommendations found in the literature review. Figure 29 shows combined morning and evening peak volumes for all three study periods.

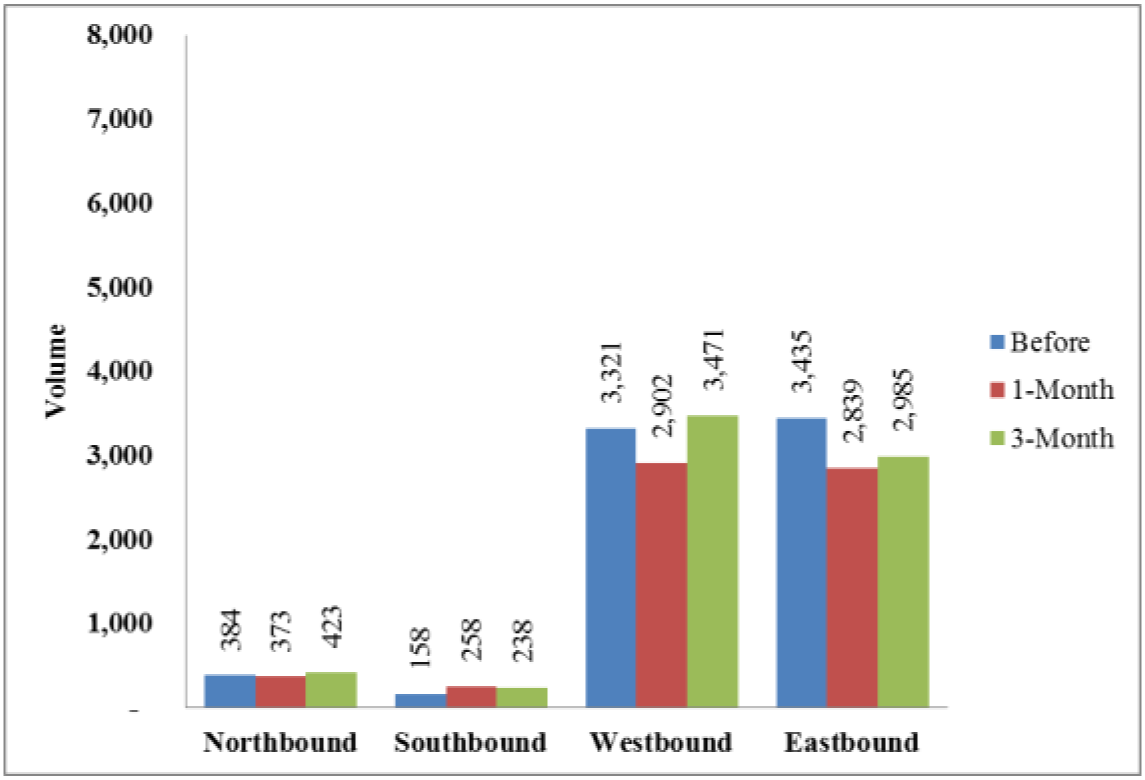


Figure 29. Total volumes for 75th Street and Conser Street

As shown in Figure 29, traffic generally proceeded through 75th Street at this intersection. Considering all studied intersections, it was found that at the intersection of 75th Street and Conser Street had the overall lowest volume. Traffic volumes recorded during the before and one-month after period were evenly split between the westbound and eastbound approaches. The before period of the study had the highest number of vehicles observed. Figure 30 shows the turning percentages at each approach.

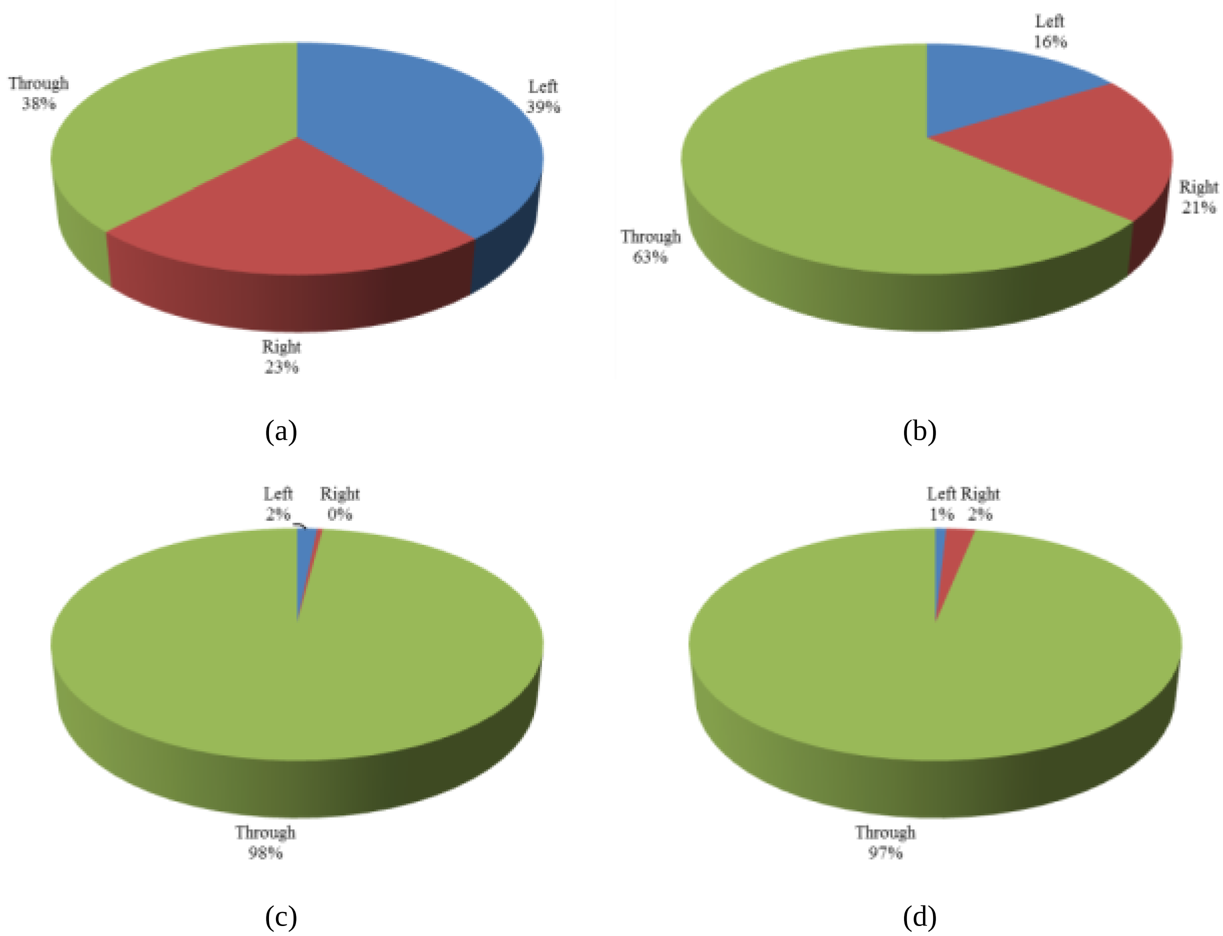


Figure 30. Turning movements at 75th Street and Conser Street for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 30, approximately 60 percent of northbound traffic turned onto 75th Street (in either direction), whereas approximately 30 percent of southbound traffic turned onto 75th Street. In total, there were 20,629 vehicles counted at this intersection. Right-turning vehicles comprised of approximately three percent of the total number of vehicles observed, four percent were left turns, and 93 percent went straight through the intersection.

79th Street and Metcalf Avenue

The intersection of 79th Street and Metcalf Avenue was chosen as a spillover site for the treatment intersections of 75th Street and Metcalf Avenue. This intersection was located in a commercial area. There was a bank at the northwest corner and commercial businesses at all the other corners of the intersection. Figure 31 shows an aerial view of the intersection.

Figure 31. 79th Street and Metcalf Avenue (aerial image, Google Earth, 2013)

As shown in Figure 31, it was found that for northbound traffic along Metcalf Avenue there was a left turn lane, a through lane, and a shared right turn/through lane. For the southbound approach there was a left turn lane, a right turn lane, and two through lanes. The posted speed limit along Metcalf Avenue was 35 mph. The posted speed limit for the westbound approach of 79th Street was 30 mph, and for the eastbound approach the posted speed limit was 20 mph. For westbound traffic there was a left turn lane and a shared through/right turn lane. Eastbound traffic had a left turn lane, a through lane, and a right turn lane. The clearance path for traffic on 79th Street was 110 feet, and 91 feet for traffic on Metcalf Avenue. All approaches had protected/permitted left turn movements, and no protected right turns. There were three overhead signals and one signal on the mast for the northbound and southbound movements. For the eastbound and westbound movements there were overhead signals and one signal on the pole. It was also found that all overhead signals have backplates. The morning and evening peak hour cycle length was 140 seconds and only the northbound and southbound phases were coordinated. Table 8 shows the yellow phase and all-red phase times per approach in seconds.

Table 8. 79th Street and Metcalf Avenue Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	3.7	1.7
Northbound Left Turn	3.2	2.1
Southbound	3.7	1.7
Southbound Left Turn	3.3	2.3
Eastbound	3.1	2.9
Eastbound Left Turn	3	2.3
Westbound	3.1	2.9
Westbound Left Turn	3.1	2

As shown in Table 8, the timings for all approaches were within the recommendations and guidelines found in the literature review and the MUTCD. The northbound and southbound approaches had close to four seconds of yellow, which was the longest yellow time for the entire intersection. This could be in part because the majority of traffic at this intersection travels along Metcalf Avenue. Figure 32 shows the volumes recorded during the study.

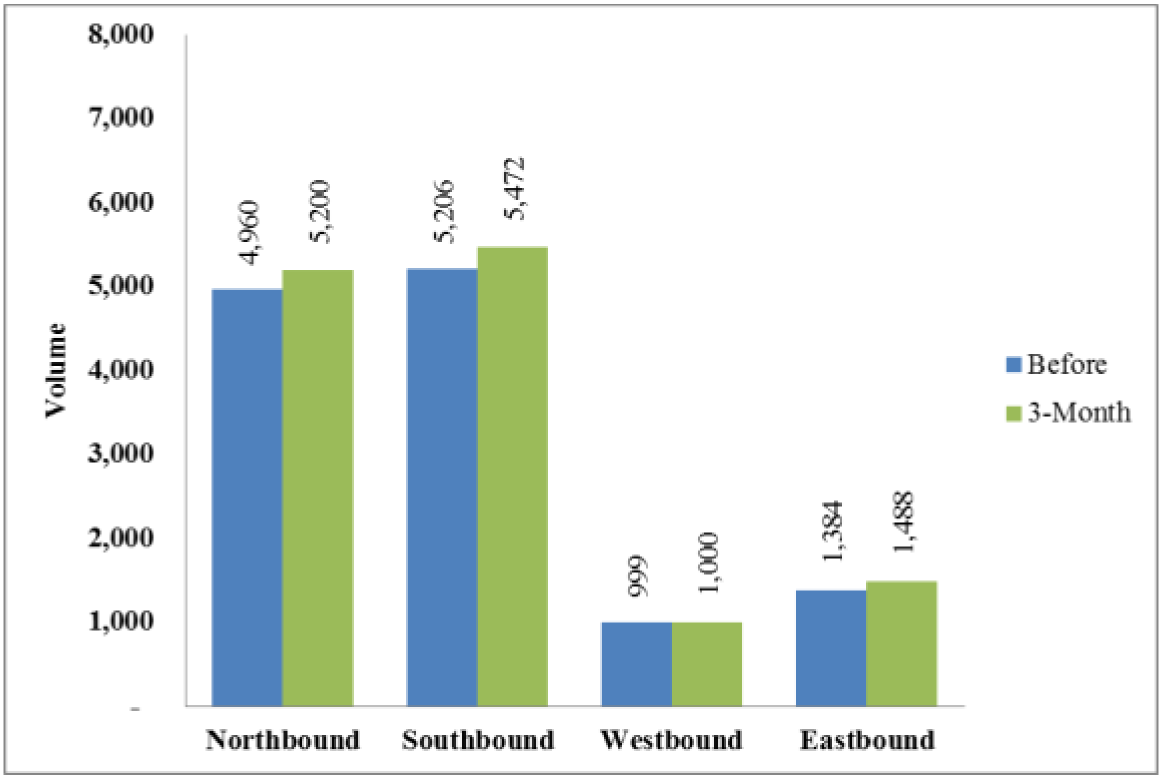


Figure 32. Total volumes for 79th Street and Metcalf Avenue

As shown in Figure 32, traffic volumes at this intersection were recorded using the intersection vehicle detector cameras. Video data were obtained for the before and three-month after periods of the study. For the before period, the City of Overland Park was able to record all approaches on the same day. For the three-month after period, traffic along Metcalf Avenue (in both directions) were recorded on the same day and the eastbound approach was recorded on October

29th, and the westbound approach was recorded on the 5th November. Also shown in Figure 31 was that the majority of the observed traffic volumes traveled along Metcalf Avenue.

For all periods of the study, it was observed that traffic volume would increase by approximately 1,300 from the morning peak to the evening peak. Figure 33 shows the turning movements observed at the intersection.

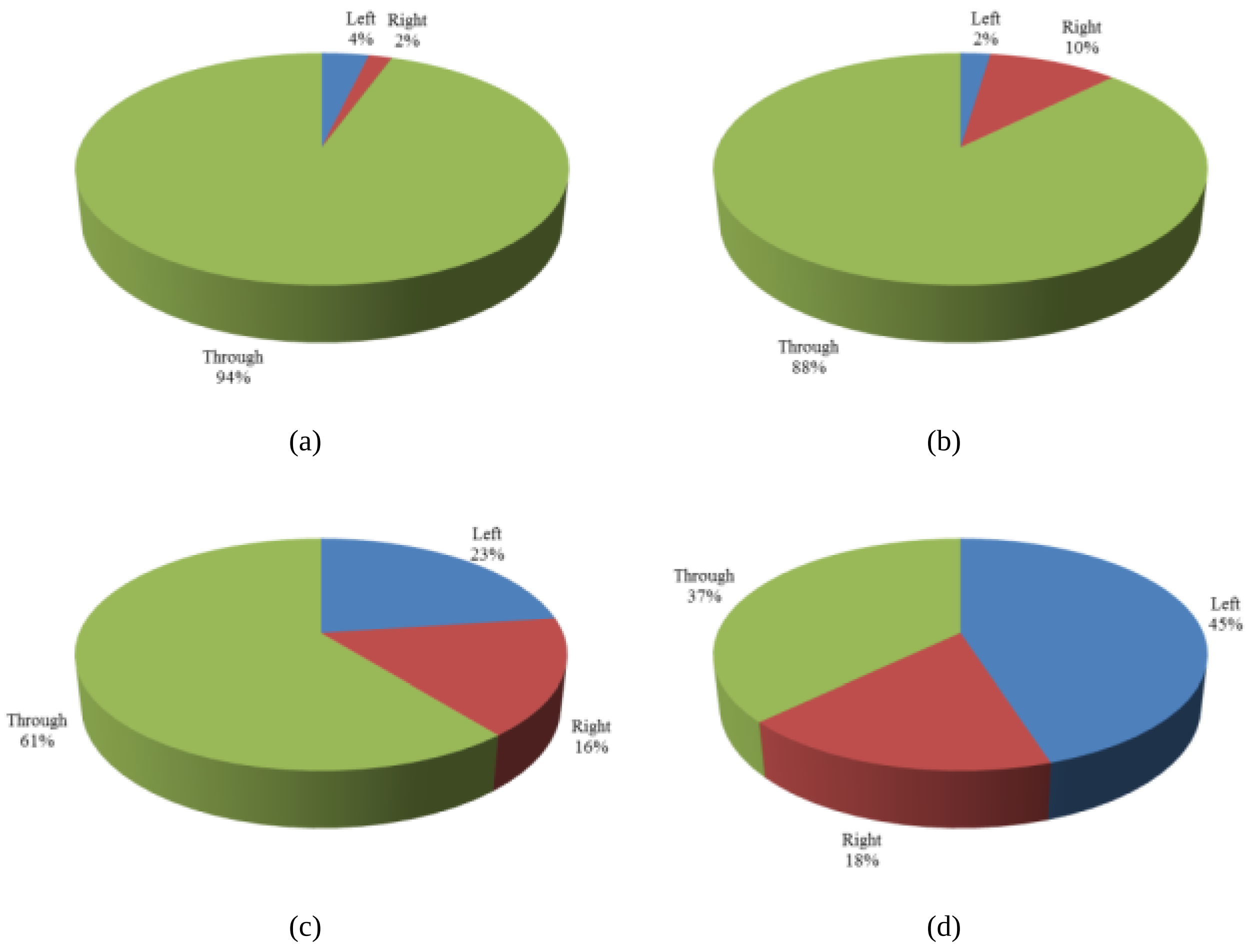


Figure 33. Turning movements at 79th Street and Metcalf Avenue for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 33, the turning movement volume percentages for all study periods were combined and graphed for each approach. Over 90 percent of the northbound traffic traveled through the intersection and over 85 percent of traffic traveled through the intersection for the southbound approach. More than 60 percent of westbound traffic traveled through the intersection while 45 percent of eastbound traffic turned left onto Metcalf Avenue. The eastbound and westbound traffic were found to have the highest volumes of left-turning vehicles, and the southbound and eastbound were found to have the highest volume of right-turning vehicles. A total of 25,709 vehicles were observed, with vehicles making a right or left turn represented less than 10 percent of traffic, respectively.

119th Street and Quivira Road

The intersection of 119th Street and Quivira Road was chosen as a spill-over site for the intersection of College Boulevard and Quivira Road. The land use around the intersection was mixed. There were apartment buildings at the northeast corner, and commercial businesses at the west side of the intersection. There was no development on the southeast corner. The posted speed limit for 119th Street and Quivira Road was 45 mph. The eastbound, westbound and southbound approaches had two left turn lanes, two through lanes, and one right turn lane. The northbound approach had one left turn lane, two through lanes, and a shared through/right turn movement lane. Figure 34 shows an aerial picture of this intersection.

Figure 34. 119th Street and Quivira Road (aerial image, Google Earth, 2013)

As show in Figure 34, the clearance path was 135 feet for traffic on Quivira Road and 130 feet for traffic on 119th Street. The intersection had a signal head per travel lane for all approaches. Additionally, all overhead signal heads have backplates. There were protected right turns for the southbound and eastbound approaches, and all left turn movements were protected only. Table 9 shows the yellow and all-red phase signal timing in seconds.

Table 9. 119th Street and Quivira Road Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	4.3	1.9
Northbound Left Turn	3.2	3
Southbound	4.3	1.9
Southbound Left Turn	3.2	3.1
Eastbound	4.3	1.9
Eastbound Left Turn	3.2	3
Westbound	4.3	1.9
Westbound Left Turn	3.2	3

It was found that there were no coordinated phases at this intersection or a set peak hour timing cycle. All values for the yellow and all-red timing phases were within the values recommended by researchers and the MUTCD. Figure 35 shows the combined morning and evening peak hour volumes observed during all periods of the study for the intersection.

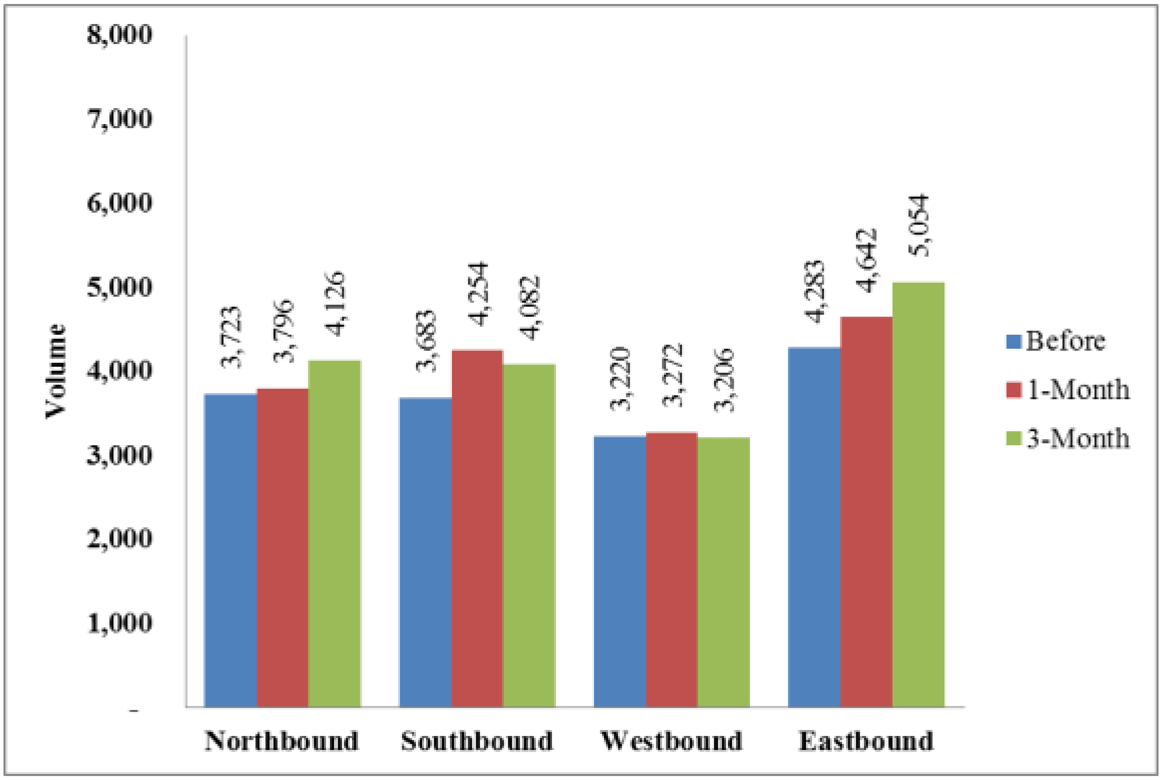
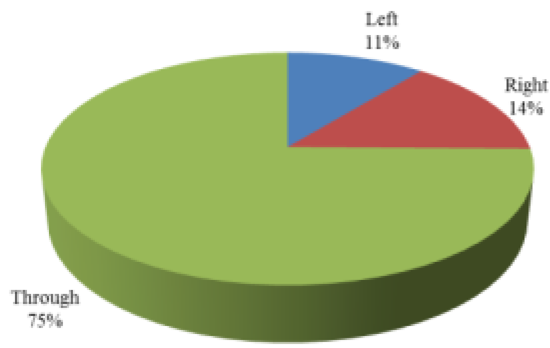


Figure 35. Total volumes for 119th Street and Quivira Road

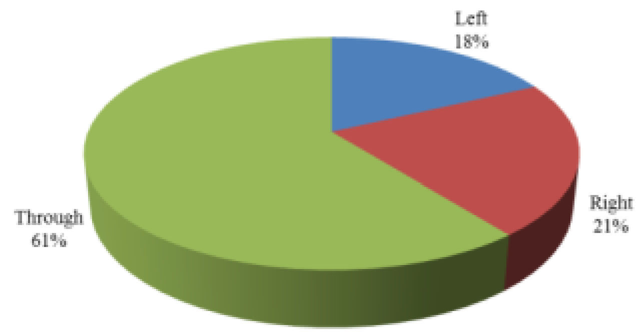
As shown in Figure 35, it was found that similar volumes were observed for all approaches for the intersection of 119th Street and on Quivira Road. For 119th Street, approximately 55 percent of the total volume was found to be for the eastbound approach. It was observed for the three-month after period of the study that the highest volume was the eastbound approach. Traffic along Quivira Road was split evenly between the northbound and southbound approaches.

The evening peak hours was found to have higher volume counts than the morning peak hours. Approximately 57 percent of the total volume was observed during the evening peak.

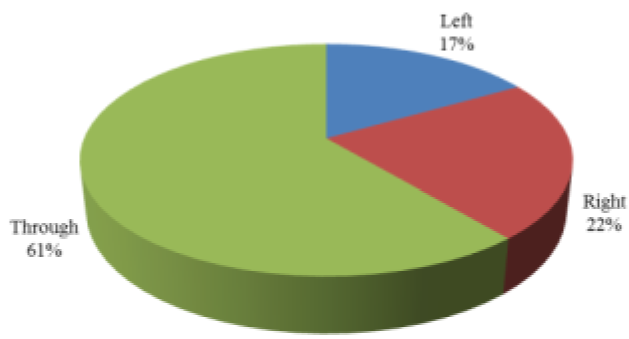
Figure 36 shows the turning movements for each approach of the intersection.



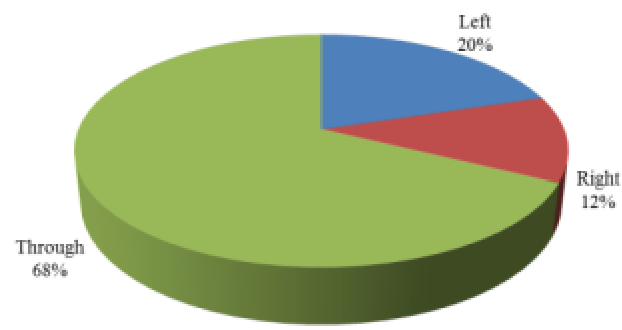
(a)



(b)



(c)



(d)

Figure 36. Turning movements at 119th Street and Quivira Road for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 36, the eastbound and southbound approaches were found to have the highest volume of left-turning vehicles at the intersection. The southbound and the westbound approaches were found to have the highest volume of right-turning vehicles. A significant percentage of the traffic was found to traverse through the intersection at all approaches. In total, approximately 47,341 vehicles were counted. Approximately 60 percent of the total number of vehicles observed traversed through the intersection, 16.6 percent of the vehicles turned left, and 17.1 percent of vehicles made a right turn.

College Boulevard and Nieman Road

The intersection of College Boulevard and Nieman Road was chosen as a spill-over site for the treatment intersection of College and Quivira. This intersection was in a mainly residential area. There were private residencies in the northeast and southwest corners of the intersection. There was a church and a preschool at the northwest corner. There was no development at the southeast corner. The posted speed limit along Nieman Road was 30 mph while the posted speed limit along College Boulevard was 45 mph. Figure 37 shows an aerial photo of the intersection.

