EVALUATION OF INTERSECTION CONFIRMATION LIGHTS IN MEDIUM TO LARGE COMMUNITIES IN IOWA TO REDUCE RED LIGHT RUNNING VIOLATIONS

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Fitzsimmons, E.J., T.E. Lindheimer, S.D. Schrock	
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16. Abstract

Red light running continues to be a serious safety concern for many communities in the United States. The Federal Highway Administration reported that in 2011, red light running accounted for 676 fatalities nationwide. Red light running crashes at a signalized intersections are more serious, especially in high speed corridors where speeds are above 35 mph. Many communities have invested in red light countermeasures including low-cost strategies (e.g. signal backplates, targeted enforcement, signal timing adjustments and improvement with signage) to high-cost strategies (e.g. automated enforcement and intersection geometric improvements). This research study investigated intersection confirmation lights as a low-cost strategy to reduce red light running violations. Two intersections in Altoona and Waterloo, Iowa were equipped with confirmation lights which targeted the through and left turning movements. Confirmation lights enable a single police officer to monitor a specific lane of traffic downstream of the intersection. A before-after analysis was conducted in which a change in red light running violations prior to- and 1 and 3 months after installation were evaluated. A test of proportions was used to determine if the change in red light running violation rates were statistically significant at the 90 and 95 percent levels of confidence. The two treatment intersections were then compared to the changes of red light running violation rates at spillover intersections (directly adjacent to the treatment intersections) and control intersections. The results of the analysis indicated a 10 percent reduction of red light running violations in Altoona and a 299 percent increase in Waterloo at the treatment locations. Finally, the research team investigated the time into red for each observed red light running violation. The analysis indicated that many of the violations occurred less than one second into the red phase and that most of the violation occurred during or shortly after the all-red phase.

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Principal Investigator
Steve D. Schrock, Ph.D., P.E.
Associate Professor
The University of Kansas
Department of Civil, Environmental and Architectural Engineering
2159B Learned Hall, 1530 West 15th Street
Lawrence, KS 66045

Co-Principal Investigator
Eric J. Fitzsimmons, Ph.D.
Post Doctoral Researcher
The University of Kansas
Department of Civil, Environmental an Architectural Engineering
2159C Learned Hall, 1530 West 15th Street
Lawrence, KS 66045

Authors
Eric J. Fitzsimmons, Steven D. Schrock, Tomás E. Lindheimer

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The Iowa Highway Research Board (IHRB Project TR-657)
Iowa Department of Transportation
800 Lincoln Way, Ames, IA 50010

A report from
Transportation Engineering Analysis Laboratory (TEAL)
The University of Kansas
Lawrence, Kansas 66049
Phone: 785-864-3418
Fax: 785-864-5631
www.ceae.ku.edu

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BACKGROUND

Vehicle crashes from red light running 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 red light running in 2009 which represents 10 percent of all intersection crashes and two percent of all roadway fatalities (FHWA, 2011). Communities across the US have responded to red light running through such countermeasures as targeted enforcement campaigns, intersection geometric and signal timing improvements, low-cost countermeasures and automated enforcement.

The Federal Highway Administration (FHWA) also reported that approximately half of the crashes in which a red light running was the primary cause in 2012 were not the driver of the vehicle, but rather were vehicle passengers, pedestrians, or bicyclists (NHTSA, 2013). Vehicles running a red light also have a significant economic impacts associated with every serious injury or fatality crash. The FHWA also reported in 2005 that the societal cost relating to red light running was approximately $14 billion annually (FHWA, 2005.)

More specially to the State of Iowa, a study conducted by Fitzsimmons et al. (2007) for the Iowa Department of Transportation (Iowa DOT) indicated that based on Iowa crash data (2001 to 2006) that an average of 8,162 crashes occurred at signalized intersections and an average of 1,682 crashes were due to red light running. A follow up study conducted by Hallmark et al. (2012) for the Iowa DOT also indicated red light running continues to be a problem in Iowa with 6,007 crashes occurring at signalized intersections of which 1,525 crashes were due to red light running (based on 2010 data).

Due to the seriousness of red light running, considerable efforts have been undertaken by state highway agencies and local jurisdictions to explore and implement countermeasures to reduce red light running violations and associated crashes at busy signalized intersections.

LITERATURE REVIEW

This chapter reviews current literature on red light running (RLR). It cites information from articles, informational and technical reports, research journals and other relevant publications pertaining to red light running. Currently, a wide range of countermeasures exists to mitigate red light running violations and crashes. These include traffic signal timing adjustments, physical improvements, advance warning for drivers, automated enforcement, targeted enforcement, and public awareness campaigns to name a few.

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. It also covers different definitions for RLR, attitudes and frequency of RLR violations, characteristics of red light runners, and factors that contribute to RLR.

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 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.

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 in predicting 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 motorists 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 doing so when it was safe to stop at least once in the previous month (AAA Foundation for Traffic Safety, 2014). Driver's attitudes toward RLR and the frequency of violations have not changed over the years. Motorists are aware of the risks implied by running a red light, and view the behavior as unacceptable. However, motorists still admit to running a red light on occasion. This shows that RLR is an ever-present danger faced by motorists at intersections

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.

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 to Red Light Running (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.

Red Light Running Countermeasures

Red light running countermeasures have 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 be 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 Red Light Running (Hallmark et al., 2012)

Possible Causes of Red Light Running	Engineering Countermeasures			Enforcement
	Signal Operation	Motorist 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.

Engineering Countermeasures

Engineering countermeasures are generally categorized into three groups, namely: signal operation countermeasures, motorist 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 motorist 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 Red Light Running

Countermeasure Category	**Red Light Running Countermeasure**	
Signal Operation	Yellow change interval	
	Green extension	
	Signal operation and coordination	
	All-red clearance interval	
Motorist 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.

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.

Yellow Change Interval

The MUTCD provides guidance with regards to minimum and maximum yellow intervals. It recommends that "A yellow change interval should have a minimum duration of 3 seconds and a maximum duration of 6 seconds. The longer intervals should be reserved for use on approaches with higher speeds" (MUTCD, 2009). In the 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 5 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-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 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.

<u>All-Red Clearance Interval</u>

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 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 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 2 to 3 seconds significantly reduced the risk of late exiting of vehicles being struck by opposing traffic streams that have green signal.

<u>Green Extension</u>

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 major roads at actuated-signaled intersection approaches 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 9 years of before crash data and about 4 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.

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).

Motorist 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).

Improve Signal Visibility

The positioning of signals either overhead or pole-mounted impacts driving behavior. 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 an 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.

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-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, 36.7 percent reduction in injury crashes and 49.6 percent 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).

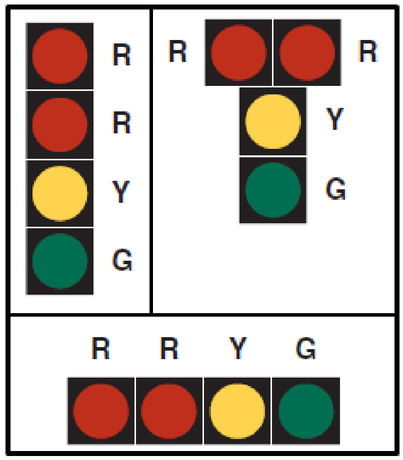


Figure 2. Redundant red light signal configurations (MUTCD 2009)

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.

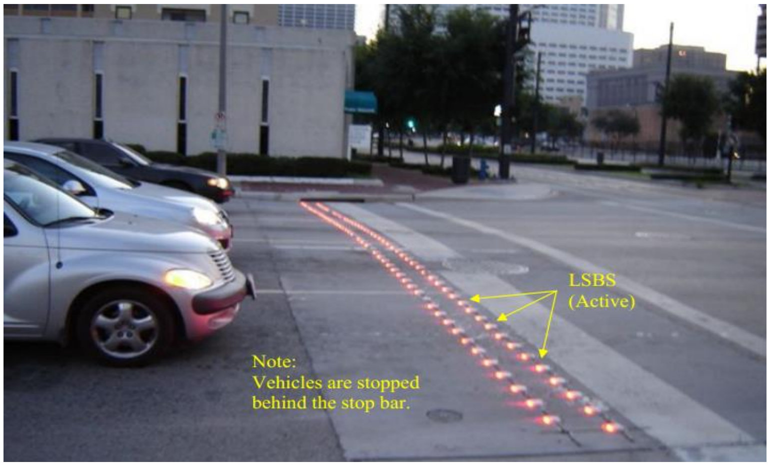


Figure 3. Lighted stop bar system (active) in Houston, Texas (Tydlacka et al., 2011)

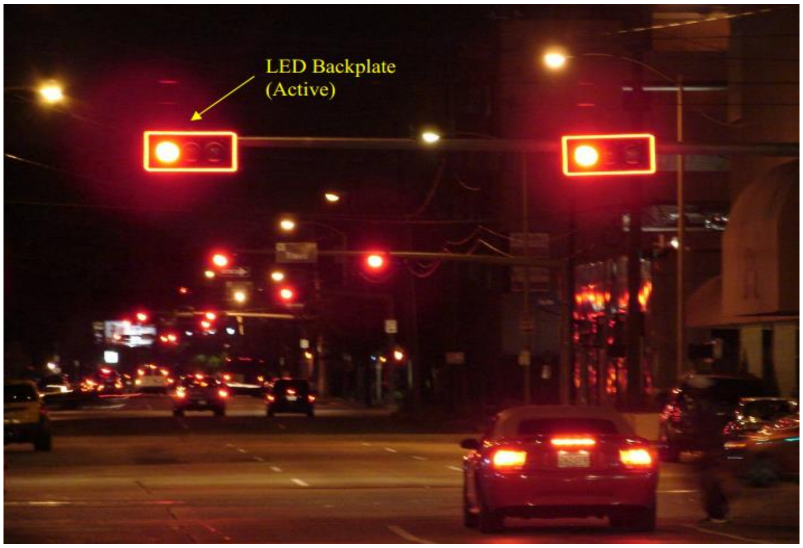


Figure 4. LED backplate (Active) in Houston, Texas (Tydlacka et al., 2011)

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 violation from 12.9 to 11.3 violations per day per 10,000 vehicles which was not statistically significant.

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

Polanis (2002) analyzed a before-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-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. Be prepared to stop sign, W3-4 (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 and when flashing plaque (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.

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 such as left-angle and right-angle 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-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.

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

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.

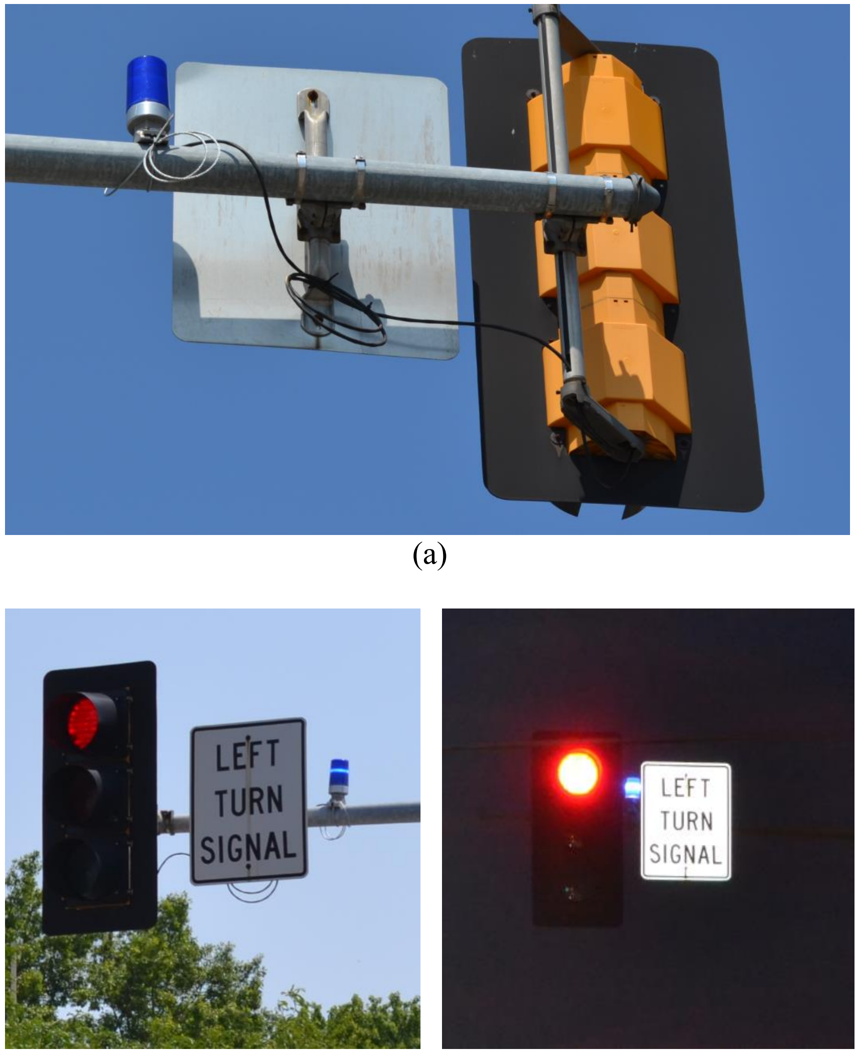
Similarly, a study conducted in North Carolina at red light camera equipped intersections showed a 17 percent reduction in total crashes, 22 percent reduction in RLR related crashes, 42 percent reduction in angle crashes and 25 percent reduction in rear-end crashes (Cunningham and Hummer, 2004). Studies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

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.

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 red light is indicated as shown in Figure 8 a, b and c also show confirmation lights in operation during the day and night times respectively in Lawrence, Kansas.



(a)

(b) (c)

Figure 8. Blue confirmation light in operation at day and night time

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 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 and data 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.

Public Education

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.

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 for the three Es (Engineering, Enforcement, and Education). As stated previously, this research project is intended to investigate a low-cost countermeasure to aid police officers and make the public aware of RLR at designated intersections in Iowa. This research will provide additional information into the effectiveness of the confirmation light system.

PROJECT OBJECTIVES

When a signalized intersection has been identified by a community as a location with a high number of RLR violations, targeted enforcement is typically used to reduce the number of violations by issuing a greater number of citations. To perform 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 bar 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.

Many communities have turned to automated enforcement to monitor and ticket red light runners at signalized intersections. Iowa communities have responded by implementing targeted enforcement programs as well as automated enforcement. There are multiple automated enforcement programs in Iowa that monitor RLR and have been shown to increase safety (Fitzsimmons, 2007 and Hallmark 2011). Since the introduction of the first automated enforcement program in Iowa (Davenport), at least one legislative challenge has been discussed in the Iowa legislature. Moreover, with an increased presence of automated enforcement in major Iowa metropolitan areas and citizen concern over privacy and communities profiting from camera revenues, a growing movement to legally ban automated enforcement has taken hold with the support of Governor Brandstad (Des Moines Register, 2013).

The objective of this study was to investigate the effectiveness of a low-cost signalized intersection treatment to reduce RLR violations and ultimately crashes at signalized intersections. The research project targeted medium and large communities in Iowa in which a limited number of large intersections that handle a considerable amount of traffic. The research team selected confirmation lights as a way to aid police officers in more easily observing RLR violations when positioned downstream from the intersection. Confirmation lights have been deployed in many communities across the United States. However, limited effectiveness data has been published that can support the effectiveness of this device. The research team also selected to test the effectiveness of this device at two busy signalized intersections in Iowa, particularly Altoona and Waterloo.

Effectiveness of the confirmation lights were determined by a before-after violation study. The changes in violations were used as a safety surrogate for the potential changes in crashes. A secondary performance measure that was used included the changes of violation time into red which is an indicator of how far after the red signal did a vehicle violates the red light.

RESEARCH APPROACH

As stated previously, the objective of this research study was to target medium to large communities in Iowa where larger signalized intersections with protected left turning movement existed and also a community where traffic peak hours occurred. A solicitation letter (in Appendix A) on behalf of the University of Kansas and the Iowa Department of Transportation was sent to the following identified communities: Altoona, Dubuque, Waterloo, Cedar Falls, Ankeny, Coralville, Iowa City, Ames, Fort Dodge, Mason City, Marion, Johnston, Waukee, and West Des Moines. The solicitation described the research project, the methodology for evaluation, and assistance with installation and maintenance. The communities were also informed via an email that they were welcomed to keep the equipment or remove it at the end of the study period. Altoona and Waterloo were the two communities selected for the research study after reaching out to the research team.

Site Selection

Prior to meeting with city officials, the research team identified possible intersections for confirmation light installation. A set of variables identified by the research team were investigated at each of the intersections including: approach geometry (e.g. number of approach lanes, pavement markings, taper, and right turning lane), posted speed limited between 30 and 50 mph, protected and/or protected/permitted left turning lanes, a safe location where a police car could monitor the intersection approaches, and moderate to high peak hour volumes.

The research team then met with city officials including the city traffic engineers, traffic signal technicians, and traffic police officers for each community. A collaborative effort was made to determine which signalized intersection would have the confirmation light installed, surrounding signalized intersections to investigate spillover effects, and control sites. Later sections explain the various intersection and their geometric and operational characteristics used for the study. A total two of treatments sites, eight spillover sites, and four control sites were used total for both Altoona and Waterloo.

Data Collection

It was determined by the research team that one intersection in each community would be equipped with the confirmation light system. The best way to collect violation data at minimal cost was to collect field video data by using video cameras. However, collecting and reducing video data was complicated and time consuming. The field of view needed to collect and reduce the data at an intersections is shown in Figure 9.

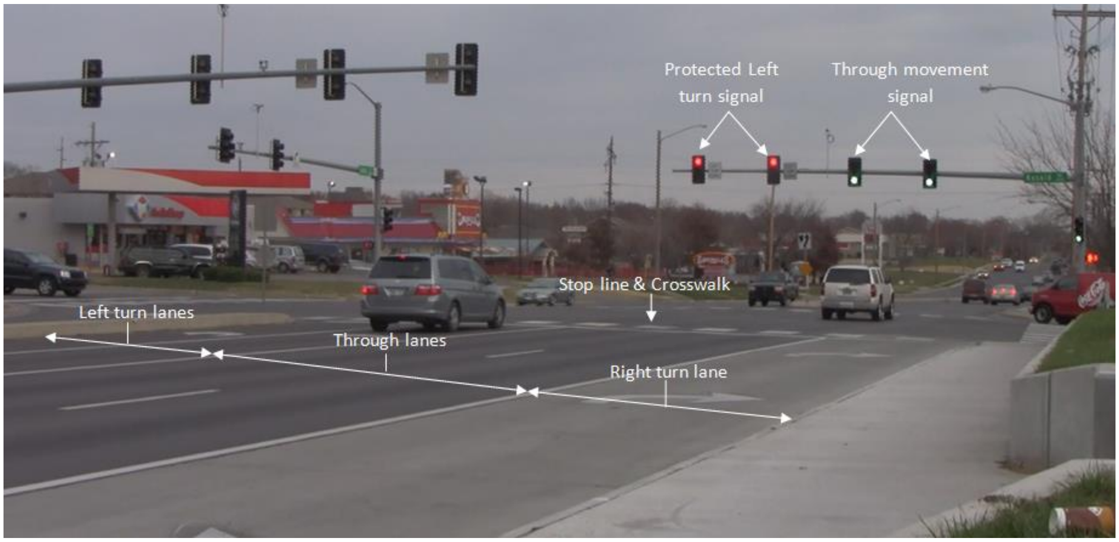


Figure 9. Example camera view of an intersection approach (Lawrence, Kansas intersection)

As shown in Figure 9, the research team was interested in a field of view that could monitor a single approach. The field of view also needed to be able to see the stop bar, all approach lanes and traffic signals. This was complicated sometimes by the rising sun and evenings where it was dark at the beginning or end of the peak hour. The research team used commonly available equipment. The high definition video cameras used to collect the data had a maximum battery life of 0.5 to 1 hour, thus needing either an extended battery pack, or a deep cell battery and inverter as shown in Figure 10.

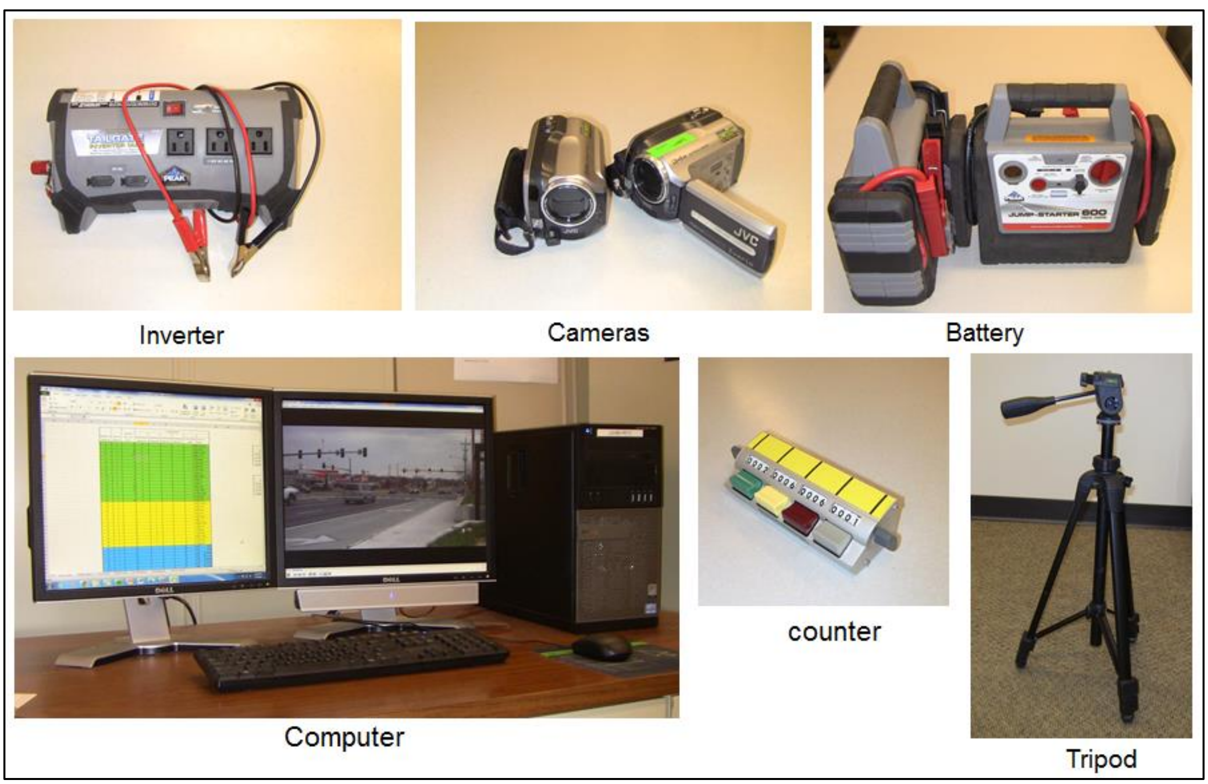


Figure 10. Equipment used for field data collection effort

Another important aspect to the data collection methodology was setting up the video camera equipment at all four approaches and subsequently not changing driver behavior while recording vehicles. Prior to video data collection at any intersection, field researchers were instructed to inform local police departments to let them know of the locations they would be filming each time they recorded traffic. The cameras were set-up near utility posts or in the median where possible. Researchers were careful to place cameras in public property, and in places where it would be hard for motorists to notice or easily be able to steal the equipment. An example of a video camera setup in the right-of-way near an intersection in Altoona, IA is shown in Figure 11.

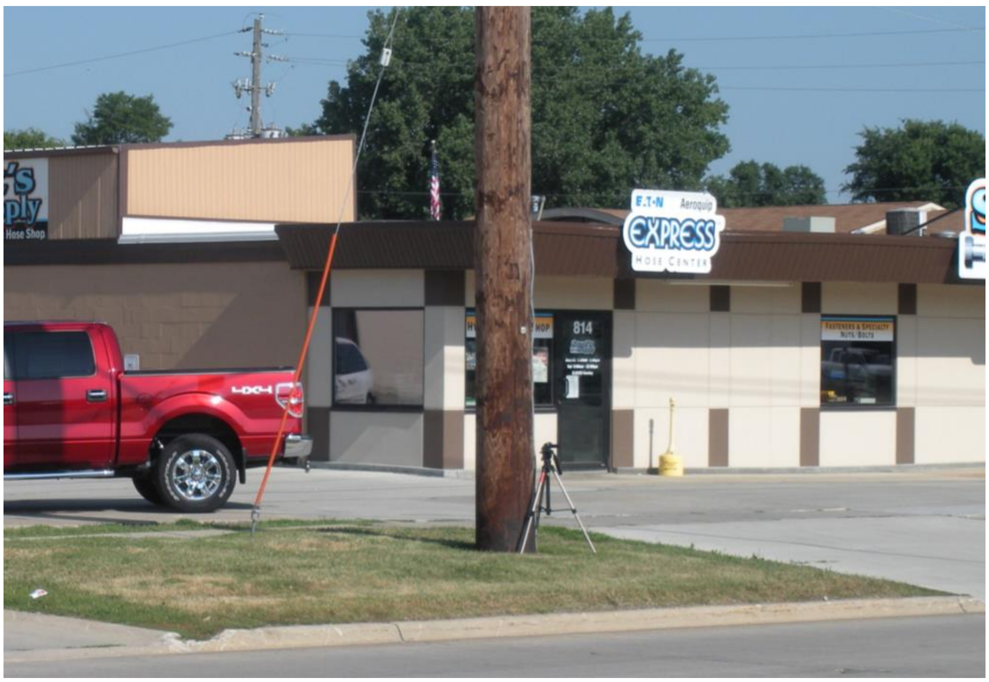


Figure 11. Camera setup at an intersection

The research team would setup the equipment using a safety vest and would monitor the cameras at the intersection from a vehicle parked nearby. Video data were collected on weekdays that were non-holidays (Tuesday, Wednesday, or Thursday). Data were collected during the morning peak hours (7 a.m. to 9 a.m.) and evening peak hours (4 p.m. to 6 p.m.). A similar data collection methodology was used for both after studies. The dates in which video data were collected, including the installation data are as follows:

- Before study - 16^{th} to 18^{th} of July, 2013
- Confirmation Light Installation – August 30^{th}, 2013
- One month after study - 1^{st} to 3^{rd} of October, 2013
- Three month after study - 3^{rd} to 5^{th} of December, 2013

As shown by these data collection dates, data collection at intersections twice for a single day took a considerable amount of time and man power with limited equipment. Quality control in the field was imperative for accurate results.

Data Reduction
The research team collected a total of 576 hours of video data for the entire project which resulted in over 2 terabytes of high definition video. Intersection video data were reduced manually by student undergraduate research assistants. A methodology developed by the research team ensured accurate video data reduction which resulted in a substantial archive of RLR and intersection operational data which was given to the communities if requested. Students reduced the peak hour data at all previously listed intersections in peak hour periods with specified breaks. The following guidelines were given to each student to reduce the video data:

- A vehicle that proceeds through (or crosses the stop bar), makes a right turn, makes a left turn after the red signal is shown is considered a RLR violation.
- A vehicle that crosses the stop bar during the yellow interval, or is in the intersection when the signal shows yellow or red is not considered a RLR violation (e.g. permitted left turns).
- If a vehicle has run a red light, stop the video and scroll back to determine the time into red the vehicle ran the red light.
- If a vehicle has run a red light, record
- While monitoring one approach at a time for RLR violations, record the traffic counts for each lane.

Illustrated in Figure 12 was the template that was used by the students that 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 12. Sample of reduced video data

The primary data of interest shown in Figure 12 are the number of vehicle that ran the red light, type of vehicle, seconds into red, which approach the violation occurred at, and the time of day the violation occurred. Additionally, the turning movement counts were recorded for each approach lane.

Once a student completed an intersection reduction (including all four approaches), the report was given to one of the research team members to perform a quality check/assurance. At this point, the research team member would view the recorded violations to ensure a RLR violation occurred and was recorded accurately. Once the data collection effort was complete, the data was aggregated into one Microsoft Excel file for analysis.

Data Collection and Reduction Limitations

Collecting field data can result in unknown and sometimes complicating situations. The research team had no control over these situations, but complicated the data collection and reduction efforts:

- During the data collection effort, Iowa weather brought rain and wind. The research team had to either shut data collection down early, or readjust the equipment (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 an issue during some recording sessions. This included malfunctioning batteries, inverters, or cameras. Identified equipment failure was noted by the research team either in the field or during the data reduction process and data recollection occurred as quickly as possible.

Installation of Confirmation Lights

The research team elected to use Pelco confirmation lights which range from $110-$140 depending on the mounting bracket. As shown in Figure 13, the cities of Altoona and Waterloo specified to the research team that they wanted the light to be mounted by a cable Pelco Astro-Brac. Also shown in Figure 13a, excess cable and wire were zip-chord strapped to the mast arm and sign bracket. The Pelco confirmation light comes in multiple colors including blue, red, and clear. A standard Edison light bulb is used and the plastic dome is sealed by a rubber weather stripping. The confirmation comes with a short three strand wire which included a ground wire. The city traffic signal technicians removed the provided wire and attached a standard two-wire.

Since the traffic signal controller cabinet and signal heads where low-powered and LED, the city asked the research team to find the brightest low-powered light bulb as a conventional 65 watt incandescent bulb would trip the intersection battery backup system. The research team purchased three LED light bulbs from a local hardware store and decided on an 800 Lumens 9 Watt LED light bulb.

On August 30, 2013, between 8 a.m. and 9 a.m., the confirmation lights were installed at 8th Street and 34th Street in Altoona, IA and University Avenue and Ansborough Avenue Waterloo, IA. Both communities were interested in monitoring RLR violations on through and left turn approaches and so at the request of the department, the lights were installed on all the approaches where possible. The southbound approach at University Avenue and Ansborough Avenue and all approaches at 8th Street and 34th Street had protected-permitted left turn signals which made it difficult for the confirmations lights to work as expected. During the permitted phase, both the red and green signal indicators would be indicated. The confirmation light was simultaneously activated during this phase. It was very difficult or nearly impossible for a police office located downstream of an intersection to tell whether a violation occurred during the permitted phase or after the signal indication was red. In order to avoid such confusion, the confirmation lights were not installed on intersection approaches that had protected/permitted left turn. Figure 13 shows a field installation of the confirmation lights by the City of Altoona and the City of Waterloo.

(a)

(b)

Figure 13. Field installation of the confirmation light in (a) Altoona and (b) Waterloo

Public Awareness of the Confirmation Lights

Prior to installation and activation of the confirmation lights at intersections in both communities, city engineers met with local law enforcement agencies who notified city council members and city prosecutors to ensure understanding of the meaning of the confirmation light system in the ticketing process of RLR violators.

Additionally, the research team consulted with the University of Kansas and the City of Altoona and the City of Waterloo to jointly release a statement regarding the project. A copy of the press release can be found in the Appendix. The coordinated press release was designed to inform drivers that a change was happening at the designated 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 by the research team and both communities. Shown in Figures 14 and 15 are the blue confirmations lights Altoona, IA and Waterloo, IA respectively.

Figure 14. Confirmation Lights at 8th Street and 34th Street in Altoona, IA

Figure 15. Confirmation Lights at University Avenue and Ansborough Avenue in Waterloo, IA

It should be noted that the effectiveness of the public awareness campaign was not evaluated as part of this study. Additionally, the research team specifically asked both of the police department to continue their regular duties monitoring of RLR and to avoid targeted enforcement during the study period unless otherwise directed by the city council or chief of police.

DESCRIPTION OF INTERSECTIONS INVESTIGATED

As stated previously, two signalized intersections were determined to be excellent locations for the confirmation lights to be installed, these included:

- 8th Street and 34th Street in Altoona, IA
- University Avenue and Ansborough Avenue in Waterloo, IA

Spillover sites are signalized intersections located directly adjacent to the two treatment intersections in both cities. Previous research relating to automated enforcement has indicated that if an intersection is treated with an enforcement device (e.g. automated RLR camera), similar effects 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 of the research team that if a reduction in red light violations occurred at the treatment intersections, a reduction would also be found at these intersections as well. The following sections give a description of these intersections and the control intersections in Altoona and Waterloo.

Altoona Intersections

The City of Altoona has a population of over 15,000 residents. The city is in central Iowa and it covers a total area of 9.35 square miles. The city consists of many signalized intersections alone 8th Street and 1st Avenue. The city is bordered by Interstate 80 (I-80) and Highway 65, and it is 13 miles northeast of Des Moines. A total of six intersections were studied in Altoona, Iowa. There was one intersection chosen for deployment, two to study spillover effects, and three control sites. The following sections provide a brief description of the sites selected for investigation.

Treatment site: 8th Street and 34th Street

The intersection of 8th Street and 34th Street was chosen as the site for deployment of the confirmation lights. Eighth Street is the East/West corridor. For the westbound approach there is one through lane, one shared through/right turn lane, and a left turn lane. For the eastbound approach there are two through lanes, one right turn lane, and one left-turn lane. 34th Street is the North/South corridor. For the southbound approach there is one through lane, one with shared right turn movement, and a left turn lane. The northbound approach has one lane for each movement. Figure 16 shows an aerial view of the intersection and a street view from the northbound approach.

Figure 16. Treatment Site, 8th Street and 34th Street (aerial image: Google Earth, 2013)

At the intersection there are gas stations at the southeast and northwest corners. Commercial areas are located at the northeast and southwest corners of the intersection. All overhead signals have backplates installed. All left turning movements are protected/permitted; therefore confirmation lights for the through movements only were installed at this intersection. The northbound and eastbound approaches have protected right turns. There are pedestrian walkways with pedestrian countdown signals on all approaches. The traffic volumes recorded in during all study periods is shown in Figure 17.

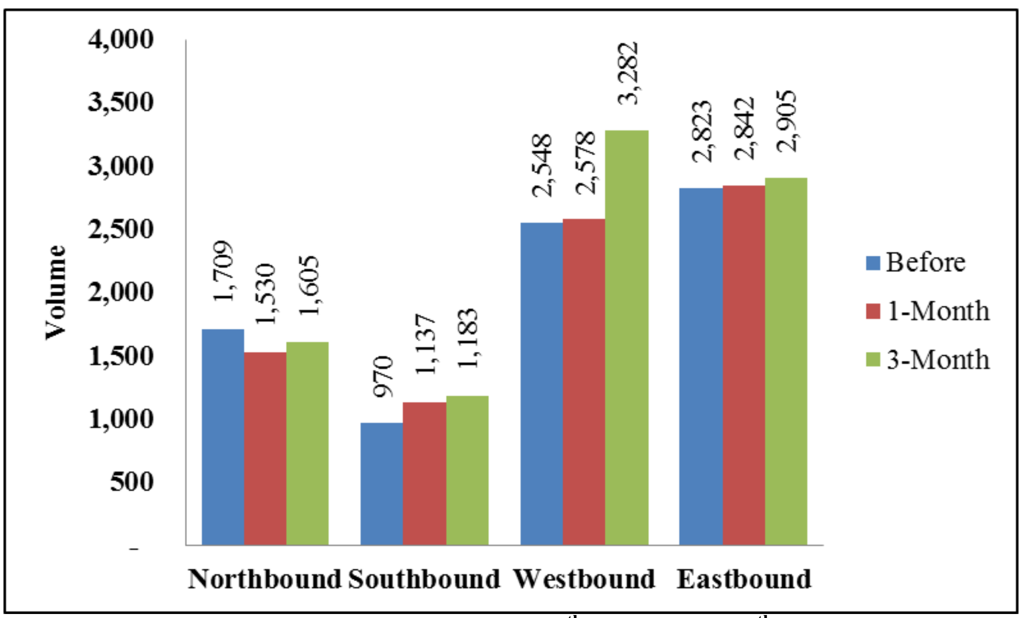


Figure 17. Traffic volumes for 8th Street and 34th Street

The eastbound and westbound approaches along 8th Street were where most of the traffic volume was observed for morning and afternoon peaks. A heavy increase was observed from the morning peak to afternoon peak for the eastbound approach and the southbound approach. For the "before" and "one-month" periods of the study the intersection handled slightly over 8,000 motorists. For the "three-month" period the overall count was 8,975 vehicles. To better understand traffic movements Figure 18 shows the percent of vehicle movements.

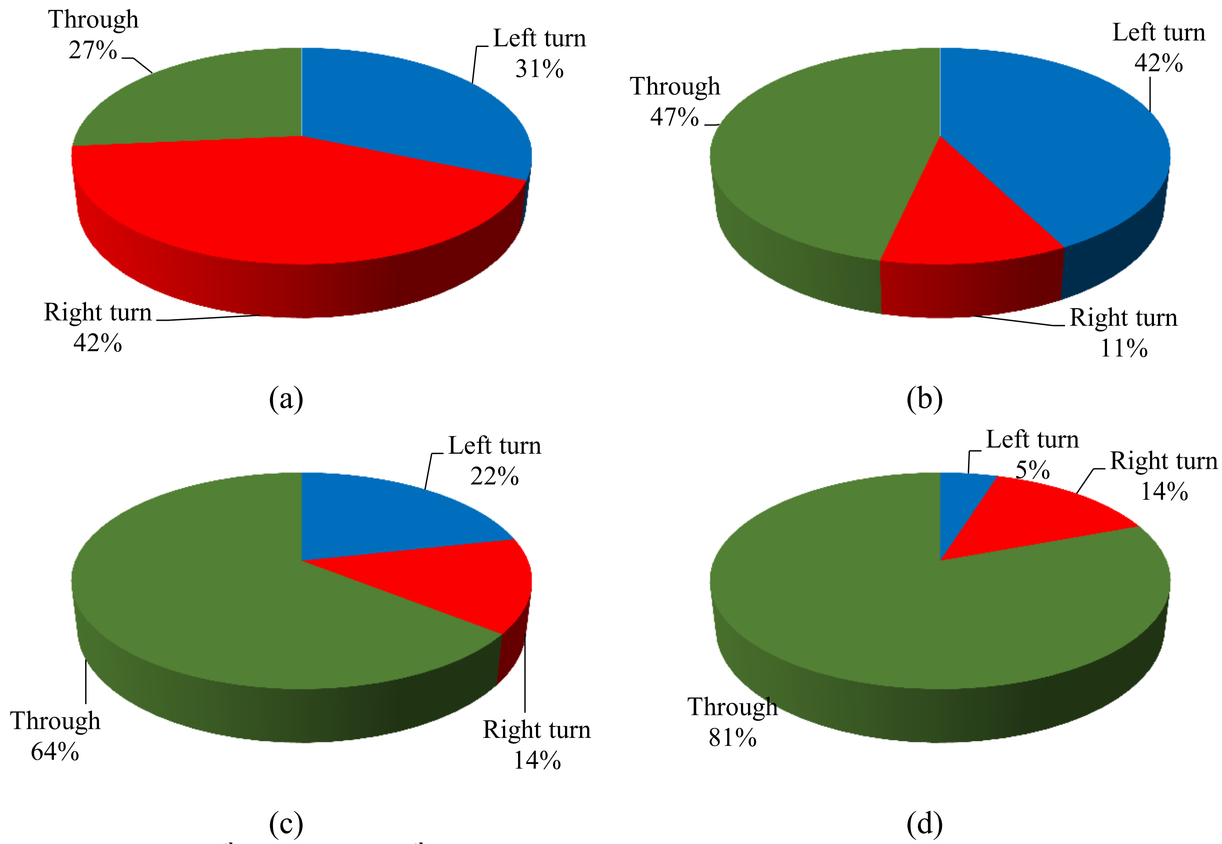


Figure 18. 8th Street and 34th Street peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

The percentages shown were calculated from the total volumes observed through all periods of the study. The ratio of turns to approach volume remained the approximately the same regardless of an increase or decrease in volume. Traffic along 8th Street traveled through the intersection. The westbound approach had the most left-turning vehicles out of all approaches, but the majority of vehicles at the southbound approach turn left onto 8th Street. The northbound approach has the highest count of right turning vehicles and the highest percentage of vehicles turning right.

Spillover Sites

Two signalized intersections were selected to study the spillover effects of the countermeasure. The two sites were 8th Street and 36th Street and 8th Street and 28th Street, which are east and west of the deployment site respectively. Figure 19 shows the location of the spillover sites with respect to the treatment site. There was no spillover sites selected north or south of the deployment site.

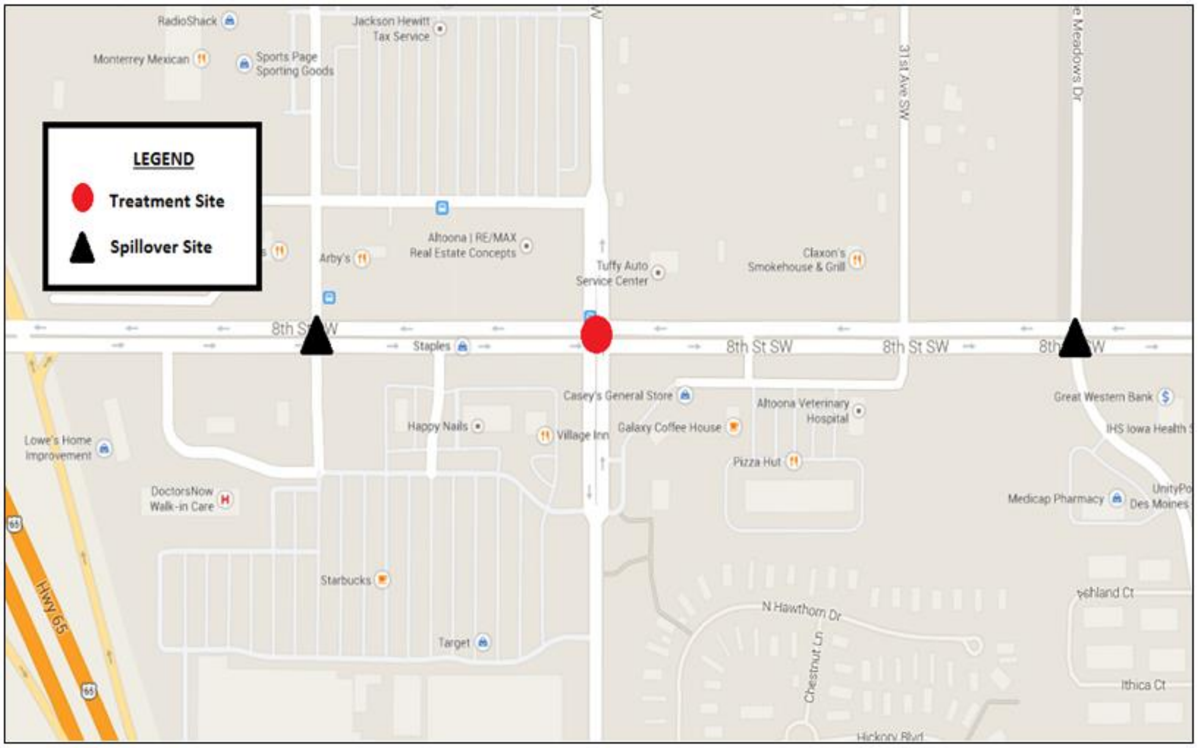


Figure 19. Layout of treatment and spillover sites in Altoona, IA (Google maps, 2014)

<u>8th Street and 28th Street</u>
For the westbound and eastbound approaches there is one through lane, one shared through/right turn lane, and a left turn lane. 28th Street is the North/South corridor. For the southbound approach there is a right turn lane, and a shared through/left-turn lane. The northbound approach has one lane for all movements. Figure 20 shows an aerial view of the intersection and a street view from the northbound approach.

Figure 20. Spillover Site, 8th Street and 28th Street (aerial image: Google Earth, 2013)

The westbound and eastbound approaches have protected/permitted left-turns, and the northbound and southbound only have permitted left-turns. The southbound approach has protected right turns. There are three overhead signal heads for traffic along 8th Street, and two overhead signal heads for traffic on 28th Street. All overhead signals have backplates installed to increase conspicuity. Figure 21 shows the total volumes recorded at the intersection.

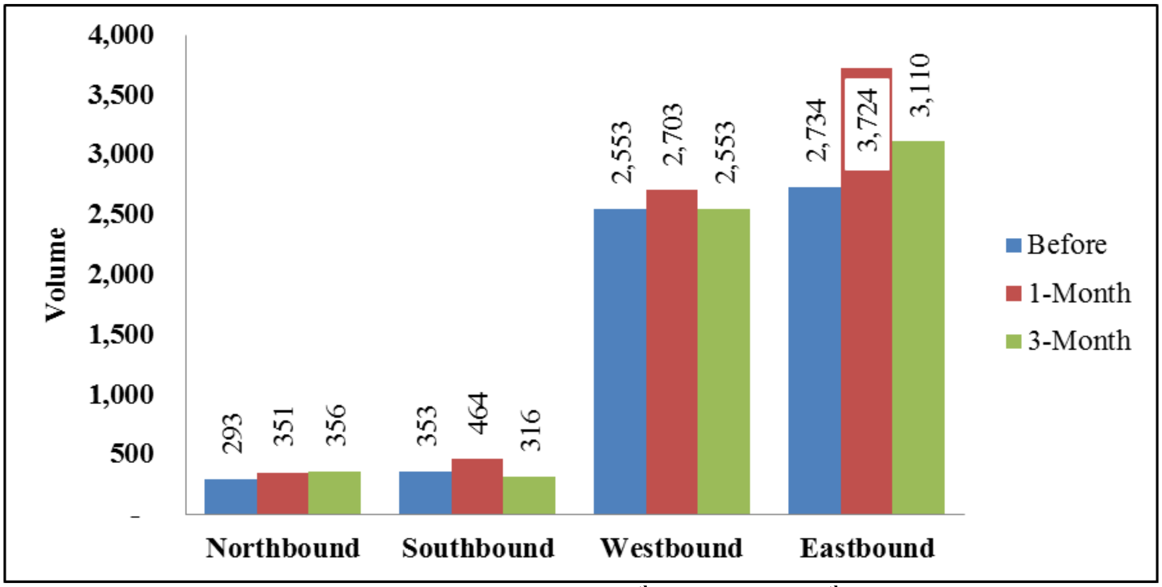


Figure 21. Traffic volumes for 8th Street and 28th Street

Traffic along 28th Street is very low in comparison to 8th Street. The eastbound approach had the highest volume count on all periods of the study. For all approaches more than half of the total volume counts were observed in the afternoon. Figure 22 shows the turning movements for each approach.

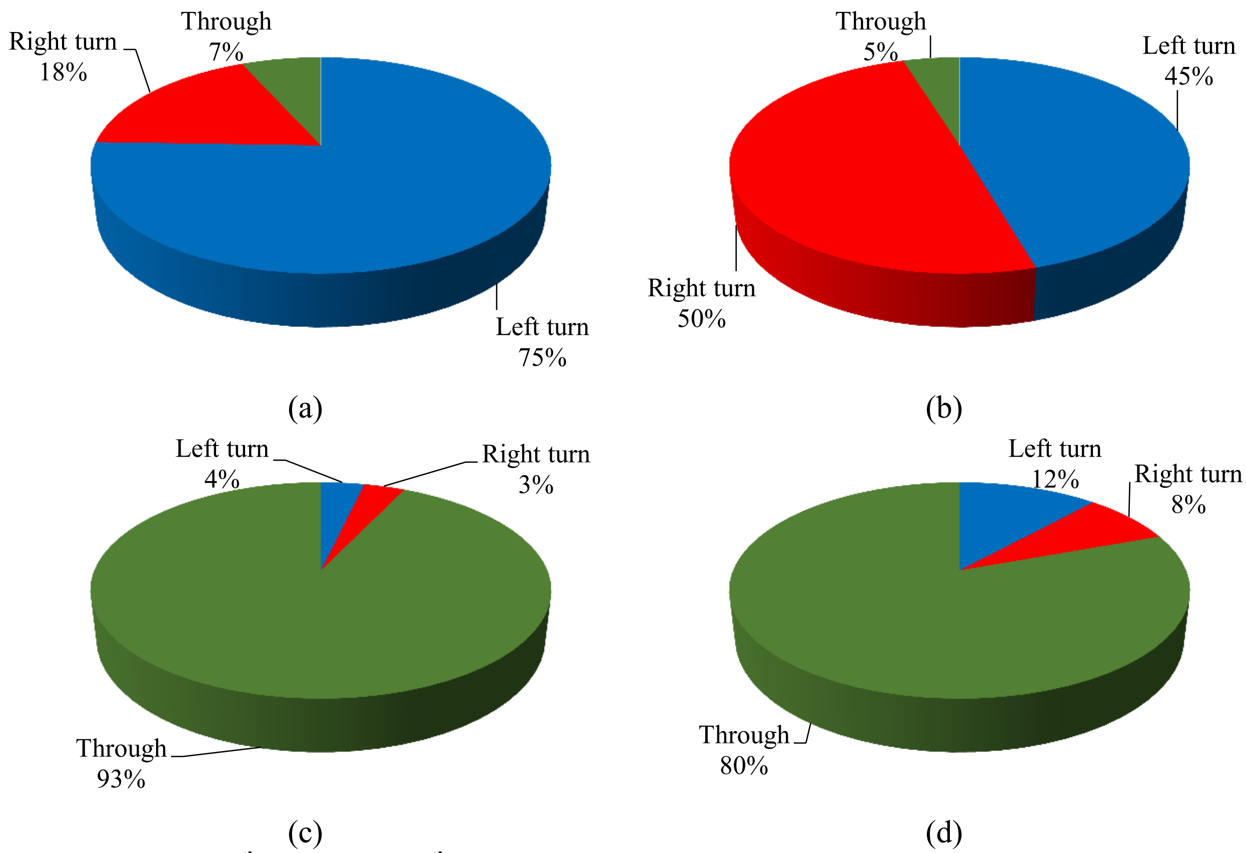


Figure 22. 8th Street and 28th Street peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

Half of motorist at the southbound approach turned right and head westbound on 8th Street. The majority of traffic on 8th Street went through the intersection. Three-quarters of northbound traffic turned left and head west on 8th Street. However, the highest left-turn counts were recorded for the eastbound approach.

<u>8th Street and 36th Street</u>

The intersection of 8th Street and 36th Street is west of the deployment site, and it is the first signalized intersection east of State Highway 65. At the westbound and eastbound approaches there are two through lanes, a right turn lane, and a left turn lane. 36th Street is the North/South corridor. For the southbound and northbound approaches there is one shared right-turn/through lane and a left turn lane. The intersection is also located in a commercial area of town. Figure 23 shows an aerial view of the intersection and a street view from the northbound approach.

Figure 23. Spillover Site, 8th Street and 36th Street (aerial and ground image: Google Earth, 2013)

All left turning movements at the intersection are protected/permitted. There are no protected right turns. There is an overhead signal for each lane of traffic, and all overhead signals have backplates installed. There are also pedestrian signals at the intersection. Figure 24 shows the volumes observed at this site during the study.