Figure 37. College Boulevard and Nieman Road (aerial image, Google Earth, 2013)

As shown in Figure 37, the northbound traffic along Nieman Road has one lane per movement. For southbound traffic there was one left turn lane, and one right turn/through movement lane. Along College Boulevard the eastbound approach had three through lanes, one right turn lane, and one left turn lane. The clearance path for traffic along Nieman Road was 138 feet, and 145 feet for traffic on College Boulevard. The northbound movement had a protected right turn and the left turns for northbound and southbound were permitted. Left turns lanes for eastbound and westbound approaches were protected only. There were two signal heads for the northbound and southbound approaches, one overhead and one on the pole. For the westbound approach there were two signal heads for the left turn movement, two overhead signal heads for through movements and one signal head on the pole. The eastbound approach had one signal head for the left turn movement, two for through movements, and one on the pole. All overhead signals had backplates. Table 10 shows the all-red and yellow phase signal timing in seconds.

Table 10. College Boulevard and Nieman Road Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	3.6	3.2
Northbound Left Turn	NA	NA
Southbound	3.6	3.2
Southbound Left Turn	NA	NA
Eastbound	4.8	1.9
Eastbound Left Turn	3.5	2.7
Westbound	4.8	1.9
Westbound Left Turn	3	3.1

The eastbound and westbound approaches were coordinated. The morning peak hour cycle length was 120 seconds, and the evening peak hour cycle length was140 seconds. The eastbound and westbound through movements have almost five seconds of yellow phase time. All phase times were within the recommendations found in the literature review and the MUTCD. Video data were provided for traffic along College Boulevard only. The observed volumes for the westbound and eastbound approaches are shown in Figure 38.

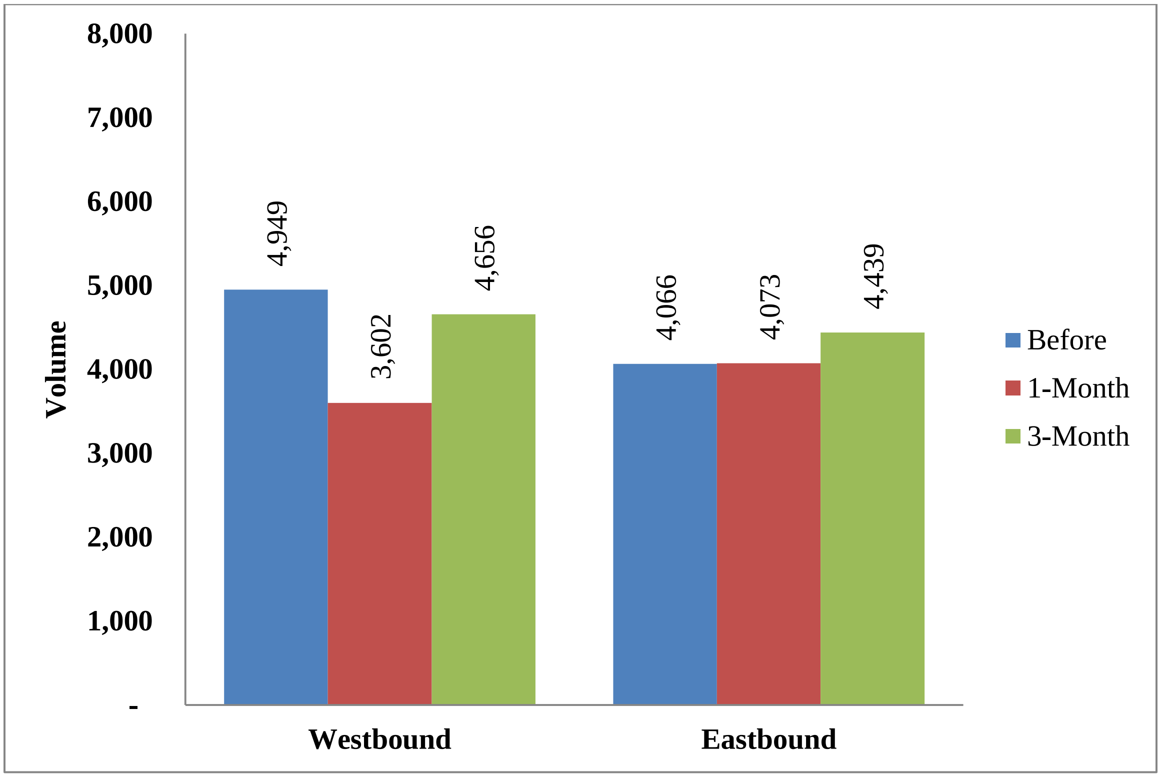
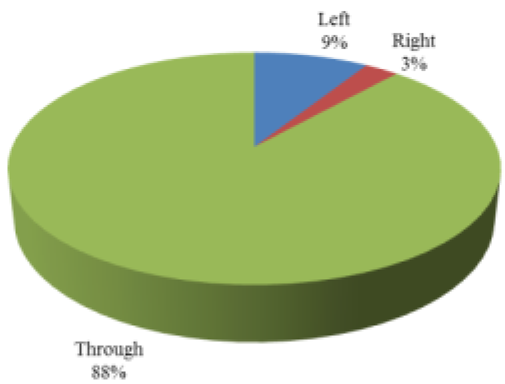
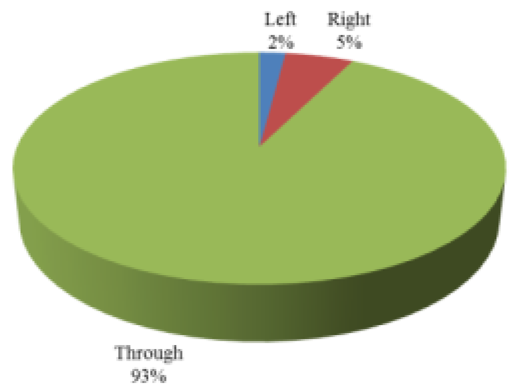


Figure 38. Total volumes for College Boulevard and Nieman Road

During the before period and the one-month after period of the study the approaches were recorded on different days. For the three-month after period both approaches were recorded on the same day. Over 9,000 vehicles were observed during the before and three-month after period of the study. The one-month had a total volume of 7,675 vehicles. Approximately 58 percent of the total volume was observed during the evening peak hours. The turning movements for the observed traffic along College Boulevard are shown in Figure 39.



(a)



(b)

Figure 39. Turning movements at College Boulevard and Nieman Road for (a) westbound (b) eastbound

As shown in Figure 39, the percentage of vehicles for each movement was calculated from the total volume between all three study periods. A majority of observed traffic traveled through the intersection, which was expected. The westbound approach was found to have the highest percentage of left-turning vehicles, and the eastbound was found to have the highest percentage of right-turning vehicles. In total, there were a total of 25,873 vehicles that traveled along College Boulevard. Left-turning vehicles represented 5.6 percent of the total observed traffic at the intersection; right-turning vehicles comprised of four percent, and through movements comprised 90.4 percent.

<u>College Boulevard and Pflumm Road</u>

The intersection of College Boulevard and Pflumm Road was a spill-over site for the intersection of College Boulevard and Quivira Road. The land use at this intersection was mixed between residential and commercial. There were residencies in the northwest and southeast corners of the intersection and commercial businesses in the southwest and northeast corners. The posted speed limit for all approaches was 45 mph and approaches had two left turn lanes, two through lanes, and a right turn lane. Figure 40 shows an aerial view of the intersection.

Figure 40. College Boulevard and Pflumm Road (aerial image, Google Earth, 2013)

The clearance path for Pflumm Road traffic was 145 feet, and 136 feet for College Boulevard traffic. There was one signal head per lane, all left turn movements were protected, and all approaches had protected right turns with all overhead signals having backplates. The eastbound and westbound cycles were coordinated. The morning hour cycle time was 120 seconds, and the evening peak hour cycle time was 140 seconds. Table 11 shows the yellow and all-red phase time in seconds for the intersection.

Table 11. College Boulevard and Pflumm Road Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	4.6	2.2
Northbound Left Turn	3.4	2.9
Southbound	4.6	2.2
Southbound Left Turn	3.3	2.8
Eastbound	4.4	1.9
Eastbound Left Turn	3.3	3
Westbound	4.4	1.9
Westbound Left Turn	3.2	2.9

As shown in Table 11, the northbound and southbound approaches had slightly longer yellow times as compared to the eastbound and westbound approaches. All values for yellow and all-red phase timing were within the guidelines and recommendations found in the literature review and MUTCD. Figure 41 shows the combined morning and evening peak hour volumes for each approach and combined study periods.

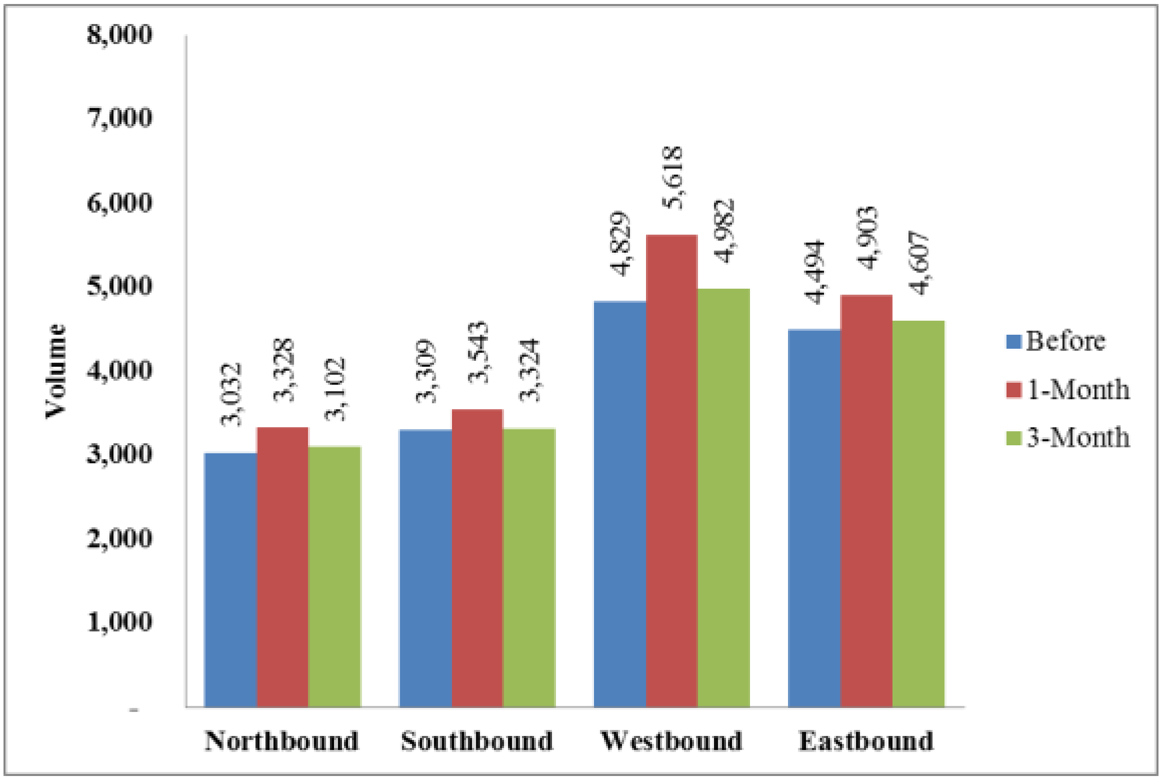


Figure 41. Total volumes for College Boulevard and Pflumm Road

For the before period, traffic data for the morning peak hour were recorded on different days as the evening peak hour. For the one-month and three-month after period, all approaches were recorded on the same day. As shown in Figure 41, the westbound and eastbound traffic were found to account for 60 percent of the total volume observed at the intersection. The one-month after period had the highest volume recorded for each approach as compared to all other periods. The evening peak accounted for approximately 54 percent of the total vehicular volume observed. Figure 42 illustrates the turning movements observed for the combined peak hours.

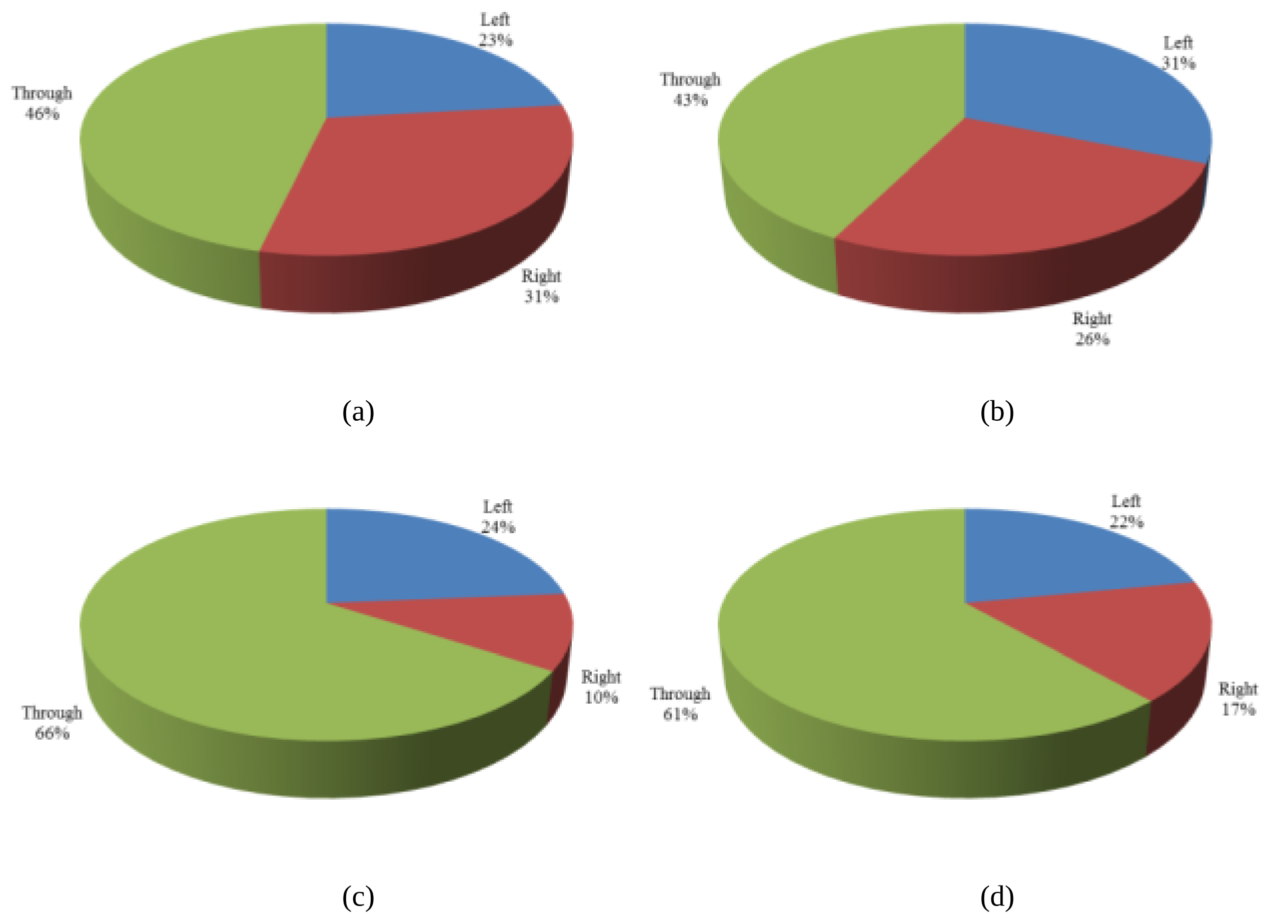


Figure 42. Turning movements at College Boulevard and Pflumm Road for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 42, less than half of the recorded traffic traversed through the intersection for the northbound and southbound approaches. Traffic turning off of Pflumm Road was found to predominantly travel eastbound on College Boulevard. The northbound approach was found to have the highest number and percentage of vehicles making a right turn when at the intersection. The southbound approach was found to have about 30 percent of the traffic turn left. However, it was found that the westbound approach had the highest volume of left-turning vehicles onto College Boulevard. It was also found that over 60 percent of vehicles along College Boulevard traversed through the intersection, and a large number of vehicles turned off of College Boulevard and proceeded southbound on Pflumm Road. A total of 49,071 vehicles were observed during all study periods. Vehicles making a left turn were found to be approximately 25 percent of the total volume counted and vehicles making a right turn accounted for approximately 19 percent.

3.3.3 Control Sites

The intersections of 95th Street and Metcalf Avenue, College Boulevard and Antioch Road, College Boulevard and Nall Avenue, 103rd Street and Antioch Road, 95th Street and Antioch Road, and 103rd Street and Metcalf Avenue were used as control sites for this study. Vehicle data were recorded by the City of Overland Park for all three study periods using the overhead vehicle detection cameras at the intersections of 95th Street and Metcalf Avenue, College Boulevard and Antioch Road, and College Boulevard and Nall Avenue. Additionally, the control intersections of 103rd Street and Antioch Road, 95th Street and Antioch Road, and 103rd Street and Metcalf Avenue were recorded in the field. The following sections explain in the detail these selected control intersections.

95th Street and Metcalf Avenue

Metcalf Avenue was the northbound and southbound approaches, and 95th Street was the eastbound and westbound approaches for this intersection. The intersection was located in a commercial business area of town. There were office buildings in the northwest corner, and commercial businesses in all other corners of the intersection. The posted speed limit on Metcalf Avenue was 45 mph, while 95th Street had a posted speed limit 35 mph.

The northbound and southbound approaches of Metcalf Avenue had three through lanes, and two left lanes, there was no right-turning lanes. The eastbound and westbound approaches of 95th Street had two left turn lanes, two through lanes, and one right-turning lane. Figure 43 shows an aerial view of the intersection.

Figure 43. 95th Street and Metcalf Avenue (aerial image, Google Earth, 2013)

The clearance path for the northbound and southbound approaches was 145 feet. For the eastbound and westbound approaches the clearance path was 150 feet. For the eastbound and westbound approaches there was one signal head per lane. There was a total of 12 signal heads, six per approach, a signal head mounted on the pole, and there was a signal head on the southeast corner and the northwest corners for the right-turning vehicles. Figure 44 shows the signal lights for all approaches.

(a) (b)

(c) (d)

Figure 44. 95th and Metcalf (a) eastbound (b) westbound (c) eastbound stop line alignment (d) southbound

For the westbound and eastbound approaches there were no U-turns allowed for left-turning vehicles and both approaches had protected right turns. The stop line for the left turns in the eastbound and westbound directions were approximately 28 feet back from the near-side line of the crosswalk. For the northbound and southbound approaches there were six signal heads per approach, five on the main mast arm and pole, and one on the near side of the intersection. There were no protected right-turning movements for either approach along Metcalf Avenue and U-turns were prohibited. Left-turning movements were protected for all approaches. All overhead signal heads mounted on the mast arm had back plates. Only the northbound and southbound approaches had coordinated phases, and the morning and evening peak hour cycle length was 140 seconds. Table 12 shows the yellow and all-red times in seconds for the intersection.

Table 12. 95th Street and Metcalf Avenue Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	4.3	2
Northbound Left Turn	3.1	3.4
Southbound	4.3	2
Southbound Left Turn	3.2	3.1
Eastbound	3.8	3
Eastbound Left Turn	3	3.2
Westbound	3.8	3
Westbound Left Turn	3.4	3.4

As shown in Table 12, all values for yellow phase and all-red phase were within the recommendations found during the literature review and MUTCD. Traffic moving along Metcalf Avenue was found to have the longest yellow phase time, and the shortest time for all-red for the through movement. The westbound left-turning movement had the longest yellow time and all-red phase time out of all left-turning movements. The combined study period vehicular volumes are shown in Figure 45.

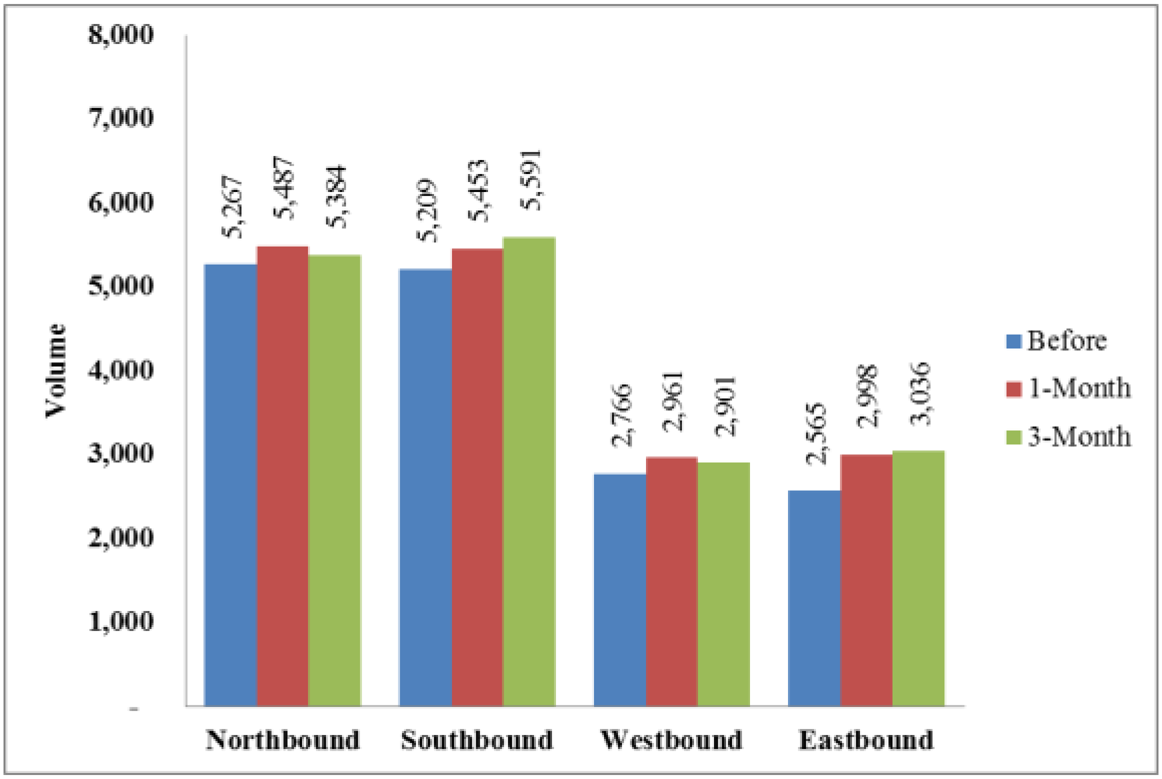


Figure 45. Total volumes for 95th Street and Metcalf Avenue

The before and the one-month study period vehicle data along 95th Street were recorded on a different days than the data collected on Metcalf Avenue. All approaches were recorded on the same day for the three-month after period. Metcalf Avenue was found to have a majority of the traffic volume during all periods of the study. Nearly 60 percent of the total volume observed were vehicles traversing through or turning at the intersection from Metcalf Avenue. The evening peak period was when 59 percent of the total volume was observed. Figure 46 shows the turning movements in observed in terms of percentage.

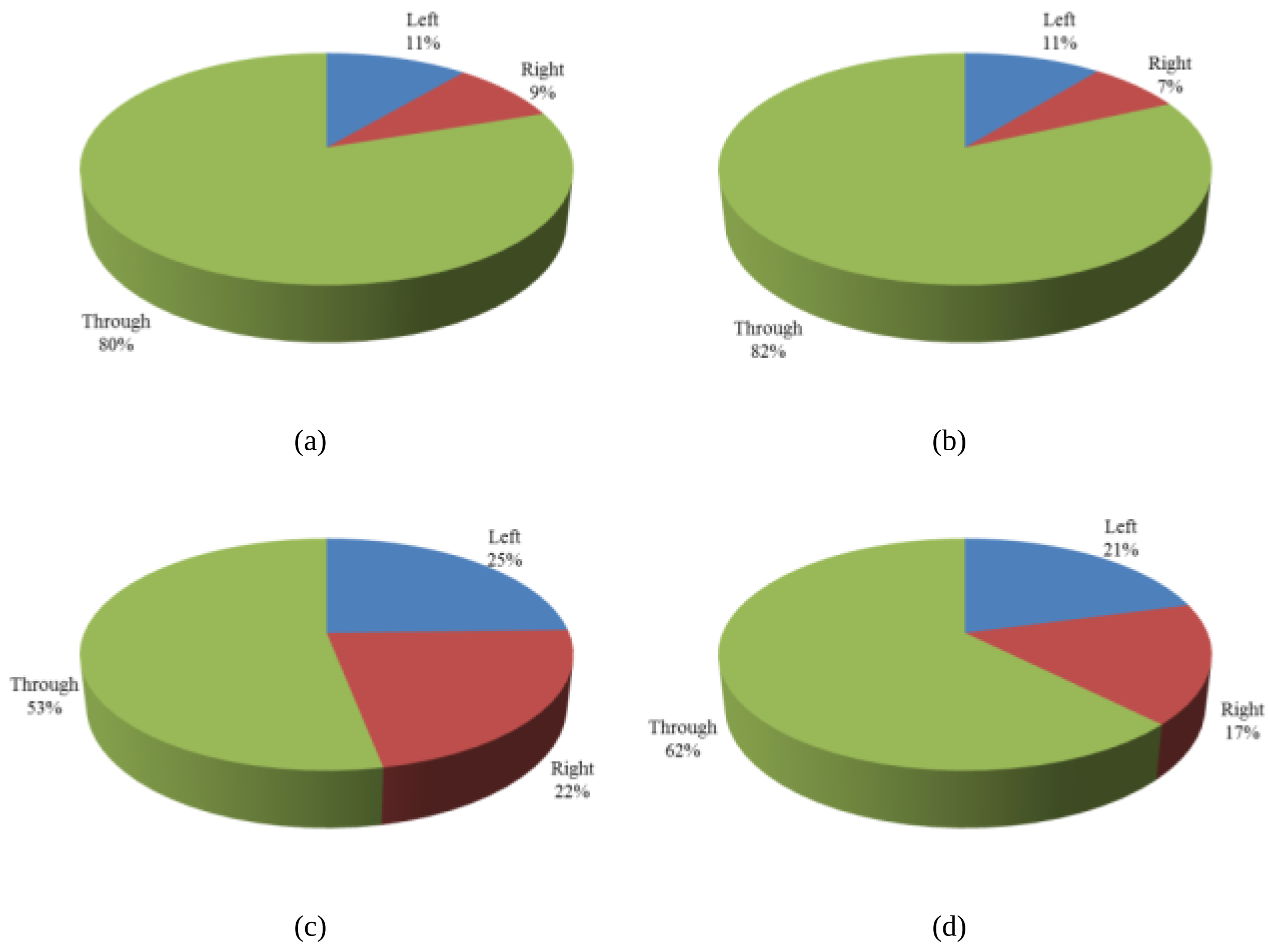


Figure 46. Turning movements at 95th Street and Metcalf Avenue for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

In terms of percentage there was little variability between periods, therefore the charts combined all periods of the study. As shown in Figure 46, approximately 80 percent of all traffic observed on Metcalf Avenue traversed through the intersection. When compared to traffic along 95th Street, Metcalf Avenue was found to have a low percentage of left and right-turning vehicles. However, both approaches were found to have over 1,100 vehicles making a right turn and over 1,700 vehicles making a left turn when combining all study periods. The westbound approach was found to have the highest percentage of turning vehicles compared to all other approaches. A total of 4,050 vehicles were found to turn left or right at the intersection, which was 47 percent of the total number of vehicle observed at this approach. In total, there was a combined 49,618 vehicles observed at all approaches. Left-turning vehicles comprised of 15 percent and right turns were 12 percent of the total volume observed.