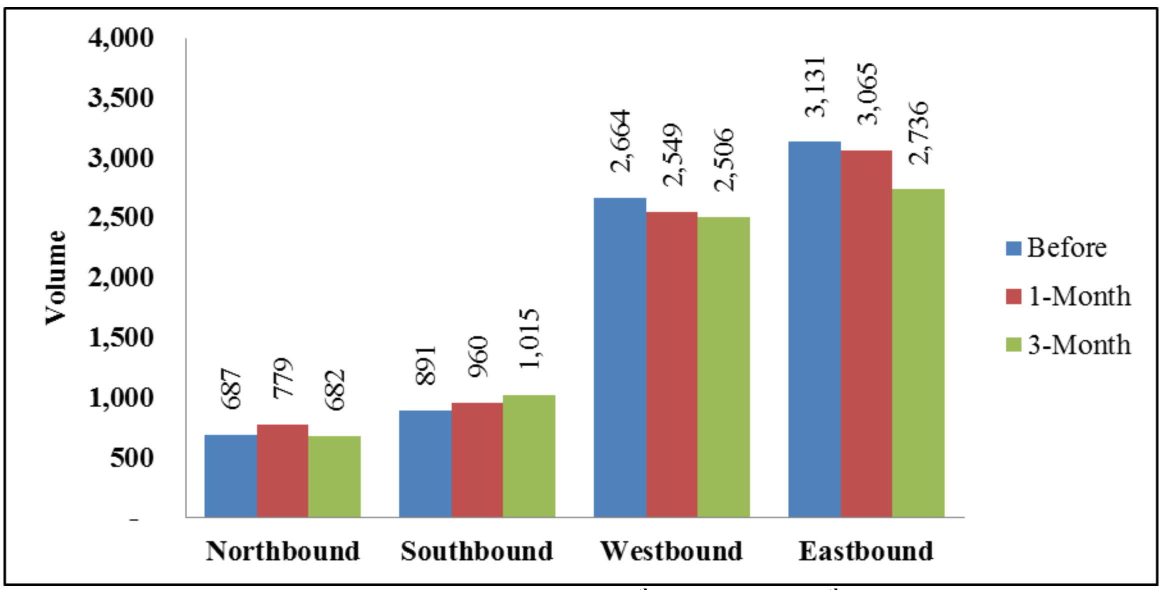


Figure 24. Traffic volumes for 8th Street and 36th Street

During all periods of the study the eastbound approach was the most traveled approach at the intersection. The northbound approach had less than 1,000 vehicles for the morning and afternoon peak during all the phases of the study. The westbound approach has the least increase in traffic from the morning to the afternoon peak. The counts for all approaches during the "before" and "one-month" were over 7,300 vehicles. During the three-month period the total vehicles counted were just over 6,900. Figure 25 shows the turning movements at the intersection.

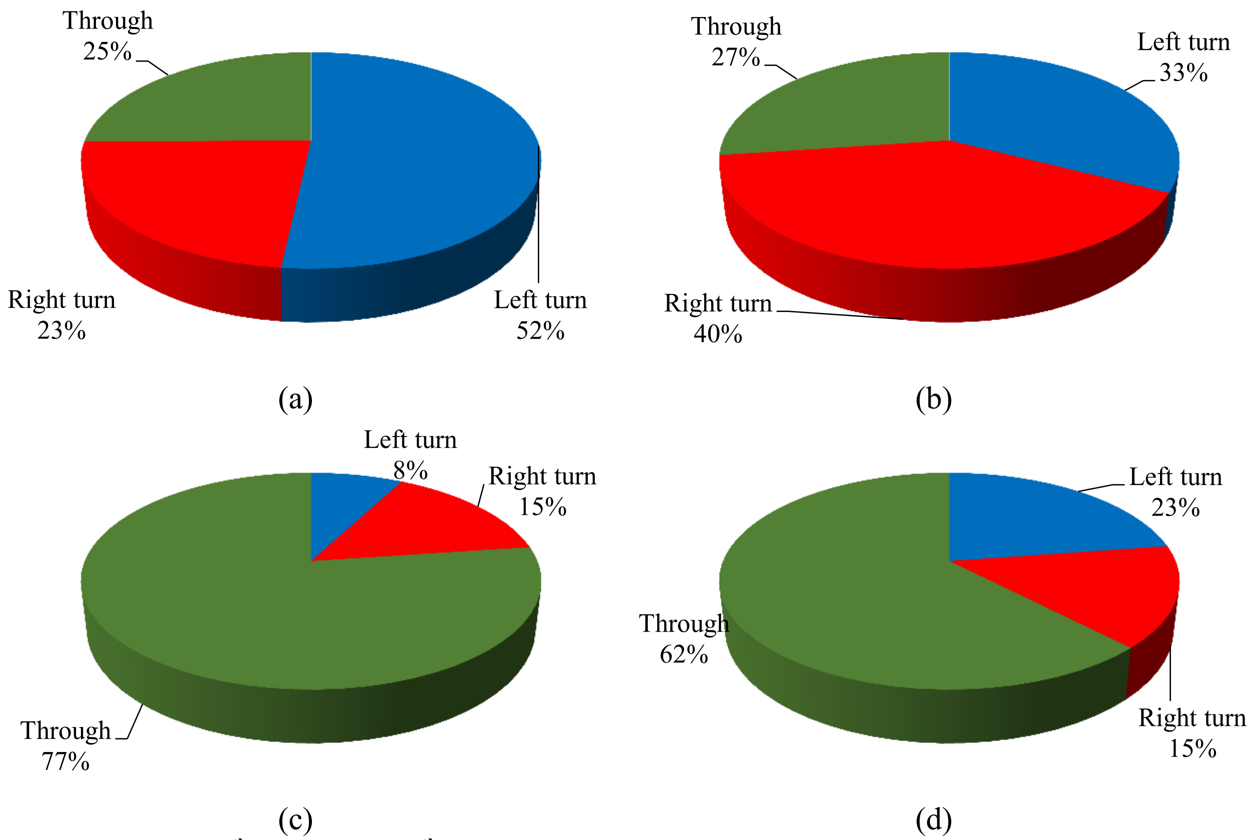


Figure 25. 8th Street and 36th Street peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

During the morning and afternoon peak hours, motorists moved through the intersection. Over half of vehicles observed at the northbound approach turn left and head west on 8th Street. The eastbound and northbound approaches have the highest count of left-turning vehicles. For the southbound approach, most vehicles turn right onto 8th Street. Nineteen percent of all vehicles at the intersection turned right.

Control Sites

There were three control sites at Altoona, Iowa. The three sites were 8th Street and 17th Street, 8th Street and 1st Avenue, and 1st Avenue and Adventureland Drive. All locations are east of the deployment site and 1st Avenue and Adventureland Drive is north east of the deployment site. Figure 26 shows the location of the control sites with respect to the treatment sites. A description of each intersection, peak hour volumes, and turning movements are provided in the following sections.

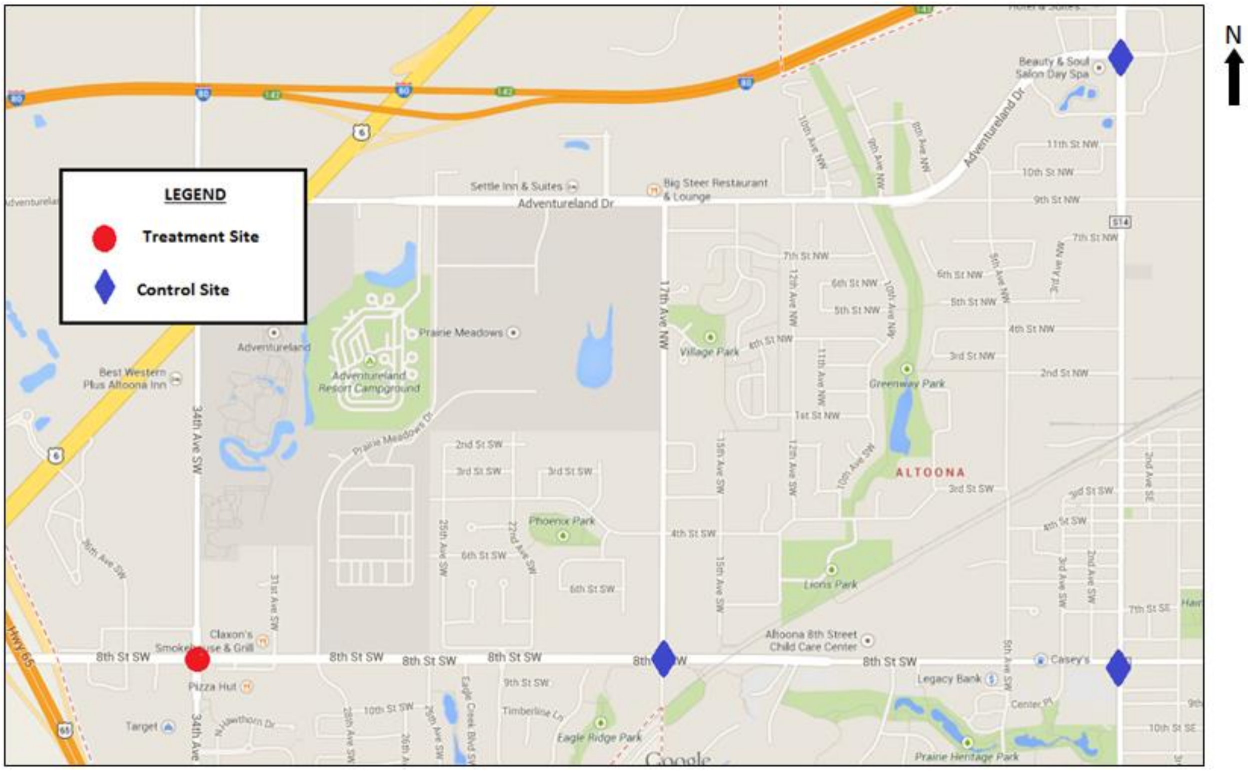


Figure 26. Layout of the treatment and control sites in Altoona (Google maps, 2014)

<u>8th Street and 17th Street</u>

The westbound and eastbound approaches consist of one through lane, one shared through/right turn lane, and a left turn lane. The southbound approach consists of one with shared left turn/through movement, and a right turn lane. The northbound approach consists of one lane for all movements. The area surrounding the intersection is mainly residential. Figure 27 shows an aerial view of the intersection and a street view from the northbound approach.

Figure 27. Control Site, 8th Street and 17th Street (aerial image: Google Earth, 2013)

At the intersection there is one overhead signal for each lane of traffic. All overhead signals have backplates that enhance signal conspicuity. Left-turning movements are protected/permitted along 8th Street. Along 17th Street, left turns are permitted only. There are no protected right turns at this intersection. The volumes counted during all periods of the study are shown in Figure 28.

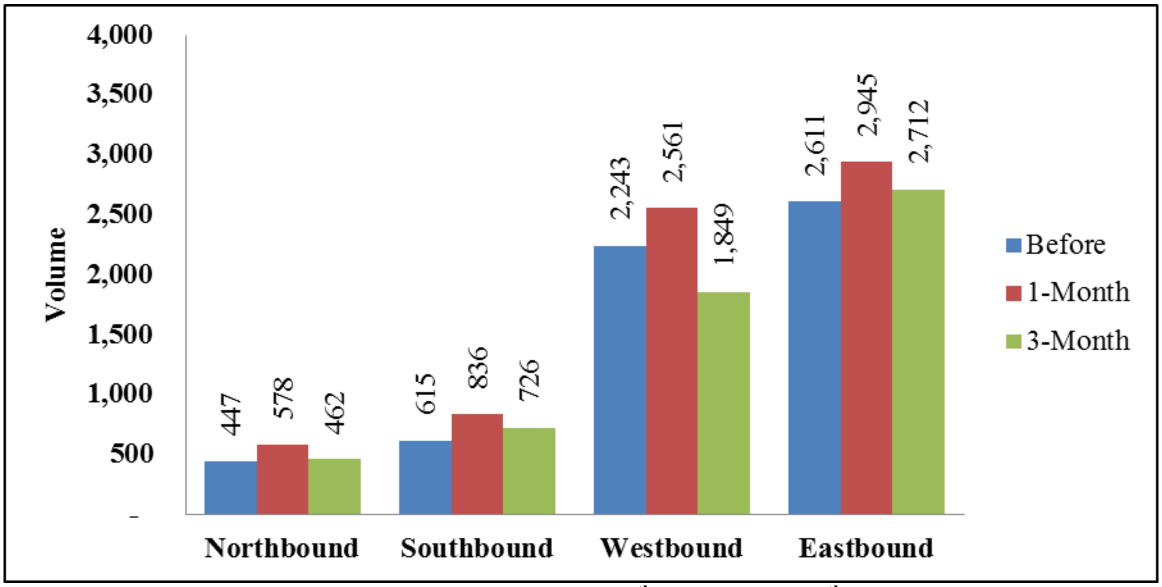


Figure 28. Traffic volumes for 8th Street and 17th Street

Traffic along 8th Street was where most of the vehicles were observed. When combining the morning and afternoon peak volumes, the eastbound approach had the most vehicles for all periods of the study. More than half of the total volumes were counted during the afternoon peak hours for all approaches. The eastbound approach experienced the highest increase from the morning to afternoon peak. Traffic along 17th Street never surpassed 1,000 vehicles during any of the study periods. Figure 29 shows the turning movements during the study.

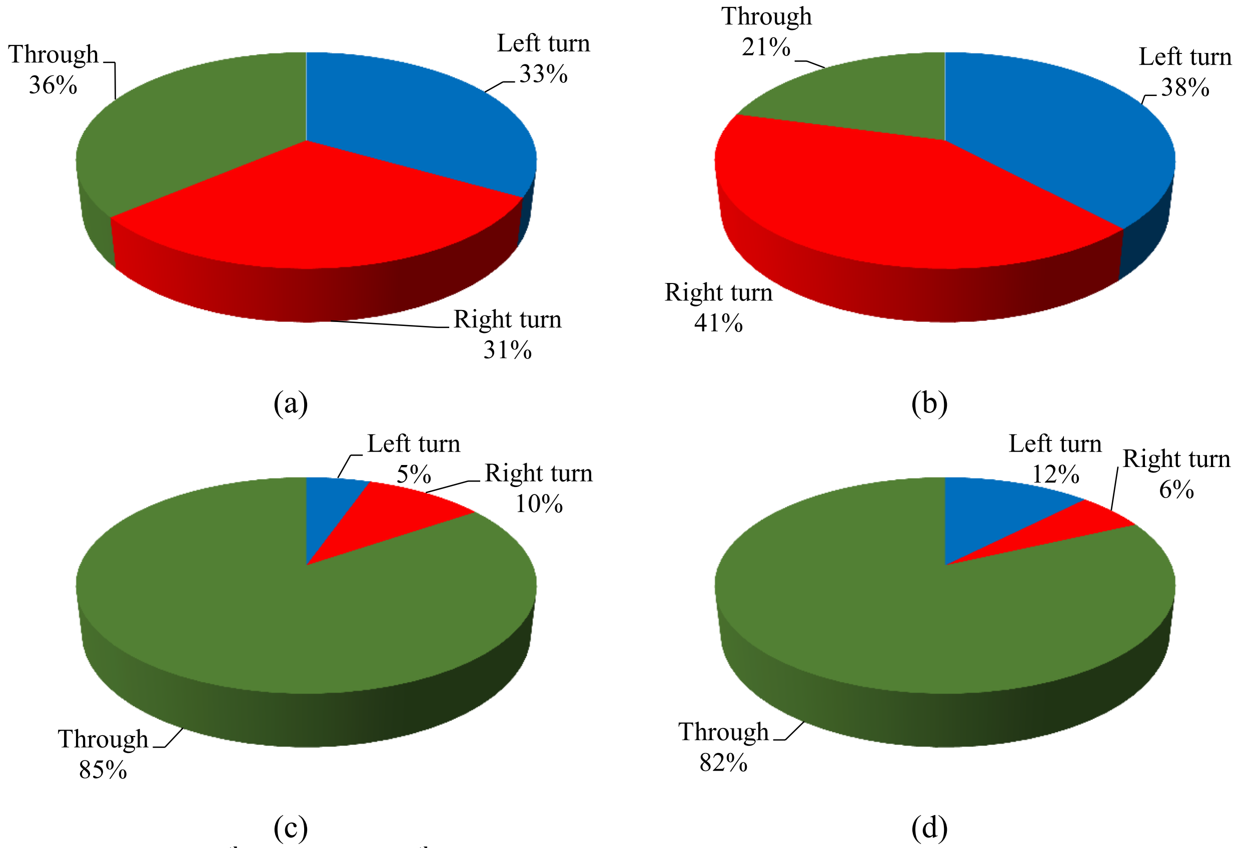


Figure 29. 8^{th} Street and 17^{th} Street peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

Over 80 percent of traffic along 8^{th} Street moved through the intersection. From the turning movements it was observed that most vehicles turning off 8^{th} Street went North on 17^{th} Street. Along 17^{th} Street the majority of traffic turns onto 8^{th} Street. The predominant direction that vehicles turn off 17^{th} Street was to head west on 8^{th} Street. In total 13 percent of motorists made a right turn, 14 percent made a left turn, and 72 percent of traffic move through the intersection.

<u>8^{th} Street and 1^{st} Avenue</u>

The westbound and eastbound approaches have two through lanes, a right turn lane, and a left turn lane. The southbound and northbound approaches have one lane for each movement. The area surrounding the intersection is commercial. There are gas stations on the west side of the intersection. On the southeast there is a strip mall, and on the northeast there is a convenience store. Figure 30 shows an aerial view of the intersection and a street view from the northbound approach.

Figure 30. Control Site, 8th Street and 1st Avenue (aerial image: Google Earth, 2013)

At this intersection all left turns are protected/permitted. The northbound and southbound approaches have protected right turns. There is an overhead signal for each travel lane and each traffic movement. All signals have backplates installed. The peak volumes observed for each period of the study are shown in Figure 31.

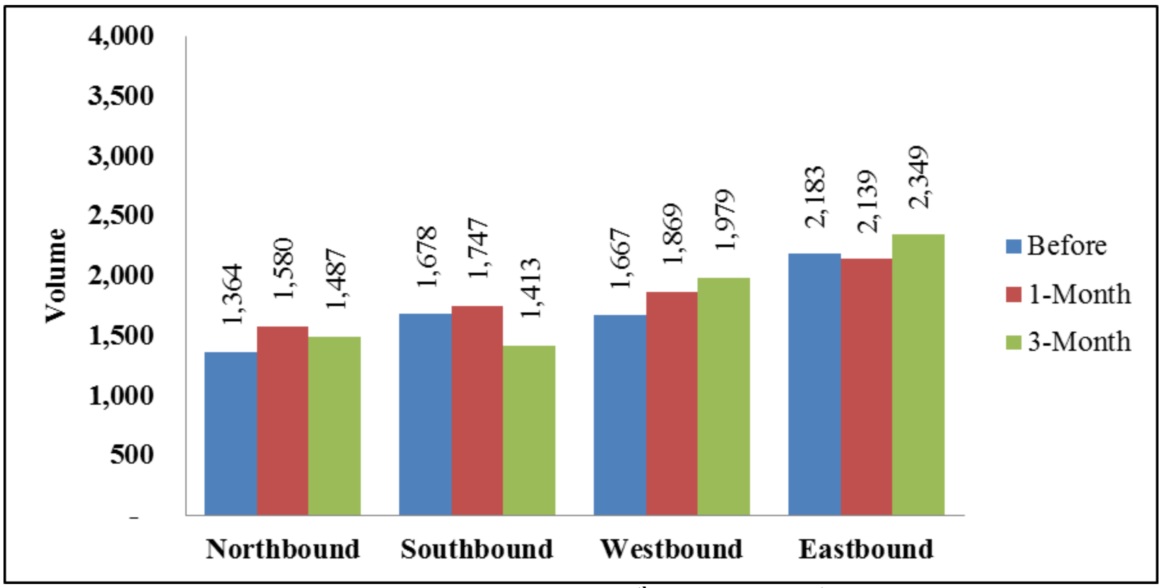


Figure 31. Traffic volumes for 8th Street and 1st Avenue

The highest volume for the intersection was observed during the one-month period with 7,335 vehicles. The three-month period had a vehicle count over 7,200 vehicles, while the before period had a vehicle count of just under 6,900. The eastbound approach on 8th Street was the most traveled by motorists during all periods of the study. For all approaches over half of the volumes shown were observed during the afternoon peak hours. The southbound and eastbound approaches showed the higher percentage of increase in volume from the morning peak to the afternoon peak out of all approaches. The turning movements are shown in Figure 32.

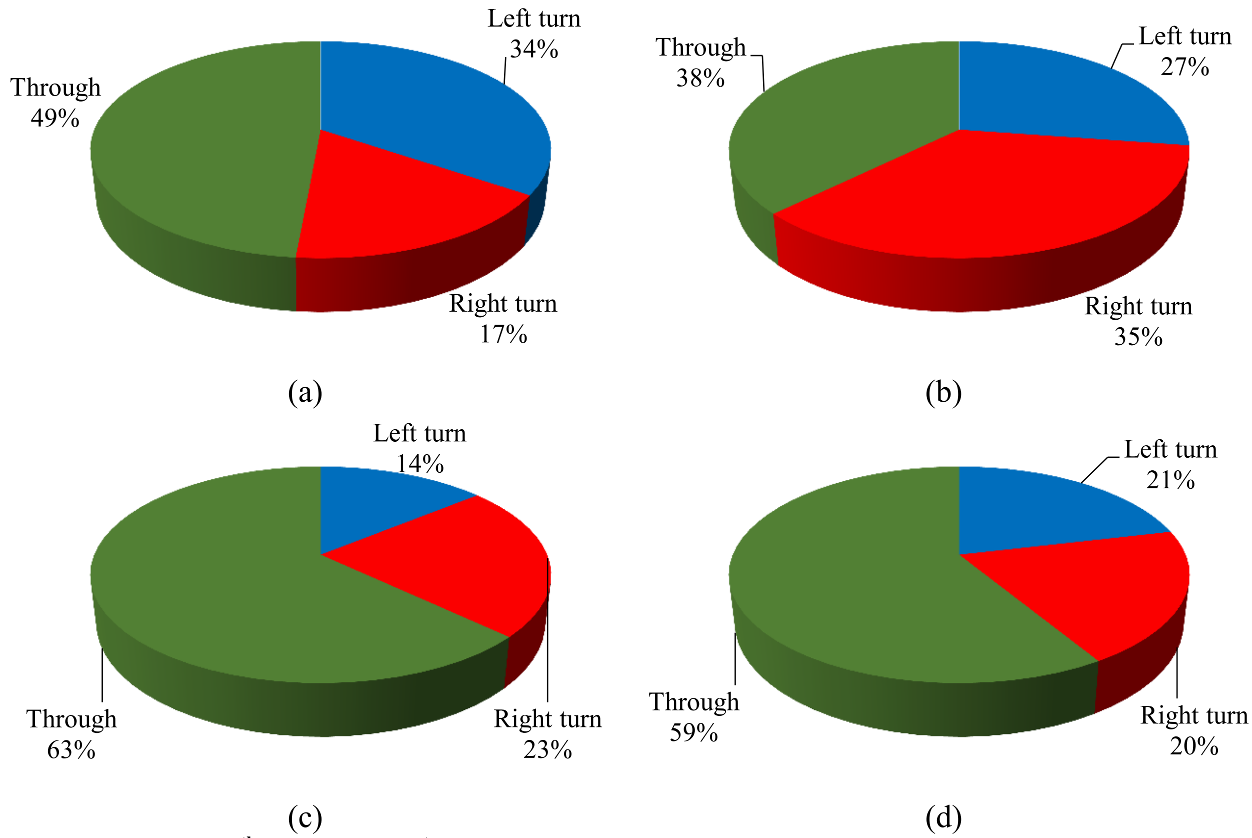


Figure 32. 8^{th} Street and 1^{st} Avenue peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

Over half of traffic traveling along 8^{th} Street went through the intersection. Most vehicles turning off 8^{th} Street headed north on 1^{st} Avenue. Less than half of vehicles along 1^{st} Avenue traveled through the intersection. The northbound approach had the highest count and percentage of left-turning vehicles at the intersection. The southbound approach had the highest count and percentage of vehicles turning right onto 8^{th} Street. Out of the 20,922 vehicles counted during the morning and afternoon peak hours, 23 percent turned left, 23 percent turned right, and 54 percent went through the intersection.

<u>1^{st} Avenue and Adventureland Drive</u>

First Avenue and Adventureland Drive is near an Interstate 80 exit. In the northeast corner of the intersection there is a gas station, and on the southwest there is a strip mall. Figure 33 provides an aerial picture of the intersection.

Figure 33. Control Site, 1st Avenue and Adventureland Drive (aerial image: Google Earth, 2013)

The northbound approach has a left-turn lane, one through lane, and a shared right-turn/through lane. The southbound approach has two through lanes, a right-turn lane, and a left-turn lane. The eastbound approach has one lane for each movement. The westbound approach has a left-turn lane and a shared through/right-turn lane. All left-turn movements are protected/permitted. The southbound and eastbound approaches have a protected right turn. There is one overhead signal for each travel lane and each movement along 1st Avenue. The eastbound approach has one overhead signal for each movement. The westbound approach has an overhead signal for the through movements and one overhead signal for all left-turn movements. All overhead signal heads have backplates installed to enhance signal conspicuity. Figure 34 shows the volumes for the morning and afternoon peak for each study period.