College Boulevard and Nall Avenue

The intersection of College Boulevard and Nall Avenue was also selected as a control site. Office buildings, healthcare facilities, and hotels were within the vicinity of the intersection. The posted speed limit along College Boulevard was 45 mph. The north approach of Nall Avenue had a posted speed limit of 45 mph, while the south approach had a speed limit of 35 mph. Figure 47 shows an aerial view of the intersection.

Figure 47. College Boulevard and Nall Avenue (aerial image, Google Earth, 2013)

The eastbound and westbound approaches of College Boulevard had two left-turning lanes, two through lanes and a right-turning lane. The northbound and southbound approaches of Nall Avenue had three through lanes, two left-turning lanes, and a right-turning lane. All approaches had protected left-turning and protected right-turning movements. The clearance path for traffic on Nall Avenue was 155 feet and 175 feet for traffic on College Boulevard. The morning peak cycle length was 120 seconds, and the evening peak hour cycle length was 140 seconds. The northbound and the southbound approaches were coordinated. Table 13 shows the phase time in seconds for yellow and all-red.

Table 13 College Boulevard and Nall Avenue Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	4.4	2.2
Northbound Left Turn	3.2	3.1
Southbound	4.4	2.2
Southbound Left Turn	3.3	3
Eastbound	5.1	2.4
Eastbound Left Turn	3.7	3.2
Westbound	5.1	2.4
Westbound Left Turn	3	3.3

As shown in Table 13, the times shown for yellow phase and all-red phase were within the recommendations found during the literature review and MUTCD. The eastbound and westbound approaches along College Boulevard had the longest yellow phase time out of all approaches and movements with 5.1 seconds. Figure 48 shows the traffic volumes observed during all periods of the study.

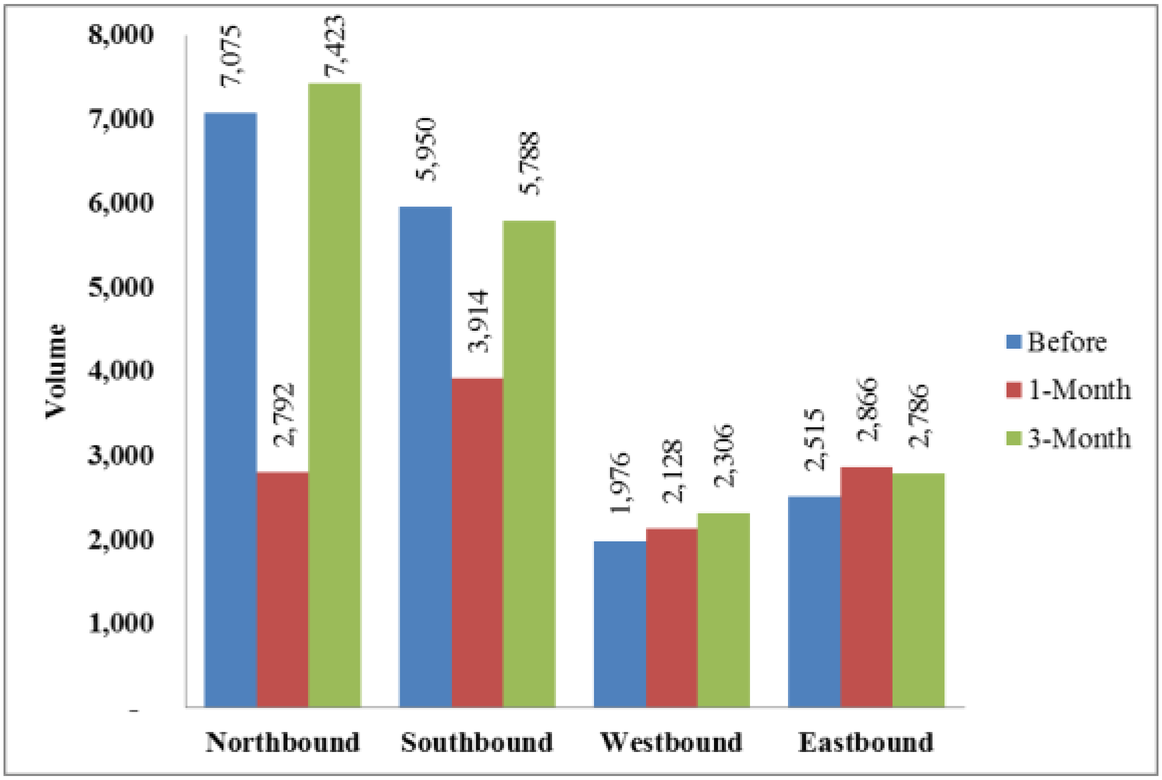


Figure 48. Total volumes for College Boulevard and Nall Avenue

Vehicle data were collected by the City of Overland Park using overhead vehicle detection cameras. For the one-month after period, only the morning peak hour video was obtained for the northbound and southbound approaches. Additionally, the eastbound approach had one lane closed for the through movement due to construction during the one-month after period. The northbound and southbound approaches of Nall Avenue were found to have the highest volumes on all periods of the study with the exception of the one-month after period. Under normal traffic and recording conditions there was an increase observed in the evening peak volume compared to the morning peak. The turning movement volumes at the intersection are shown in Figure 49.

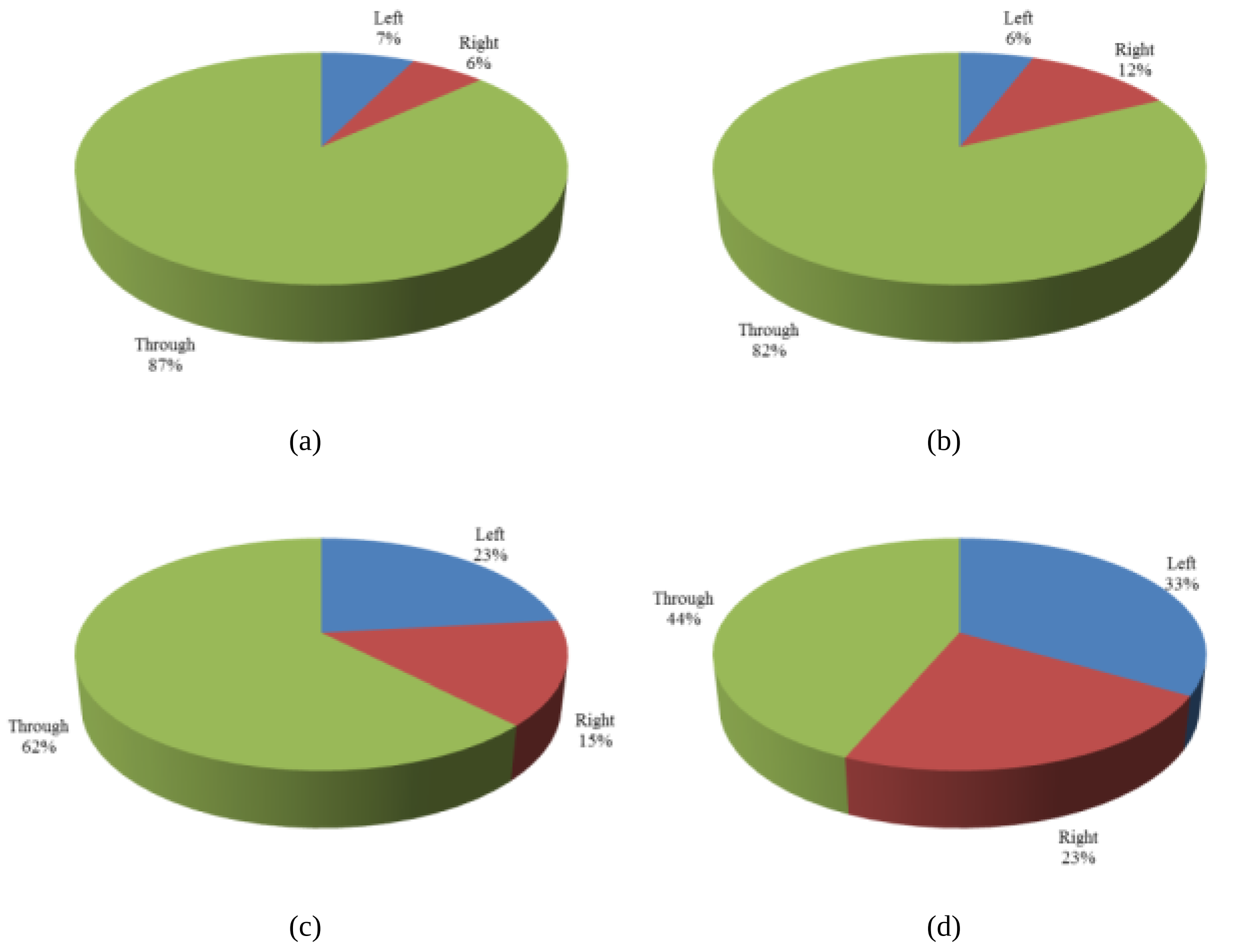


Figure 49. Turning movements at College Boulevard and Nall Avenue for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 49, over 80 percent of the observed traffic on Nall Avenue traveled through the intersection. Over half of the eastbound traffic observed on College Boulevard was found to turn onto Nall Avenue. Additionally, approximately 30 percent of the total volume observed for the eastbound approach made a left turn at the intersection, which was the highest volume of left turns movement as compared to all other approaches. The eastbound approach also had the highest percentage of vehicles making a right turn. In total, there were 47,519 vehicles recorded for all periods of the study. Left-turning vehicles represented approximately 13 percent of the total volume, right-turning vehicles represented 12 percent, and 75 percent of the vehicles observed traveled through the intersection.

College Boulevard and Antioch Road

College Boulevard and Antioch Road was selected as a control site. This intersection was located in a commercial area of town. The Corporate Woods Office Park was at the northwest corner, and commercial businesses were located at all other corners of the intersection. All intersection approaches had two left-turning lanes, three through lanes, and a right-turning lane. The posted speed limit for all approaches was 45 mph. Figure 50 shows an aerial view of the intersection.

Figure 50. College Boulevard and Antioch Road (aerial image, Google Earth, 2013)

It was found that the clearance path for the approaches on Antioch Road and College Boulevard was 164 feet. All approaches had four overhead signal heads and one on the pole, and a signal located on the nearside of the intersection for the right turn movement. Two signal heads were for left-turning traffic and the other three were for through and right turn movements. All approaches had protected right-turning and protected left-turning movements. Table 14 shows the time in seconds for yellow and all-red phase.

Table 14 College Boulevard and Antioch Road Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	4.3	2.4
Northbound Left Turn	3.2	3.3
Southbound	4.3	2.4
Southbound Left Turn	3.1	3.4
Eastbound	4.1	2.5
Eastbound Left Turn	3	3.2
Westbound	4.1	2.5
Westbound Left Turn	3.1	3.5

As shown in Table 14, the morning peak hour cycle length was 120 seconds, and the evening peak hour cycle length was 140 seconds. The yellow phase and all-red phase times were within the recommendations outlined in the literature review and MUTCD. The north and south phasing were coordinated. The volumes recorded for all periods of the study are shown in Figure 51.

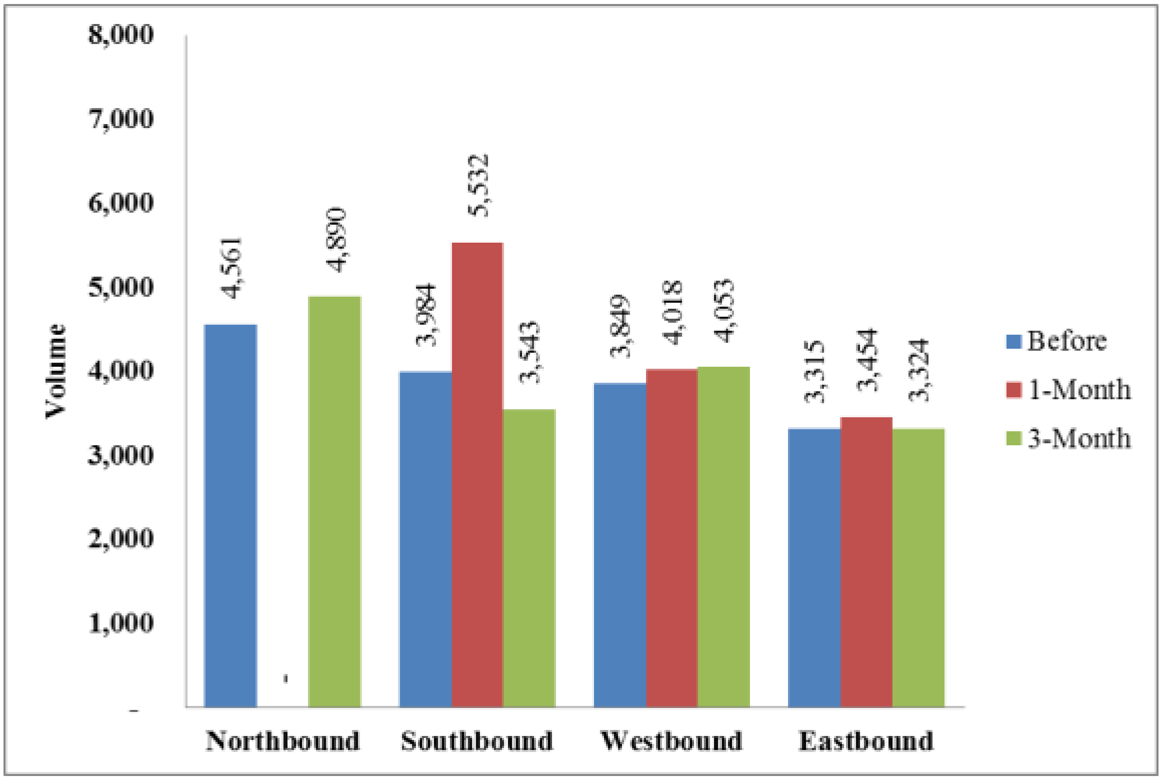


Figure 51. Total volumes for College Boulevard and Antioch Road

Video data were recorded by the City of Overland Park using overhead vehicle detection cameras. Video data were not obtained for the northbound approach during the one-month after period. The morning and evening peak hours were filmed on different days for all approaches, except the westbound approach for the before period. For the one-month after period the southbound, westbound, and eastbound approaches were recorded in different days. The northbound and southbound approaches were recorded on the same day, and the westbound and eastbound approaches were recorded on the same day for the three-month after period. Traffic at this intersection traveled along Antioch Road at this intersection. There was a considerable increase in observed volume during the one-month after studio period for the southbound approach, which was filmed on August 20th, 2013. It was found that during the one-month study, 3,119 out of the 5,532 vehicles traversed the intersection during the evening peak. Additionally, for the southbound approach during the three-month after period only one hour and ten minutes of traffic was recorded. Traffic counts were higher during the evening peak volume. From the total volume counts for all three periods, 57 percent was observed during the evening peak hours. Figure 52 illustrates the turning movement percentages.

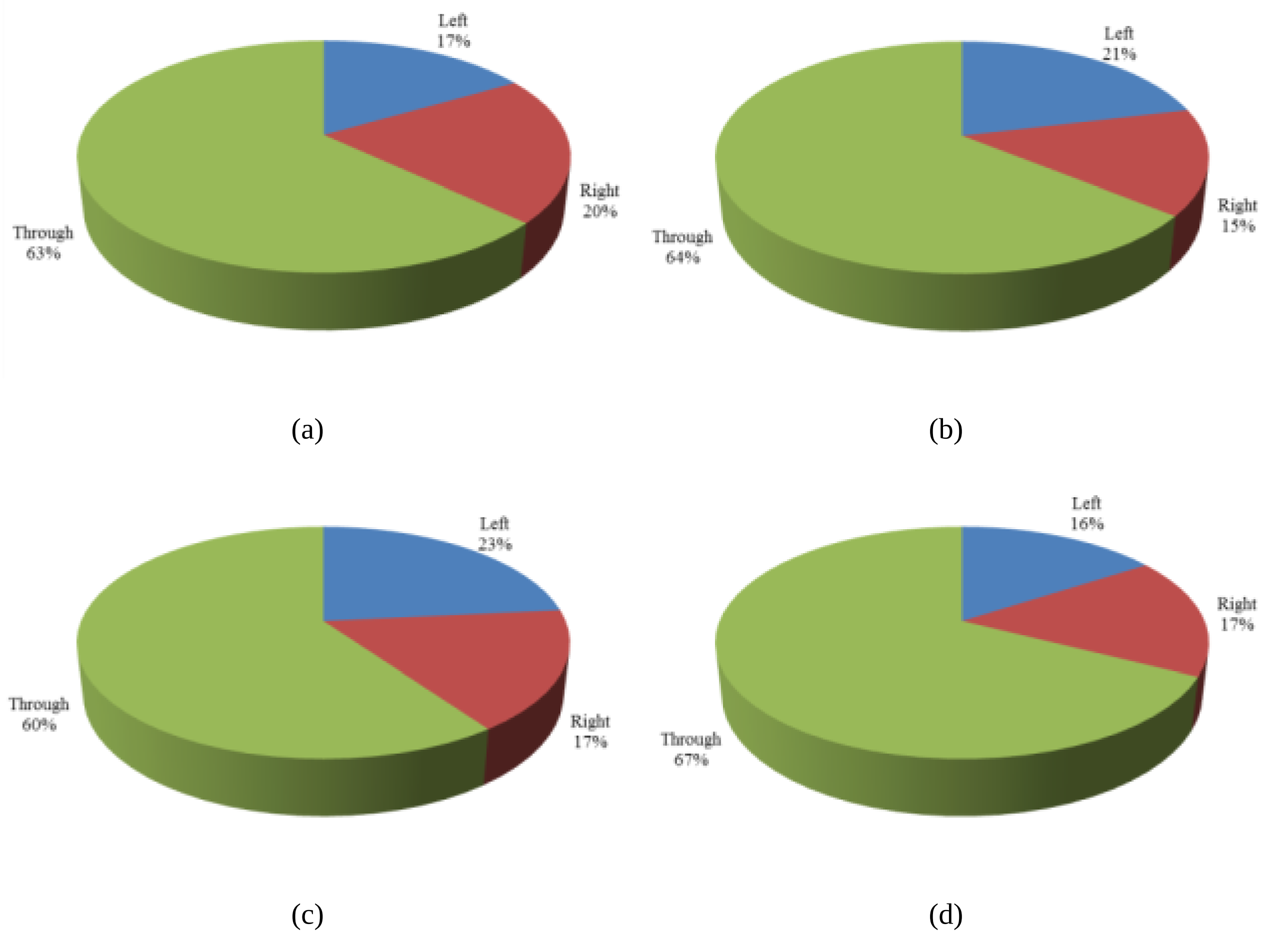


Figure 52. Turning movements at College Boulevard and Antioch Road for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 52, considering all approaches at the intersection, over 60 percent of the observed vehicles traversed through the intersection. It was found that between 15 and

20 percent of the observed traffic on all approaches made a right turn, and that 16 to 23 percent of the observed traffic made a left turn. Furthermore, the westbound approach had the highest percentage of turning vehicles out of all approaches. In total, there were 44,523 vehicles counted at this intersection. Left-turning vehicles accounted for 20 percent of the total volume and right-turning vehicles account for 17 percent of the total volume.

95th Street and Antioch Road

The intersection of 95th Street and Antioch Road was selected as a control site. The posted speed limit on 95th Street was recorded as 35 mph and the posted speed limit on Antioch road was recorded as 35 mph. There were no right-turning lanes at any of the approaches at this intersection. However, each approach had a left turn lane, a through lanes and a shared through/right turn lane. This intersection was located on a dense commercial area. At the south end of the intersection there were many commercial businesses, including Walgreens and another grocery store. At the time of data collection there was construction for a bank and other shops at the south end of the intersection. There was a gas station on the northwest corner, and a dentist office on the northeast corner of the intersection. Figure 53 shows an aerial view of the intersection.

Figure 53. 95th Street and Antioch Road (aerial image, Google Earth, 2013)

It was found that clearance path for the northbound and southbound approaches were approximately 105 feet and for the eastbound and westbound approaches was about 107 feet. For the northbound approach the left-turning movement was protected only, there were four signal heads, and no restrictions on U-turns. For the southbound approach, the left-turning movement was protected only. For eastbound approach there were four signal heads, protected left-turning movement, and no restrictions on U-turns. For the westbound approach the left-turning movement was protected, there were four signal heads and no restrictions on U-turns. The signal phases on Antioch Road were coordinated, and the cycle length for the morning peak hour was 120 seconds, and 140 seconds for the evening peak. Table 15 shows the yellow and all-red phase times in seconds for the intersection.

Table 15. 95th Street and Antioch Road Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	3.8	2.1
Northbound Left Turn	3	2.2
Southbound	3.8	2.1
Southbound Left Turn	3.4	2.3
Eastbound	3.6	2.1
Eastbound Left Turn	3.1	2.2
Westbound	3.6	2.1
Westbound Left Turn	3.2	2.2

As shown in Table 15, the yellow and all-red times were within the recommendations found in the literature review and MUTCD. Drivers traversing through the intersection on Antioch Road had the longest yellow time out of all approaches and movements in the intersection. The traffic volumes at the intersection are shown in Figure 54.

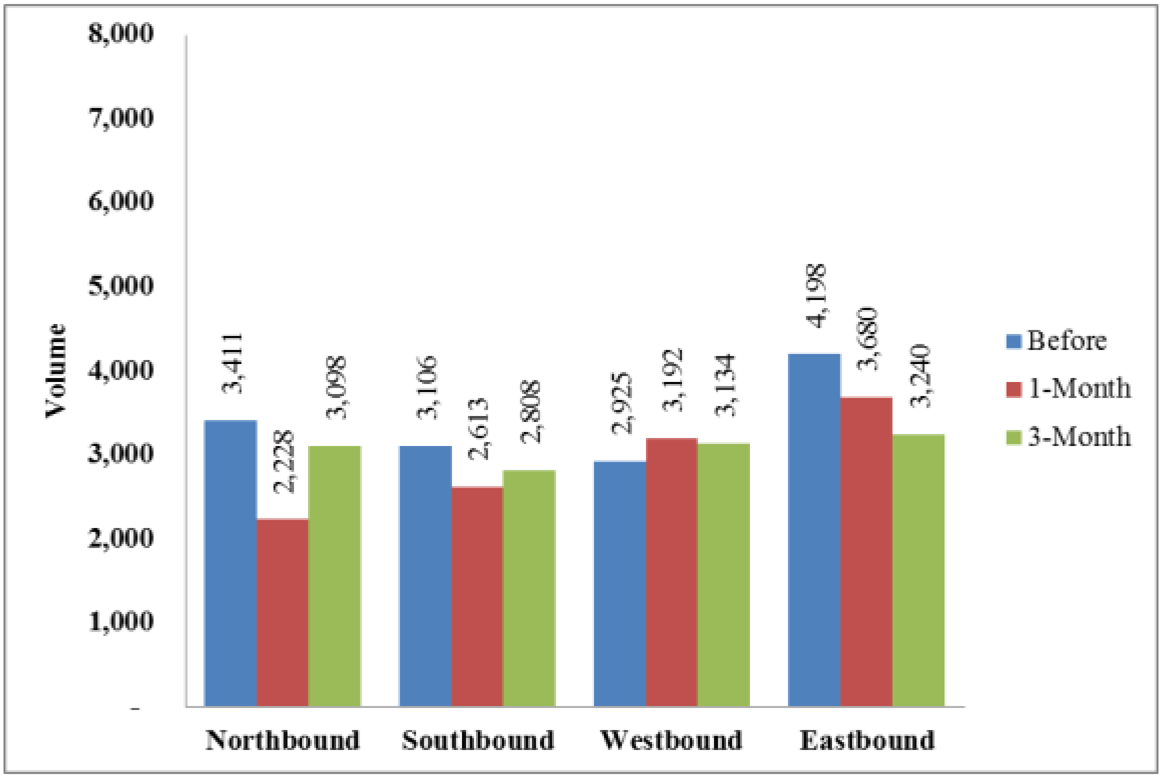


Figure 54. Total volumes for 95th Street and Antioch Road

Figure 54 shows the combined morning and evening peak hour volumes for each approach at each period of the study. Traffic was recorded by a researcher during the 23rd of May, 2013 for the before period, September 18th, 2013 for the one-month after period, and November 5th, 2013 for the three-month after period. For the northbound and southbound approaches during the one-month after study there was a work zone present at the time of the data recording. For the northbound approach traffic was guided to one through lane and one left turn lane. For the southbound approach, traffic operated on one lane, but this work zone was located upstream from the intersection. At the intersection all lanes operated as normal. Despite the presence of a work zone, the one-month after period had the highest volume count out of all other periods of the study. A significant portion of traffic observed was traveling along 95th Street. The highest volume for any period was observed during the before period at the eastbound approach. From the total volume count, 60 percent was observed during the evening peak hours. Figure 55 shows the turning movements at each approach. It should be noted that the percentages shown in Figure 55 have small differences between periods of the study. Since turning movements volumes are presented in terms of a percentage derived from the total volume observed from all three periods of the study.