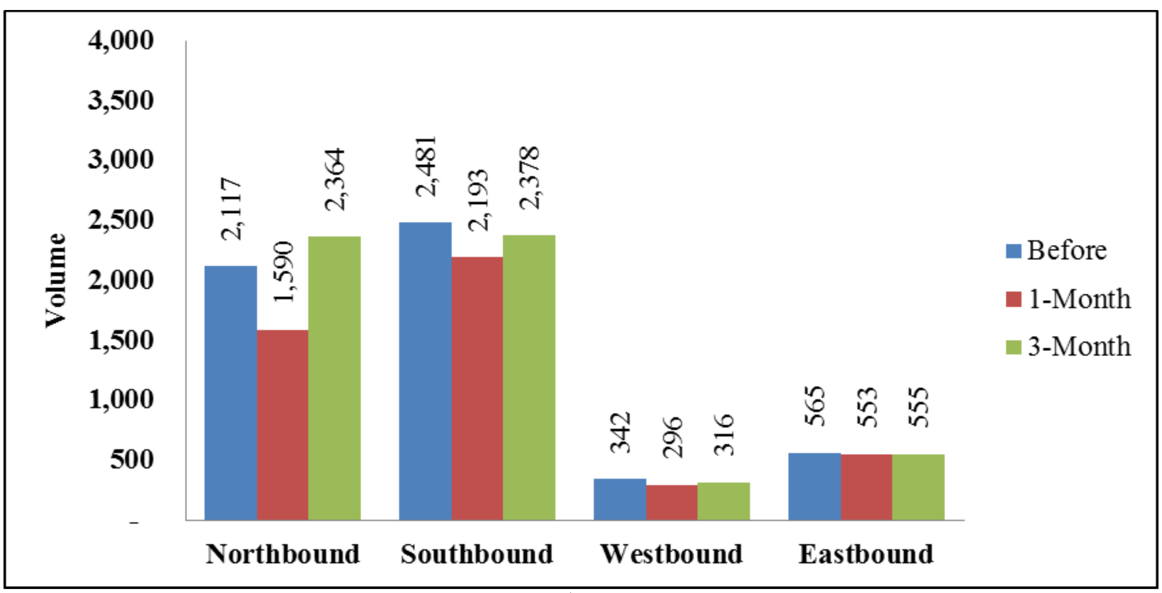


Figure 34. Traffic volumes for 1st Avenue and Adventureland Drive

1st Avenue is the main corridor that motorists use. The westbound corridor was used mainly by trucks and customers exiting the gas station on the northwest corner of the intersection. The southbound approach had the highest volume out of all approaches. Additionally, the southbound approach saw the most increase in volume from the morning to afternoon peak. Figure 35 shows the movement of traffic at the intersection.

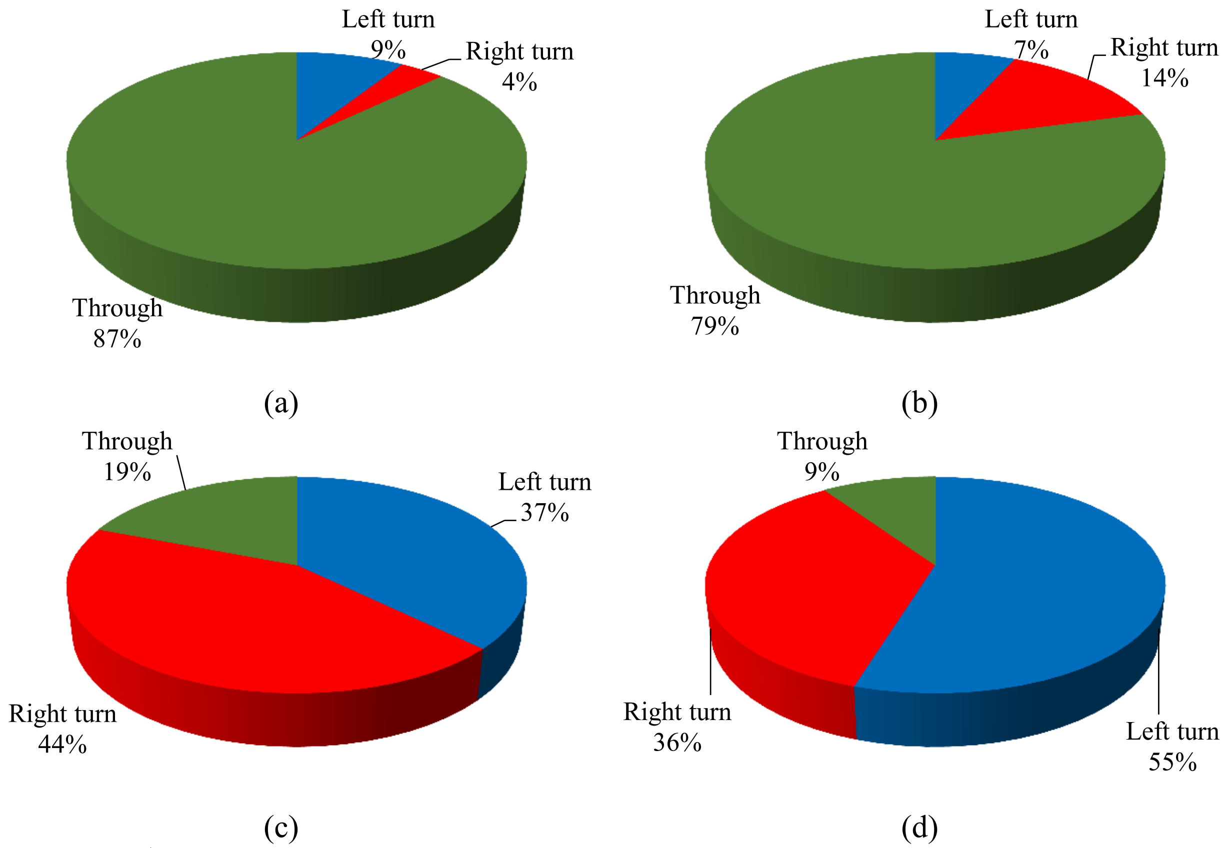


Figure 35. 1st Avenue and Adventureland Drive peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

Vehicles traveling along 1st Avenue went through the intersection to either enter the highway or head into town from the highway. The majority of traffic turning off 1st Avenue headed west onto Adventureland Drive. The majority of traffic coming off Adventureland Drive headed north towards the highway. The northbound approach had the highest proportion of traffic turning left, but the eastbound approach had the highest count of left-turning vehicles. Overall, there were a total of 15,750 vehicles counted. Seventy-one percent traveled through the intersection, 15 percent turned left, and 14 percent turned right at the intersection.

Summary of Altoona intersections

All study sites had an overhead signal head for each travel lane, and all overhead signal heads had backplates. Four of the six intersections were located in commercial areas. Twenty out of 24 approaches had protected/permitted left-turns, and there were no protected only left-turns at any of the sites. From the 24 different approaches there were 7 that had a protected right turn. For most of the approaches on all sites there was an increase in traffic when comparing morning peak to afternoon peak. There were a total of 121,546 vehicles counted for Altoona. The three intersections with the highest volumes were 8th Street and 36th Street, 8th Street and 34th Street, and 8th Street and 1st Avenue. Those intersections carried 56 percent of the total count for Altoona. For all intersections left turns made up 18 percent of the total volume, right turns 17 percent, and through movement 65 percent.

Waterloo intersections
The City of Waterloo has a population of over 68,000 residents which makes it the sixth largest city in the state. The city is located in northeast Iowa and covers an area of 63.23 square miles. The city is near Cedar Falls, and state highways 63, 20, and Interstate 380 (I-380) run through the city. A total of six intersections were studied in Waterloo, Iowa. There was one intersection chosen for deployment, four to study spillover effects, and one control site. The following sections provide a description of the sites selected

Treatment Site: University Avenue and Ansborough Avenue
The intersection of University Avenue and Ansborough Avenue was chosen as the site for deployment of the confirmation lights. University Avenue is the East/West corridor. The eastbound and westbound approach consists of two through lanes, one shared through/right turn lane, and a left turn lane. Ansborough Avenue is the North/South corridor. The northbound/southbound approaches consists of two through lanes, one with shared right turn movement, and a left turn lane. Figure 36 shows an aerial view of the intersection.

Figure 36. Treatment Site, University Avenue and Ansborough Avenue (aerial image: Google Earth, 2013)

The site has restaurants on the northwest and southwest corners, a closed shop in the northeast corner, and a fire station on the southeast corner. There are frontage roads along University Avenue, west of Ansborough Avenue. At the time of this research the north frontage road was closed due to construction. Eastbound traffic is travels on a curve on University Avenue. To enhance awareness of the upcoming traffic signal, the city installed a flashing advance warning system that is located approximately 520 feet upstream from the intersection. All overhead signals have backplates to enhance visibility. There is one signal head per lane, per movement. The eastbound, westbound, and northbound left turn movements are protected only. The southbound left turn movement is protected-permitted, so a confirmation light was not installed for this movement. There is a median separating traffic along University Avenue, but there is no median along Ansborough Avenue. The volume counts for both peak periods are shown in Figure 37.

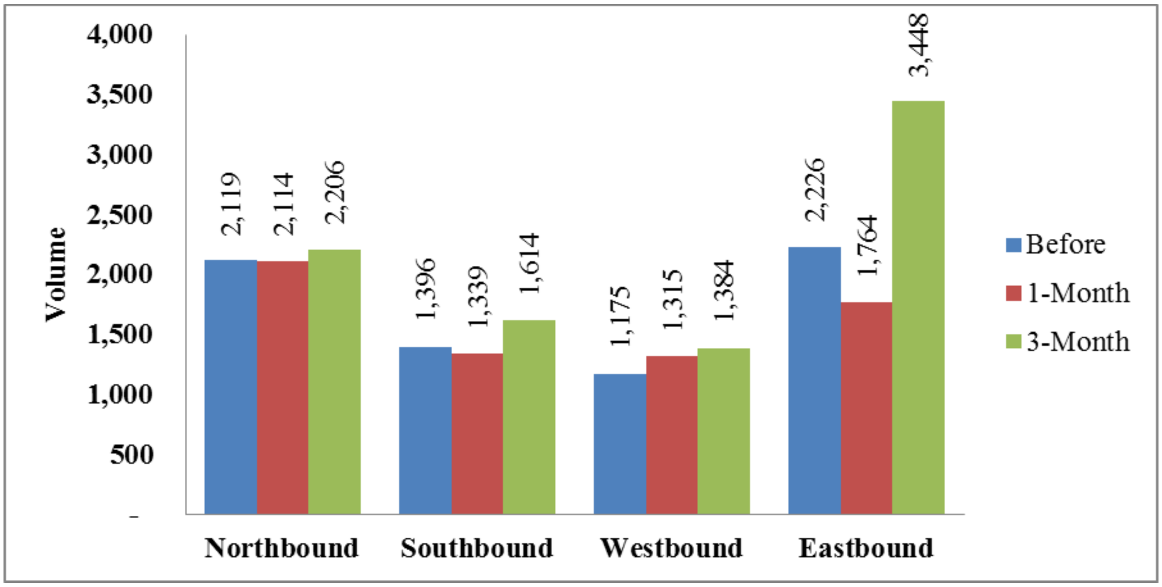


Figure 37. Traffic volumes for University Avenue and Ansborough Avenue

The eastbound approach on University Avenue and the northbound approach have the higher volumes during both peak periods. There is an overall increase in volume observed from the before period to the three-month after study. The before period had a vehicle count of 6,916 vehicles and 6,532 vehicles were counted on the one-month period of the study. The three-month after period had a vehicle count of 8,652 vehicles. There were no counts made of vehicles turning onto the frontage roads. Figure 38 shows the percentage of turning movement for every approach of the intersection.

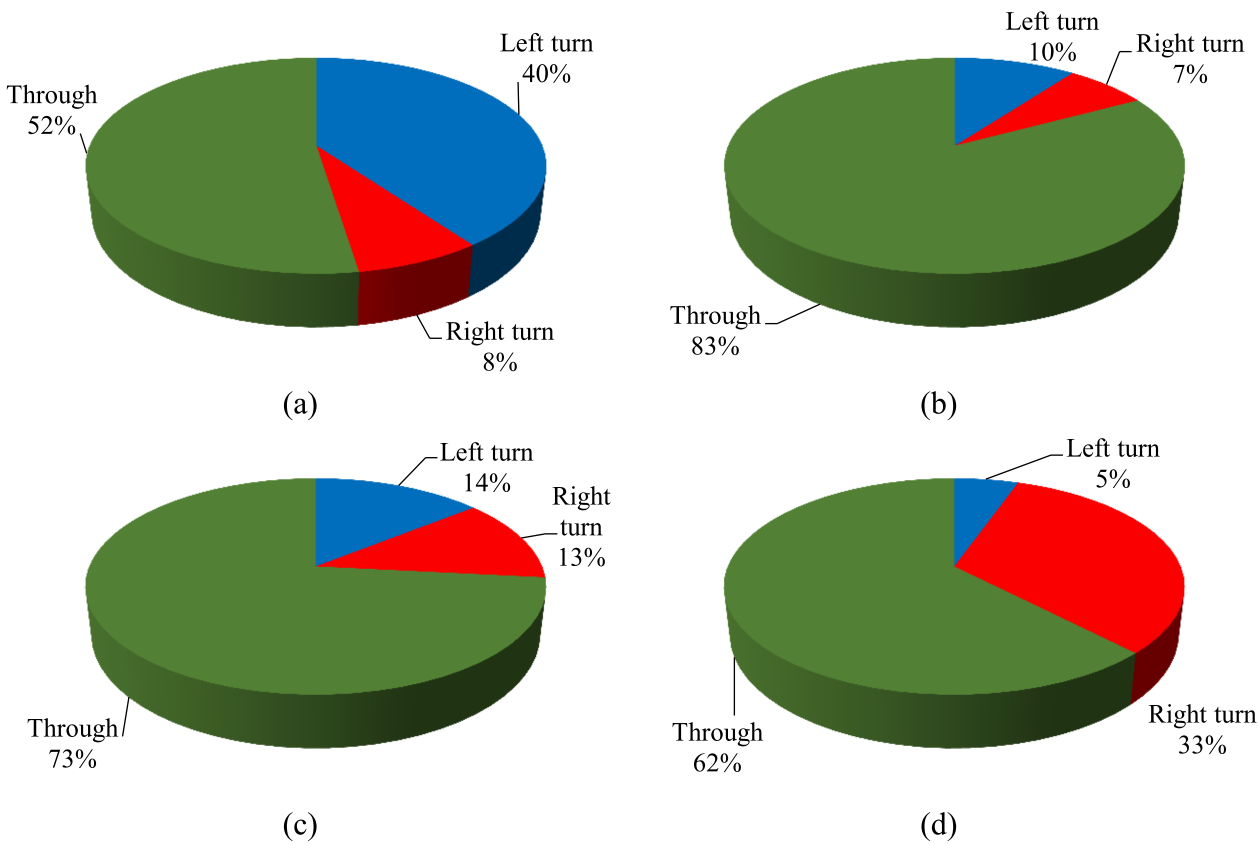


Figure 38. Peak hour turning movement percentages for University Avenue and Ansborough Avenue (a) northbound (b) southbound (c) westbound (d) eastbound

For the northbound approach, more than 50 percent of traffic traveled through the intersection, and 40 percent turned left onto University Avenue during both the morning and afternoon peak hours. For the Eastbound approach, 62 percent traveled through, and roughly 33 percent turned right and headed south on Ansborough Avenue. More than 80 percent on the southbound approach of Ansborough Avenue traversed through the intersection, and more than 70 percent traversed through the intersection on the westbound approach.

Spillover Sites

Four signalized intersections were selected to study the spillover effects of the countermeasure. The sites were University Avenue and Fletcher Avenue, University Avenue and Sager Avenue, Ansborough Avenue and Falls Avenue, and Ansborough Avenue and Downing Avenue. The following sections describe the site, the volume observed for all three periods of the study and the turning movements. Figure 39 shows the location of the spillover sites with respect to the treatment site.

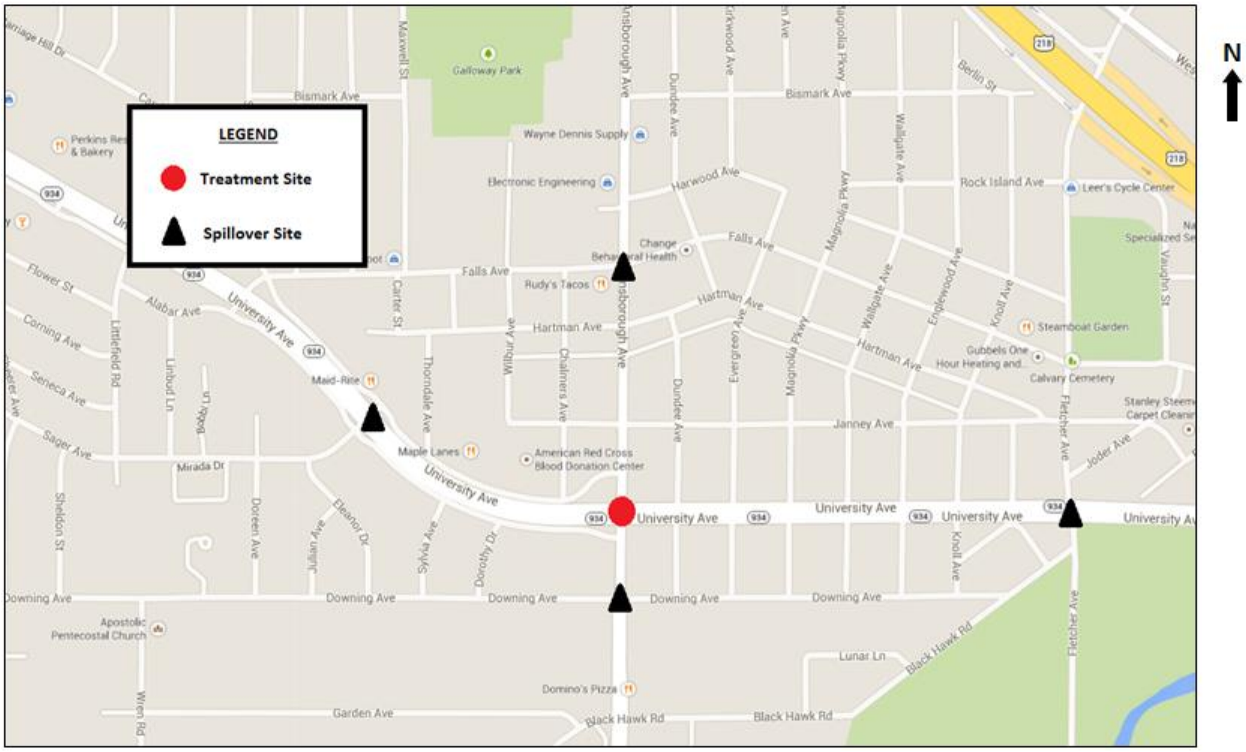


Figure 39. Layout of the spillover and treatment sites, Waterloo, IA (Google maps, 2014)

University Avenue and Fletcher Avenue

University Avenue and Fletcher Avenue is located east of the deployment intersection. For the westbound and eastbound approaches on University Avenue there are three through lanes, one left turn lane, and no right turn lane. As shown in Figure 40, on the northbound approach there is one left turn lane and a shared through/right turn lane. The southbound approach along Fletcher Avenue has one lane for each movement.

Figure 40. Spillover Site, University Avenue and Fletcher Avenue (aerial image: Google Earth, 2013)

In the northwest corner of the intersection there are shops on the north side of the intersection, and a residential neighborhood on the southwest corner of the intersection. There are medians on along University Avenue and the north side of Fletcher Avenue. There is one signal head per lane per movement. All overhead signals have backplates. All left turn movements at the intersections are protected/permitted. Figure 41 shows volumes at each approach for each period of the study.

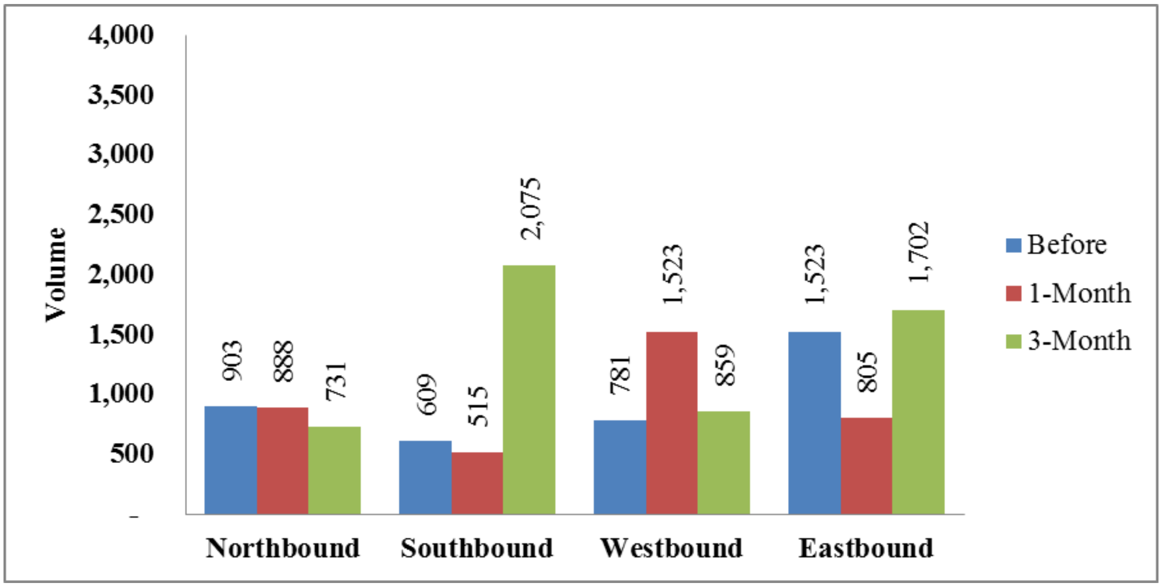


Figure 41. Traffic volumes for University Avenue and Fletcher Avenue

From figure 41 it can be seen that for both peak periods most of the traffic is eastbound at this intersection. During the first two periods of the study the overall volume of the intersection was 3,816 and 3,731 total vehicles. During the three-month after period the vehicle count was 5,367. The southbound approach had the highest volumes, with 904 vehicles being counted in the morning and 1,171 vehicles in the afternoon. Turning movements for all approaches at the peak hour are shown in Figure 42.

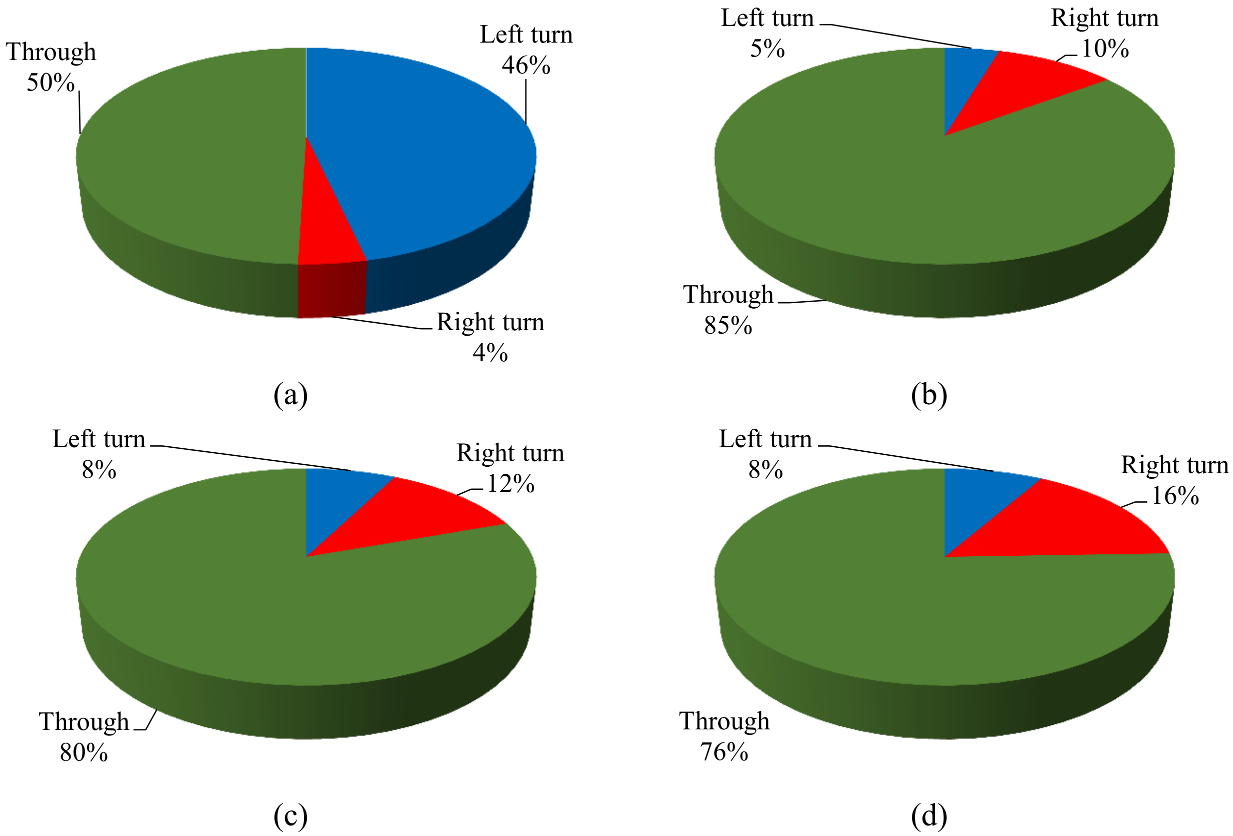


Figure 42. University Avenue and Fletcher Avenue peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

For the eastbound, westbound, and southbound approaches most of the traffic traversed through the intersection. The northbound approach had the highest percentage and number of left turns. The eastbound approach had the most right turns. Though the eastbound and westbound had the same percentage of left-turns, the eastbound approach had a higher number of total left-turning cars.

University Avenue and Sager Avenue

University Avenue and Sager Avenue is the next signalized intersection west of University Avenue and Ansborough Avenue as shown in Figure 43. For both approaches on University Avenue there are three through lanes, and one left turn lane. Sager Avenue gives access to the frontage road along University Avenue, and a residential area. Both approaches at Sager Avenue have a left turn lane and a shared through/right turn lane.

Figure 43. Spillover Site, University Avenue and Sager Avenue (aerial image: Google Earth, 2013)

Although the intersection is on a curve, movements along University Avenue are defined as eastbound and westbound, while traffic on Sager Avenue is northbound and southbound. On the south and north end of Sager Avenue there are commercial and residential areas. There was construction on the frontage road in the north end of the intersection when counts were being taken. There is one signal head per lane per movement. All overhead signals have backplates. Left turns for westbound and eastbound approaches are protected/permitted and left-turn movements along Sager Avenue are permitted only. Figure 44 shows the recorded peak hour volumes for all periods of the study.

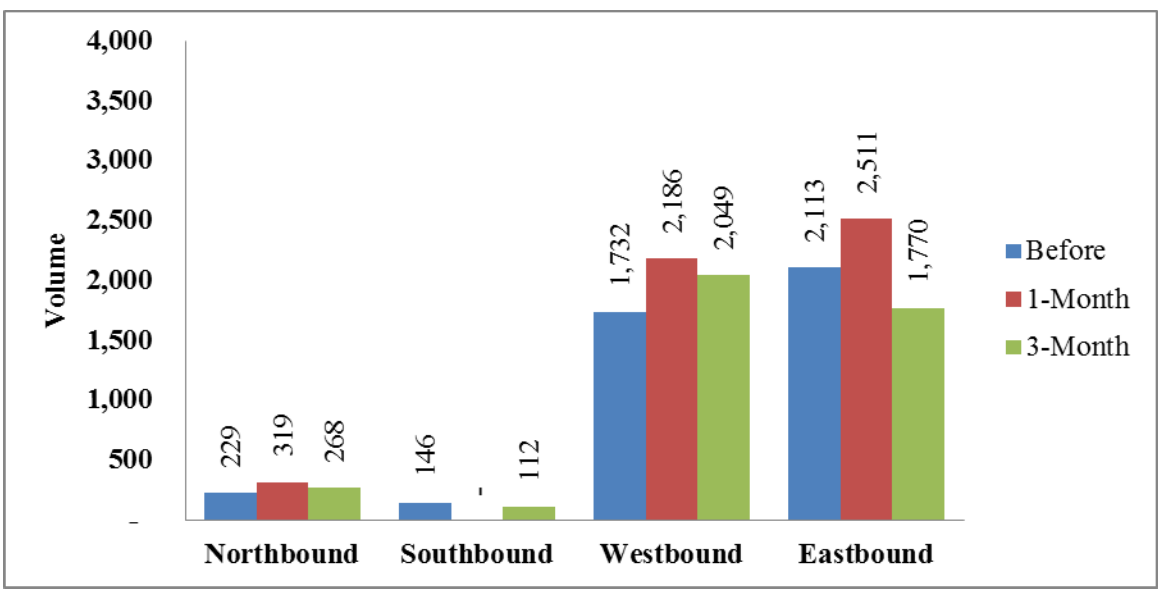


Figure 44. Traffic peak hour volumes for University Avenue and Sager Avenue

As shown in Figure 44, most of the traffic traveled along the eastbound and westbound corridor of this intersection. For both the morning and afternoon peak the majority of traffic observed was eastbound. At the time of the one-month after study, access to the southbound approach was blocked due to maintenance on the frontage road. Figure 45 shows the percentage of recorded volumes for the morning and afternoon peak hours.

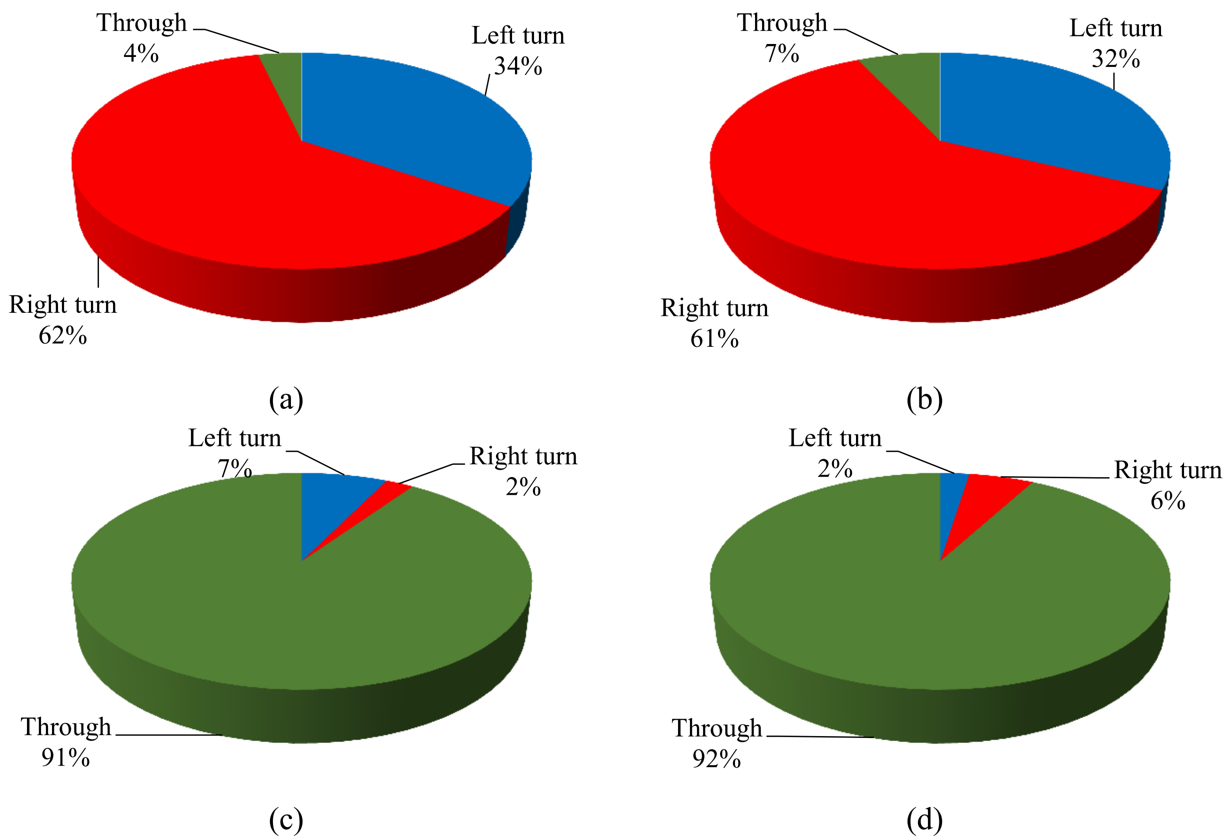


Figure 45. University Avenue and Sager Avenue peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

Sager Avenue is a minor collector road and University Avenue is a major arterial. The majority of the traffic at the northbound/southbound approach turned right onto University Avenue. It was observed that left turns comprised slightly over 30 percent of the traffic. Over 90 percent of the traffic along University Avenue moved through the intersection.

<u>Ansborough Avenue and Downing Avenue</u>

Ansborough Avenue and Downing Avenue is the first signalized intersection south of University Avenue and Ansborough Avenue as shown in Figure 46. The northbound and southbound approaches have two lanes with shared turning movements. The eastbound and westbound approaches along Downing Avenue have one lane. Downing Avenue is a collector road that gives access to residential areas, while Ansborough Avenue is a collector road.

Figure 46. Spillover Site, Ansborough Avenue and Downing Avenue (aerial image: Google Earth, 2013)

On the east side of the intersection there are commercial shops. For the westbound approach there are no overhead signals, it only has a post mounted signal. The eastbound approach has one overhead signal with a backplate and a post mounted signal. The approaches along Ansborough Avenue have two overhead signal heads with backplates, and a post mounted signal. All left turn movements at the intersection are permitted only. Figure 47 shows the total peak volumes for each approach.

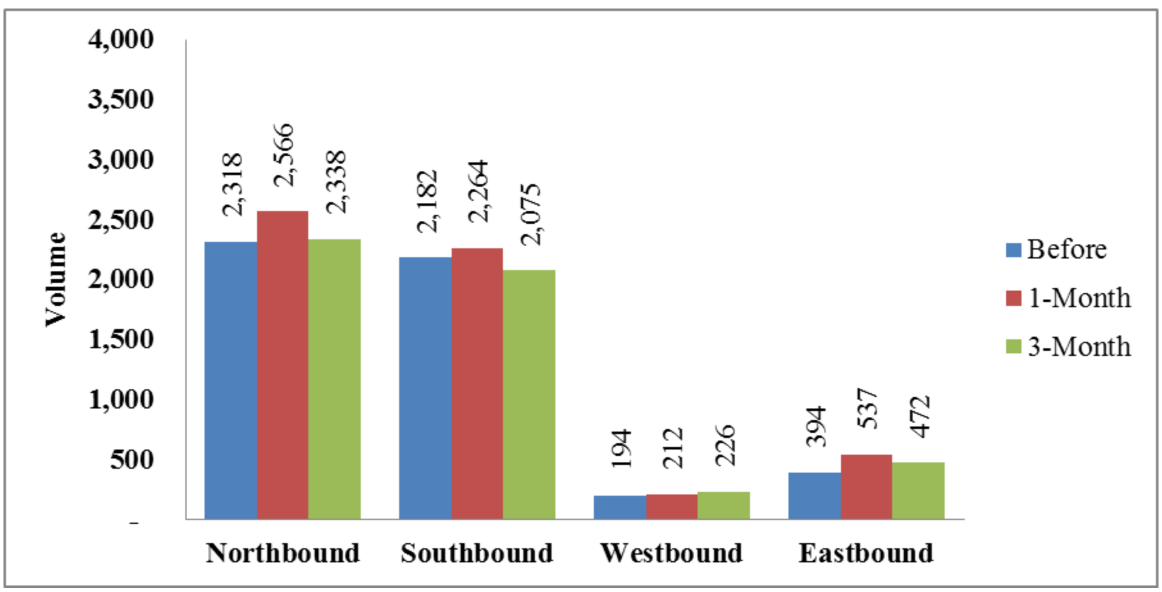


Figure 47. Traffic volumes for Ansborough Avenue and Downing Avenue

The northbound and southbound approach is where most of the traffic was observed. Around 60 percent of the total traffic for both of these approaches happened in the afternoon peak hour. The eastbound approach experiences more traffic than the westbound approach. Over 60 percent of the total traffic was observed during the afternoon peak hours. Figure 48 shows the percentage of turning movement based on the total volumes observed for all periods of the study.

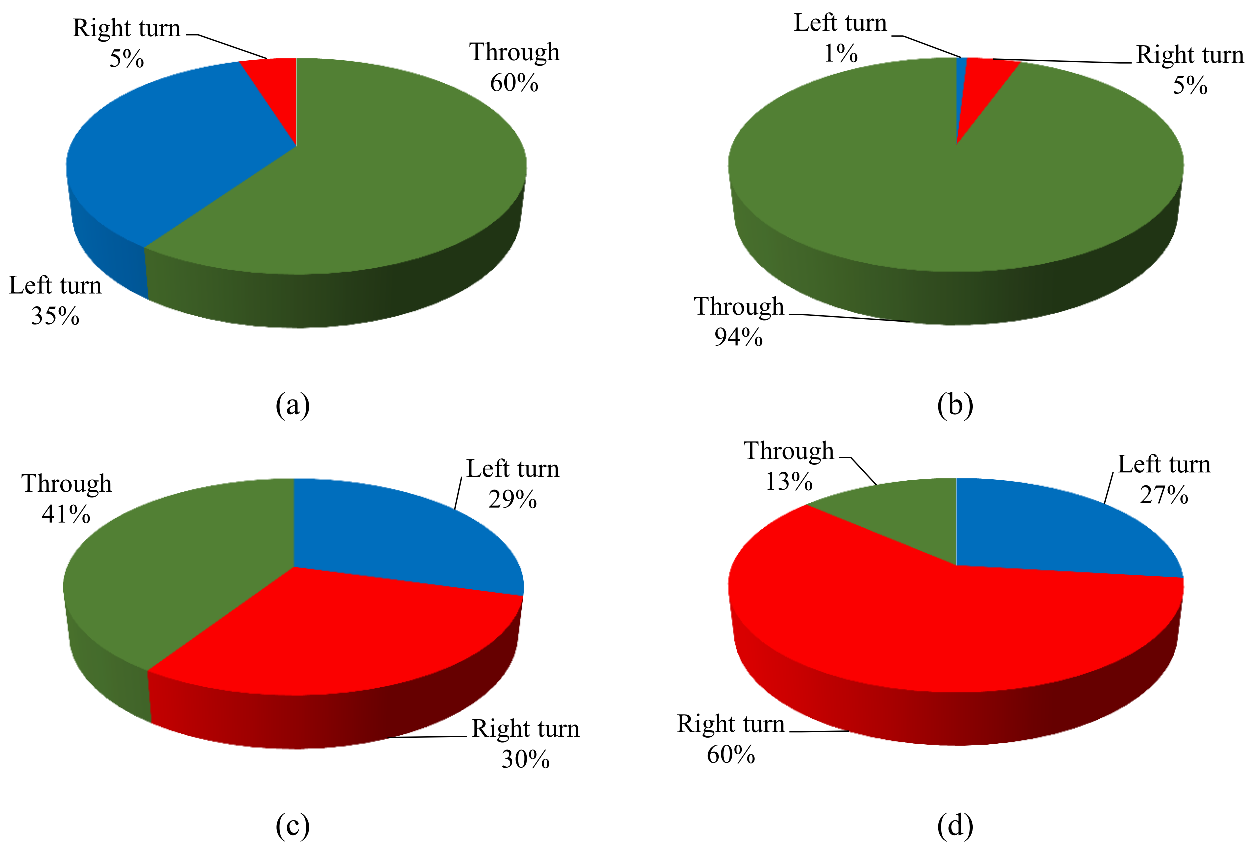


Figure 48.Ansborough Avenue and Downing Avenue peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

Most of the traffic along Ansborough Avenue traveled through the intersection. More than 90 percent of the southbound traffic traveled through the intersection, and a combined six percent made a right turn onto Downing Avenue. The northbound approach had the highest percentage of left-turning vehicles. Thirty-five percent of motorist turned left onto Downing Avenue and headed west. For the eastbound approach most of the volume turned right onto Ansborough Avenue. The majority of the westbound vehicles traveled through or turned right.

<u>Ansborough Avenue and Falls Avenue</u>

This intersection is located north of the deployment site and shown in Figure 49. The southbound, northbound, and westbound approaches have two lanes and no separate lanes for turning movements. The eastbound approach has a left-turn lane and a through/right turn lane. There is an overhead signal for each travel lane. All overhead signals have backplates installed. The eastbound approach has three signal heads, one overhead signal and one mounted on the post. The westbound, northbound and southbound approaches have permitted left turn movements. The eastbound approach has protected/permitted left turns.

Figure 49. Spillover Site, Ansborough Avenue and Falls Avenue (aerial image: Google Earth, 2013)

The intersection is located in a mixed commercial and residential area of town. There is a gas station at the northeast corner of the intersection. There are commercial businesses to the west of the intersection. There are apartment buildings at the southeast corner of the intersection. The volumes recorded for each study period at this intersection are shown in Figure 50.

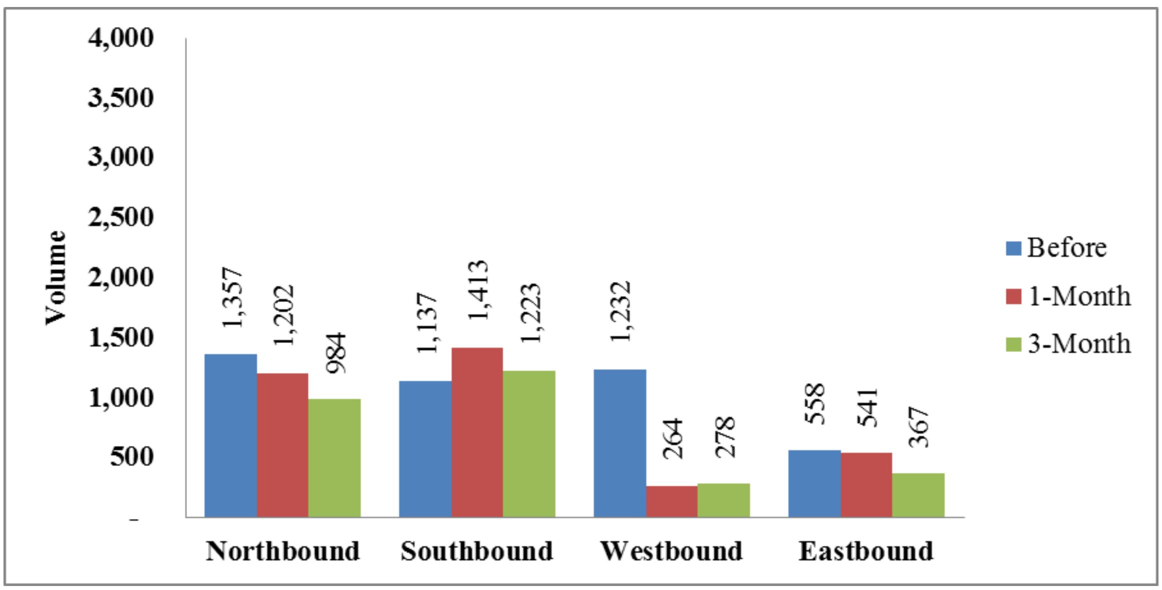


Figure 50. Total peak volumes for Ansborough Avenue and Falls Avenue

The northbound and southbound approaches are the most traveled during peak hours. The figure also shows that the Falls Avenue is the minor approach. To further understand how traffic behaves at this intersection, the percentages of the turning movements are shown in Figure 51. These percentages were calculated from the total volume for the approach from all three study periods.

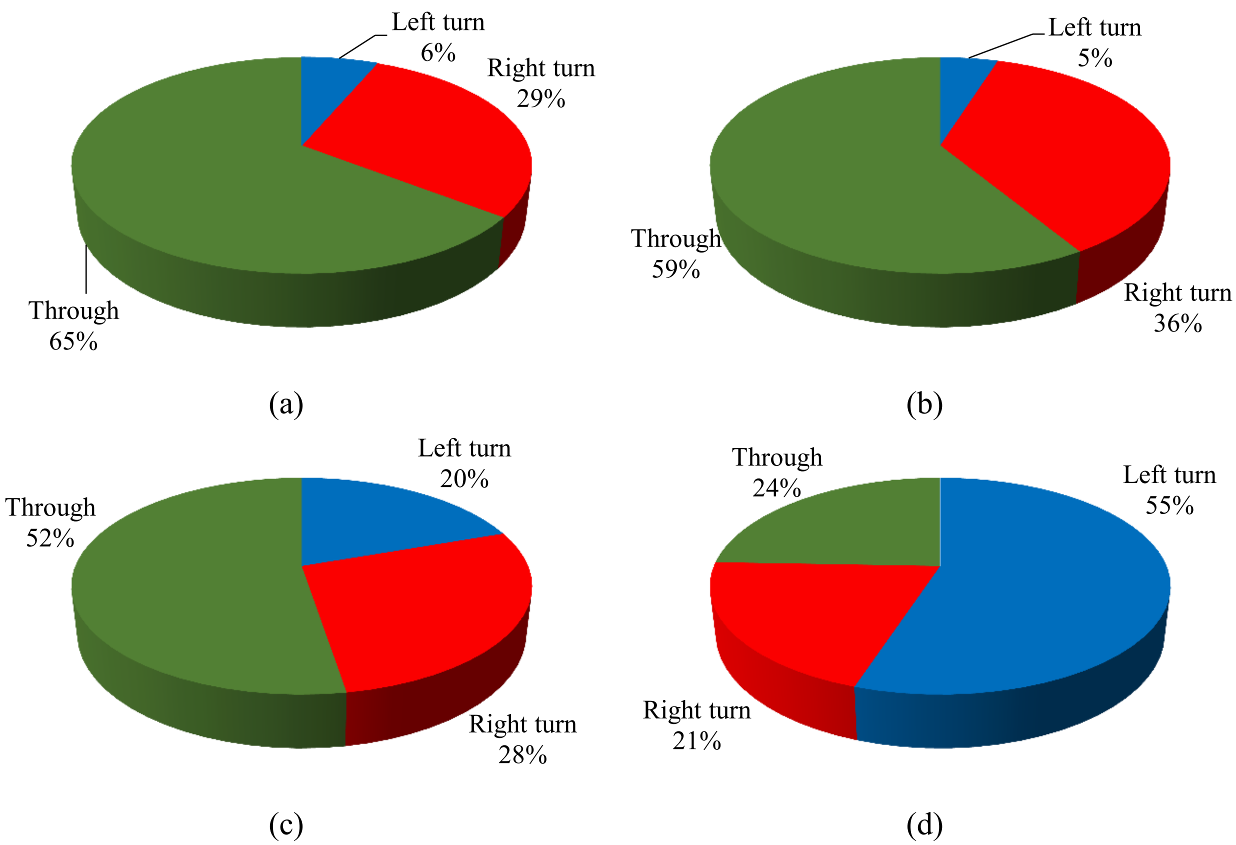


Figure 51. Ansborough Avenue and Falls Avenue peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

From figure 51 it can be noted that most of the traffic travels through the intersection. Over half of the total volume was composed of through traffic for the northbound, southbound and westbound approaches. The eastbound approach had the highest percentage and number (807) of left turns overall out of all the approaches. The highest volume of right turns was observed at the northbound and southbound approaches.

Control Site

The intersection of E. San Marnan Drive and La Porte Road was chosen as a control site. The intersection is located to the southeast of the treatment intersection. Figure 52 shows the location of the control site with respect to the treatment site.

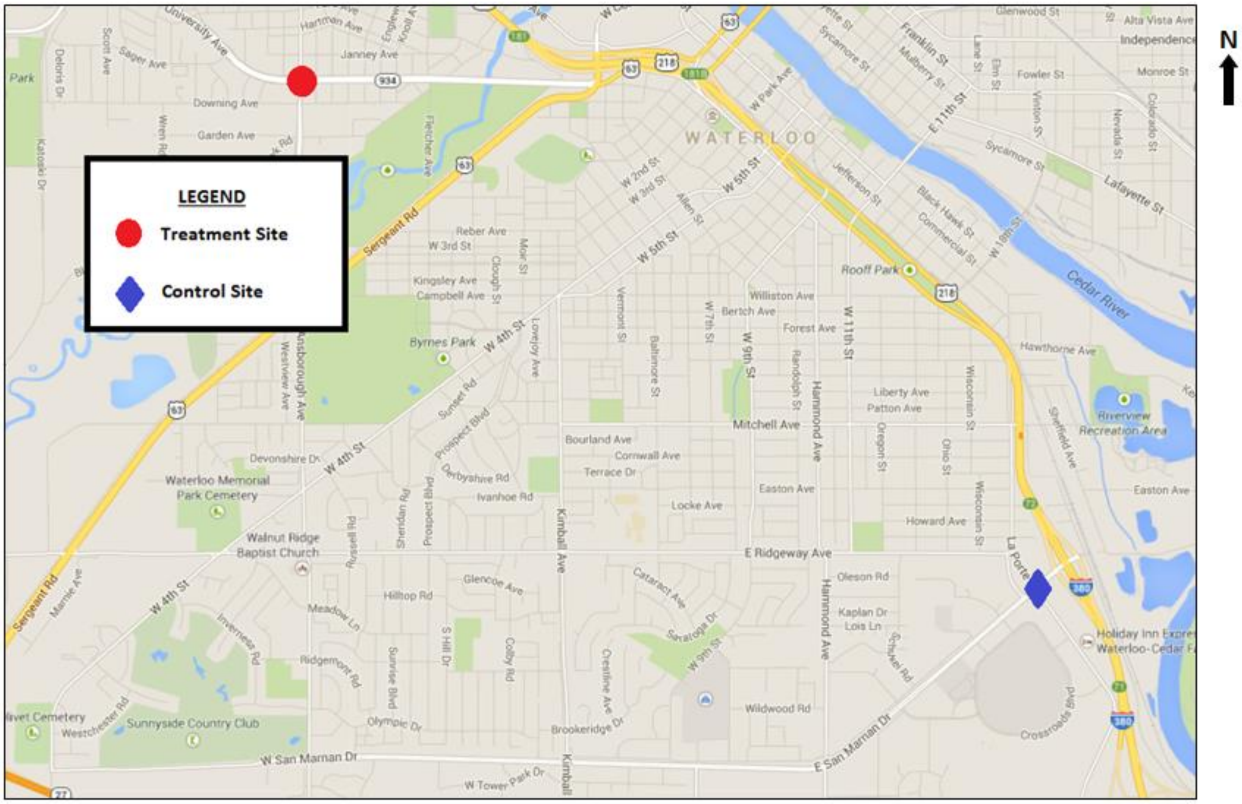


Figure 52. Layout of the control and treatment sites in Waterloo, IA (Google maps, 2014)

<u>E. San Marnan Drive and La Porte Road</u>
This intersection is located in a commercial area in town and shown in Figure 53. The intersection is near an I-380 interchange. For traffic along E. San Marnan Drive there is a left turn lane, and two through lanes. The both approaches of La Porte Road have a left turn lane, a through lane, and a right turn lane.