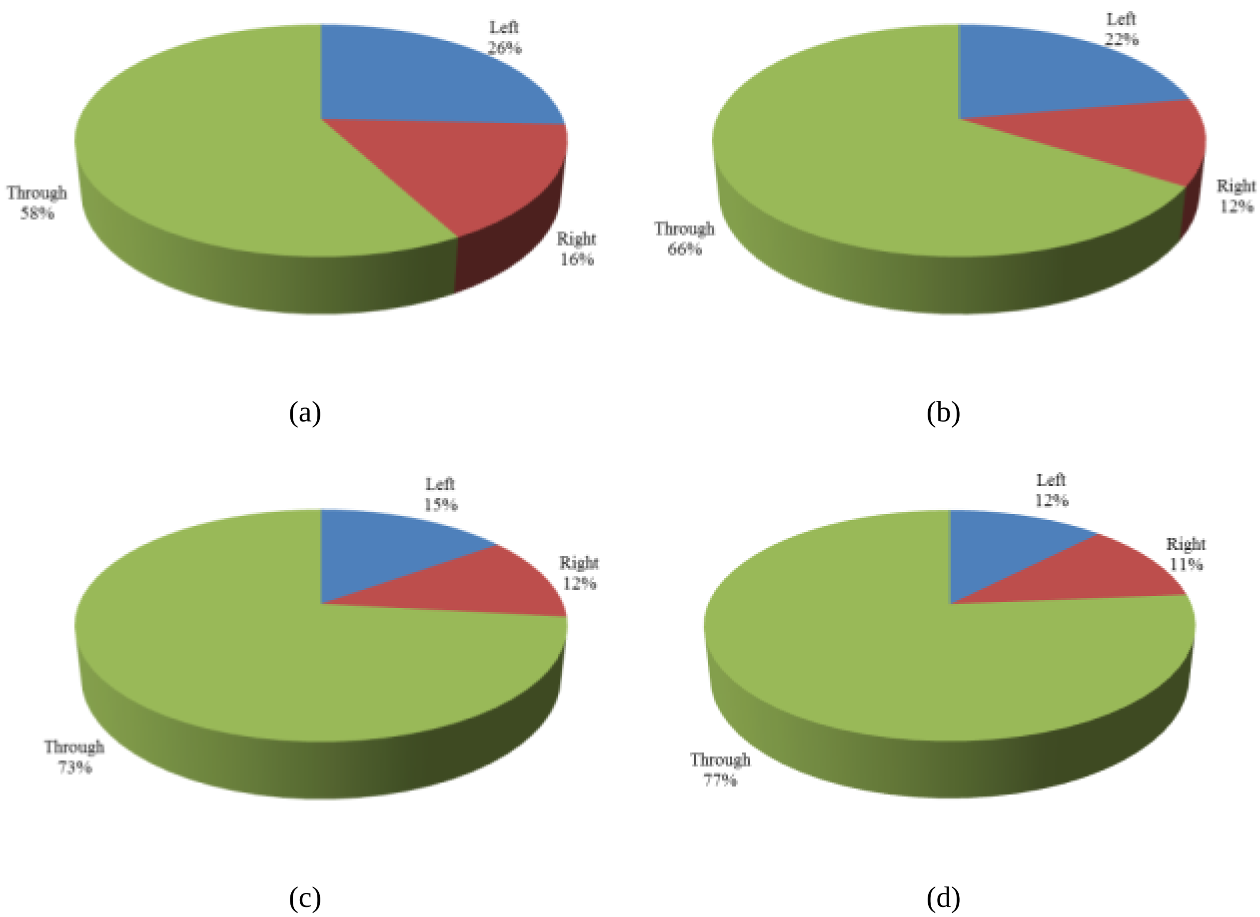


Figure 55. Turning movements at 95th Street and Antioch Road for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 55, a high percentage of traffic on Antioch Road traversed through the intersection. The northbound approach was found to have the highest percentage and the highest volume of left-turning vehicles. The eastbound approach was also found to have the highest observed volume turn right onto Antioch Road. It was also found that the westbound approach had nearly 75 percent of the observed volume travel through the intersection. There were a total of 37,633 vehicles counted at this intersection. Left-turning vehicles represented 18 percent and right-turning vehicles represented 13 percent of the total volume observed.

<u>103rd Street and Antioch Road</u>

The intersection of 103rd Street and Antioch Road was selected as a control site. For and southbound traffic on Antioch Road, the posted speed limit was 35 mph and for eastbound and westbound traffic on 103rd Street the posted speed limit was 40 mph. For the northbound and southbound approaches, there were two through lanes, one left-turning lane, and no right turn lanes. There were no U-turns allowed for the southbound traffic. The westbound approach had a right-turning lane, a left-turning lane, and two through lanes. There were no restrictions of movement for U-turns. The eastbound approach had one through lane, a shared through/right-turning lane, and one left-turning lane. There were no prohibited movements (e.g. U-turns) for eastbound traffic. Figure 56 shows an aerial view of the intersection.

Figure 56. 103rd Street and Antioch Road (aerial image, Google Earth, 2013)

The intersection was located in a residential area of town. There was a church in the southwest corner of the intersection, and housing in all other corners. As shown in Figure 56, the clearance path for vehicles on Antioch Road was approximately 100 feet, while for the eastbound and westbound approaches of 103rd Street the clearance path was 94 feet. For the westbound approach there was a protected right-turning signal, protected left-turning signal, and two through signals for a total four signals for this approach. All signal heads that were mounted on the mast have backplates. The signal on the pole had four aspects, with the fourth aspect corresponding to the protected right turn similar to the one noted at College Boulevard and Quivira Road. For the eastbound, the left-turning lane was protected and there was no signal for the right turn. There were four signals, one for left-turning lane and the rest for through movement. For the northbound approach there were two through lanes, a left-turning lane, and no right-turning lane. There was a bus stop by the southeast corner. There were four signal heads, no restrictions on U-turns, no protected right turn, and the left-turning movements were protected only. For the southbound approach there was a protected left-turning lane only, four signal heads, and no protected right-turning lane. Two through lanes and one left turn lane. The traffic signals at this intersection were not coordinated. Table 16 shows the yellow phase and all-red phase in seconds for all movements in the intersection.

Table 16. 103rd Street and Antioch Road Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	3.6	2
Northbound Left Turn	3.2	2.2
Southbound	3.6	2
Southbound Left Turn	3.2	2.1
Eastbound	4.1	1.7
Eastbound Left Turn	3.3	2.2
Westbound	4.1	1.7
Westbound Left Turn	3	2.1

As shown in Table 16, the values for the yellow and all-red phases were within the recommendations found in the literature review and the MUTCD. The westbound and eastbound approaches had the longest yellow times and the shortest all-red times out of all movements and approaches. The volumes observed at the intersection are shown in Figure 57.

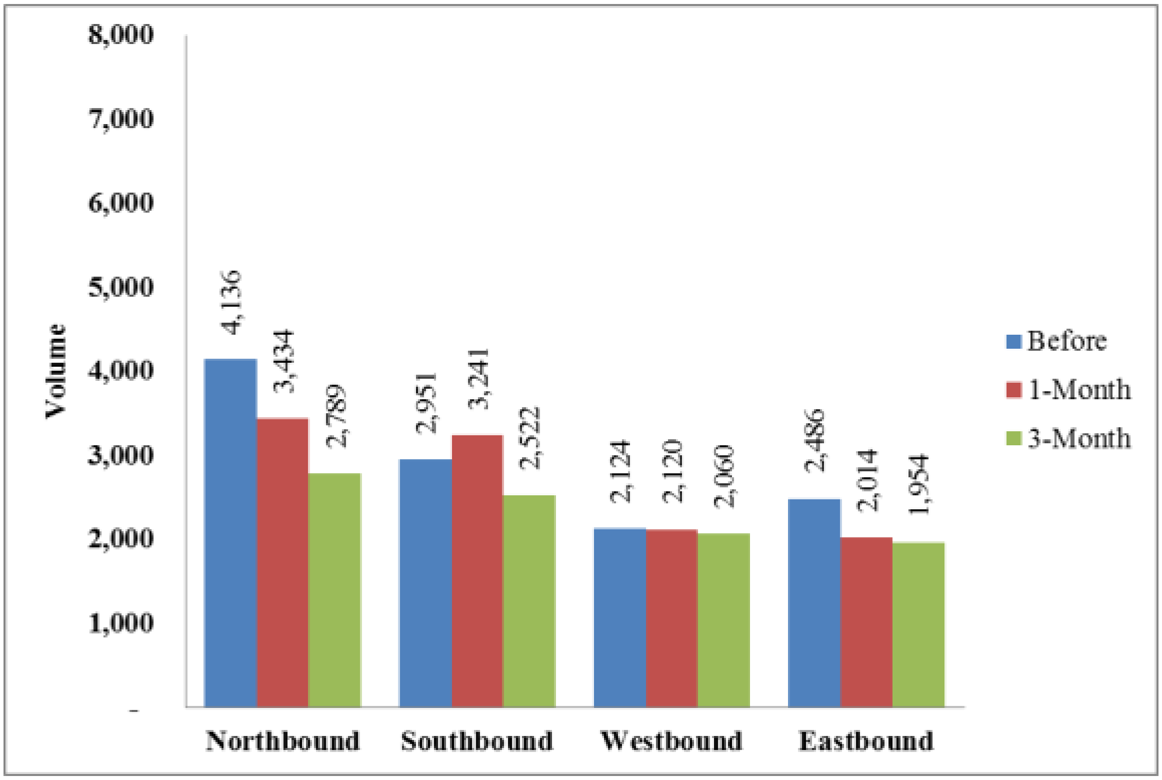


Figure 57. Total volumes for 103rd Street and Antioch Road

Figure 57 shows the morning and evening peak hour volumes for each approach during each study period. The intersection was recorded on the 22nd of May, 2013 for the before period, September 10th, 2013 for the one-month after period, and November 7th, 2013 for the three-month after period. It was found that a majority of traffic traveled along Antioch Road (northbound and southbound). For all periods of the study there was an increase in volume between the morning and evening peak periods. Furthermore, it was found that the before study period had the highest volume count out of all study periods. Figure 58 shows the turning movements for all approaches.

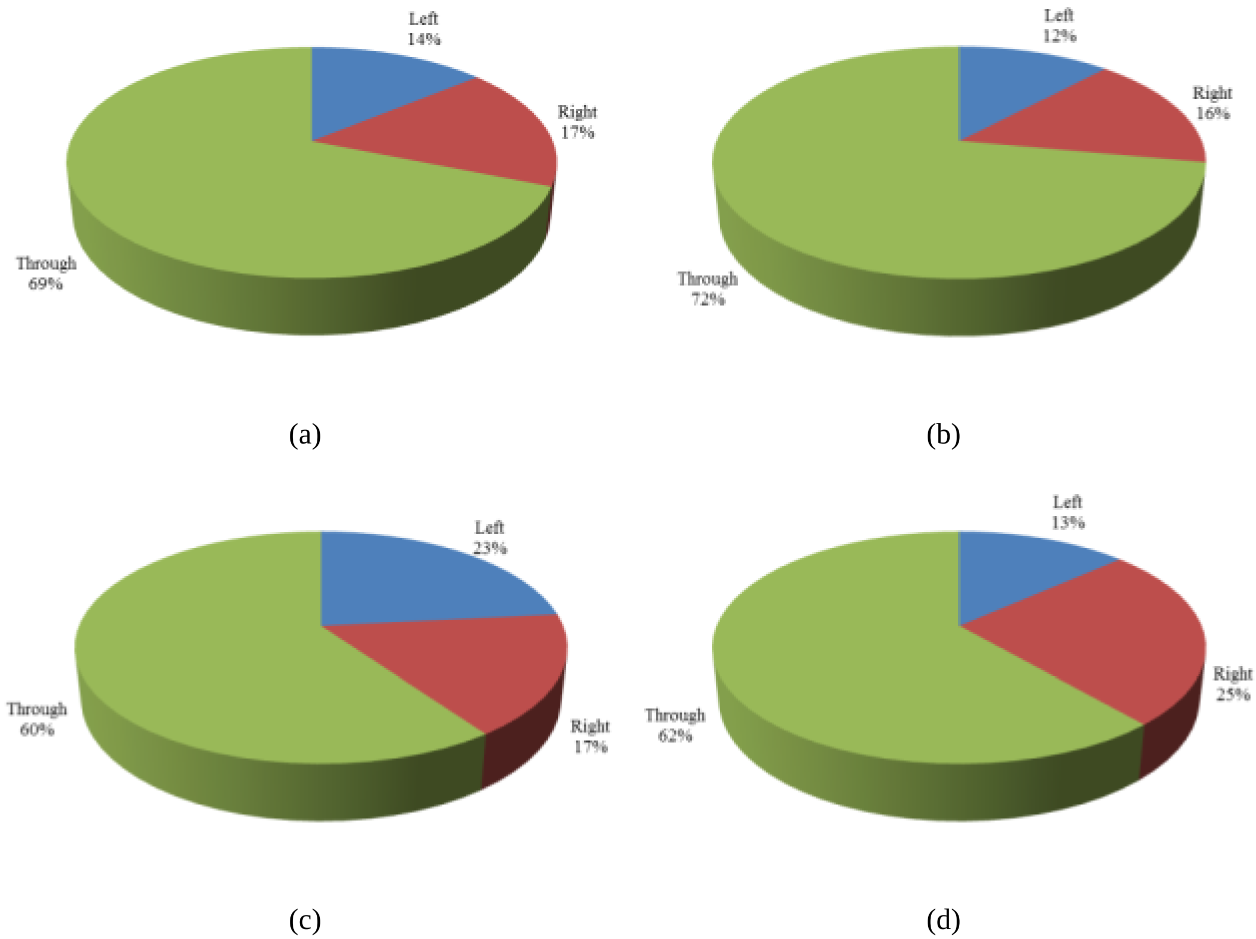


Figure 58. Turning movements at 103rd Street and Antioch Road for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 58, it was found that over 60 percent of traffic traversed through the intersection for all approaches. The northbound approach had the highest observed volume of left- and right-turning vehicles. Approximately 25 percent of the observed traffic for the eastbound approach turned right at the intersection. Furthermore, it was found that a total of 32,358 vehicles were counted for all periods of the study. Approximately 60 percent of the total observed volume was vehicles traveling through the intersection, 18 percent were turning right, and 15 percent were turning left.

103rd Street and Metcalf Avenue

The intersection of 103rd Street and Metcalf Avenue was selected as a control site. The surrounding land use was a mixed commercial and recreational. There were commercial businesses south of 103rd Street, and Pinehurst Park was located north of 103rd Street. For the southbound approach there were three through lanes, two left-turning lanes, and one right-turning lane. The northbound approach had three through lanes, two left-turning lanes, and one right-turning lane. For both the westbound and eastbound approaches there were two through lanes, two left-turning lanes, and one right-turning lane. The posted speed limit for Metcalf Avenue was 45 mph; posted speed limit for 103rd Street was 40 mph. There were no U-turns allowed for both northbound and westbound traffic. Southbound and eastbound traffic were allowed to make U-turns. Figure 59 shows an aerial view of the intersection.

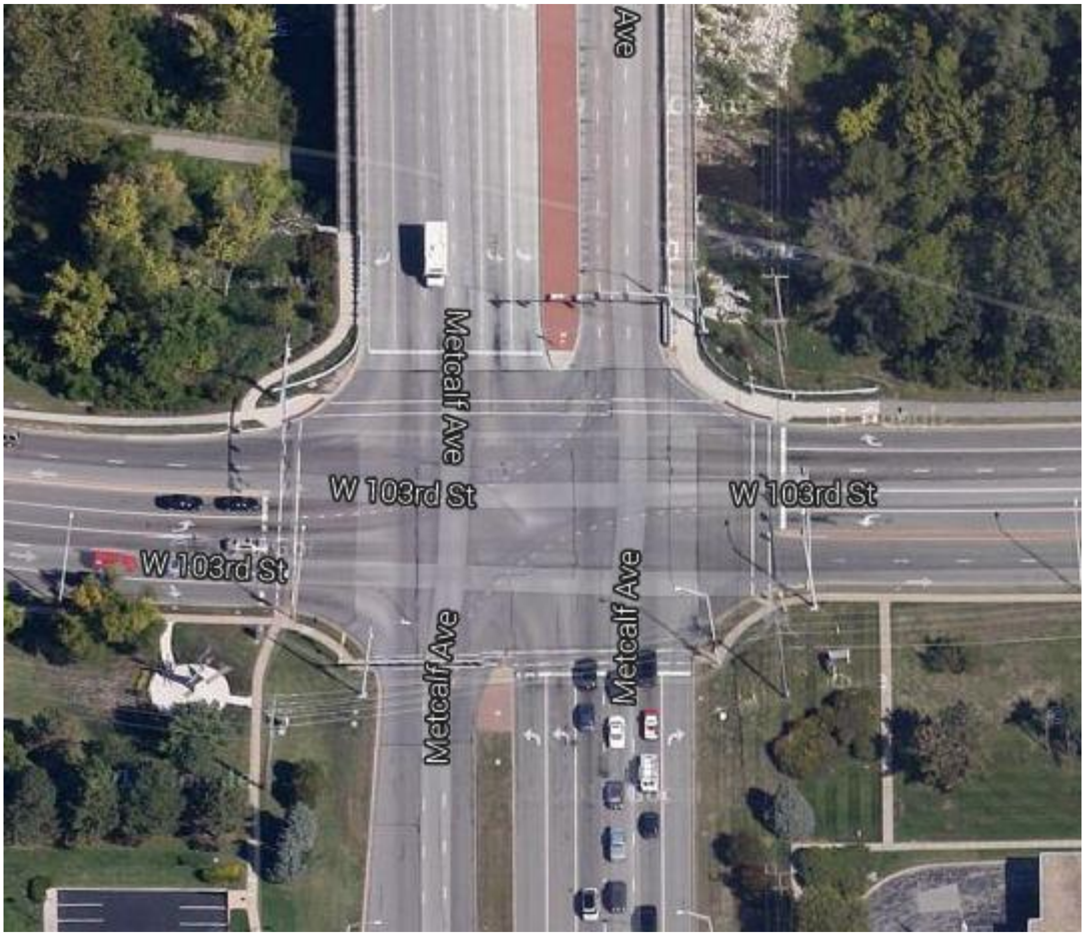


Figure 59. 103rd Street and Metcalf Avenue (aerial image, Google Earth, 2013)

As shown in Figure 59, the clearance path for northbound and southbound movements was approximately 165 feet. For the eastbound and westbound movements the clearance path distance was 196 feet. There were six signal heads for each approach at the intersection. For the eastbound and westbound approach there was one signal head per travel and movement lane. There was also a signal head placed on the nearside of the intersection. For the northbound and southbound approaches there were two signal heads for the left turn, two for the through movements, and two for the through and right-turning movements with one of the signal heads placed on the nearside of the approach. Figure 60 shows the signal mountings for all approaches.

(a) (b)

(c) (d)

Figure 60. 103rd and Metcalf signals at (a) northbound (b) southbound (c) eastbound (d) westbound

As shown in Figure 60, all overhead signals had back plates. It was found that the only approach that did not have a protected right turn was the westbound approach. All left-turning movements were protected at the intersection. Only the north and south phases were coordinated, and the peak hour cycle length for morning and evening was 140 seconds. The yellow and the all-red intervals in seconds are in Table 17.

Table 17. 103rd Street and Metcalf Avenue Yellow and All-Red times in seconds

Traffic Movement	Phase	
	Yellow (seconds)	All-Red (seconds)
Northbound	4.3	2.2
Northbound Left Turn	3.2	3.2
Southbound	4.3	2.2
Southbound Left Turn	3.2	3.2
Eastbound	3.6	3.4
Eastbound Left Turn	3.2	3.2
Westbound	3.6	3.4
Westbound Left Turn	3.2	3.2

As shown in Table 17, the times for yellow and all-red were within the recommended times described in the literature review and MUTCD. Through movement traffic along Metcalf Avenue was found to have the longest yellow phase time. The yellow and all-red time for all left turn movements were the same for all other approaches. The volumes for each period are shown in Figure 61.

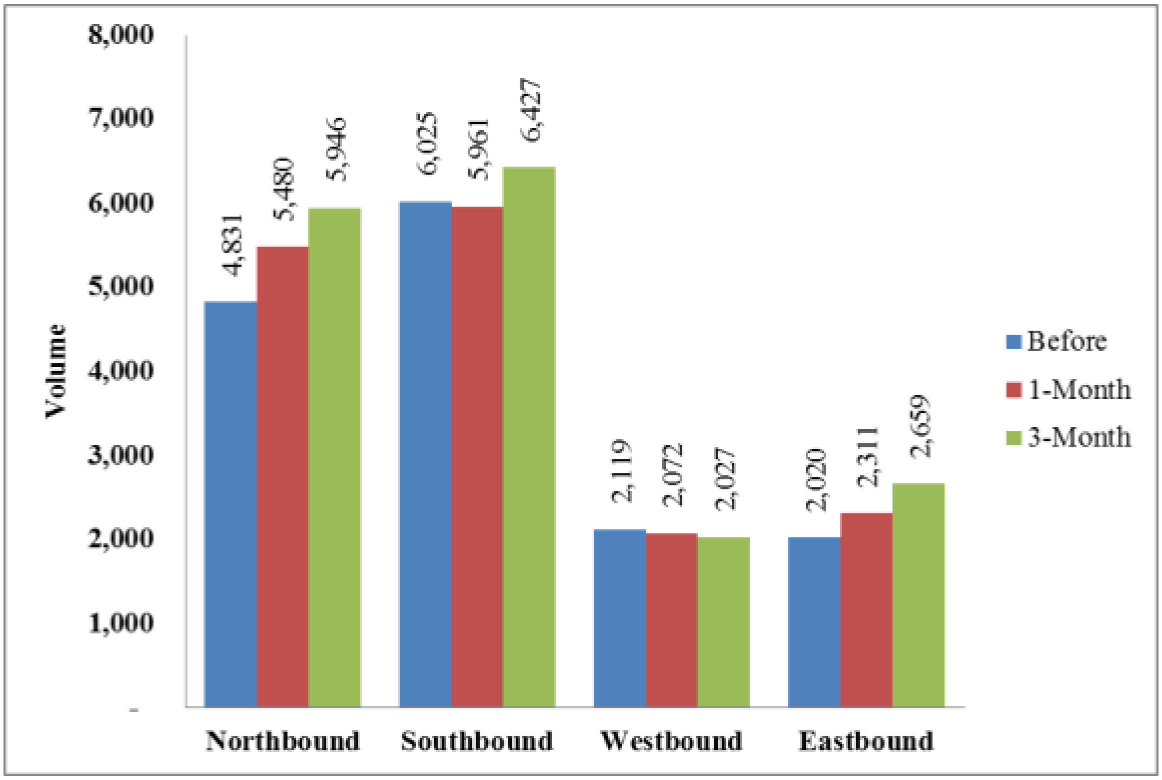


Figure 61. Total volumes for 103rd Street and Metcalf Avenue

Traffic was observed and recorded on the 29th of May, 2013 for the before period, and on the 28th of August, 2013 for the one-month after period. Video data were recorded by the City of Overland Park using overhead vehicle detection cameras for the three-month after period. Traffic along 103rd Street was recorded on November 5th, 2013, and traffic along Metcalf Avenue was recorded on November 7th, 2013. As shown in Figure 61, over 70 percent of traffic observed at this intersection traveled on Metcalf Avenue. The three-month after period of the study had the highest volume count of all periods of the study. More than half of the total volume was observed during the evening peak hour. Figure 62 shows the turning movements observed during the study.

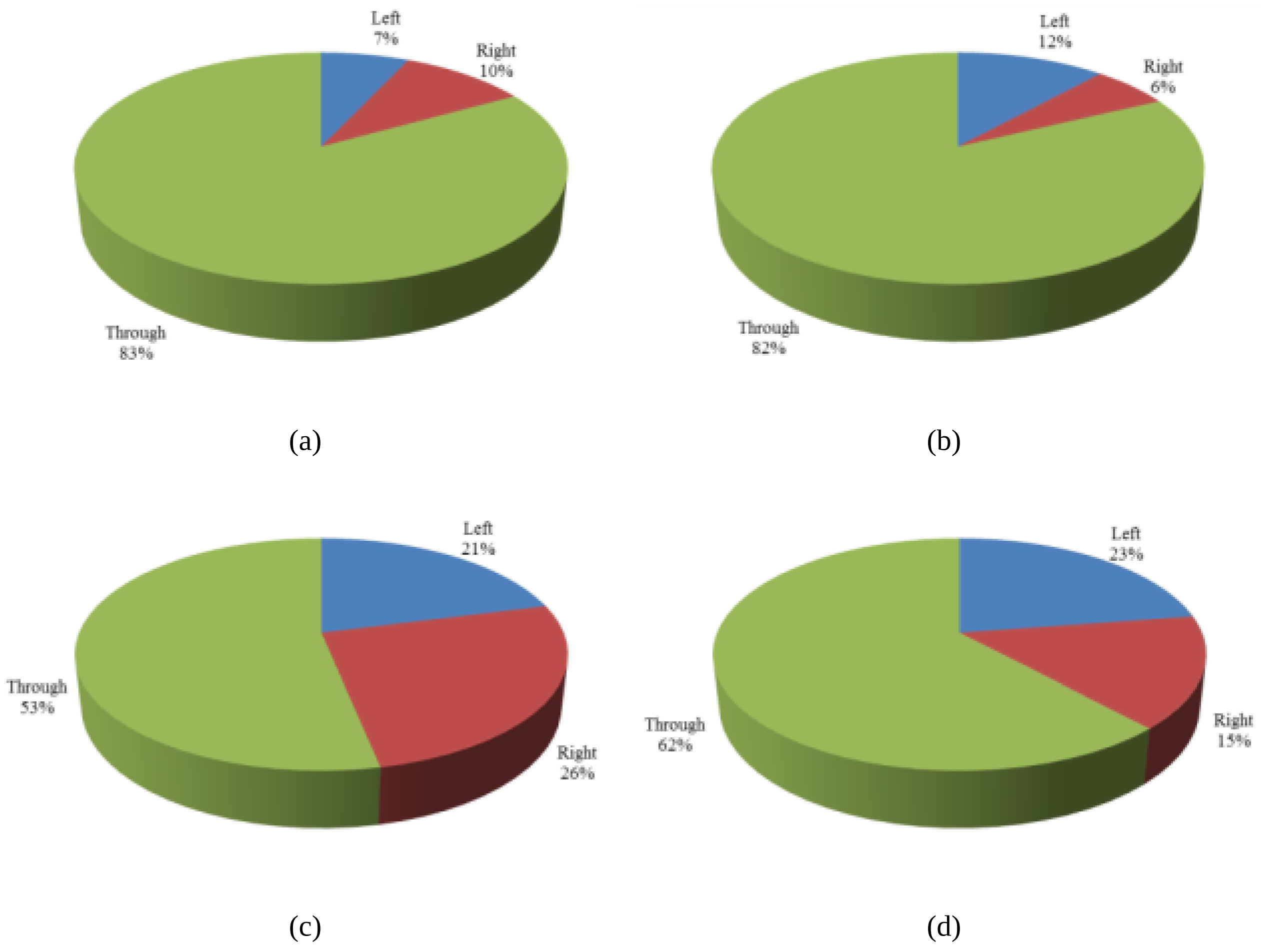


Figure 62. Turning movements at 103rd Street and Metcalf Avenue for (a) northbound (b) southbound (c) westbound (d) eastbound approaches

As shown in Figure 62, more than 80 percent of the traffic along Metcalf Avenue traveled through the intersection. It was found that the southbound approach had the highest number of observed vehicles making a left turn at the intersection. Additionally, the westbound approach had the highest volume of right-turning vehicles. A total of 47,878 vehicles were observed in all three periods of the study at this intersection. Left-turning vehicles were comprised of 13 percent of the total volume, right-turning vehicles were 11 percent, and through movements accounted for 76 percent of the total movement.

3.3.4 Summary

As stated in the previous sections, a total of 14 intersections were used to investigate the effectiveness of the confirmation lights. From the 14 selected intersections, two treatment sites, six spillover sites, and six control sites were identified. Intersection geometry and lane configurations differed between sites as noted by the each description. Both treatment intersections were located in commercial areas of town. Most of the spillover sites were in residential areas, and most of the control sites were in commercial areas. Out of possible 54 approaches investigated, 42 of these approaches had a protected left-turning movement present, eight approaches had protected/permitted left-turning movements, and four had permitted left-turning movements. It was also noted that only 15 approaches had a protected right-turning movement. The signal timing at all studied intersections for yellow and all-red phase were found to be within the recommendations that were detailed in the literature review and current guidance. All intersections were equipped with a single signal head per lane, and all overhead signal heads had black backplates. There were a total of 563,997 vehicles observed through all periods of the study. Figure 63 shows how the volumes were noted between treatment, spillover, and control sites.

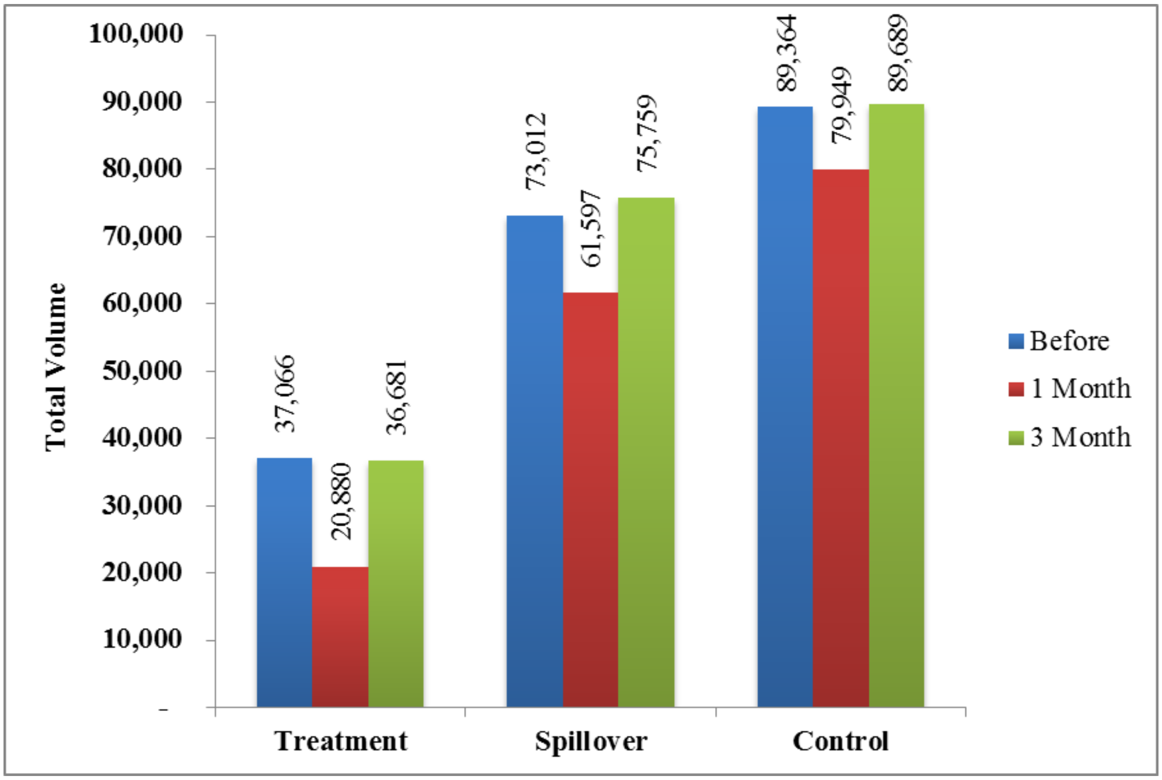


Figure 63. Volumes for all periods between sites

As shown in Figure 63, there was a decrease in volume observed during the one-month after period. This was due to missing video data. Overall, the spillover sites experienced lower volumes than the control sites. The treatment sites were left-turning vehicles represented 15 percent of the total volume, 14 percent of the total volume were right-turning vehicles, and 71 percent of the total volume observed were vehicles proceeding through intersection. It was found that the intersections with the highest vehicle volume counts were College Boulevard and Quivira Road, College Boulevard and Pflumm Road, and 95th Street and Metcalf Avenue.

CHAPTER 4 DATA COLLECTION AND METHODOLOGY

A before and after violation study was conducted to determine the effectiveness of the blue confirmation lights at two signalized intersections in Overland Park, KS. The easiest way to obtain and reduce RLR violation data was using video data on each approach of an intersection. However, capturing and reducing traffic video data using video cameras can be complicated and time consuming. The City of Overland Park was consulted about using permanently-installed overhead vehicle detector cameras located at all of the intersections. Even though vehicle detection cameras were located at all of the identified intersections, some intersections were not equipped to record digital video, thus on field data collection equipment was used. Figure 64 shows the view of the overhead video provided by the camera.

Figure 64. Overhead camera view of an intersection approach

As shown in Figure 64, a view of the intersection in which a single approach could be monitored was of interest in the data collection process. As stated in the previous section, almost all of the intersections under investigation had multiple turning movements, including a protected/permitted right-turning lane. The field of view also needed to view the approach stop line and current phase of the traffic signal. As shown in Figure 64, the recorded field of view by the vehicle detection cameras show the stop line, the vehicles, and path traveled. At the lower corners of the image was the current phase for the through (left) and left-turning movements (right). However, the field of view was not able to indicate when right-turning vehicles had either a protected, or permitted left turn. It was assumed that if an intersection had a protected/permitted left turn, the signal display would indicate red for left turns, but the through movement would remain green. In order to avoid confusion when the data were reduced, student researchers were required to become familiar with the intersection signal operations prior to reducing the video data. A total of five intersections were found to not have the capabilities of utilizing vehicle detection cameras to collect data. Therefore, a student researcher setup multiple video cameras at these intersections and recorded the data. When data were collected using ground-based cameras, the field of view that was required of the student researcher was shown in Figure 65.

Figure 65. Camera view of an intersection approach

As shown in Figure 65, the camera setup had to be deployed close to the intersection so that the stop line could be visible, and far enough away so the field of view could capture all of the approach lanes. Additionally, all signal heads had to be clearly visible in the field of view. This was complicated at some locations due to the rising sun in the morning and early nighttime conditions at the end of the evening peak hour. Commonly available video equipment was used for data collection as shown in Figure 65.

Figure 66. Equipment used for field data collection effort

As shown in Figure 66, high definition video cameras were used in conjunction with an extended battery and inverter. An important aspect to the data collection effort was deploying and monitoring the video camera equipment at all four intersection approaches while not affecting driver behavior with the presence of the student researchers or equipment. Prior to any video data collection effort, the City of Overland Park Police Department dispatch center was notified to facilitate driver or business curiosity. A common setup of the ground-level video equipment is illustrated in Figure 67.

Figure 67. Camera setup at an intersection

Student researchers in the field were instructed to setup the video equipment in a safety vest and would then monitor the cameras at the intersection during both peak hours from a vehicle parked nearby. Video data were collected on weekdays that were non-holidays or when there would be no a special events on a Tuesday, Wednesday, or Thursday. Data were also collected during the identified morning peak hour (7 a.m. to 9 a.m.) and evening peak hour (4 p.m. to 6 p.m.). The data collection methodology described was used for all study periods of the project. The dates which video data were collected in the Overland Park included the following:

- Before study: January 16 to May 29, 2013;
- Confirmation Light Installation: July 2, 2013;
- One-month after study: August 7 to September 19, 2013; and

- Three-month after study: October 23 to November 14, 2013.

Collecting video data at each intersection required a substantial amount time as shown by the dates listed. A quality assurance protocol was developed to ensure the field collected data met the field of view requirements as stated previously.

4.1 Data Reduction

A total of 583 hours of video data were reduced resulting in over two Terabytes of high definition video. Video data were reduced manually by student undergraduate research assistants and all red light violations noted by the assistant were verified. The methodology ensured accurate video data reduction, which resulted in a substantial archive of RLR violations, and signalized intersection operational data. Assistants reduced each peak hour for each intersection with scheduled breaks in the reduction process. The following guidelines were given to each assistant to reduce the video data:

- A vehicle that proceeded through (or crosses the stop line), made a left turn after the red signal was shown was considered a RLR violation.
- A vehicle that crossed the stop line during the yellow interval, or was in the intersection when the signal shows yellow or red was not considered a RLR violation (e.g. permitted left turns).
- If a vehicle ran a red light, then the video was stopped, and scrolled back to determine the time into red the vehicle ran the red light.
- If a vehicle ran a red light, the video time stamp at which the event occurred was recorded.

- While monitoring one approach at a time for RLR violations, record the traffic volume for each turning movement.

Illustrated in Figure 68 is the template that was distributed to the students who reduced the video data.

Number of Vehicles	Type of Vehicle	Seconds into Red	NB	SB	EB	WB	Time of Day (a.m./p.m.)
1	2	2		1			7:35 a.m.
2	1	6	3				4:15 p.m.
3	3	2				7	8:20 a.m.
4	1	2				7	5:50 p.m.
5	4	1			2		
6							

Approach	Morning or Evening Peak Volume			
	Left turn	Through	Right turn	Total Volume
NB	55	7	61	**123**
SB	6	3	13	**22**
EB	24	951	18	**993**
WB	140	1579	75	**1794**

Figure 68. Sample of reduced video data

As shown in Figure 68, the primary data of interest was the number of vehicles that ran the red light (number of violations), time into red (seconds), which approach the violation occurred at, and the time of day the violation occurred (am or pm peak hour). Additionally, the turning movement counts were recorded for each approach in the same data reduction sheet.

Once the assistant completed an entire intersection (all four approaches), the sheet was turned in to perform a quality check/assurance. At this point each of the recorded violations were reviewed to ensure a RLR violation occurred and the required information was noted accurately. Once the entire data collection effort was completed, data were aggregated into archival format as an excel file.

4.2 Data Collection and Reduction Limitations

Collecting field data can sometimes result in unknown and complicating events. These situations often complicated the data collection and reduction efforts:

- During the data collection over the duration of the project, Kansas weather brought rain, wind, sleet, and snow. Either the data collection effort was shut down early, or, in the case of wind, the equipment was readjusted to ensure continuous data collection (e.g. plastic bags or chain tie-downs).
- Since the research project utilized commonly available video recording and power source equipment, limitations on equipment reliability was found to be an issue during some data collection periods. This included malfunctioning batteries, overloaded inverters, or unresponsive cameras. Identified equipment failures were noted either in the field or during the data reduction process. If the failure affected the quality or quantity of the video data, a recollection effort occurred as quickly as possible.
- At many intersection sites, pedestrians passing by the camera setup were found to tamper with the units.

4.3 Installation of Confirmation Lights

The light elected was a Pelco confirmation light which ranges from $110-$140 depending on the mounting bracket. As shown in Figure 69, the City of Overland Park specified that they wanted the light to be mounted by a cable Pelco Astro-Brac. Also shown in Figure 69, excess cable and wire were zip-cord strapped to the mast arm and sign bracket. The Pelco confirmation light came in multiple colors including blue, red, and clear. A standard Edison light bulb was used and the plastic dome was sealed by a rubber weather strip. The confirmation light came with a short three strand wire which included a ground wire. The Overland Park traffic signal technicians removed the provided wire and attached a standard two-wire hookup.

Since the traffic signal controller cabinet and signal heads were low-powered with LED, lights the city asked to find the brightest low-powered light bulb because conventional 65 watt incandescent bulbs would trip the intersection battery backup system. Three LED light bulbs were purchased from a local hardware store and it was decided to use an 800 Lumens 9 Watt LED light bulb.

On the July 2, 2013 at approximately 9 a.m., the City of Overland Park Traffic Engineering Department installed the confirmation lights at 75th Street and Metcalf Avenue intersection and then College Boulevard and Quivira Road. Figure 69 shows how the city installed the lights using a boom truck.

Figure 69. Field installation of the confirmation light

4.4 Public Awareness of the Confirmation Lights

Prior to installation and activation of the confirmation lights at both intersections, the City of Overland Park consulted with the city and county traffic judges as well as the city and county prosecutors so unintentional confusion would not happen if the court system saw the words “blue light” on a RLR citation.

The University of Kansas and the City of Overland Park public relations offices were consulted to jointly release a statement regarding the project. A copy of the press release can be found in Appendix A.1. The coordinated press release was designed to inform drivers that a change was going to occur at two intersections and a different color was going to be present besides red, yellow and green. The press release was also designed to show a commitment to intersection safety and reducing RLR by the all parties involved. Shown in Figures 70 and 71 are the blue confirmations lights at 75th Street and Metcalf Avenue, and College Boulevard and Quivira Road.

Figure 70. Confirmation Lights at 75th Street and Metcalf Avenue

Figure 71. Confirmation Light at College Boulevard and Quivira Road

Additionally, the research project was spotlighted by local television and newspaper media. A photo of a KU researcher answering questions by the local media is shown in

Figure 72.

Figure 72. Project investigator meeting with the media at one of the treatment intersections

It should be noted that the effectiveness of the public awareness campaign was not evaluated as part of this study. Additionally, it was specifically asked of the Overland Park Police Department to continue their regular duties monitoring RLR and to avoid targeted enforcement during the study period.

CHAPTER 5: COMPARISON OF VIOLATION RATES AFTER CONFIRMATION LIGHT INSTALLATION

5.1 Background

Studies that have assessed the effectiveness of a roadway safety device rely ideally on a before and after crash analysis. These studies involve at least three years of before data and three years of after data (Nicholson, 1985). However, many communities want to know the effectiveness of a device or treatment shortly after installation to determine if the investment in the device was a good decision. Many times, in place of a before and after crash analysis, researchers will use a safety surrogate measure in place of crash data.

Researchers have previously used the reduction in RLR violations as a crash surrogate for a reduction in RLR crashes. This relationship was directly due to the fact that RLR violations occur more frequently than RLR crashes since they are rare and random events. Research has also shown that red light runners tend to have common traits such as age, driving experience, speed convictions, and vehicle type (Retting and Williams, 1996). However, a reduction in violations means there was a reduction in exposure, or a reduction in the chances for a RLR crash to occur.

Additionally, besides considering a change in RLR violations before and after the confirmation lights were installed, the change in violations three months after installation was investigated. Unlike previous research studies, it was unknown if the confirmation lights (or really any safety countermeasure) becomes less effective over time as drivers become accustomed to the treatment and associated enforcement. However, changes in driver behavior or changes in enforcement using the confirmation lights may be more effective over time.

5.2 Methodology

The RLR violation rate was the metric used to compare changes during the before period, 1 month after, and three months after installation of the confirmation lights. Violation rate was used instead of the number of violations to account for varying intersection volumes (exposure). The RLR rate was expressed in 10,000 entering vehicles as shown in Equation 3.

$$Rate(TEV) = \frac{N_i}{V_i} \times 10{,}000\ Entering\ Vehicle \qquad \textbf{Eq.3}$$

Where: N_i = total number of violations (N) observed during the study period i; and

V_i = total number of entering vehicles (V) during the study period i.

Once a violation rate was determined for each data collection period, changes in the violation rates were determined using Equation 4.

$$Change\ (\%) = \frac{\hat{\pi}_i - \hat{\pi}_b}{\hat{\pi}_b} \times 100\% \qquad \textbf{Eq. 4}$$

Where: $\hat{\pi}_b$= violation rate for before period; and

$\hat{\pi}_i$ = violation rate for after period.

To compare the calculated rates for the before period, one month, and three months after installation of the confirmation lights, a test of proportions was used to determine if the changes in rate were statistically significant. Equation 5 was used to perform this step of the analysis.

$$Z = \frac{(\hat{\pi}_b - \hat{\pi}_i)}{\sqrt{\frac{\hat{\pi}_b(1-\hat{\pi}_b)}{V_b} + \frac{\hat{\pi}_i(1-\hat{\pi}_i)}{V_i}}} \qquad \textbf{Eq. 5}$$

Where: Z = z-test statistic;

$\hat{\pi}_b$ = violation rate for before period;

V_b = volume for before period;

$\hat{\pi}_i$ = violation rate for after period i; and

V_i = volume for after period i.

The calculated z-test statistic was compared to a Z table with $\alpha = 0.05$ to determine significance at the 95 percent level of confidence. If the Z was greater than 1.96, the resulting *decrease* in violation rate was statistically significant. Similarly, if the Z was less than -1.96 the resulting *increase* in violation rate was statistically significant.

5.3 Results for Change in Red Light Running Violations

The results of the violation study for all intersections are presented in this section. As stated previously, the confirmation lights were installed at two intersections for the left-turning movement and through movements. The change in violations was evaluated for left-turning movements and through movements separately and the results are presented in the following sections.

5.3.1 Analysis of Left-turning Movement Red Light Running Violations

Table 18 shows the results of the analysis for the left-turning movements only. The morning and evening peak hour data were combined. The table shows: the intersection, RLR violations recorded, number of vehicles counted, RLR rates per 10,000 vehicles, and percent change in violation rates between periods. For the percent change in violation rates, a dot represents periods of the study where there were no data obtained. A total change in RLR rates was the average rate for the treatment site, spillover sites, and control sites.

Table 18. Results of the RLR Violation Analysis for Left-Turning Movements

	Number of Violations			Violation Rate per 10,000 vehicles			Percent Change	
Treatment Sites	**Before**	**1-Month**	**3-Month**	**Before**	**1-Month**	**3-Month**	**1-Month**	**3-Month**
75th Street and Metcalf Avenue	27	•	19	108.56	•	77.55	•	-29% A
College Boulevard and Quivira Road	27	55	29	62.27	129.66	73.07	108% A	17% A
Total	**54**	**55**	**48**	**79.14**	**129.66**	**74.78**	**64% A**	**-6% A**
Spillover								
71st Street and Metcalf Avenue	4	6	5	34.16	44.05	42.41	29% A	24% A
75th Street and Conser	2	2	6	74.63	78.74	202.7	6%	172% A
79th Street and Metcalf Avenue	1	0	2	8.58	•	16.53	•	93% A
119th Street and Quivira Road	6	8	6	23.95	31.03	21.7	30% A	-9% A
College Boulevard and Nieman Road	9	1	2	165.14	25.32	39.45	-85% A	-76% A
College Boulevard and Pflumm Road	9	20	9	22.97	48.05	22.47	109% A	-2%
Total	**31**	**37**	**30**	**32.38**	**42.28**	**30.11**	**31 % A**	**-7% A**
Control Sites								
95th Street and Metcalf Avenue	8	21	15	34.53	81.59	58.41	136% A	69% A
College Boulevard and Nall Avenue	6	14	17	28.4	70.85	73.56	150% A	159% A
College Boulevard and Antioch Road	5	15	4	16.66	54	13.69	224% A	-18 % A
95th Street and Antioch Road	21	16	9	81.05	83.38	37.78	3%	-53% A
103rd Street and Antioch Road	8	1	3	42.8	6.27	21.02	-85% A	-51% A
103rd Street and Metcalf Avenue	7	14	7	33.61	69.9	33.57	108% A	0%
Total	**55**	**81**	**55**	**39.36**	**63.06**	**40.16**	**60% A**	**2%**

A Change in violation rate is statistically significant at the 95 percent level of confidence

As shown in Table 18, overall the confirmation lights showed inconclusive results at the treatment intersections/approaches for left-turning movements. The intersection of 75th Street and Metcalf Avenue experienced a significant reduction of left-turning RLR violations three months after the confirmation lights were installed. The treatment site of College Boulevard and Quivira Road experienced a significant increase of left-turning RLR violations rate after the confirmation lights were installed. At College Boulevard and Quivira Road the largest increase in RLR violations were experienced during the one-month after period of the study. There was also a significant increase in left-turning RLR violations at the spillover sites and the control sites for the one-month after period of the study.

During the one-month after period of the study, the treatment intersection site of College Boulevard and Quivira Road, the spillover site of College Boulevard and Pflumm Road, and the control sites of 95th Street and Metcalf Avenue, College Boulevard and Nall Avenue, College Boulevard and Antioch Road, and 103rd Street and Metcalf Avenue all experienced an increase of over 100 percent in the RLR violation rate. Traffic was recorded for all the listed intersections between August 15 and 18, 2013. The intersection of 119th Street and Quivira Road was also recorded in August, and it was the only intersection to not experience an increase of over a 100 percent in the RLR violation rate, however, the calculated increase of 30 percent was statistically significant. The remaining control and spillover intersections were recorded in September. The difference in time when the video data were recorded, can most likely explain the fluctuations in increases and decreases of red light violations. Considering all the intersections, there was a significant increase in left-turning RLR violations at the treatment, spillover, and control sites.

This suggests that the increase in violations was due to other factors and not the installation of the blue confirmation lights. Further analysis of College Boulevard and Quivira Road is documented in a later section.

Three months after the confirmation lights were installed, it was found that there was a global decrease in left turn red light violations at the treatment sites based on data collected from the control intersections. The treatment intersection of 75th Street and Metcalf Avenue experienced a decrease of 29 percent which was found to be significant for left-turning red light violations when compared to the before period. The intersection of College Boulevard and Quivira Road experienced an increase in RLR violation rate when compared to the before period. However, the increase during this period was found to be less than the increase observed during the one-month after period, and there was a significant decrease in RLR violation rate between the one-month after period and the three-month after period. The spillover intersection sites experienced an overall decrease in left-turning RLR violations. All spillover intersection sites adjacent to the intersection of 75th Street and Metcalf Avenue experienced a significant increase, while all spillover sites near the intersection of College Boulevard and Quivira Road experienced a decrease in violation rate for left turn movements. During the three-month after period of the study there was an overall increase (2 percent) of violations for all control sites. However, this global increase was found to be not statistically significant. The intersections of College Boulevard and Nall Avenue, College Boulevard and Antioch Road, and 95th Street and Metcalf Avenue saw a significant increase in left-turning RLR violation rates. The intersections of 95th

Street and Antioch Road, and 103rd and Antioch Road experienced a significant decrease in violation rates.

5.3.2 Analysis of Through Movement Red Light Running Violations

Table 19 shows the results of the analysis for the through movements only. Morning and evening peak hour data were combined. The table shows: the intersection, RLR violations recorded, number of vehicles counted, RLR rates per 10,000 vehicles, and percent change in violation rates between periods. For the percent change in violation rates, a dot represents that no data were available for that intersection at that time period.

Table 19. Results of the RLR Violation Analysis for Through Movements

	Number of Violations			Violation Rate per 10,000 vehicles			Percent Change	
Treatment Site	**Before**	**1-Month**	**3-Month**	**Before**	**1-Month**	**3-Month**	**1-Month**	**3-Month**
75th Street and Metcalf Avenue	11	•	14	7.31	•	9.46	•	29%[A]
College Boulevard and Quivira Road	7	17	7	4.61	10.22	4.53	122%[A]	-2%
Total	**18**	**17**	**21**	**5.95**	**10.22**	**6.94**	**72%**[A]	17%[A]
Spillover								
71st Street and Metcalf Avenue	15	22	10	12.09	17.14	7.86	42%[A]	-35%[A]
75th Street and Conser	32	10	15	45.52	16.35	21.99	-64%[A]	-52%[A]
79th Street and Metcalf Avenue	9	•	8	7.91	•	6.69	•	-15%[A]
119th Street and Quivira Road	8	5	6	6.45	3.74	4.38	-42%[A]	-32%[A]
College Boulevard and Nieman Road	1	1	1	1.18	1.37	1.16	17%[A]	-1%[A]
College Boulevard and Pflumm Road	5	4	1	4.26	3.02	0.83	-29%[A]	-80%[A]
Total	**70**	**42**	**41**	**11.03**	**7.94**	**6.23**	**-28%**[A]	**-44%**[A]
Control Sites								
95th Street and Metcalf Avenue	8	10	11	5.93	6.98	7.67	18%[A]	29%[A]
College Boulevard and Nall Avenue	1	5	8	0.65	5.14	5	692%[A]	671%[A]
College Boulevard and Antioch Road	2	7	2	1.57	6.85	1.55	335%[A]	-1%
95th Street and Antioch Road	11	18	11	9.95	18.38	11.11	85%[A]	12%[A]
103rd Street and Antioch Road	10	6	3	10.18	6.51	3.8	-36%[A]	-63%[A]
103rd Street and Metcalf Avenue	6	8	5	4.65	5.79	3.34	25%[A]	-28%[A]
Total	**38**	**54**	**40**	**5.04**	**8.05**	**5.26**	**60%**[A]	**4%**[A]

[A] Change in violation rate is statistically significant at the 95 percent level of confidence

The confirmation light had little effect for through movement violations at the treatment sites. At College Boulevard and Quivira Road there was a significant increase in violation rate of over 120 percent from the before period to the one-month after period. During the one-month after period of the study, there was an overall decrease in violation rate for spillover sites. Only the intersections of 71st Street and Metcalf Avenue, and College Boulevard and Nieman Road experienced a significant increase in through movement violations. All other intersections experienced a significant decrease in violation rates, with 75th Street and Conser Street, and 119th Street and Quivira Road experiencing the biggest decreases. A significant increase for all control sites was observed during the one-month after period. The control sites of College Boulevard and Nall Avenue, and College Boulevard and Antioch Road experienced the highest increases in violation rates. The intersection of 103rd Street and Antioch Road was the only control site that experienced a decrease in through movement violation rate during the one-month after period of the study.