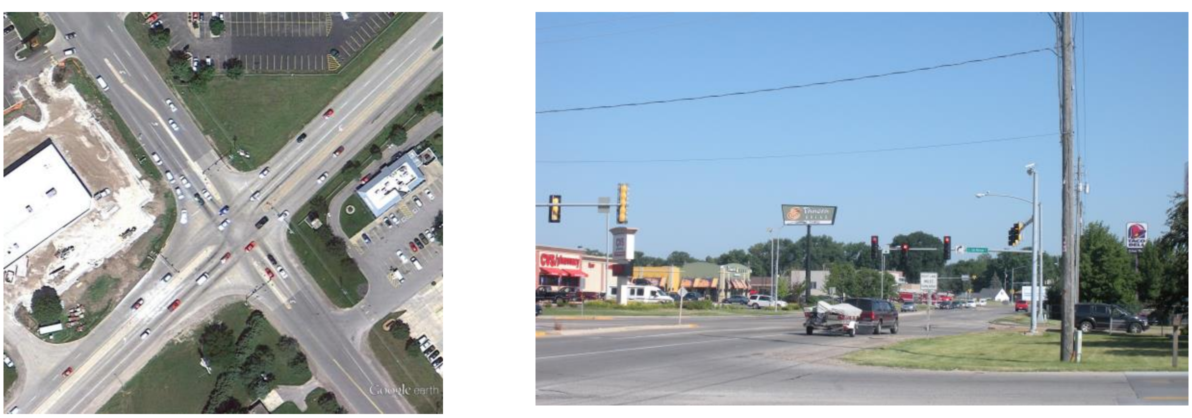


Figure 53. Control Site, La Porte Road and East San Marnan Drive (aerial image: Google Earth, 2013)

San Marnan Drive was considered the eastbound and westbound corridor, and La Porte Road was defined as the northbound and southbound road. There are three signal heads per approach. All signal have backplates installed. For the eastbound/westbound approaches on East San Marnan Drive left turns are protected only. The northbound/southbound approaches of La Porte Road have a protected/permitted left turn and a protected right turn. Figure 54 shows the summation of the morning and afternoon peak volumes for all three periods of the study.

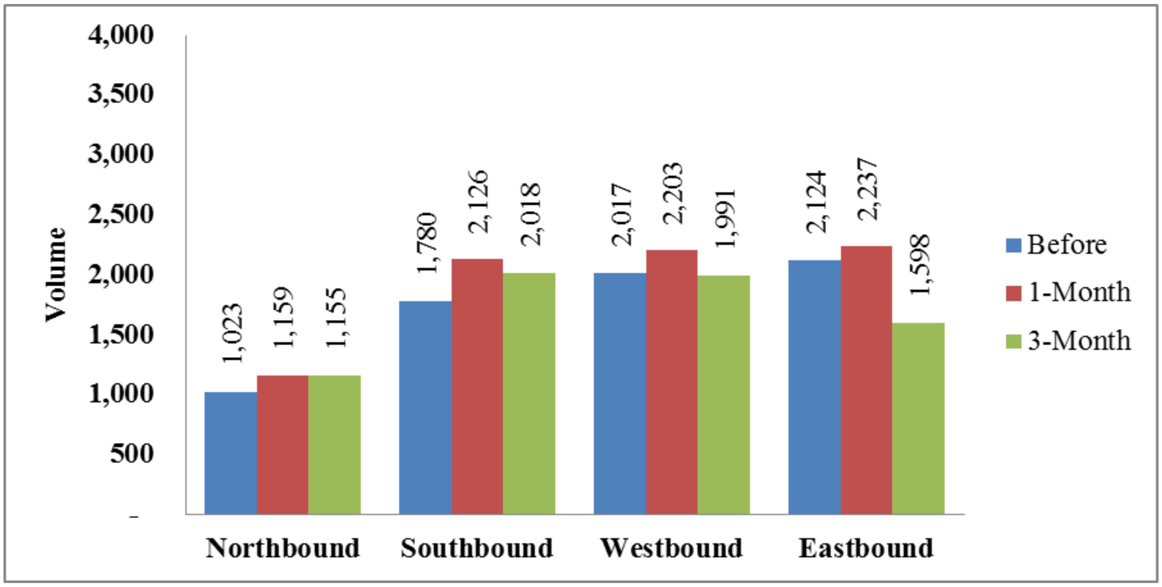


Figure 54. Total volumes for E. San Marnan Drive and La Porte Road

The intersection of East San Marnan Drive and La Porte Road had the second highest peak volume. A total of 21,431 cars were counted for all three period of the study. The highest counts were observed during the one-month after deployment period. The southbound and westbound approaches have the most of the volume at the intersection. The northbound approach on La Porte Road had the lowest volume on all three periods. To better understand how traffic flows throughout the intersections the movements are displayed Figure 55.

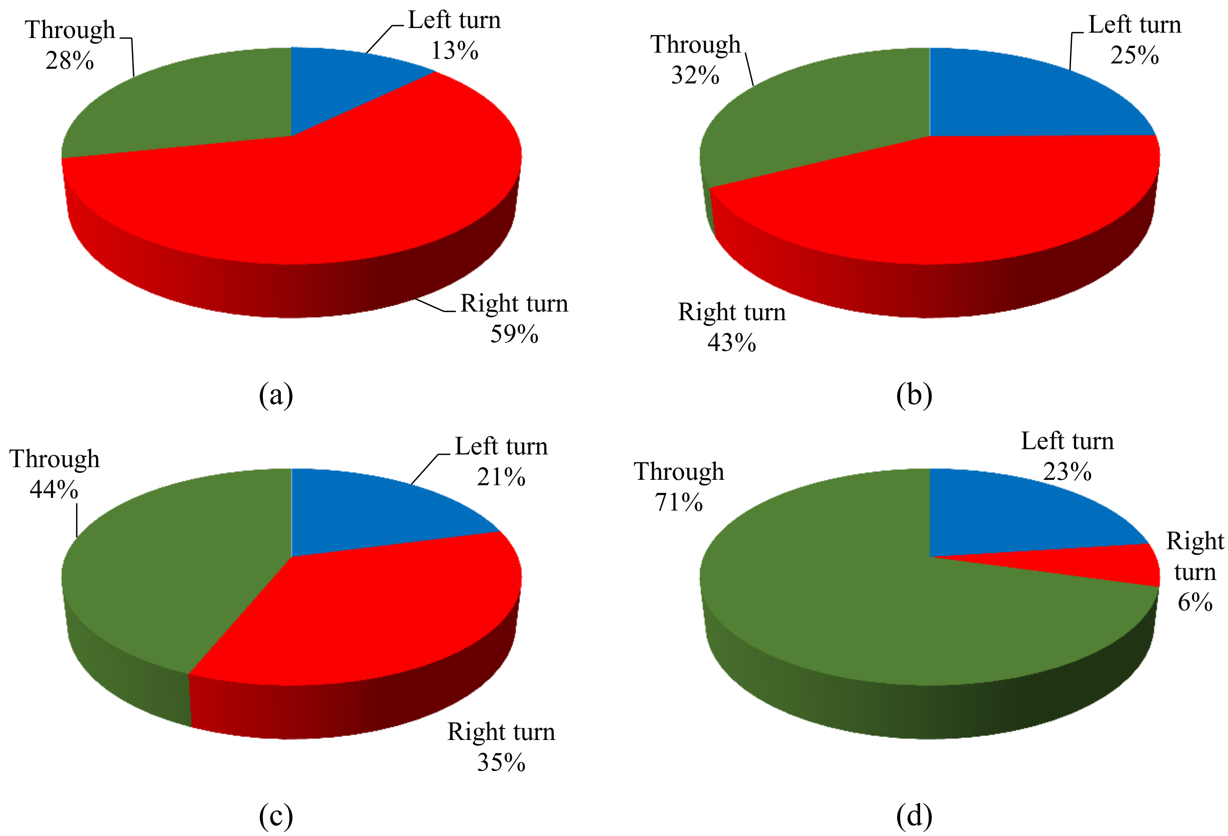


Figure 55. E. San Marnan Drive and La Porte Road peak hour movement percentages (a) northbound (b) southbound (c) westbound (d) eastbound

At the northbound approach, the majority of traffic turned right on East San Marnan Drive and headed towards the freeway. For the southbound approach right turns were also the most observed movement. Along East San Marnan Drive most of the traffic traveled through the intersection. A low percentage of cars for come from the eastbound approach and turn right onto La Porte Road.

Summary of Waterloo intersections

At the study sites all overhead signal lights had back plates. All six intersections were located in commercial areas, or in mixed commercial-residential area. Out of the 24 approaches studied, 10 had protected/permitted left-turns, five had protected only left turns, and nine had permitted only left-turning movements. From the 24 different approaches there are two that had a protected right turn. For most of the approaches on all sites there was an increase of traffic when comparing morning peak to afternoon peak. There were a total of 96,214 vehicles counted for Waterloo. For all intersections left turns made up 15 percent of the total volume, right turns 19 percent, and through movements 66 percent.

RED LIGHT RUNNING VIOLATION ANALYSIS

For a vehicle to be considered running a red light the following criteria had to be met:

- Both axles of the vehicle had to be behind stop bar when the signal turned red, and
- Vehicles had to traverse through the intersection after the red light activated.

The first requirement eliminates vehicles making a left-turn who are yielding to oncoming traffic and clearing the intersection during the all red cycle as being considered red light runners. Also, if a left-turning vehicle is trailing another vehicle and the light turns red, if one of the wheels is over the stop bar then that vehicle is not considered as a red light runner. After one surveyor would write down the violations for a particular approach, another surveyor would verify that the violation met the criteria outlined. Once the violation was verified the approach, the time of day, the traffic lane, and the time into the red phase were written down. In order to compare intersections to each other, RLR rates were calculated per 10,000 entering vehicles. This study only observed left and through movements for red light running. This is in part due to the repeated behavior of motorist not coming to a complete stop, or making a rolling stop, before making a right turn. Reporting all such occurrences can be misleading since it may over-represent the number of violations overall at an intersection. Right turning vehicles composed 18 percent of vehicles counted for both Altoona and Waterloo. Red light violations were written down by intersection, approach, movement, time of day (morning/afternoon), and period of study. The results as shown in the following sections.

Red Light Running Violations in Altoona

This section shows the RLR violations recorded by intersection, peak period, movement, and study period. Table 4 shows the violations recorded during the before deployment phase. Traffic was recorded July 16th - 18th, 2013.

Table 4. Red light running violations per movement before deployment in Altoona

Site Class	Intersection	Peak Time	Left	Through	Total
Deployment	8th Street and 34th Street	Morning	0	0	**2**
		Evening	1	1	
Spillover	8th Street and 36th Street	Morning	2	0	**2**
		Evening	0	0	
	8th Street and 28th Street	Morning	0	1	**1**
		Evening	0	0	
Control	Adventureland Drive and 1st Avenue	Morning	5	3	**12**
		Evening	3	1	
	8th Street and 17th Street	Morning	0	0	**1**
		Evening	0	1	
	8th Street and 1st Avenue	Morning	3	4	**9**
		Evening	1	1	

As shown in Table 4, before the implementation of the confirmation lights, researchers observed a total of 27 RLR violations at all sites combined. The intersections of 8th Street and 1st Avenue and Adventureland Drive and 1st Avenue combine for 21 out of the 27 violations noted. Left-turning motorists accounted for 15 of the violations, and 8 out the 15 left turn violations happened at the control site. The intersection of 8th and 1st Avenue had the highest number of violations for the through movement with five. Nearly two-thirds of the violations occurred during the morning peak hours of 7 to 9 in the morning. Table 5 shows the RLR violations during the one-month after period in Altoona. During this period of the study traffic was recorded October 1st - 3rd, 2013.

Table 5. Red Light Running violations one-month after deployment in Altoona

Site Class	Intersection	Peak Time	Left	Through	Total
Deployment	8th Street and 34th Street	Morning	1	0	**1**
		Evening	0	0	
Spillover	8th Street and 36th Street	Morning	0	0	**1**
		Evening	1	0	
	8th Street and 28th Street	Morning	0	0	**0**
		Evening	0	0	
Control	Adventureland Drive and 1st Avenue	Morning	2	1	**7**
		Evening	3	1	
	8th Street and 17th Street	Morning	0	0	**2**
		Evening	2	0	
	8th Street and 1st Avenue	Morning	4	2	**11**
		Evening	4	1	

As shown in Table 5, one month after the confirmation lights were deployed there was total of 22 red light running violations at all sites. The highest reduction was the amount of through movement violations from 12 in the before study to 5 violations. There was also a reduction of violations at Adventureland Drive and 1st Avenue, 8th Street and 34th Street, 8th Street and 36th Street, and 8th Street and 28thStreet. There were a total of 17 left-turn violations during this period, and 8 of the left-turn violations occurred at 8th Street and 1st Avenue. A total of 10 violations happened in the morning, and 12 took place in the afternoon. The violations observed during the three-month period of the study are shown in Table 6. During this period of the study traffic was recorded December 3rd - 5th, 2013.

Table 6. Red light running violations three-months after deployment in Altoona

Site Class	Intersection	Peak Time	Left	Through	Total
Deployment	8th Street and 34th Street	Morning	1	1	**2**
		Evening	0	0	
Spillover	8th Street and 36th Street	Morning	1	0	**5**
		Evening	3	1	
	8th Street and 28th Street	Morning	0	0	**0**
		Evening	0	0	
Control	Adventureland Drive and 1st Avenue	Morning	0	2	**4**
		Evening	1	1	
	8th Street and 17th Street	Morning	0	0	**1**
		Evening	0	1	
	8th Street and 1st Avenue	Morning	2	7	**14**
		Evening	0	5	

As shown in Table 6, three months from installation of the confirmation lights, a total of 26 violations were observed at all intersections. The intersection of 8th Street and 1st Avenue accounts for 14 of the total violations observed. Eighteen violations out of the 26 total violations were motorists moving through the intersection, and 12 out the 18 violations were noted at 8th Street and 1st Avenue. The morning peak hours account for 14 out of the 26 occurrences. The violations at the deployment site were the same during this period as in the before deployment study. A reduction of red light running violations was observed at Adventureland Drive and 1st Avenue from 12 to 4 violations.

Red Light Running Violations in Waterloo

This section shows the RLR violations recorded by intersection, peak period, movement, and study period. Table 7 shows the violations recorded during the before deployment phase. Traffic was recorded July 16th - 18th, 2013.

Table 7. Red light running violations in Waterloo before deployment

Site Class	Intersection	Peak Time	Left	Through	Total
Deployment	University Avenue and Ansborough Avenue	Morning	0	1	**1**
		Evening	0	0	
Control	E. San Marnan Drive and La Porte Road	Morning	1	0	**5**
		Evening	4	0	
Spillover	University Avenue and Fletcher Avenue	Morning	0	1	**2**
		Evening	0	1	
	University Avenue and Sager Avenue	Morning	0	0	**0**
		Evening	0	0	
	Ansborough Avenue and Downing Avenue	Morning	0	0	**2**
		Evening	0	2	
	Ansborough Avenue and Falls Avenue	Morning	0	0	**0**
		Evening	0	0	

As shown in Table 7, from all six intersections studied, there were a total of 10 violations observed before deployment of the confirmation lights. Half of the violations occurred on left-turning movements and 70 percent of violations were observed during the afternoon peak hours. The intersection with the most violations is the control site of E. San Marnan Drive and La Porte Road with five total violations, which is also the intersection with the highest volume during this period of the study. For the control site, 80 percent of observed violations occurred in the afternoon peak and it was observed that in the afternoon the volume increases by 85 percent when compared to the morning peak. All five violations were left-turning movements, four out of the five took place at the westbound approach.

At University Avenue and Ansborough Avenue the only violation was observed during the morning peak at the eastbound approach, which had the highest observed volume during the morning. The only spillover sites with RLR violations were University Avenue and Fletcher Avenue, and Ansborough Avenue and Downing Avenue. At University Avenue and Fletcher Avenue the violations took place at the southbound approach in the morning and the northbound approach in the afternoon. Neither approach has the highest volume at the intersection, but both violations were motorists traveling through the intersection which is the predominant movement for both approaches. At Ansborough Avenue and Downing Avenue both violations took place at the northbound approach in the afternoon, which is the approach with the highest volume observed in the intersection. During this period of the study half of violations observed were left-turning movements, and half were through movements. To identify any immediate effect of the confirmation light Table 8 shows the number of violations for the one-month after deployment study period. Traffic was recorded October 1st - 3rd, 2013.

Table 8. Red light running violations in Waterloo one-month after deployment

Site Class	Intersection	Peak Time	Left	Through	Total
Deployment	University Avenue and Ansborough Avenue	Morning	0	0	**2**
		Evening	1	1	
Control	E. San Marnan Drive and La Porte Road	Morning	2	0	**3**
		Evening	0	1	
Spillover	University Avenue and Fletcher Avenue	Morning	0	0	**0**
		Evening	0	0	
	University Avenue and Sager Avenue	Morning	0	0	**1**
		Evening	0	1	
	Ansborough Avenue and Downing Avenue	Morning	0	0	**1**
		Evening	1	0	
	Ansborough Avenue and Falls Avenue	Morning	0	0	**1**
		Evening	0	1	

As shown in Table 8, one-month after the confirmation lights were implemented, there were a total of eight red light running violations observed. The control and the deployment sites accounted for five out of the eight violations observed. When compared to the before period, there was a decrease in violations for E. San Marnan Drive and La Porte Road, University Avenue and Fletcher Avenue, and Ansborough Avenue and Downing Avenue. Both violations that happened in the morning at the control site were left-turns from the westbound approach. At this time of day the westbound approach had the highest volume of left-turns observed. The violation in the afternoon was a motorist going eastbound, which was the approach with the most motorists. At Ansborough Avenue and Downing Avenue the only violation observed was a through vehicle from the northbound approach.

There was an observed increase in violations for University Avenue and Ansborough Avenue, University Avenue and Sager Avenue, and Ansborough Avenue and Falls Avenue. At the deployment site, both violations were southbound vehicles in the afternoon. The southbound approach of the deployment site had the second lowest volume out of all approaches. At Ansborough Avenue and Falls Avenue, the only violation observed was at the eastbound approach of the intersection, and at University Avenue and Sager Avenue the motorist was traveling through the intersection at the westbound approach. During this phase of the study five out of the eight violations were done by vehicles moving through the intersection. To see the long-term effects of the confirmation lights Table 9 shows the RLR violations three months after deployment of the countermeasure. During this period of the study traffic was recorded during the days of 3rd to 5th of December, 2013.

Table 9. Red light running violations three-months after deployment in Waterloo

Site Class	Intersection	Peak Time	Left	Through	Total
Deployment	University Avenue and Ansborough Avenue	Morning	2	1	**5**
		Evening	2	0	
Control	E. San Marnan Drive and La Porte Road	Morning	1	1	**9**
		Evening	7	0	
Spillover	University Avenue and Fletcher Avenue	Morning	0	0	**0**
		Evening	0	0	
	University Avenue and Sager Avenue	Morning	0	0	**3**
		Evening	3	0	
	Ansborough Avenue and Downing Avenue	Morning	0	0	**0**
		Evening	0	0	
	Ansborough Avenue and Falls Avenue	Morning	0	0	**0**
		Evening	0	0	

As shown in Table 9, three months after the countermeasure was deployed there were a total of 17 red light violations observed. Fifteen out of the 17 red light runners were motorists making a left turn. The violations were observed only in East San Marnan Drive and La Porte, University Avenue and Ansborough Avenue, and University Avenue and Fletcher Avenue. The control intersection was where more than half of the violations were observed. All violations took place along East San Marnan Drive, where four out of the seven violations in the afternoon came from the eastbound approach. In the afternoon the eastbound approach did not have the highest overall volume, but it did have the most vehicles making a left turn (333) at the intersection. The rest of the violations in the afternoon took place at the westbound approach which had fewer vehicles turning left and volume than the southbound approach. In the morning all violations took place at the westbound approach.

At the deployment site there was an increase from one violation to five violations three months after deployment. Four out of the five violations were found to be motorist from the northbound approach. All violations from the northbound approach were left-turning vehicles, half of the violations were observed in the morning and half in the afternoon where the northbound approach has the highest volume of left turns out of all approaches. The other violation was a vehicle heading southbound. At University Avenue and Sager Avenue all violations were left-turning vehicles at the northbound approach in the afternoon.

Red Light Running Rate

Red light running rates were calculated for each intersection in each period of the study. The rate was calculated by the following equation:

Eq. 3

$$\text{RLR rate} = \left(\frac{{}_{vn}}{V}\right)*10{,}000$$

Where N_{vn} = Total number of violations at the intersection; and
V = Volume of all entering vehicles at intersection.

Calculating RLR rates facilitates comparisons between intersections by taking into account fluctuations in the intersection volumes observed during each period. The following sections show the RLR rates for Altoona and Waterloo.

Red Light Running Rates in Altoona

The RLR rates were calculated for all intersections in Altoona. The rates were plotted on a bar graph in order to compare rates between periods of the study and between study sites as shown in Figure 56.

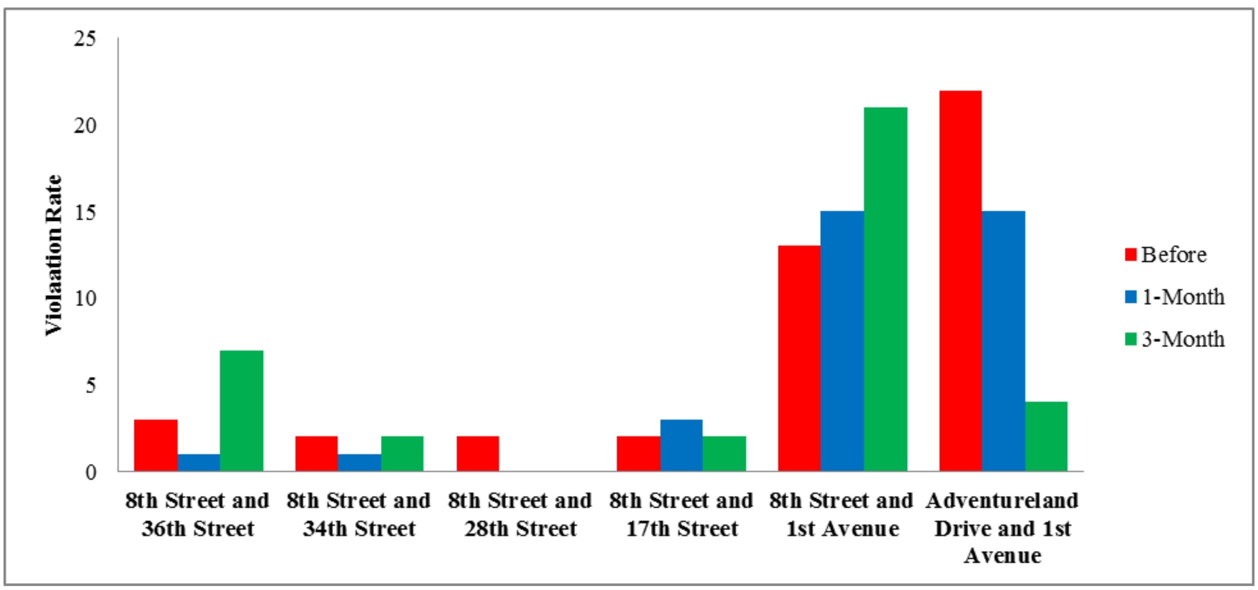


Figure 56. Red light running rates per 10,000 vehicles entering the intersection in Altoona

As shown in Figure 56, it was that out of the three intersections with the highest recorded volumes, the deployment site had the lowest RLR rate after three months of installation. The intersection of 8th Street and 1st Avenue had an increasing RLR rate throughout the study. Adventureland Drive and 1st Avenue experienced a decrease in RLR rate. The three-month period was when this intersection had its highest total volume and the lowest RLR violations. Whether that drop in rate was significant it will be discussed later in this report. The three-month period for 8th Street and 36th Street was the highest noted for that intersection. When comparing the rate calculated for the before period (three violations) against the after three-month period (7 violations) there was a difference of four more violations per 10,000 vehicles. The total violations at this intersection went up from two to five, but it must be taken into account that the three-month period was lowest volume count at this intersection.

Red Light Running Rates in Waterloo

The RLR rates were calculated for all intersections in Waterloo. The rates were plotted on a bar graph in order to compare rates between periods of the study and between study sites as shown in Figure 57.

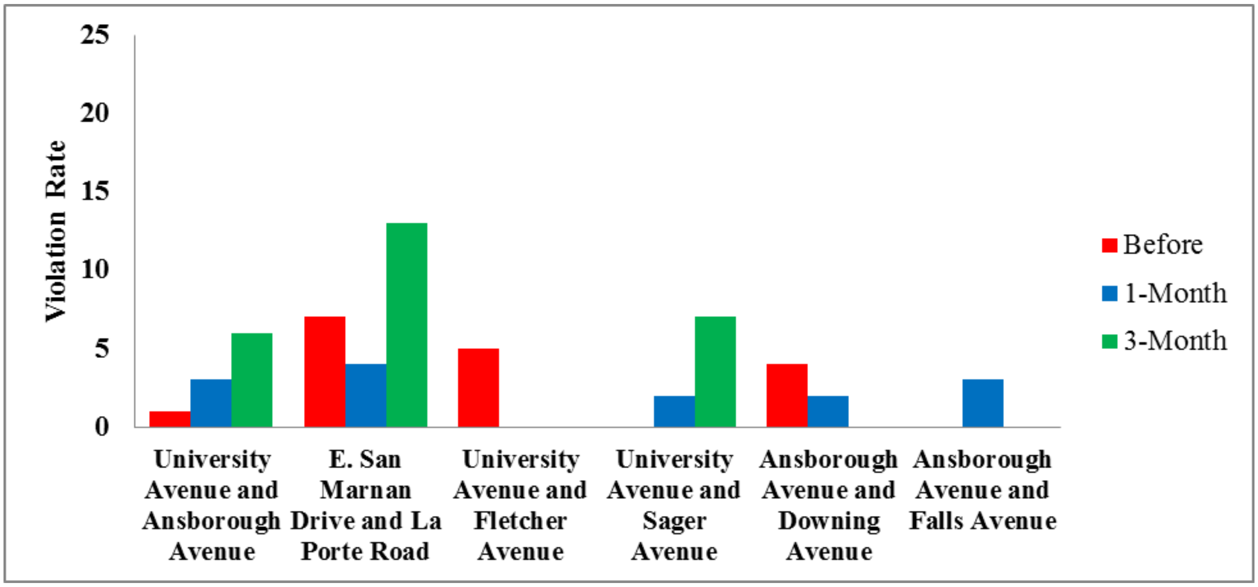


Figure 57. Red light running rates per 10,000 vehicles entering the intersection in Waterloo

As shown in Table 57, the deployment site of University Avenue and Ansborough Avenue had an increasing rate through the study. The rate increased from one violation per 10,000 entering vehicles to six violations. The period of time and approach that was the highest contributor the rate was the northbound morning peak period observed during the three-month after study period. During the three-month after period the rate increased for the control site and the spillover site of University Avenue and Sager Avenue. At both intersections the rate in the three-month period was greater than the previous periods of the study.

STATISTICAL ANALYSIS OF RED LIGHT RUNNING VIOLATIONS

Studies that assess the effectiveness of a roadway safety device rely on a before-after crash analysis. These studies ideally 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-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 is not direct 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 is a reduction in exposure, or a reduction in the chances of a RLR crash to occur.

Additionally, besides considering a change in RLR violations before and after the confirmation lights were installed, the research team investigated the change in violations three months after installation. Unlike previous research studies, it is 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.

RLR violation rate was the metric used to compare changes during the before, one 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). 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, one month, and three months after installation of the confirmation lights, the research team decided to use a test of proportions 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 α = 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. This analysis was performed for Altoona and Waterloo separately. Table 10 shows the violations, volume and percent change volume for all intersections in Altoona.

Table 10. Statistical analysis for Altoona violations

Site category	Number of Violations			Number of Vehicles			RLR rate per 10,000 vehicles			Percent Change	
	Before	1-month	3-month	Before	1-month	3-month	Before	1-month	3-month	1-month	3-month
Treatment											
8th Street and 34th Street	2	1	2	8,050	8,087	8,975	2.5	1.2	2.2	**-50.2%**	**-10.3%**
Spillover											
8th Street and 36th Street	2	1	5	7,373	7,353	6,939	2.7	1.4	7.2	-49.9%	165.6%
8th Street and 28th Street	1	0	0	5,933	7,242	6,335	1.7	0.0	0.0	-100%	-100%
Total	3	1	5	13,306	14,595	13,274	2.3	0.7	3.8	**-69.6%**	**67.1%**
Control											
8th Street and 17th Street	1	2	1	5,916	6,920	5,749	1.7	2.9	1.7	71.0%	2.9%
8th Street and 1st Avenue	9	11	14	6,892	7,335	6,695	13.1	15.0	20.9	14.8%	60.1%
Adventureland Drive and 1st Avenue	12	7	4	5,505	4,632	5,613	21.8	15.1	7.1	-30.7%	-67.3%[A]
Total	22	20	19	18,313	18,887	18,057	12.0	10.6	10.5	**-11.9%**	**-12.4%**

[A] Violation rate change is statistically significant at 0.05 level

As shown in Table 10, the intersection of 8th Street and 36th Street saw the highest increase in violation rate out of all intersections from before deployment to three months after installation. The highest decrease in rate was observed at 8th Street and 28th Street. The deployment site of 8th Street and 34th Street experienced the highest reduction in violation rates one month after installation of the confirmation lights. Three months after deployment, there was still a reduction in the RLR rate. The only statistically significant change in violation rate was observed at Adventureland Drive and 1st Avenue. Table 11 shows the results calculated for Waterloo.

Table 11. Statistical analysis for Waterloo violations

Site category	Number of Violations			Number of Vehicles			RLR rate per 10,000 vehicles			Percent Change	
	Before	1-month	3-month	Before	1-month	3-month	Before	1-month	3-month	1-month	3-month
Treatment											
University Avenue and Ansborough Avenue	1	2	5	6,916	6,532	8,652	1.4	3.1	5.8	**111.8%**	**299.7%**
Spillover											
University Avenue and Sager Avenue	0	1	3	4,220	5,016	4,199	0.0	2.0	7.1	•	•
University Avenue and Fletcher Avenue	2	0	0	3,816	3,731	5,367	5.2	0.0	0.0	-100%	-100%
Ansborough Avenue and Downing Avenue	2	1	0	5,088	5,579	5,111	3.9	1.8	0.0	-54.4%	-100%
Ansborough Avenue and Falls Avenue	0	1	0	4,284	3,420	2,852	0.0	2.9	0.0	•	•
Total	4	3	3	17,408	17,746	17,529	2.3	1.7	1.7	**-26.4%**	**-25.5%**
Control											
E. San Marnan Drive and La Porte Road	5	3	9	6,944	7,725	6,762	7.2	3.9	13.3	**-46.1%**	**84.8%**

[A] Violation rate change is statistically significant at 0.05 level

As shown in Table 11, the greatest percentage increase in violation rates was observed at the deployment site of University Avenue and Ansborough Avenue. During both periods the increase in rate was over 100 percent. During the one-month period of the study the only intersections that experienced an increase in violations were deployment site, and the spillover sites of University Avenue and Sager Avenue, and Ansborough Avenue and Falls Avenue. Overall, there was a decrease in violation rate at both the spillover and control sites. While all other study sites were experiencing a reduction the deployment site experienced an increase. The greatest increase in rate happened when comparing the before and three-month period. During the three-month period there was an overall rate decrease at the spillover sites, and an increase in rate at the control site. This increase was found to not be statistically significant.

The spillover sites of Ansborough Avenue and Downing Avenue, and University Avenue and Fletcher Avenue experienced the highest reduction in RLR rate after three months. The control site of E. San Marnan Drive and La Porte Road experienced the second highest increase in RLR rate after three months. The only statistically significant change in RLR rate was observed at University Avenue and Sager Avenue. This intersection experienced an increase in violations from a zero violation rate in the before period to seven in the three month after period. This increase was significant at the 90 percent level of confidence.

Summary of Findings

Twelve intersections were surveyed for RLR violations in three different periods. There were six intersections in Altoona and six in Waterloo. Each city had one intersection equipped with confirmation lights as a low cost countermeasure for RLR. For all three periods of the study there were a total of 110 RLR violations observed. More than half of the violations (57%) were observed to be left-turning vehicles. The deployment site at waterloo experienced an increase in violation rate, while the deployment site at Altoona experienced a slight decrease. A statistical analysis showed that neither change in rate was significantly significant.

TIME INTO RED ANALYSIS
An important aspect to a vehicle running a red light is how far into the red 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 dilemma zone or at the end of a platoon and intentionally run the red light. The dilemma zone of an intersection is an area prior to the stop bar where the driver is unsure if he or she should brake or proceed through the intersection during the yellow phase.

However, drivers that enter the intersection past the all-red phase create a situation more likely to result in a serious crash, particularly if the conflicting movement has a green light. Hallmark et al (2012) 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. also found when evaluating RLR cameras in Cedar Rapids, IA that over 120 violations occurred from zero to less than one second 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 has found that 95 percent of RLR violations occur in the first 2 seconds of the red phase (Beeber, 2011).

Time in the red phase for Altoona
There were a total of 75 RLR violations for the through and left turn movements during the study periods. For all violations the time it takes for both axles of the vehicle cross the stop bar and enter the intersection was measured. This is referred into as time into red and is shown in Figure 58 for all violations recorded.

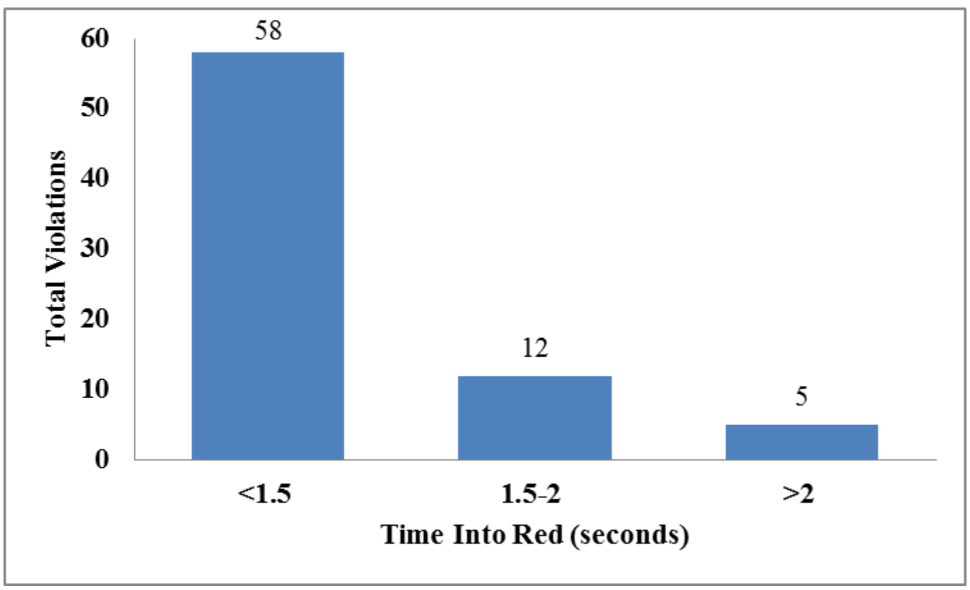


Figure 58. Time in the red phase for all violations in Altoona

As shown in Figure 58, most of the violations occured within the one second of the red phase. Out of the 17 violations were vehicles crossed the intersection, almost a third happened more than two seconds into the red phase. The measured time for those violations varied between 5 and 49 seconds. From the five violations recorded, four were vehicles turning left and one going through the intersection. In the instance were the vehicle went through the intersection with 17 seconds into the red, the motorist rolled to the stop line, checked for crossing traffic and then traversed the intersection. Time into the red was also plotted for each movement at the deployment, spillover, and control sites.

Deployment Site

There were a total of five violations observed at the deployment site. As shown in Figure 59 for left turning violations at 8th Street and 34th Street, three out of the five violations were made by vehicles making a left turn at the intersection.

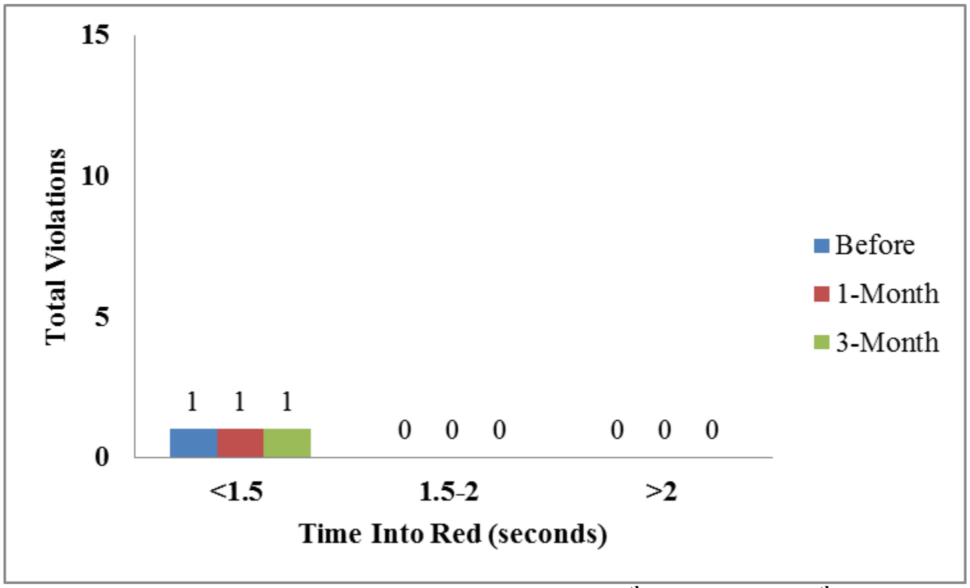


Figure 59. Time into the red for left turns at 8th Street and 34th Street

As shown in Figure 59, there was one violation for the left turn movement during each period. All violations recorded happened within one second into the red phase. Two of the violations took place at the southbound approach and one at the northbound approach. Figure 60 shows the time into red measured for the through movement.

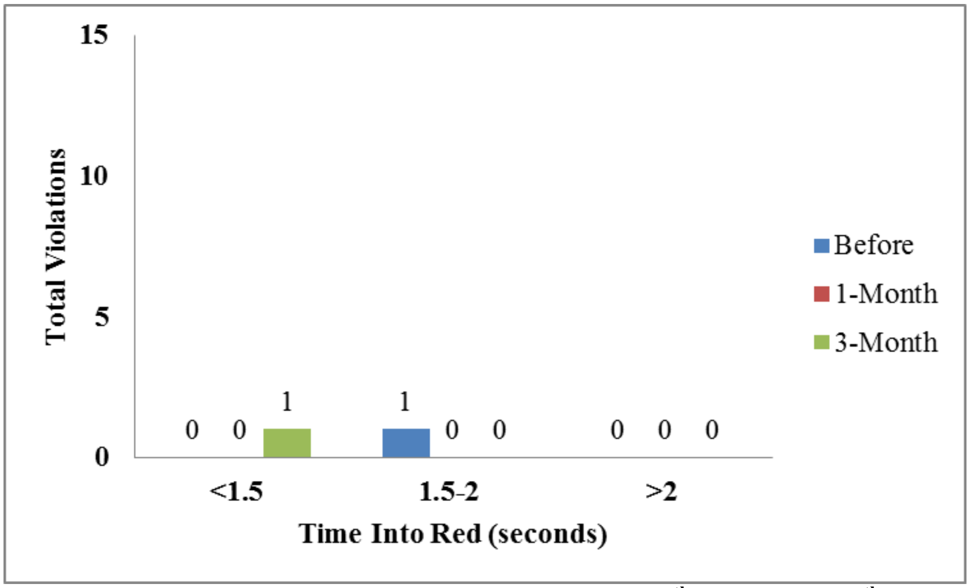


Figure 60. Time into the red for through vehicles at 8th Street and 34th Street

As shown in Figure 60, two violations out of five were made by vehicles traveling through the intersection. The violation that occurred within two seconds into the red took place at the westbound approach. The vehicle was the first in the queue; there were no other vehicles in front. Motorists in the other lanes were already stopped, and the through vehicle traversed the intersection. There were no violations with a measured time higher than two seconds at 8th Street and 34th Street.

Spillover sites

For both spillover sites there were a total of nine violations observed. Shown in Figure 61 for left turning violations, eight out of the nine violations took place at the intersection of 8th Street and 36th Street.

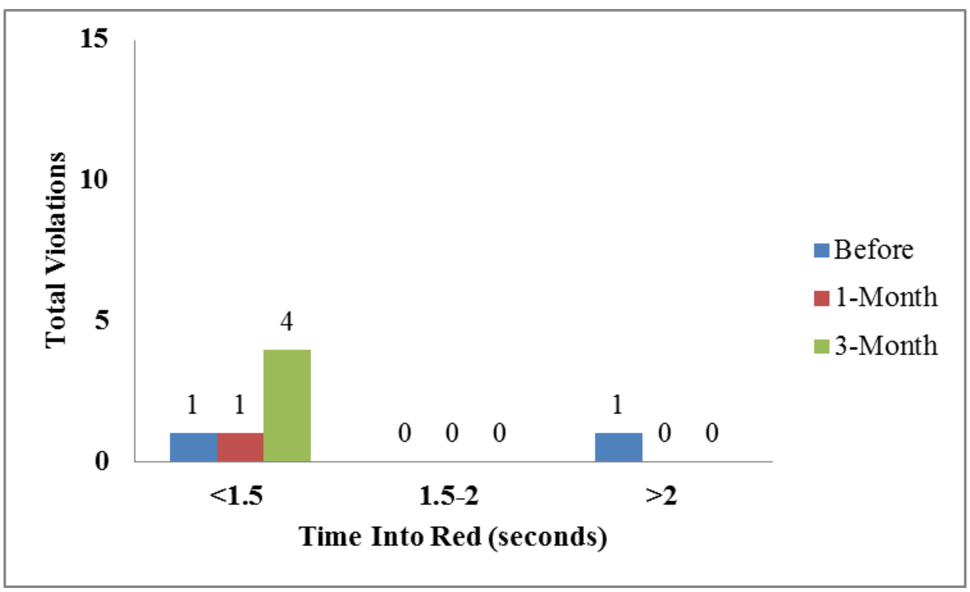
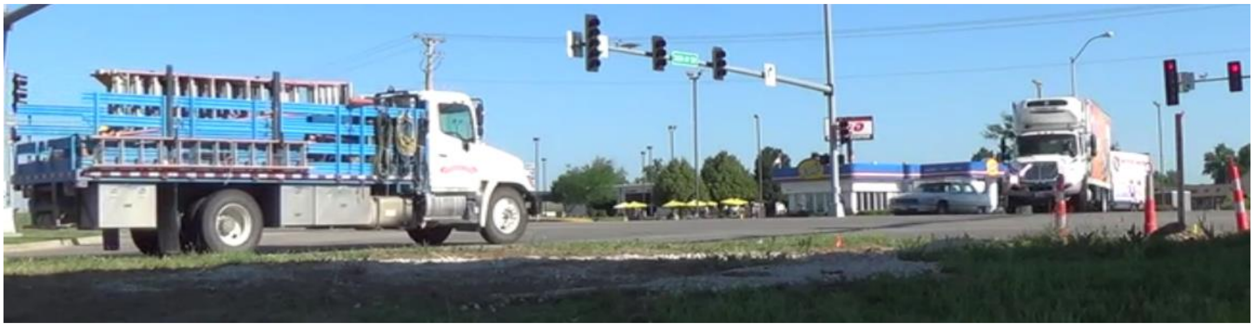
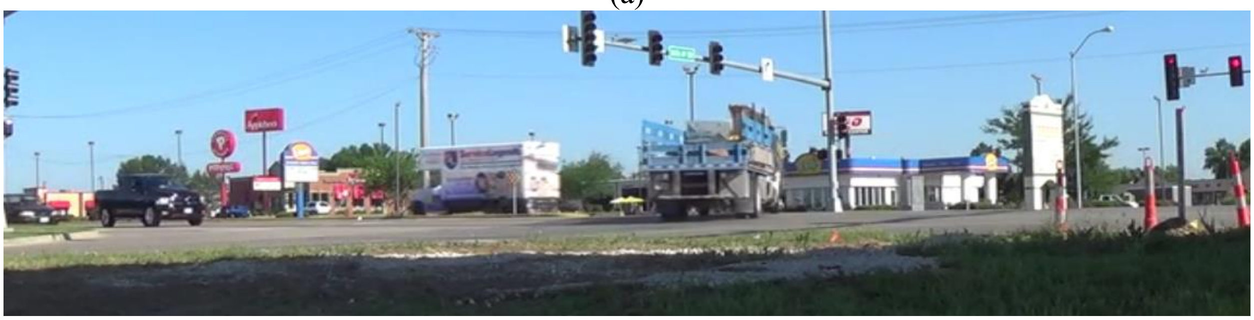


Figure 61. Time into the red for left turns at the spillover sites

As shown in the previous figures, seven out of the nine violations were left-turn movements. Six violations occurred within one second into the red phase. There was one violation that occurred 49 seconds into the red at the northbound approach of 8th Street and 36th Street. Figure 62 shows the sequence of events for this violation.



(a)



(b)

Figure 62. Left turn at the spillover sites 49 seconds into the red

The truck in Figure 62 (a) pulled up to the intersection when the opposing traffic had the green signal. The driver waited for opposing traffic to clear out before proceeding into the intersection and turning. Figure 62 (b) shows that while traversing the intersection the approach was still in the red phase. Shortly after the truck finished crossing the intersection, the light turned green for all movements at the approach. Figure 63 shows the time into the red for the through movement.

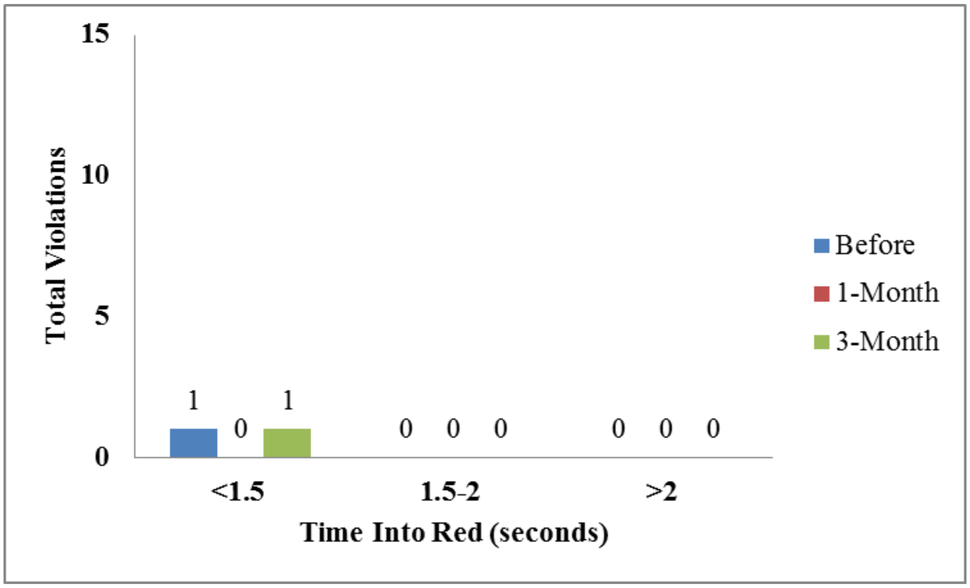


Figure 63. Time into the red for through vehicles for the spillover sites

As shown in Figure 63, only two out of nine violations at the spillover sites were through movements. Both violations happened within one second into the red.

Control sites

There were 61 total violations observed at the control sites. Twenty-three out of 61 violations occurred at Adventureland Drive and 1st Avenue, and 34 violations were observed at 8th Street and 1st Avenue. Thirty violations were made by vehicles turning left as shown in Figure 64.

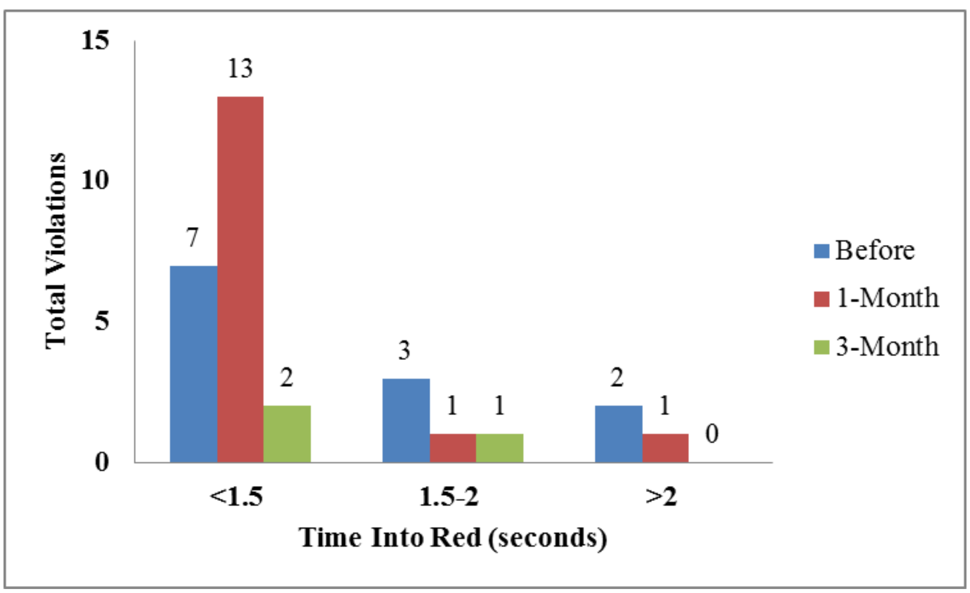
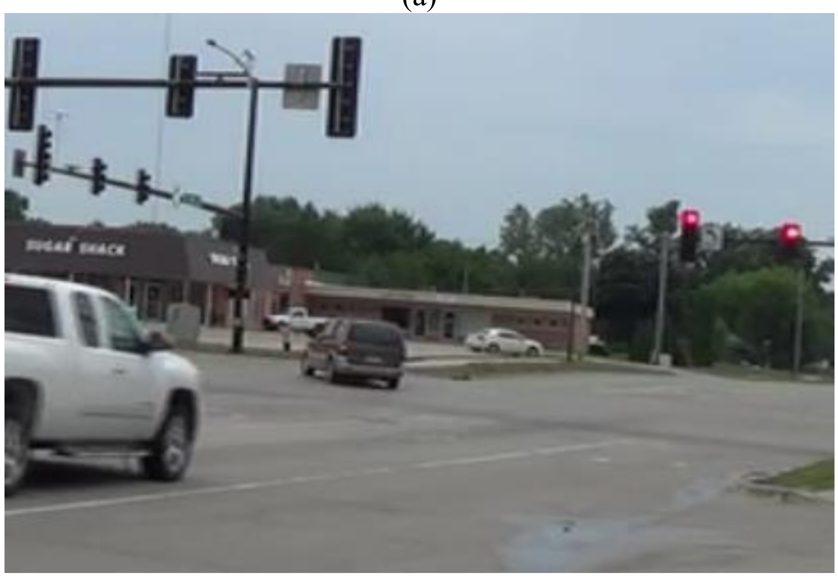


Figure 64. Time into the red for left turns at the control sites

Figure 64 shows that the majority of left-turn violations happened within one second into the red. The violations with a time longer than two seconds occurred at 8th Street and 1st Avenue, and Adventureland Drive and 1st Avenue. All three violations had a measured time into the red of five, 10, and 12 seconds. In the occurrence where the vehicle crossed the intersection five seconds into the red the motorists was behind a heavy truck. The violation that occurred 12 seconds into the red was a vehicle making a left turn and disregarding the red signal. Figure 65 show the events for the violations that took place 12 seconds into the red.