For the three-month after period the treatment sites experienced an overall significant increase in through movement RLR violation rates. The site at 75th Street and Metcalf Avenue had a significant increase during this period. The spillover sites near 75th Street and Metcalf Avenue experienced a significant decrease in violation rates with the highest decrease found at 75th Street and Conser Street. College Boulevard and Quivira Road experienced a small decrease in through violations. All spillover sites near College Boulevard and Quivira Road experienced a decrease in violation rates, with the highest decrease observed at College Boulevard and Pflumm Road. Globally, there was a significant decrease at the spillover sites.

In total, a significant increase was observed during the three-month after period of the study for all control sites. Only the intersections of 103rd Street and Antioch Avenue, and 103rd Street and Metcalf Avenue experienced a statistically significant decrease in through movement violation rate. The intersections of College Boulevard and Nall Avenue, and 95th Street and Metcalf Avenue experienced the highest significant increase in through movement violations. When comparing violation periods, the volume of through and right movement violations were at their peak at College Boulevard and Quivira Road when volume was the highest. At all spillover sites the highest decrease was observed when volumes were highest. For control sites when the volumes were the highest, the increases in violation rates were the lowest. To further clarify which approaches at the treatment sites experienced an increase in violations during the one-month after period, an analysis of violations per approach and time of day is described in section

5.3.3 Violation Analysis for Treatment Sites

For all periods of the study, a total of 231 RLR violations were recorded at both treatment intersections. To further investigate the possible effects of the confirmation lights and the increase of violations at these sites, the time of day and the approach of which the violations occurred were analyzed. The following section presents the RLR violations per movement, according to approach and peak period when they occurred. Table 20 shows the violations for left-turning movements at both treatment sites.

Table 20. Left-turn Violations at Treatment Sites.

Study Period	Approach	75th Street and Metcalf Avenue		College Boulevard and	
		Morning	Evening	Morning	Evening
Before	Northbound	2	3	3	7
	Southbound	2	1	6	-
	Eastbound	8	4	3	5
	Westbound	-	7	3	-
One Month	Northbound	-	-	3	4
	Southbound	-	-	10	1
	Eastbound	-	-	14	12
	Westbound	-	-	2	9
Three Month	Northbound	1	2	1	4
	Southbound	-	3	5	1
	Eastbound	8	4	4	10
	Westbound	-	1	2	2

As shown in Table 20, left-turning RLR violations represented 157 out of the 231 total violations at the treatment sites. The intersection of College Boulevard and Quivira Road was found to have the most left-turning violations with 111. When compared to the total number of RLR violations at the intersection of College Boulevard and Quivira Road between the periods of this study, there were 34 violations observed during the before period, 55 during the one-month after period, and 29 total left turn violations during the three-month after period.

Approximately 50 percent of the violations for left-turning vehicles at College Boulevard and Quivira Road were observed during the one-month after deployment period of the study. Approximately 29 out of 55 RLR violations were observed during the morning peak hour. It should be noted the during the two hour morning peak hour in the one-month after period, there were the same number of left turn violations as found during the whole three-month after period of the study. The eastbound approach was found to have the highest number of left turn violations on all approaches at College Boulevard and Quivira Road. Left-turning (eastbound) traffic proceeded northbound on Quivira Road towards Interstate 435. During the one-month after period the southbound and westbound approaches experienced 11 violations, respectively, for both the morning and evening peak hours. The southbound approach experienced a decrease from ten violations in the morning peak hour to one violation in the evening peak hour. The westbound approach experienced an increase in violations from two violations in the morning peak hours to nine in evening peak hour for this period of the study.

Comparing the different approaches between study periods showed that three out of four approaches experienced the highest number of violations during the one-month after period at College Boulevard and Quivira Road. The northbound approach of College Boulevard and Quirvira Road experienced a decrease through all periods of the study. During the three-month after period the eastbound approach experienced the highest number of violations for all approaches, similar results were observed during the one-month after period. At the intersection of 75th Street and Metcalf Avenue, the eastbound approach experienced the highest number of left-turning RLR violations for the before and three-month after period. This intersection also saw a decrease in left-turning RLR violations from 27 in the before period to 19 in the three-month after period. Table 21 shows the recorded volumes for left-turning movements at the treatment sites.

Table 21. Left turn Volumes at Treatment Sites

Study Period	Approach	75th Street and Metcalf Avenue		College Boulevard and Quivira Road	
		Morning	Evening	Morning	Evening
Before	Northbound	213	246	385	576
	Southbound	319	276	810	560
	Eastbound	349	371	462	677
	Westbound	322	309	303	563
One Month	Northbound	-	-	419	514
	Southbound	-	-	691	525
	Eastbound	-	-	540	685
	Westbound	-	-	255	613
Three Month	Northbound	307	296	357	440
	Southbound	302	323	567	473
	Eastbound	315	273	502	660
	Westbound	360	356	359	611

At 75th Street and Metcalf Avenue there was a decrease in total violations even though there was an increase in left-turning traffic. For the before period the eastbound and westbound approaches had the highest number of vehicles turning left at the intersection. Also, in the before period of the study the eastbound approach had the highest volume and left turn violations out of all approaches. The eastbound approach had the highest left turn violations during the three-month after period, however, the westbound approach had the highest volume and lowest total violations during that period. In addition, the northbound approach experienced an increase in left-turning volume, and a decrease in total violations. The southbound approach experienced an increase in volume from the before period to the three-month after period, but no change in total violations.

At College Boulevard and Quivira Road left-turning traffic decreased at each subsequent period of the study. For all periods observed the eastbound and southbound approaches had the highest left-turning volumes.

The eastbound approach experienced a peak in left turn movements during the one-month after period, which consequently was when the highest total violations were observed. Overall, left-turning volumes were lower in the morning peak hours than the evening peak period. The southbound approach was the only approach that experienced a decrease in left-turning movements from morning peak to evening peak. Table 21 shows that the southbound movement also experienced a decrease in violations from the morning peak to the evening peak. The eastbound approach experienced an increase in volume from the morning peak to the evening peak. In summary, there was no consistent relation between volume and total violations when comparing morning and evening peak hours. However, it can be noted that traffic approaches with the highest combined morning and evening left turn traffic counts had the most violations. The following table shows the number of violations for the through movements at the treatments sites.

Table 22. Through Movement Violations at the Treatment Site

Study Period	Approach	75th Street and Metcalf Avenue		College Boulevard and	
		Morning	Evening	Morning	Evening
Before	Northbound	2	2	3	-
	Southbound	1	-	-	1
	Eastbound	-	3	3	-
	Westbound	1	2	-	-
One Month	Northbound	-	-	1	1
	Southbound	-	-	2	3
	Eastbound	-	-	7	-
	Westbound	-	-	-	3
Three Month	Northbound	3	1	2	1
	Southbound	-	1	2	-
	Eastbound	1	6	-	1
	Westbound	2	-	-	1

There were a total of 25 through movement violations at 75th Street and Metcalf Avenue, and 31 through movement violations at College Boulevard and Quivira Road for all periods of the study. When comparing between periods of the study at College Boulevard and Quivira Road, there were seven violations during the before period, 17 violations during the one-month after period, and seven violations during the three-month after period of the study. During all periods of the study most of the through movement violations were observed during the morning peak hours at College Boulevard and Quivira Road. During the before period the eastbound and northbound approaches had the highest violations. The eastbound approach had the highest violations at the one-month after period. All seven violations observed during the one-month after period at the eastbound approach occurred during the morning peak hours. The violations observed in the eastbound approach during this period of the study equal the total violations observed during the before study period and the total violations observed during the three-month after period. At

75th Street and Metcalf Avenue most of the violations were observed during the evening peak hours. The northbound approach had the highest number of violations in the before period and the eastbound approach had the highest violations for the three-month after period. When comparing violations between approaches, the northbound and southbound approaches experienced the same total number of through violations. For the westbound approach through movement violations decreased by one violation from the before period to the three-month after period. The eastbound approach experienced an increase in through violations from three violations in the before period to seven violations in the three-month after period. Volume fluctuations for each approach are shown in Table 23.

Table 23. Through Movement Volumes at Treatment Sites

Study Period	Approach	75th Street and Metcalf Avenue		College Boulevard and Quivira Road	
		Morning	Evening	Morning	Evening
Before	Northbound	2,238	2,339	2,376	1,918
	Southbound	2,157	2,769	1,877	3,200
	Eastbound	1,047	1,556	1,493	1,630
	Westbound	1,422	1,521	805	1,895
One Month	Northbound	-	-	2,518	1,838
	Southbound	-	-	2,394	3,625
	Eastbound	-	-	1,850	1,529
	Westbound	-	-	951	1,933
Three Month	Northbound	2,120	2,547	2,663	1,957
	Southbound	2,260	2,728	1,959	3,059
	Eastbound	1,016	1,227	1,132	1,565
	Westbound	1,347	1,549	996	2,137

Table 23 shows the combined through and right turn volumes for each approach. At both intersections there was an increase in volume from the morning peak to the evening peak hour during all periods of the study. However, the approach with the highest volume did not have the highest number of violations. For example, the eastbound approach at 75th Street and Metcalf Avenue during the three-month after period, and the eastbound approach at College Boulevard and Quivira Road during the before and one-month after period have a low total volume count but some of the highest total violations when compared to other approaches. When comparing morning peak to evening peak hours, at 75th Street and Metcalf Avenue there was an increase in volume and violations from the morning to evening peak. The opposite was observed at College Boulevard and Quivira Road. It must be noted that although the eastbound approach during the one-month after period had the second lowest total volume from all approaches, it had a higher volume in the morning peak than the evening peak hours, and all violations were observed in the morning peak hours. There were 18 right turn violations that were recorded for eastbound traffic at College Boulevard and Quivira Road. This was the only approach were right turn violations were studied because of the “no turn on red” signal that was described in section 3.3.1. However, these violations were not taken into account when performing a statistical analysis because the study did not take into account right turns.

In summary, the one-month after period of the study at College Boulevard and Quivira Road found a violation rate much higher than the before and three-month after period of the study. The violation rate in the three-month after period was not as high as the one-month after period, indicating that the increase was not due to the confirmation lights, but due to other factors. When looking at the violations per approach, the eastbound and southbound approaches had the highest number of violations during this period. This could be due in part to students attending Johnson County Community College since classes started on the 19th of August and the intersection was recorded on the 27th of August. Morning peak volumes were lower than evening peak volumes, however, more violations were observed in the morning peak hours, indicating that volume may not be a factor. Since the highest violation increase was experienced in August, targeted enforcement was recommended during this time period. The confirmation lights can help targeted enforcement at this intersection by reducing the number of officers needed. In addition, the confirmation lights can assist in enforcing left turns, which was where most violations were observed.

CHAPTER 6. TIME INTO RED ANALYSIS

6.1 Background

An important aspect to a vehicle running a red light is how far into the red cycle did the violation occur. Violations found within the all-red time (generally one to two seconds) are most likely due to a driver caught in the intersection indecision zone or at the end of a platoon and intentionally run the red light. The indecision zone of an intersection is an area prior to the stop line where the driver is unsure if he or she should break or proceed through the intersection during the yellow phase.

However, drivers that enter the intersection past the all-red phase create a more hazardous situation, particularly as the conflicting movement has a green light. Hallmark et al. stated that drivers that run a red light late into the red phase are more likely unintentional and involve a distraction, impairment, or fatigue. Hallmark et al. (2012) also found when evaluating RLR cameras in Cedar Rapids, Iowa that over 120 of violations occurred from zero to less than one seconds into the red phase, while over 60 violations occurred 25 seconds into the red phase during a pre-ticket evaluation period of seven intersection approaches. Another research study found that 95 percent of RLR violations occur in the first two minutes of the red phase (Beeber, 2011).

As explained in detail in the previous chapter, the effectiveness of the confirmation light system was investigated by determining if the change in RLR violations were statistically significant before and after the confirmation light installation. Effectiveness of the confirmation light system was also extended into investigating the change of the time into red for violations captured by the video data.

6.2. Methodology

The time into red was evaluated similar to the previous chapter where the treatment intersections were compared to the spillover and control intersections for three study periods (before, one month after installation, and three months after installation). Time into red was plotted where the x-axis was the number of violations and the y-axis was time into red (in seconds). Violations were aggregated in the y-axis for seconds with a maximum time plotted of greater than five seconds. It should be noted that as stated in the previous section that the number of violations in each study period changed, so the total number of violations plotted in the following figures is not a consistent number for each study period.

6.3 Results

6.3.1 Left-turning Movement

Figures 73, 74, and 75 show the results of the RLR time into red for the left-turning movement for all of the intersections studied. Figure 73 shows the left-turning movement time into red for the two treatment intersections.

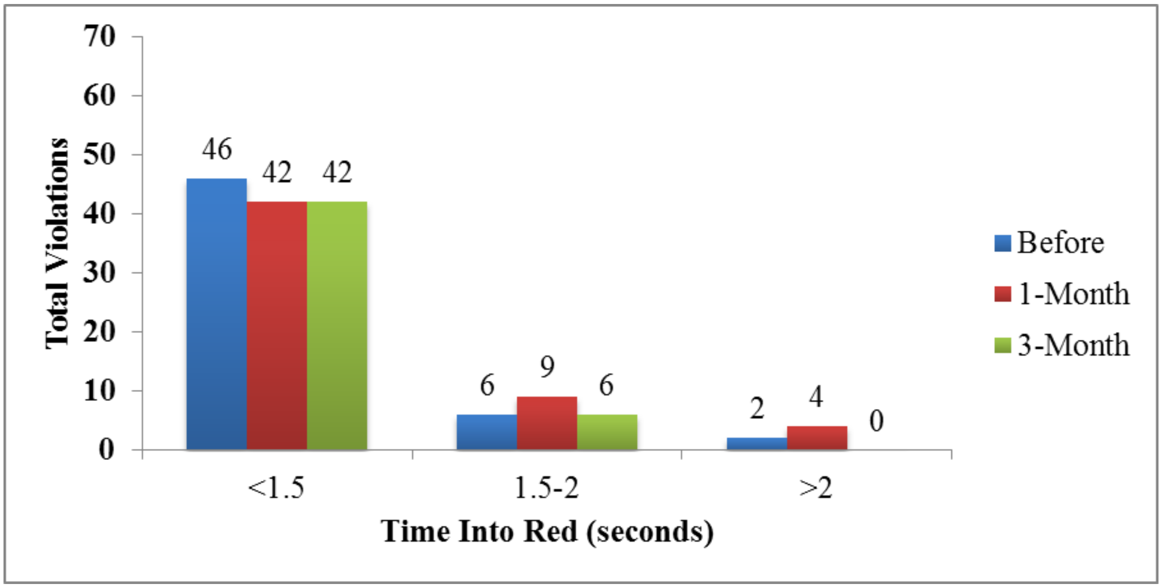


Figure 73. Left-turning movement time into red at treatment intersections

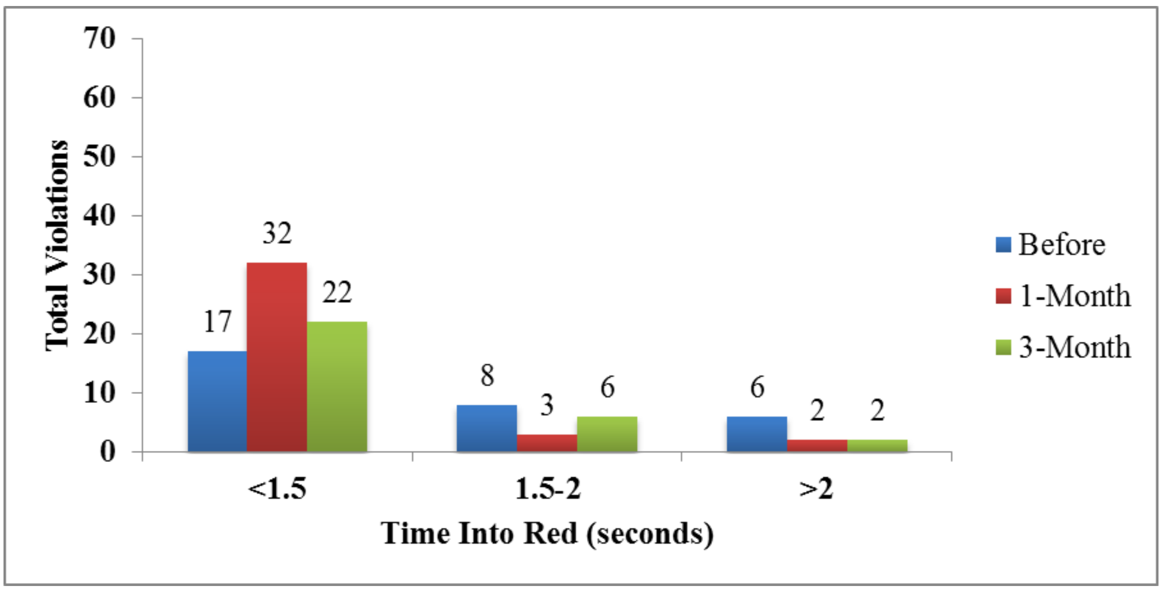


Figure 74. Left-turning movement time into red at spillover intersections

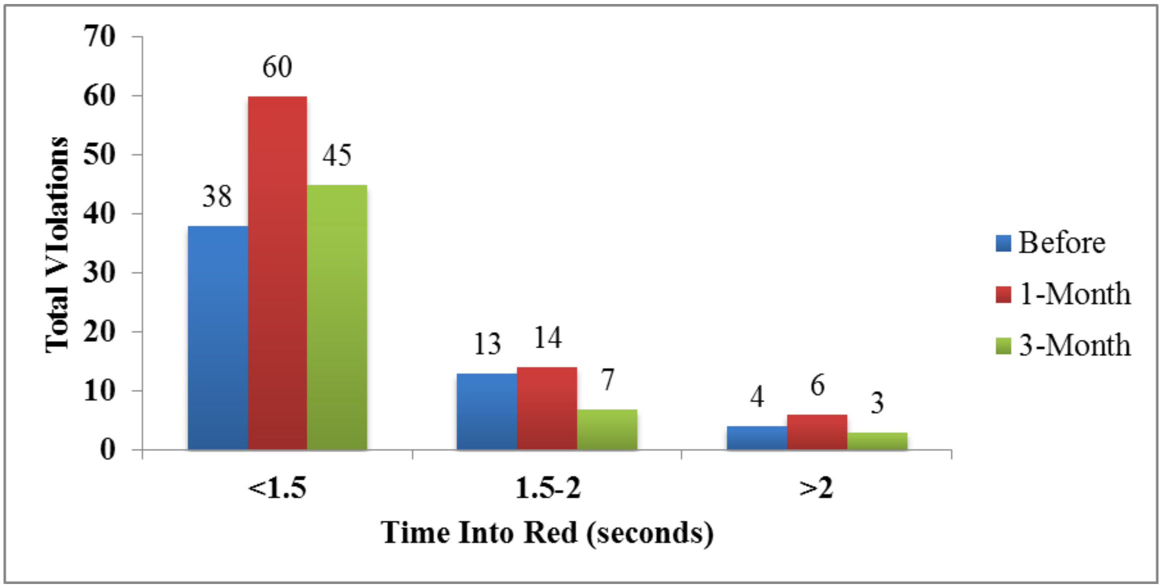


Figure 75. Left-turning movement time into red at control intersections

As shown in Figure 73, most of the violations occurred less than one second after the onset of the red light at the treatment sites. The before period of the study observed two violations with a time into the red of over two seconds. One violation took place at 75th Street and Metcalf Avenue, where a westbound driver turned left three seconds into the red. The other occurrence took place in College Boulevard and Quivira Road where a northbound vehicle made a U-turn 48 seconds into the red. During the one-month after period of the study there was an increase in violations around two seconds into the red and violations of over two seconds into the red. All four violations that occurred over two seconds into the red took place at College Boulevard and Quivira Road. All four violations happened three seconds into the red. One was observed during the morning peak and three were observed during the evening peak. There were no violations of over two seconds into the red during the three-month after period.

Figure 74 shows the left-turning movement time into red at the spillover intersections adjacent to the two treatment intersections. Most of the violations at the spillover sited occurred within one second into the red. The spillover sites had more violations after two seconds into the red than the treatment sites. The range of time into the red for over two seconds was 3-154 seconds. College Boulevard and Nieman Avenue had the most violations of over two seconds into the red with a total of five.

Figure 75 shows the left-turning movement time into red at the control intersections. Similar to the previous two figures, most of the RLR violations occurred within one second into the red. At the control sites there were a total of 13 violations that occurred over two seconds into the red, which was more than the spillover sites. The intersections of 103rd Street and Antioch Road, and 103rd Street and Metcalf Avenue had four violations each of over two seconds into the red. Violations of over two seconds occurred in the range of 3 - 192 seconds into the red.

6.3.2 Through Movement

Figures 76, 77, and 78 show the time into red for the through movement violations at all of the intersections studied. Figure 76 shows the through movement violations' time into red for the two treatment intersections.

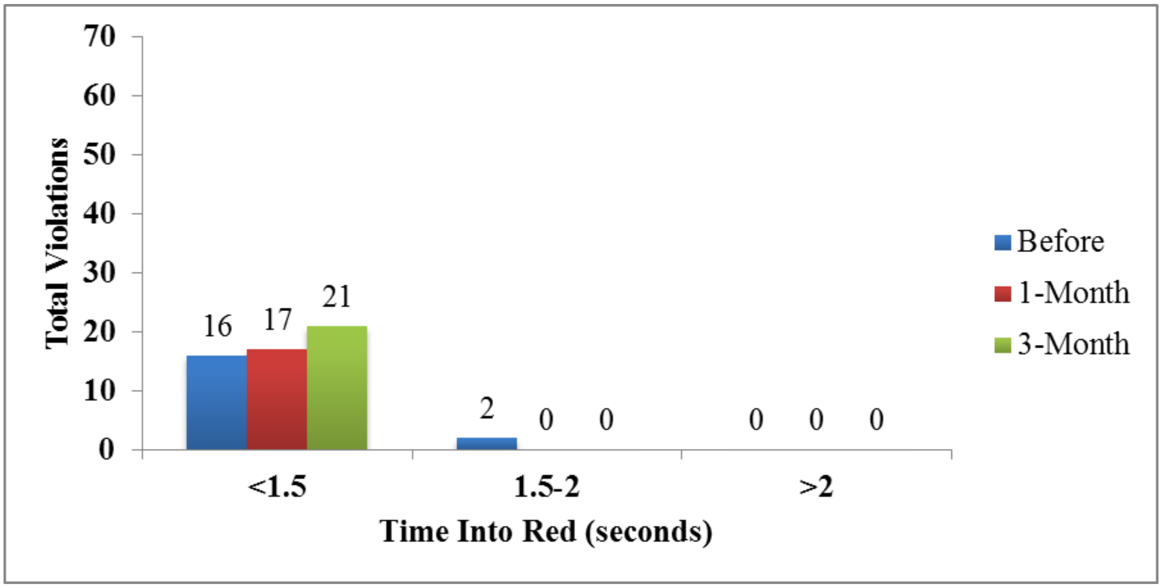


Figure 76. Through movement time into red at treatment intersections

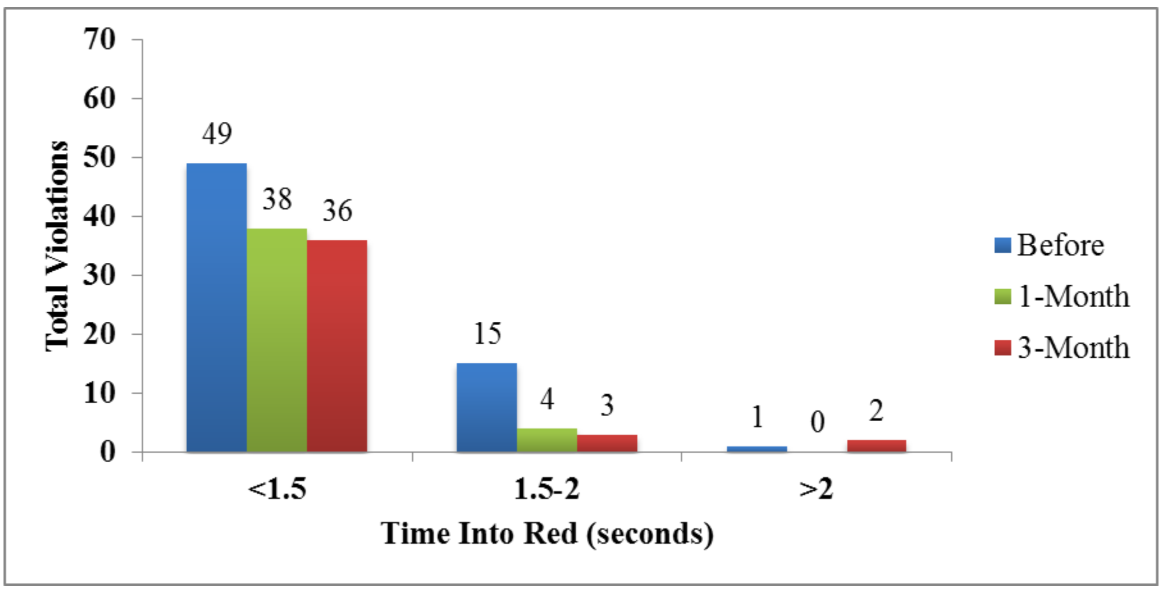


Figure 77. Through movement time into red at spillover intersections

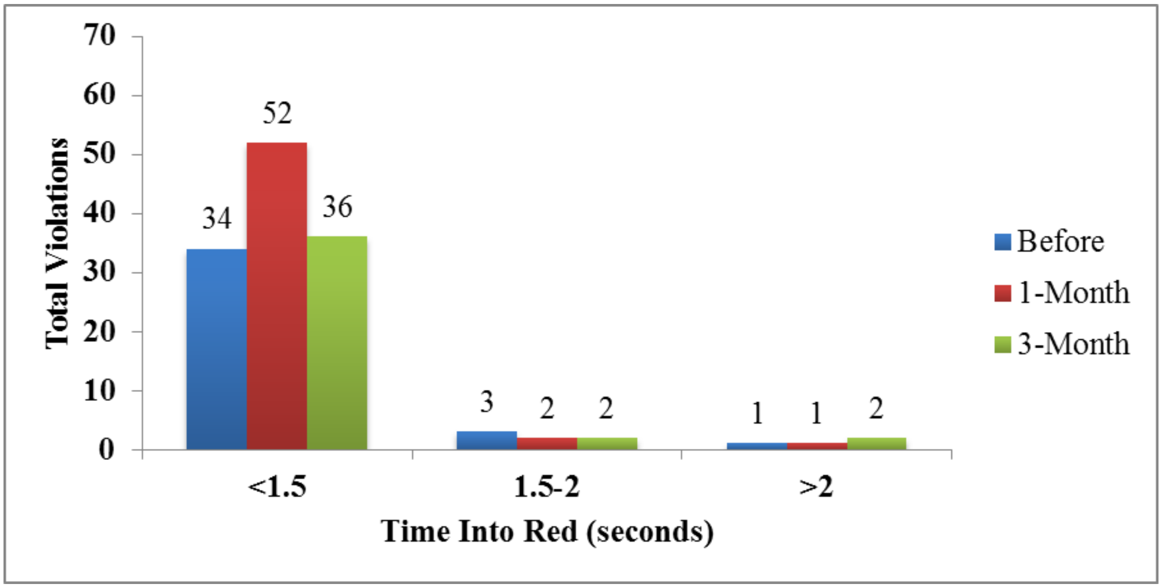


Figure 78. Through movement time into red at control intersections

As shown in Figure 76, most of the through movement violations occurred within one second into the red at the treatment intersections. Other violations were found to occur between 1.5 and two seconds into the red. There were no violations of over two seconds into the red for any of the study periods at the treatment sites.

Figure 77 shows the through movement RLR violations at the spillover intersections. Similar to the treatment intersections in Figure 76, most of the through movement violations occurred within one second into the red. There were three violations that took place over two seconds into the red. One occurrence took place at 75th Street and Conser Street, and the other two violations took place at 79th Street and Metcalf Avenue. The time into the red for these violations was between three and four seconds.

Similar to Figures 76 and 77, the control intersections saw many through movement violations occurring within one second into the red phase indicating that RLR violations were likely intentional. The control sites had four total violations that took place over two seconds into the red. The range in time into the red was 3 - 66 seconds. The intersection of 95th Street and Antioch Road was where two of these incidents were observed.

6.3.3 Incidents over Two Seconds into the Red

There were a total of 36 violations that occurred over two seconds into the red. Twenty-nine were left-turning violations and seven were through movements. This section describes some of the events for violations over two seconds into the red. Only events over 50 seconds are described.

95th Street and Metcalf Avenue, 51 Seconds into the Red

(a)

(b)

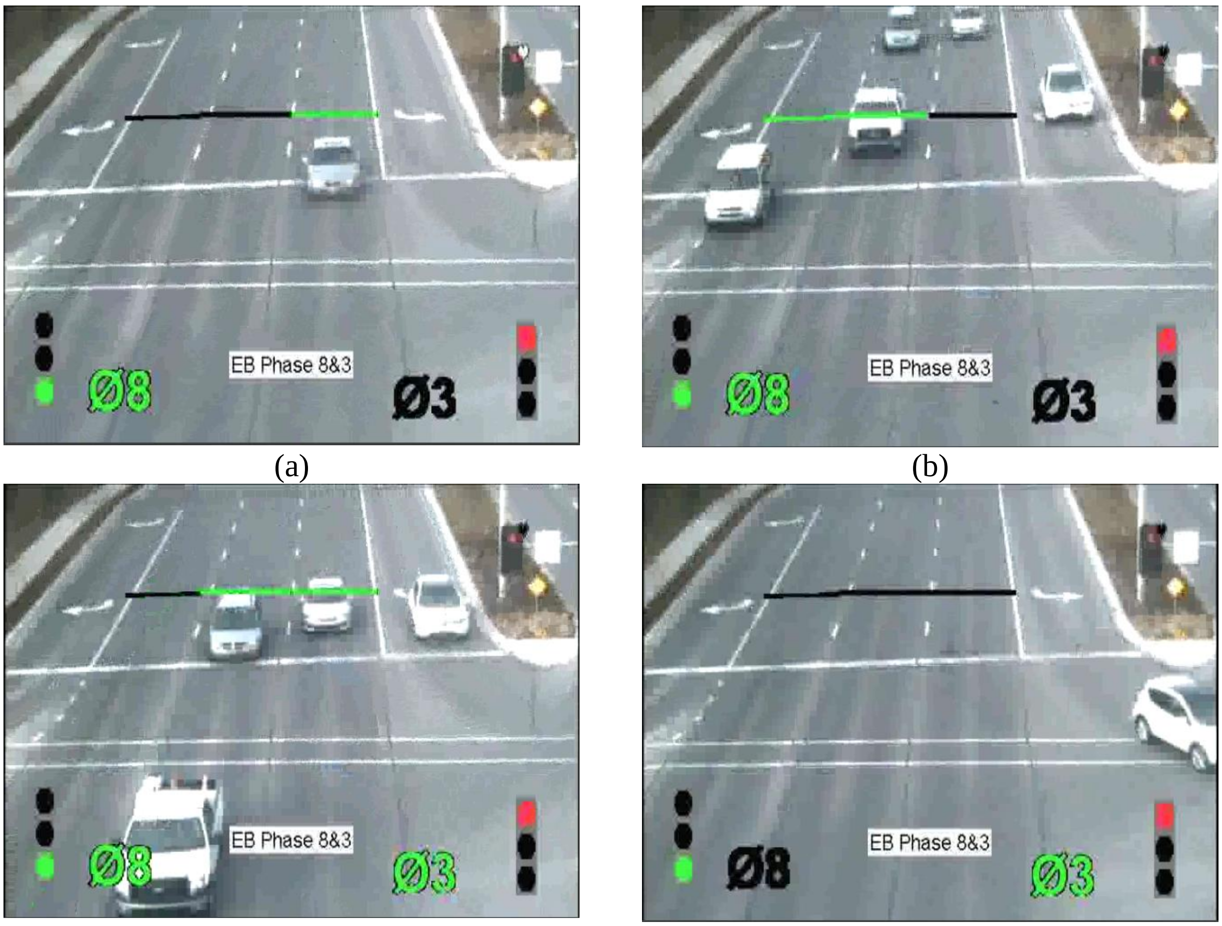
(c)

(d)

Figure 79. Through movement violation at 95th Street and Metcalf Avenue

At 95th Street and Metcalf Avenue a northbound vehicle crossed the intersection 51 seconds into the red. Figure 79 (a) shows a car already stopped past the stop line and another car approaching the intersection. The grey car that was pulling up on the through lane next to the dual left turn lanes was the driver that committed the violation. As shown in Figure 79 (b) all vehicles at the northbound approach were stopped as traffic along 95th Street travel through the intersection. After there was no more traffic traveling along 95th Street the driver crossed the intersection during the all-red interval, before southbound left-turning started crossing the intersection as shown in Figures 79 (c) and (d). Figure 80 shows a violation at College Boulevard and Nieman Road.

College Boulevard and Nieman Road, 154 Seconds into the Red



(d)

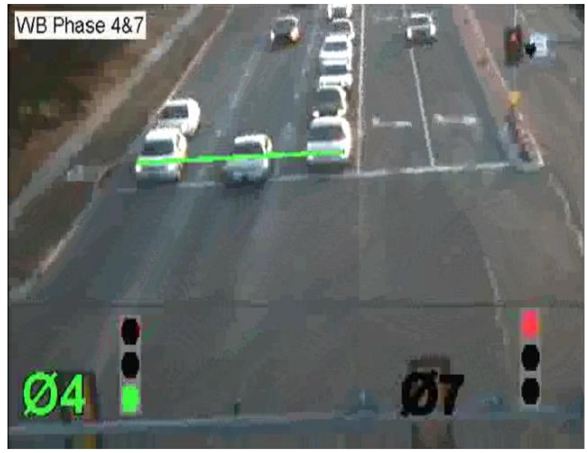
Figure 80. Eastbound left turn violation at College Boulevard and Nieman Road

Figure 80 shows a left turn violation observed during the before period at College Boulevard and Nieman Road. An eastbound driver making a left turn crossed the intersection 154 seconds into the red during the morning peak hours. Figure 80 (a) shows that the left lane was cleared and the platoon of through vehicles had cleared the approach. The through and right turn movements had the green light, and the left turn movement was on the red phase. Figure 80 (b) shows the drivers approached the intersection on the left lane along with a platoon. Figure 80 (c) and (d) show that the driver did a rolling stop, and once there was a gap in oncoming traffic the driver turned proceeded to turn left.

College Boulevard and Nieman Road, 131 Seconds into the Red

A similar occurrence to the previously mentioned violation was observed during the evening peak at this period of the study. A driver was waiting on the left turn lane for most of the red cycle, and when the driver saw a gap the vehicle turned left 131 seconds into the red.

(a)



(b)

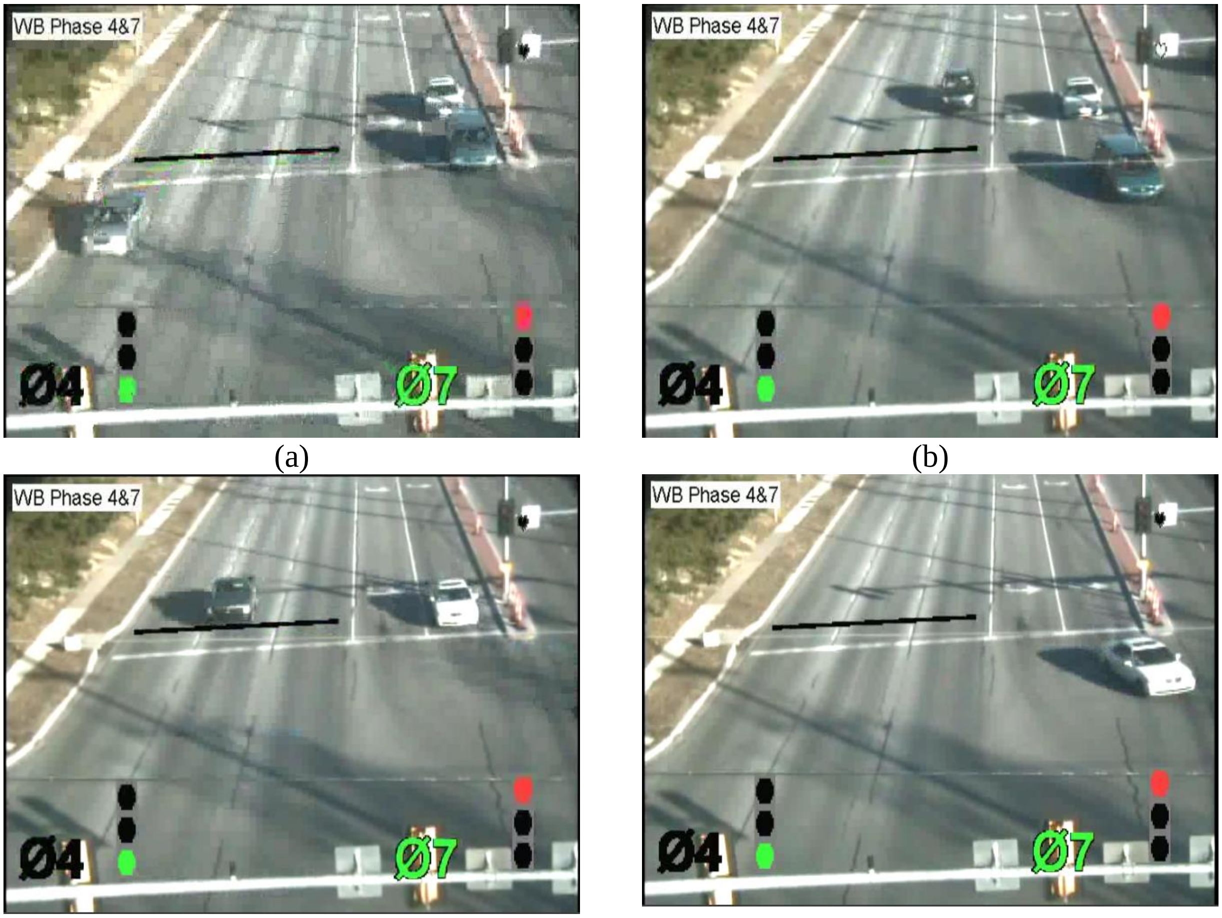
(c)

(d)

Figure 81. Westbound violation at College Boulevard and Nieman Road

Figure 81 shows a violation recorded on the before period of the study at westbound College Boulevard and Nieman Road. The violation was observed during the morning peak period. Figure 81 (a) shows westbound traffic waiting at the intersection for the green light. The video shows that, when the through movement was given a green light, a vehicle from the back of the queue drove onto the left turn lanes as pictured in Figure 81 (b). The driver approached the intersection while driving on both left turn lanes (Figure 81 (c)) and then the vehicles proceeded to make a left turn as seen on Figure 81 (d) while the left turn signal was red. Another violation at this approach was seen in the afternoon. Figure 82 shows the violation.

College Boulevard and Nieman Road, 52 Seconds into the Red



(a) (b) (c) (d)

Figure 82. Afternoon violation at College Boulevard and Nieman Road

As pictured in Figure 82 (a) there were two vehicles in the far left lane. The protected left turn movement was on the red phase, and through movements had the green light. Figure 82 (b) shows that the first driver started to turn left and crossed the stop line 46 seconds into the red. As shown in Figure 82 (c) and (d) the first car in the queue made the left turn and then the second vehicle stopped at the stop line and then proceeded to turn left 52 seconds into the red.

95th Street and Antioch Road, 66 Seconds into the Red

(a) (b)

Figure 83. Violation 66 seconds into the red at 95th Street and Antioch Road

At 95th Street and Antioch Road an eastbound vehicle ran the red light 66 seconds into the red. Figure 83 (a) shows the eastbound and westbound left turn movements turning at the intersection and the through movement at the red phase. After the last left-turning vehicle turned left, the first vehicle in the right through lane drove through the intersection therefore jumping the red light as seen in Figure 83 (b). This was not due to distraction or inattention, but rather the driver blatantly crossed the intersection. A violation that could be due to inattention was shown in Figure 84.

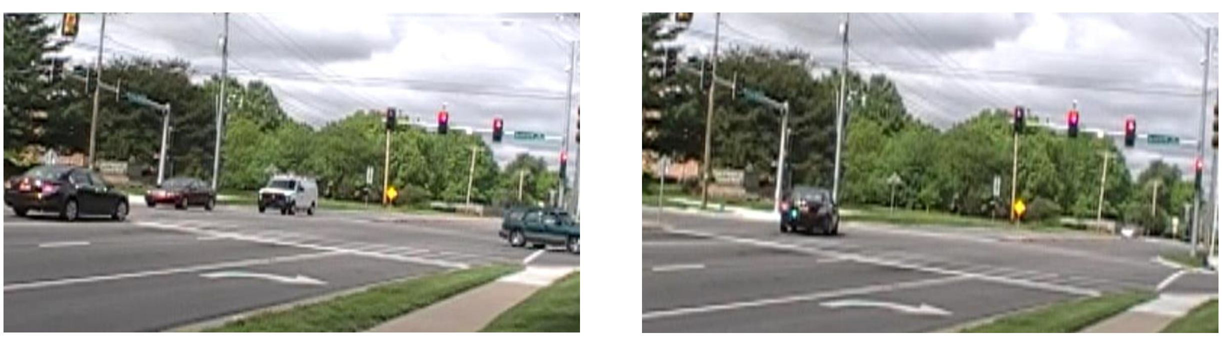
95th Street and Antioch Road, 57 Seconds into the Red

(a) (b)

Figure 84. Violation at 95th Street and Antioch Road 57 seconds into the red

At 95th Street and Antioch Road a driver crossed the intersection 57 seconds into the red. As shown in Figure 84 (a) the all movements for the northbound approach were on the red phase. The vehicle on the left through lane traveled through the intersection as soon as the left turn arrow was green as seen in Figure 84 (b). This situation could be attributed in part to driver inattention.

103rd Street and Antioch Road, 82 Seconds into the Red

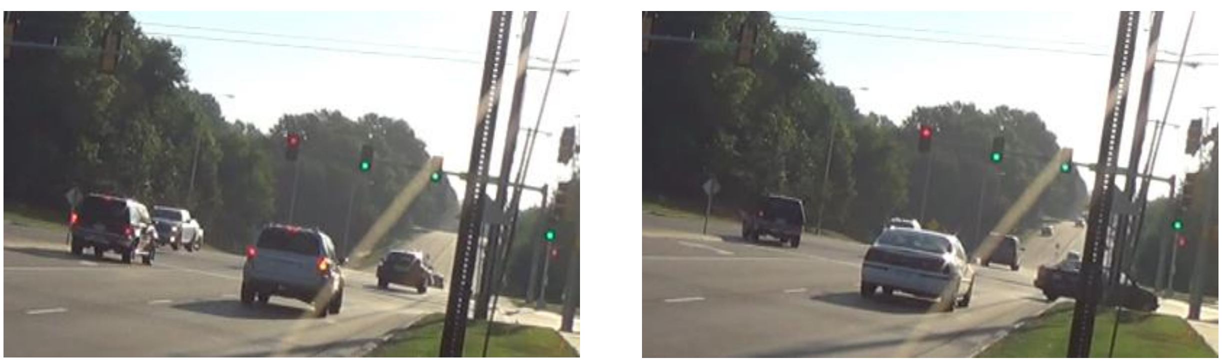


(a) (b)

Figure 85. Violation at 103rd Street and Antioch Road 82 seconds into the red

At 103rd Street and Antioch there was another driver that made a left turn 82 seconds into the red. The eastbound approach traveling along 103rd Street was on the green phase for all movements, while the westbound approach was in all-red for all movements. Figure 85 (a) shows that the vehicle arrived at the intersection and it was the only vehicle on the approach. After oncoming traffic crossed the intersection and there were no more oncoming vehicles, the driver made a left turn onto southbound Antioch Road. This case could be due to driver inattention, since the driver could have assumed that the lights were green for all approaches. It could also be due to a blatant disregard of the traffic signal.

<u>103rd Street and Antioch Road, 192 Seconds into the Red</u>



(a) (b)

Figure 86. Violation at 103rd Street and Antioch Road 192 seconds into the red

At the eastbound approach of 103rd Street and Antioch Road a left turn vehicle ran the red light 192 seconds into the red of the left turn cycle. The driver waited at the approach for 192 seconds (Figure 86 (a)) and after the through movements were cleared, the driver did not wait any longer and crossed the intersection as pictured in Figure 86 (b). The driver could have been impatient or had an assumption the arrow would never turn green.

Summary

In summary, many factors contributed to violations over 2 seconds into the red. The examples described show that early departure for the through movement does occur at urban intersections. There were drivers who were willing to cross the intersection during the all-red cycle or they looked for a gap in opposing traffic to cross the intersection. Distracted driving or disregard for the traffic signal was also observed. It is worth noting that all examples given were violations that occurred over 50 seconds into the red, and all examples were observed at control or spillover intersections and not treatment intersections. The majority of this type of violation was observed during the morning peak hours and they were mostly left-turning vehicles.

CHAPTER 7: STATISTICAL MODEL AND DISCUSSION

As a part of this research study, a statistical model was developed from the traffic data recorded. The goal of the model was to understand how RLR behavior changes according to the traffic volume, peak period, and intersection geometry. A second goal of the model was to measure the significance and the impact of the countermeasure employed during this project. The variables under consideration are listed, in no particular order:

- Violations
- Period of the study
- Traffic movement (through or left turn movement)
- Time (a.m. vs. p.m.)
- Lane volume
- Movement volume
- Total approach volume
- Total lanes for traffic movement
- Total lanes for the intersection approach
- Yellow phase timing
- Red phase timing
- Right turn lane present at the approach
- Clearance path
- Speed limit for the approach
- Presence of confirmation lights

The variable “violations” is the dependent variable and it represents the total violations observed at one approach, per movement, according to the peak period. The variable “period” refers to the period of the study when the violation took place. Period of the study was coded according to the period of time that the countermeasure was in place and it was coded as 0 for the before period, and one for three months after. Traffic movement refers to the movement of the vehicle running the red light and it was coded as 0 for left and 1 for through movement. The variable “time” indicates whether the violation took place in morning (0) or evening (1) peak period. Lane volume is the volume of the lane that the violation occurred at the time of violation. Movement volume is the total volume of all lanes for a particular movement. Approach volume is the total volume (left turns, through, and right turns) observed at a specific approach of an intersection. The variable “total lanes for traffic movement” refers to the lanes designated for a specific movement at the approach. The approach lanes are all the travel lanes for a certain approach. Yellow and red phase timing variables are the times shown in the intersection description section. The presence of a right turn lane was coded as 0 for no right turn lane at the approach, and 1 if there was a right turn lane at the approach. Clearance path is the distance between the stop lines measured in feet, and the posted speed limit for each approach was referred to as the variable “speed limit” in the model. Presence of confirmation lights was coded as 0 when there was no confirmation light installed and 1 when there was a confirmation light installed. Because there were traffic data recorded during the before period and the three months after period for both treatment sites, one-month after data for all intersections are omitted from the statistical model.

The nature of reducing the traffic data was to count the number of vehicles and the number of RLR violations. Since the number of violations was a count from the number of vehicles observed a count regression model such as Poisson or Negative Binomial could be used to model the data set. The Poisson distribution requires that the mean equals the variance. When the mean and the variance are not equal, the data are overdispersed and the Negative Binomial distribution can be used to account for that overdispersion (Washington et al., 2011). Table 24 shows the descriptive statistics of the available variables for the model.

Table 24. Model Variable Statistics

Variable	Mean	Std Dev.	Minimum	Maximum	Variance
Period of Study	0.49	0.5	0	1	0.25
Traffic Movement	0.52	0.5	0	1	0.25
Time of Day	0.55	0.49	0	1	0.25
Lane Volume	500.58	366.49	15	1,723	134,315.41
Movement Volume	1,011.50	866.26	33	4,214	750,421.46
Approach Volume	2,056.78	891.82	96	4,700	795,341.67
Movement Lanes	1.91	0.59	1	3	0.35
Approach Lanes	4.26	1.43	1	6	2.04
Yellow Phase	3.59	0.48	3	4.8	0.23
Red Phase	2.45	0.61	1.4	3.5	0.38
Right Lane Presence	0.57	0.49	0	1	0.25
Path Length	131.08	33.62	70	196	1,130.39
Speed Limit	39.59	5.85	20	45	34.17
Total Violations	2.42	2.23	1	17	4.95
Confirmation Light	0.12	0.33	0	1	0.11

As shown in Table 24, RLR violations have a mean of 2.42 violations per peak period per movement and a variance of 4.95 violations per peak period per movement. Because of the overdispersion, a negative binomial distribution was used to model the data. The program SAS was used to calculate the coefficients of the model. The “countreg” procedure was used in SAS which gives the Log likelihood for the model. Table 25 shows the parameter estimates for all variables.

Table 25. Negative Binomial model results with all variables

Parameter Estimates					
Parameter	**DF**	**Estimate**	**Standard Error**	**t-Value**	**Approx Pr>t**
Intercept	1	2.568	0.97	2.65	0.0081
Period	1	-0.248	0.116	-2.14	0.0322
Traffic Movement	1	-0.556	0.269	-2.07	0.0386
Time	1	0.131	0.116	1.13	0.2578
Lane Volume	1	0.0004	0.0004	0.89	0.371
Movement Volume	1	0.0003	0.0002	1.27	0.2043
Volume	1	-0.0001	0.0001	-1.07	0.2845
Movement Lanes	1	0.258	0.229	1.12	0.2618
Approach Lanes	1	-0.046	0.136	-0.34	0.7332
Yellow Phase	1	-0.572	0.291	-1.97	0.0491
Red Phase	1	-0.025	0.205	-0.12	0.9022
Right Turn Lane	1	-0.248	0.191	-1.3	0.1939
Path Length	1	-0.0006	0.004	-0.13	0.8949
Speed	1	0.008	0.019	0.43	0.6651
Confirmation Lights	1	0.402	0.1176	2.29	0.0223
Dispersion	1	0.135	0.043	3.17	0.0015

Table 25 shows the estimates, standard error, t-value, and p-value associated with each parameter. The dispersion of the dependent variable was significant at the 95 level of confidence, showing that the Negative Binomial model was more appropriate than a Poisson model. The Log-likelihood for this model is -374.18. The results showed that the only variables that were significant at the 95 percent confidence level were:

- Period of the study;
- Traffic movement;
- Yellow time; and
- Confirmation lights.

To determine the reasons why only four variables were significant, a linear correlation procedure was performed to find if any dependencies between variables existed. At first, the volume counts for lane, movement, and approach volume were tested to each other. Table 26 shows the Pearson Sample Correlation and p-value for each variable.

Table 26. Linear Correlation between volumes

Variable	With Variable	Sample Correlation	p-Value
Lane Volume	Movement Volume	0.90934	<.0001
Lane Volume	Volume	0.34081	<.0001
Movement Volume	Volume	0.43092	<.0001

As shown in table 26 there was a significant linear correlation between all volumes. The correlation coefficient was positive between all variables, meaning that an increase in one variable translates to an increase in the other variable. In other words, an increase in lane volume lead to an increase in movement volume, and an increase in movement volume lead to an increase in approach volume. This meant that only one volume variable should be selected. In order to determine if there were any other correlations between variables, all variables were tested for correlations using the SAS correlation procedure. Table 27 shows some of the correlation results.

Table 27. Correlation results between variables

Variable	With Variable	Sample Correlation	p-Value
Period	Volume	0.5925	0.3968
Volume	Red	0.10122	0.1469
Time	Period	-0.01408	0.8407
Lane Volume	Speed	-0.05874	0.4009
Movement Volume	Approach Lanes	0.04341	0.535
Movement Volume	Right Turn	-0.0494	0.4799
Movement Volume	Path	-0.01072	0.1243
Movement Lanes	Red	0.07851	0.2612
Yellow	Right Turn	0.0917	0.1891
Yellow	Path	0.0773	0.2686
Traffic Movement	Time	-0.0569	0.4159
Traffic Movement	Volume	-0.05777	0.4088
Traffic Movement	Period	-0.06268	0.3701
Time	Lane Volume	0.09086	0.1932
Time	Movement Volume	0.0652	0.3511
Time	Movement Lanes	-0.00888	0.8991
Time	Approach Lanes	0.03965	0.571
Time	Yellow	-0.02145	0.7593
Time	Red	0.04256	0.543
Time	Right Turn	0.0199	0.7762
Time	Path	0.0009	0.9895
Time	Speed	0.003	0.9656

Table 27 only shows the variables that were not correlated. In summary most of the variables were correlated to each other. It is worth to noting that none of the variables in the model were linearly correlated to RLR violations. In order to select an appropriate model, a stepwise regression procedure was performed. The procedure chose the variables according their Chi-Square score. Table 28 shows the initial analysis of variables.

Table 28. Stepwise analysis for parameters eligible for entry

Analysis of Effects Eligible for Entry			
Effect	**DF**	**Score Chi-Square**	**Pr>ChiSq**
Period of Study	1	0.382	0.5365
Traffic Movement	1	1.2909	0.2559
Time of Day	1	1.1359	0.2865
Lane Volume	1	1.4397	0.2302
Movement Volume	1	0.5692	0.4506
Approach Volume	1	0.9109	0.3399
Movement Lanes	1	0.2071	0.649
Approach Lanes	1	0.5037	0.4779
Yellow Phase	1	2.1703	0.1407
Red Phase	1	0.0139	0.906
Right Lane Presence	1	2.607	0.1064
Path Length	1	0.4071	0.5234
Speed Limit	1	0.0446	0.8328
Confirmation Light	1	0.3794	0.5379

In the stepwise procedure, it was specified that a variable had to be significant to the 70 percent level to enter the model, and be significant to the 85 percent level to stay in the model. These numbers were chosen because less than half of the variables were found to fit the criteria. As shown in Table 28, five out of the 14 variables in the model were eligible for entry in the function. These variables were:

- Traffic movement;
- Time of day;
- Lane volume;
- Yellow time; and
- Right turn lane presence.

Table 29 shows the parameters selected by the procedure.

Table 29. Stepwise procedure results

Summary of Stepwise Selection							
Step	Effect		DF	Number In	Score Chi-square	Wald Chi-Square	Pr>Chi-Square
	Entered	Removed					
1	Right turn		1	1	2.607		0.1064
2	Traffic Movement		1	2	2.5641		0.1093
3	Lane Volume		1	3	8.7299		0.0031
4	Yellow		1	4	1.3681		0.2421
5		Yellow	1	3		1.372	0.2415

The variables that were selected for the best model were yellow time, lane volume, presence of a right turn lane, and traffic movement. A negative binomial regression was run again using these four variables. Table 30 shows the parameter estimates results obtained from SAS.

Table 30. Negative Binomial Regression results

Parameter Estimates					
Parameter	**DF**	**Estimate**	**Standart Error**	**t Value**	**Approx Pr>t**
Intercept	1	1.805451	0.623124	2.9	0.0038
Traffic Movement	1	-0.395143	0.196357	-2.01	0.0442
Lane Volume	1	0.000804	0.000207	3.88	0.0001
Yellow	1	-0.282142	0.2025	-1.39	0.1635
Right Turn	1	-0.246621	0.1156	-2.13	0.0329
Alpha	1	0.159988	0.045559	3.51	0.0004
Log Likelihood			-380.28934		
Number of Iterations			16		

Table 30 shows the parameter estimates for the variables in the model. According to the model motorists that traveled through the intersection were less likely to run the red light than left-turning motorists. The higher the lane volume, the more likely that a violation will be observed. The presence of a right turn lane reduces the likelihood of a red light violation. Alpha refers to the dispersion of the dependent variable (violations). From this model, only the yellow phase time is not significant to the 95 percent level of confidence. Table 31 shows the reduced model with the yellow timing variable was omitted.

Table 31. Negative Binomial Regression Model results

Parameter Estimates					
Parameter	**DF**	**Estimate**	**Standart Error**	**t Value**	**Approx Pr>t**
Intercept	1	0.950672	0.114121	8.33	<0.0001
Traffic Movement	1	-0.569004	0.154733	-3.68	0.0002
Lane Volume	1	0.000737	0.000202	3.64	0.0003
Right Turn	1	-0.302303	0.108615	-2.78	0.0054
Alpha	1	0.162293	0.045938	3.53	0.0004
Log Likelihood			-381.26149		
Number of Iterations			10		

In order to estimate the goodness of fit of the model found in Table 31, the likelihood ratio test statistic was used. The test used the log likelihood of the unrestricted model (-374.18) and the log likelihood of the restricted model (-381.26149) to calculate a Chi-squared scored. The degrees of freedom for the Chi-squared score statistic were 11, which is the difference in number of variables between the unrestricted model and the restricted model. The likelihood ratio test statistic yielded a Chi-squared score of 14.16. This score suggest that there was not enough evidence to reject the fit of the reduced model. The McFadden pseudo R-squared value for this model was 0.27. The sign convention for each parameter remained the same. The model from the data obtained follows the equation:

$$V = e^{(0.95-0.57(tm)+.00074(lv)-.302(rt))} \quad \textbf{Eq. 6}$$

Where *v* = violations;

tm= traffic movement (0 for left, 1 for through);

lv = lane volume and;

rt = right turn lane (0 for no right turn lane at approach, 1 for right turn lane present).

According to Equation 6, if there was no volume, RLR violations would still be observed. Because this observation is not in accordance with actual field observations, a reduced model is presented to account for when there are no cars on the road as shown in Equation 7.

$$V = e^{(-0.57(tm)+.00074(lv)-.302(rt))} - 1 \quad \textbf{Eq. 7}$$

In Equation 7, if all variables are zero, the violations will equal zero, therefore, reflecting field conditions. Discussion about general findings and interpretation of the model are presented in Chapter 8.

CHAPTER 8: DISCUSSION AND GENERAL FINDINGS

The statistical model found that the confirmation lights had no significant effects on RLR behavior because it showed that lane volume, traffic movement, and the presence of a right turn lane were significant factors that affected RLR violations. According to the developed model left-turning traffic movements increase the number of RLR violations. This result coincided with the observed data because more than half of the violations observed were left-turning vehicles. Increases in lane volume lead to an increase in violations in the statistical model. During the data reduction process it was observed that an increase in volume also lead to an observed increase in RLR violations. The applicability of this variable in the model could be difficult for practitioners that intend to use the model. Most cities only have overall counts for an approach and not the volume per lane. The presence of a right-turn lane was found to decrease the number of violations in the model. This behavior was not noted during the data reduction process. There were few occasions were a vehicle behind a right-turning motorist performed an overtaking maneuver and ran the red light.

The model also found that the presence of confirmation lights is not a significant factor for RLR violations. This further disproves the hypothesis that the presence of the confirmation light would reduce RLR behavior. The study also found that the confirmation lights did not affect driver behavior in jumping the red light (i.e., departing from the stop line just prior to the green indication). The time into the red analysis showed occurrences were drivers ran the red light after two seconds into the red, but most of these occurrences took place at control or spillover sites and not the treatment sites. This finding indicates that the H_a in the second set of hypotheses could be correct. Drivers did not use the confirmation lights to traverse the intersection during the all-red cycle. Other factors such as driver distraction and blatantly running the red light were likely bigger factors for such behavior.

The confirmation light has the potential to be an effective low-cost countermeasure for targeted enforcement. In an anecdotal discussion with a police officer after a meeting it was mentioned that the lights at 75th and Metcalf Avenue were used on occasion and were helpful in enforcement. The study found that RLR violations have a peak in the month of August. Intersections that were recorded towards the end of August saw a significant increase in both left turn and through movement violations. Targeted enforcement during the month of August could be more efficient at intersections equipped with the confirmation lights. It was also mentioned in the conversation that officers had a difficult time using the confirmation lights at College Boulevard and Quivira Road. The intersection of College Boulevard and Quivira Road experienced an increase of over 100 percent in RLR violation rate. This intersection is equipped with confirmation lights and could assist in targeted enforcement by reducing the amount of police officers needed, and enabling effective enforcement of left-turning movements. However, visibility of the light during daylight hours and the vertical curvature for the northbound approach made it hard for the officers to use the confirmation lights when enforcing RLR. Based on the results of the study, it is recommended that the confirmation light be installed at intersections that have a history of RLR, and where officers are able to pull over and utilize the confirmation lights for enforcement. Visibility is a topic for future research addressed in section 8.2 of this chapter.

8.1 Contributions to Highway Safety

RLR violations are a serious safety concern for many communities nationwide. In the past decade, state highway agencies, counties and cities implementing effective countermeasures and programs to reduce RLR violations and the associated crashes. This research study demonstrated that confirmation lights do not affect RLR behavior. However, they have the potential to be a cost effective option to mitigate RLR behavior when used in combination with enforcement efforts.

8.2 Limitations of Current Research

8.2.1 Equipment Limitations

Because of equipment limitations mentioned in section 4.2 not all data were used. There were traffic data missing for some intersections during the one-month after deployment period. In addition, some intersection approaches were recorded on different days and some approaches were not recorded at all. Traffic data for some intersection were provided by the city of Overland Park and the camera system would be temporarily unavailable. In addition, data were recorded on a DVR and then transferred onto a DVD. Once the files were transferred onto a DVD the files on the DVR would be deleted because of the limited memory space. Data could have been not transferred to a DVD, and then deleted by mistake.

8.2.2 Feedback from Law Enforcement

Formal surveys for police and driver feedback were not conducted during this study. During meetings with city officials and police officers, some feedback was received, however, official feedback from all officers who have monitored traffic at the treatment intersections was not collected.

8.2.3 Statistical Model Limitations

The statistical model assumes that each approach at the intersection is an independent site. This assumption may not be true since many intersections were located in commercial areas of Overland Park. The same driver could have traversed the intersection more than once. The statistical model does not take into account visibility factors for the confirmation light.

8.3 Future Research

8.3.1 Daytime and Nighttime Effects of Confirmation Lights

During this study only the morning and evening peak hours were studied. Because of the sunrise and sunset hours, visibility of the confirmation lights was not taken into account. Performance of the confirmation lights according to visibility of the light can better assess the effect that the light can have on drivers. This would require more than four hours of traffic data. If 24-hour traffic data are recorded, then the hours of sunrise and sunset can be deleted, and a proper analysis of the confirmation light can be performed with the metrics shown in this research.

8.3.2 Factors that Affect Confirmation Light Effectiveness

Development of guidelines of when to install the confirmation lights can be of use to communities. Developing thresholds for intersection volume where the confirmation light is better noticed, recommended placement of the light, and characteristics of an intersection where police can better use the confirmation light were aspects that could be useful to communities looking to deploy such system. Installing confirmation light in rural and urban communities and comparing RLR violation before and after deployment could provide a means to evaluation thresholds of when the light is more effective, and develop further guidelines for deployment.

8.3.3 Delay and Red Light Running

Signal operations and delay along a corridor can play a factor into RLR behavior. If drivers face a greater delay, it can be assumed that they are more likely to run a red light. Signal timing and traffic data along selected corridors in a community would clarify if traffic delay is a factor in

RLR behavior. A study of delay and RLR behavior can further help in developing guidelines for countermeasures and enforcement.

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APPENDICES

A.1 Press Release for Overland Park and Lawrence

KU Engineering Researchers Study System to Improve Intersection Safety

LAWRENCE - Researchers at the University of Kansas School of Engineering have partnered with the cities of Lawrence, Kan. and Overland Park, Kan., to increase safety at four busy intersections by reducing red light running violations and simplifying law enforcement efforts to monitor potential infractions.

The project is funded by the Kansas Department of Transportation and the Mid-America Transportation Center and is under the direction of Steven Schrock and Eric Fitzsimmons with the KU School of Engineering. Red light running at intersections with traffic signals continues to be a serious safety concern for Kansas drivers, pedestrians, and bicyclists. In 2011, the Federal Highway Administration reported 676 fatalities (10 percent of all signalized intersection crashes) were due to red light running in the United States that based on 2009 state highway agency crash data. Since automated enforcement by traffic camera is not used in Kansas, researchers will install a blue confirmation light system at the following intersections starting the first week of July:

- Iowa Street and 23rd Street in Lawrence
- Louisiana Street and 23rd Street in Lawrence
- College Boulevard and Quivira Road in Overland Park
- 75th Street and Metcalf Avenue in Overland Park

These intersections were selected based on recommendations from each city's public works department, police department and the KU research team.

The blue confirmation light system is a low-cost, non-invasive countermeasure that is designed to help police officers safely identify and pull over drivers who run a red light while sitting downstream of the intersection. Each traffic signal mast arm will have one or two blue lights, one adjacent to the left turn signal, the other next to the through signal. While the traffic signal is green, the blue lights remain off. The blue light comes on the moment the traffic signal turns red, so law enforcement officials monitoring an intersection can use the blue light as a visual cue. If it's illuminated, no cars from that movement should enter the intersection. The blue light is visible from 360 degrees, so officers will know a motorist has run a red light even if they cannot see the traffic signal change colors.

The goal is to reduce the number of officers needed to monitor an intersection and reduce the need to interrupt traffic to chase a violating vehicle through an intersection. KU School of Engineering researchers will evaluate the confirmation light system over the next six months and report effectiveness results to city and state officials. The system has shown promising results in similar communities located in Florida, Kentucky, Texas, and Minnesota.

"The School of Engineering is excited to partner with the cities of Lawrence and Overland Park in the effort to improve driver safety at these busy intersections," said Steve Schrock, associate professor of civil, environmental and architectural engineering at the University of Kansas. "We believe this system can be a valuable tool for law enforcement, while substantially reducing the instances of red light running and making the roads safer for everyone."

Overland Park Police Chief John Douglass had this to say about the concept: "The safety of our citizens and the officers who serve them are paramount to what we do on a daily basis. This simple, yet innovative system will allow us to safely monitor and enforce traffic violations at two of the city's busiest intersections in regard to traffic accidents".

# # #

A.2 SAS Code for Statistical Model

```
proc import out= alldata
datafile="C:\Users\t0311691\Desktop\alldata.xlsx";
      getnames=yes;
 RUN;
proc print data= alldata;
var period trafficmov time approach lanevolume movvolume volume movementlanes
apprlanes yellow red rightturn path speed violations conflights;
title 'all violation data';

run;
proc univariate data = alldata noprint;
```

```
  histogram violations / midpoints = 0 to 20 by 1 vscale = count ;
run;
proc univariate data = alldata noprint;
  histogram path / midpoints = 0 to 20 by 1 vscale = count ;
run;
proc univariate data = alldata noprint;
  histogram speed / midpoints = 0 to 20 by 1 vscale = count ;
run;
proc univariate data = alldata noprint;
  histogram yellow / midpoints = 0 to 20 by 1 vscale = count ;
run;
proc univariate data = alldata noprint;
  histogram red / midpoints = 0 to 20 by 1 vscale = count ;
run;
proc univariate data = alldata noprint;
  histogram apprlanes / midpoints = 0 to 20 by 1 vscale = count ;
run;

proc means data= alldata mean std min max var;
      var period trafficmov time lanevolume movvolume volume movementlanes
apprlanes yellow red rightturn path speed violations conflights;
      run;

proc corr data= alldata fisher;
      var lanevolume movvolume;
      run;
proc corr data= alldata fisher;
      var lanevolume volume;
      run;
proc corr data= alldata fisher;
      var movvolume volume;
      run;
proc corr data= alldata fisher;
      var movementlanes volume;
      run;
proc corr data= alldata fisher;
      var apprlanes movementlanes;
      run;
proc corr data= alldata fisher;
      var apprlanes volume;
      run;
proc corr data= alldata fisher;
      var yellow red;
      run;
proc corr data = alldata fisher;
      var path volume;
      run;
proc corr data = alldata fisher;
      var path apprlanes;
      run;
proc corr data = alldata fisher;
      var speed volume;
      run;
```

```
proc corr data = alldata fisher;
      var period volume;
      run;
proc corr data = alldata fisher;
      var violations volume;
      run;
proc corr data = alldata fisher;
      var rightturn volume;
      run;
proc corr data = alldata fisher;
      var volume time;
      run;
proc corr data = alldata fisher;
      var volume approach;
      run;
proc corr data = alldata fisher;
      var volume yellow;
      run;
proc corr data = alldata fisher;
      var volume red;
      run;
proc corr data = alldata fisher;
      var violations trafficmov;
      run;
proc corr data = alldata fisher;
      var violations period;
      run;
proc corr data = alldata fisher;
      var time period;
      run;
proc corr data = alldata fisher;
      var approach lanevolume;
      run;
proc corr data = alldata fisher;
      var approach movvolume;
      run;
proc corr data = alldata fisher;
      var approach movementlanes;
      run;
proc corr data = alldata fisher;
      var approach apprlanes;
      run;
proc corr data = alldata fisher;
      var approach violations;
      run;
proc corr data = alldata fisher;
      var volume yellow;
      run;
proc corr data = alldata fisher;
      var volume red;
      run;
proc corr data = alldata fisher;
      var volume approach;
```

```
      run;
proc corr data = alldata fisher;
      var lanevolume movementlanes;
      run;
      proc corr data = alldata fisher;
      var lanevolume apprlanes;
      run;
      proc corr data = alldata fisher;
      var lanevolume yellow;
      run;
      proc corr data = alldata fisher;
      var lanevolume red;
      run;
      proc corr data = alldata fisher;
      var lanevolume path;
      run;
      proc corr data = alldata fisher;
      var lanevolume rightturn;
      run;
      proc corr data = alldata fisher;
      var lanevolume speed;
      run;
      proc corr data = alldata fisher;
      var lanevolume violations;
      run;
proc corr data = alldata fisher;
      var movvolume movementlanes;
      run;
      proc corr data = alldata fisher;
      var movvolume apprlanes;
      run;
      proc corr data = alldata fisher;
      var movvolume yellow;
      run;
      proc corr data = alldata fisher;
      var movvolume red;
      run;
      proc corr data = alldata fisher;
      var movvolume rightturn;
      run;
      proc corr data = alldata fisher;
      var movvolume path;
      run;
      proc corr data = alldata fisher;
      var movvolume speed;
      run;
      proc corr data = alldata fisher;
      var movvolume violations;
      run;
proc corr data = alldata fisher;
      var movementlanes yellow;
      run;
      proc corr data = alldata fisher;
```

```
        var movementlanes red;
        run;
        proc corr data = alldata fisher;
        var movementlanes rightturn;
        run;
        proc corr data = alldata fisher;
        var movementlanes path;
        run;
        proc corr data = alldata fisher;
        var movementlanes speed;
        run;
        proc corr data = alldata fisher;
        var movementlanes violations;
        run;
proc corr data = alldata fisher;
        var apprlanes yellow;
        run;
        proc corr data = alldata fisher;
        var apprlanes red;
        run;
        proc corr data = alldata fisher;
        var apprlanes rightturn;
        run;
        proc corr data = alldata fisher;
        var apprlanes speed;
        run;
        proc corr data = alldata fisher;
        var apprlanes violations;
        run;
proc corr data = alldata fisher;
        var yellow rightturn;
        run;
        proc corr data = alldata fisher;
        var yellow path;
        run;
        proc corr data = alldata fisher;
        var yellow speed;
        run;
        proc corr data = alldata fisher;
        var yellow violations;
        run;
proc corr data = alldata fisher;
        var red rightturn;
        run;
        proc corr data = alldata fisher;
        var red path;
        run;
        proc corr data = alldata fisher;
        var red speed;
        run;
        proc corr data = alldata fisher;
        var red violations;
        run;
```

```
proc corr data = alldata fisher;
      var rightturn path;
      run;
      proc corr data = alldata fisher;
      var rightturn speed;
      run;
      proc corr data = alldata fisher;
      var rightturn violations;
      run;
proc corr data = alldata fisher;
      var path speed;
      run;
      proc corr data = alldata fisher;
      var path violations;
      run;
proc corr data = alldata fisher;
      var speed violations;
      run;
proc corr data = alldata fisher;
      var time violations;
      run;
proc corr data = alldata fisher;
      var trafficmov time;
      run;
      proc corr data = alldata fisher;
      var trafficmov approach;
      run;
      proc corr data = alldata fisher;
      var trafficmov lanevolume;
      run;
      proc corr data = alldata fisher;
      var trafficmov movvolume;
      run;
      proc corr data = alldata fisher;
      var trafficmov volume;
      run;
      proc corr data = alldata fisher;
      var trafficmov movementlanes;
      run;
      proc corr data = alldata fisher;
      var trafficmov apprlanes;
      run;
      proc corr data = alldata fisher;
      var trafficmov yellow;
      run;
      proc corr data = alldata fisher;
      var trafficmov red;
      run;
      proc corr data = alldata fisher;
      var trafficmov rightturn;
      run;
      proc corr data = alldata fisher;
      var trafficmov path;
```

```
      run;
      proc corr data = alldata fisher;
      var trafficmov speed;
      run;
      proc corr data = alldata fisher;
      var trafficmov period;
      run;
proc corr data = alldata fisher;
      var time approach;
      run;
      proc corr data = alldata fisher;
      var time lanevolume;
      run;
      proc corr data = alldata fisher;
      var time movvolume;
      run;
      proc corr data = alldata fisher;
      var time volume;
      run;
      proc corr data = alldata fisher;
      var time movementlanes;
      run;
      proc corr data = alldata fisher;
      var time apprlanes;
      run;
      proc corr data = alldata fisher;
      var time yellow;
      run;
      proc corr data = alldata fisher;
      var time red;
      run;
      proc corr data = alldata fisher;
      var time rightturn;
      run;
      proc corr data = alldata fisher;
      var time path;
      run;
      proc corr data = alldata fisher;
      var time speed;
      run;
proc corr data = alldata fisher;
      var approach yellow;
      run;
      proc corr data = alldata fisher;
      var approach red;
      run;
      proc corr data = alldata fisher;
      var approach rightturn;
      run;
      proc corr data = alldata fisher;
      var approach path;
      run;
      proc corr data = alldata fisher;
```

```
      var approach speed;
      run;
proc corr data = alldata fisher;
      var conflights yellow;
      run;
      proc corr data = alldata fisher;
      var conflights red;
      run;
      proc corr data = alldata fisher;
      var conflights rightturn;
      run;
      proc corr data = alldata fisher;
      var conflights path;
      run;
      proc corr data = alldata fisher;
      var conflights speed;
      run;
      proc corr data = alldata fisher;
      var conflights violations;
      run;
      proc corr data = alldata fisher;
      var conflights trafficmov;
      run;
      proc corr data = alldata fisher;
      var conflights time;
      run;
      proc corr data = alldata fisher;
      var conflights approach;
      run;
      proc corr data = alldata fisher;
      var conflights lanevolume;
      run;
      proc corr data = alldata fisher;
      var conflights movvolume;
      run;
      proc corr data = alldata fisher;
      var conflights volume;
      run;
      proc corr data = alldata fisher;
      var conflights movementlanes;
      run;
      proc corr data = alldata fisher;
      var conflights apprlanes;
      run;
proc glm data = alldata;
      model violations = period trafficmov time lanevolume movvolume volume
movementlanes apprlanes yellow red rightturn path speed conflights /ss3;
      run;
proc glm data = alldata;
      model violations = period trafficmov time movvolume movementlanes
yellow rightturn conflights/ ss3;
      run;
proc glm data= alldata;
```

```
      model violations = period trafficmov time movvolume yellow rightturn
conflights / ss3;
      run;
proc glm data= alldata;
      model violations = period trafficmov movvolume yellow rightturn
conflights / ss3;
      run;
proc glm data= alldata;
      model violations = trafficmov movvolume yellow rightturn conflights /
ss3;
      run;

proc glm data=alldata;
      class trafficmov movvolume yellow rightturn conflights;
      model violations= trafficmov movvolume yellow rightturn conflights;
      random trafficmov movvolume yellow rightturn conflights / q;
      run;
proc countreg data = alldata;
      model violations = period trafficmov time lanevolume movvolume volume
movementlanes apprlanes yellow red rightturn path speed conflights
/dist=poisson;
      run;
proc countreg data= alldata;
      model violations = period trafficmov time lanevolume movvolume volume
movementlanes apprlanes yellow red rightturn path speed conflights
/dist=negbin (p=2);
      run;
proc phreg data = alldata;
      model violations = period trafficmov time lanevolume movvolume volume
movementlanes apprlanes yellow red rightturn path speed conflights
            /     selection = stepwise
                  slentry = .3
                  slstay = 0.15 details;
                  run;
proc phreg data = alldata;
      model violations = period trafficmov time lanevolume movvolume volume
movementlanes apprlanes yellow red rightturn path speed conflights
            /     selection = score
                  best = 3;
                  run;
proc countreg data = alldata;
      model violations = trafficmov lanevolume yellow rightturn /dist=negbin
(p=2);
      run;
proc countreg data = alldata;
      model violations = trafficmov lanevolume rightturn /dist=negbin (p=2);
```

run;# # #