(a)



(b)

Figure 65. Left turn at a control site sites 12 seconds into the red

Figure 65 (a) shows the vehicle approaching the intersection when the red bulb is activated. The vehicle waited for oncoming traffic to clear and then proceeded to turn left as shown in figure 65 (b). This violation took place during the morning peak on the southbound approach of 8th Street and 1st Avenue. The violation with ten seconds into the red was a motorist making a u-turn during the morning peak at the southbound approach of 1st Avenue and Adventureland Drive. Figure 66 shows the time into red for the through violations.

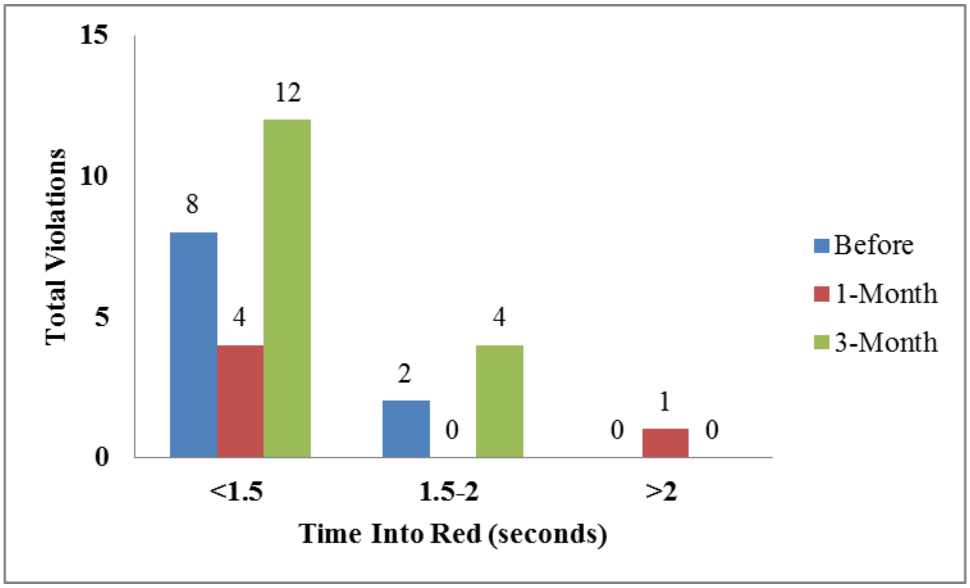


Figure 66. Time into the red for through vehicles for the control sites

As shown in Figure 66, the majority of the through violations occurred within one second into the red. Twenty out of the 31 violations occurred at the intersection of 8th Street and 1st Avenue. The only violation that happened with a measured time longer than two seconds was at the intersection of Adventureland Drive and 1st Avenue. The motorist was headed southbound in the morning. The vehicles approached the intersection, checked for crossing traffic and then proceeded through the intersection 17 seconds into the red phase.

Time in the Red for Waterloo

There were a total of 35 RLR violations for the through and left turn movements during the study periods as shown in Figure 67. For all violations the time it takes for the vehicle cross the stop bar and enters the intersection was measured.

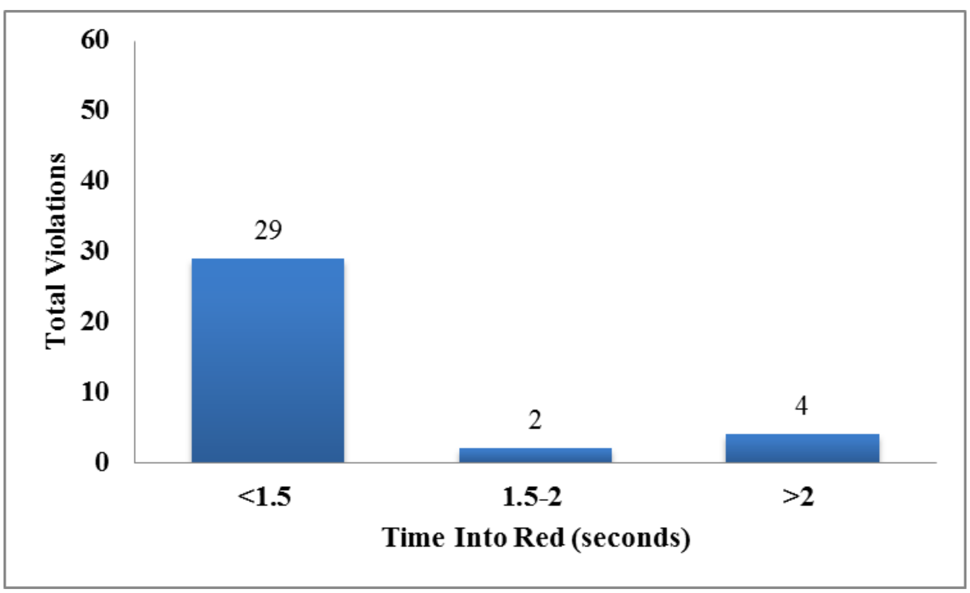


Figure 67. Time in the red for all Waterloo violations

As shown in Figure 67, the majority of motorists that ran a red light entered the intersection within one second of the red phase. There were four violations were the vehicles crossed the stop line more than two seconds into the red phase. The times ranges from 3 to 70 seconds into the red, and three out of the four occurrences were vehicles moving through the intersection. The time in the red is reported for the deployment, control, and spillover sites according to movement.

Deployment site

For all study periods there were a total of eight violations observed. Five out of the eight violations were made by vehicles making a left turn at the intersection. Figure 68 shows the time in the red for all left-turn violations at University Avenue and Ansborough Avenue.

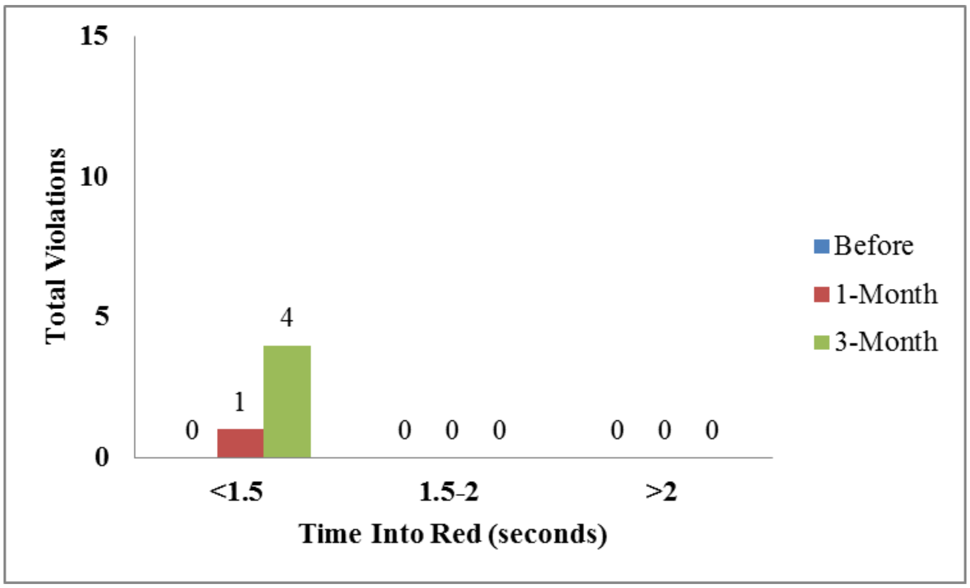


Figure 68. Time in the red for left-turn violations at University Avenue and Ansborough Avenue

As shown in Figure 68, there were no violations for left turns before deployment of the countermeasure. The violations increased each period after the confirmation light was installed. At all five violations the vehicles crossed the stop bar and entered the intersection within one second into the red phase. During the three-month study all violations occurred at the northbound approach which had the confirmation light installed. The violation observed at the one-month after period happened at the southbound approach which did not have the confirmation light installed. Figure 69 shows the time in the red for the through movement.

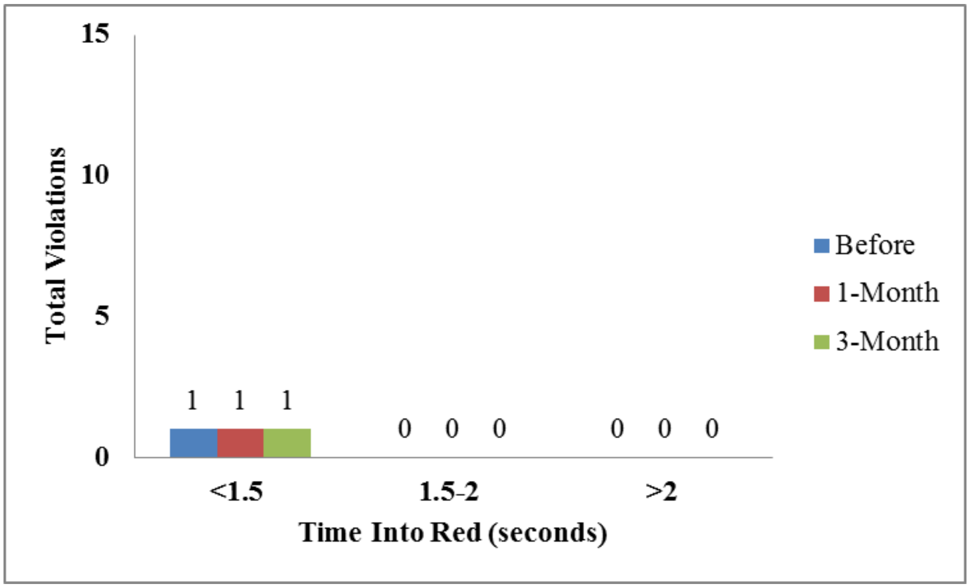


Figure 69. Time in the red for through violations at University Avenue and Ansborough Avenue

As shown in Figure 69, there were three violations that were vehicles traveling through the intersection. As with the left-turns all violations happened within one second of the red phase. In conclusion, all RLR violations that took place at University Avenue and Ansborough Avenue occurred within the first second of the red phase.

Spillover sites

The spillover sites are University Avenue and Sager Avenue, University Avenue and Fletcher Avenue, Ansborough Avenue and Downing Avenue, and Ansborough Avenue and Falls Avenue. At all four of these intersections there were a total of 10 RLR violations observed. Figure 70 shows the time in the red for all left-turn violations at the spillover sites.

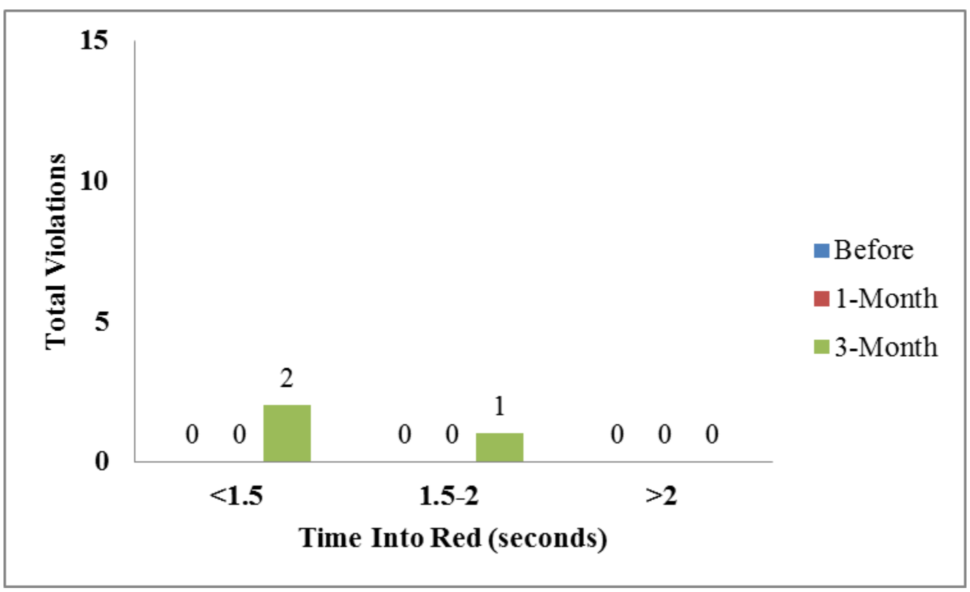


Figure 70. Time in the red for left-turn violations at all spillover sites

As shown in Figure 70, all left-turn violations at the spillover sites occurred during the three-month after deployment study period. Two out of the three violations happened within one second of the red phase. The left-turn violation that occurred at two seconds into the red happened at the intersection of University Avenue and Sager Avenue. Seven out of the ten violations at the spillover sites were through movements. Figure 71 shows the time in the red for all through violations.

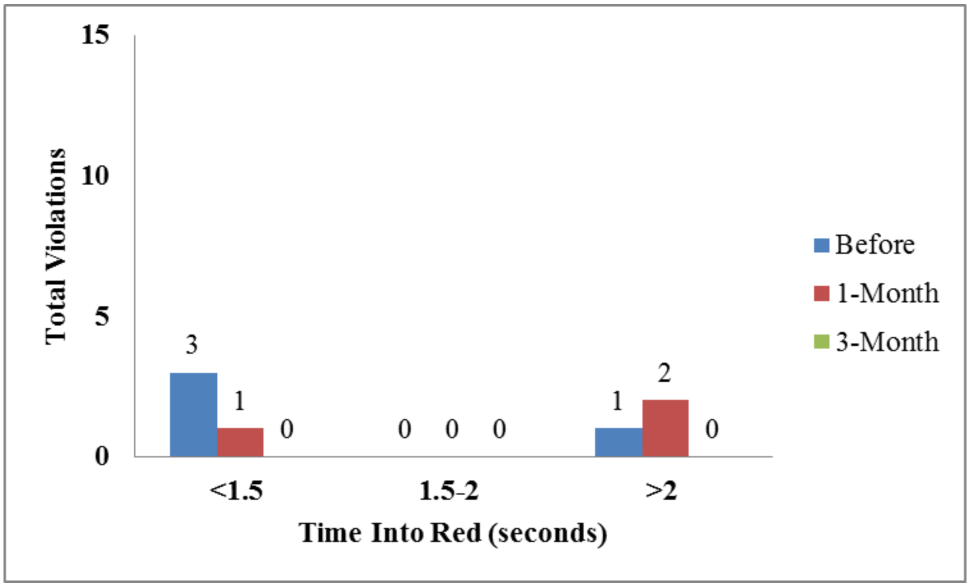


Figure 71. Time in the red for through violations at all spillover sites

As shown in Figure 71, four out of seven violations occurred within one second of the red phase. The rest of the violations occurred over two seconds into the red-phase; there were no violations within two seconds. University Avenue and Falls Avenue is the only intersection that did not have a vehicle cross the intersection more than two seconds into the red phase of the approach. Various events contributed to motorist traversing through the intersection. Figure 72 shows the sequence of events observed at University Avenue and Fletcher Avenue.

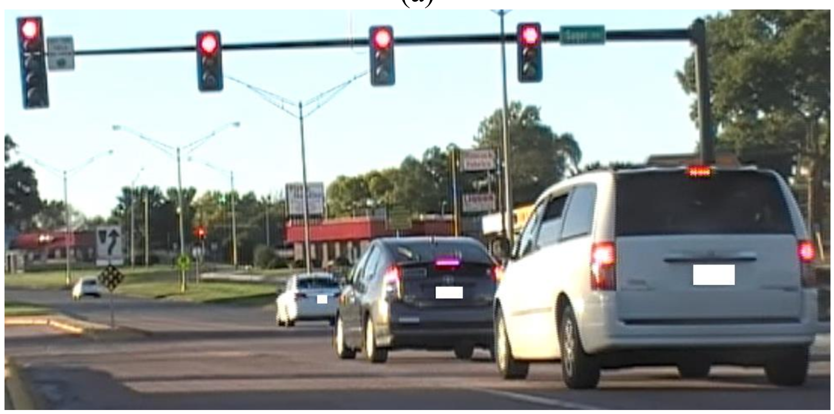
(a)

(b)

Figure 72. Sequence of events at University Avenue and Fletcher Avenue (a) vehicle stopped at intersection (b) vehicles crossing intersection

As shown in Figure 72, the events happened at the northbound approach of University Avenue and Fletcher Avenue. The motorist was stopped for most of the cycle as shown in Figure 72(a) and when the green arrow for the protected left turn came on the motorist proceeded through the intersection as seen in Figure 72 (b). This violation occurred 70 seconds into the red. Another violation happened at University Avenue and Sager Avenue. Figure 73 shows pictures of the violation.

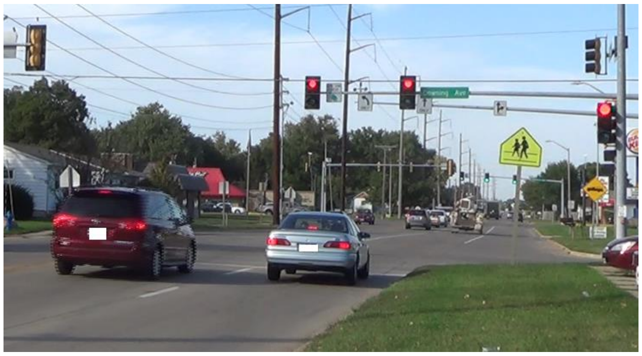
(a)



(b)

Figure 73. Sequence of events at University Avenue and Sager Avenue (a) vehicle stopped at intersection (b) vehicles crossing intersection

As shown in Figure 73 (a) the car was stopped at the westbound approach of the intersection. A vehicle from the northbound approach turned left onto University Avenue. After the left-turning vehicle drove away, the motorist in the white car began to roll forward. Figure 73 (b) shows that after there were no more vehicles approaching, the white car proceeded through the intersection. This was filmed during one-month after the deployment of the countermeasure. The southbound approach was closed to traffic during this time, which could have played a factor into the decision making of the motorist. Additionally, Sager Avenue carried very low volumes compared to University Avenue, and that the path length to cross was not very long may also be factors that contributed to such a decision. The vehicle started crossing the intersection 23 seconds into the red phase. The third violation occurred at Ansborough Avenue and Downing Avenue as shown in Figure 74.



(a)

(b)

Figure 74. Sequence of events at Ansborough Avenue and Downing Avenue (a) vehicle stopping at intersection (b) vehicles crossing intersection

As shown in Figure 74, at Ansborough Avenue and Downing Avenue a vehicle crossed the intersection three seconds into the red. In Figure 74 (a) the vehicle was approaching the intersection already applying the brakes. In Figure 74 (b) the vehicle was still applying the brakes while crossing the intersection. The motorists did not start applying the brakes in time to stop before the entering the intersection. When the vehicle was by the traffic signal it released the brakes and drove through the intersection. This sequence of events could be attributed to speeding and/or distracted driving.

Control Site

About half of the total violations observed in Waterloo happened at the control site. Fifteen out of the 17 violations observed at E. San Marnan Drive and La Porte Road were vehicles making a left turn. Figure 75 shows the time in the red for all left-turn violations.

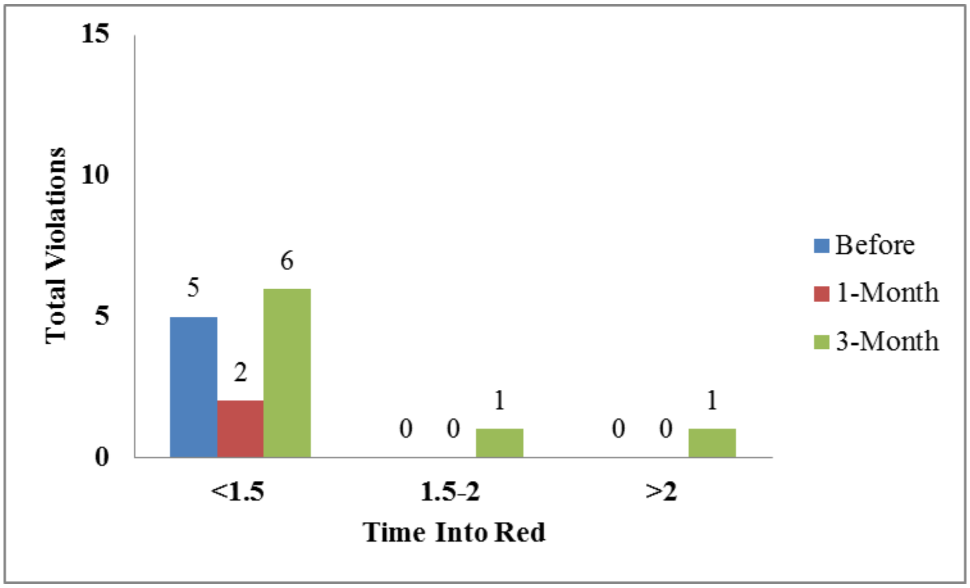


Figure 75. Time in the red for left-turn violations at E. San Marnan Drive and La Porte Road

As shown in Figure 75, thirteen out of the fifteen violations occurred within one second of the red phase. One violation occurred within two seconds, and one violation took place over two seconds. Both of those violations were motorists at the eastbound approach during the afternoon peak hour, which at the time it had the highest volume of vehicles turning left. One violation happened at four seconds into the red, the driver treated the protected left turn as a permitted left hand turn. Even though the left turn arrow was red, the driver proceeded into the intersection, waited for a gap in oncoming traffic and then made the left turn. Figure 76 shows the time into red for the through movement.

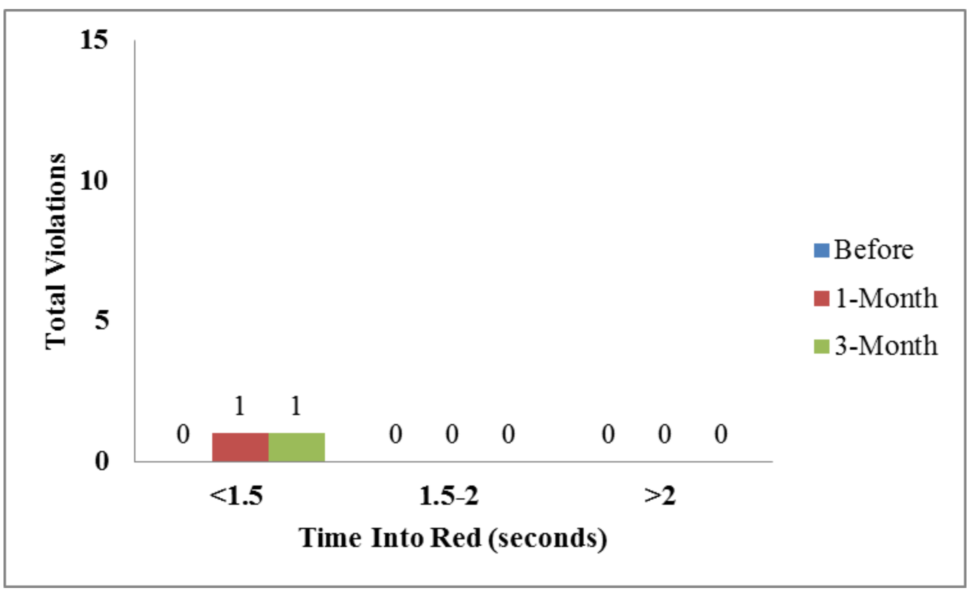


Figure 76. Time in the red for through violations at E. San Marnan Drive and La Porte Road

As shown in Figure 76, all through violations took place within one second of the red phase. The violation that occurred during the one-month portion of the study took place at the eastbound approach, which had the highest volume of through vehicles. For the violation that happened at the three-month portion of the study the vehicle was traveling westbound, which had the second highest count for through vehicles.

Summary of Findings

The time in the red for violations in Altoona and Waterloo ranges from less than one second to 70 seconds. The violations were broken down into ranges to better assess the risk. The majority of violations, whether vehicles were turning left or traveling through the intersection, occurred within one second. This means that motorists were crossing during the all-red phase of the intersection, and were not exposed to opposing vehicles. Violations that occurred at times longer than two seconds are when the vehicle committing the violation has the most risk. Four out of the nine violations that happened after two seconds into the red were vehicles driving through the intersection. Speeding, distracted driving, and disregard for the red light were among of the possible factors that led to the violation. It is important to note that none of these violation occurred at the deployment site. From the time into the red data it can be determined that motorists were not using the confirmation light as an early start to cross the intersection during the all-red phase.

DISCUSSION

Red light violations at signalized intersections continued to be a significant safety concern for many communities. A possible result of a RLR violation can lead to a serious right-angle crash if conflicting traffic is not aware of the violating vehicle. Many communities rely on traditional enforcement practices to monitor dangerous intersections for RLR violators. The process involves targeted enforcement, many times with multiple police officers having to watch both the traffic movement and signal. Many communities have turned to automated enforcement as a way to enforce RLR and studies have shown a positive impact on safety, but programs have opposition in the court system. Low-cost engineering countermeasures (both self-enforcing and aiding law enforcement) are another alternative to help in reducing RLR violations. Confirmation lights have been installed in multiple communities in the United States; however a literature search indicated that limited data has quantified the effectiveness of this common countermeasure.

The objective of this research study was to assess the effectiveness of the confirmation lights in medium to large communities in Iowa where larger signalized intersections with protected left turning movement existed and also where traffic peak hours occurred. A solicitation letter on behalf of the University of Kansas and the Iowa DOT was sent to several communities. Altoona and Waterloo were the two communities selected for the research study. It was determined by the research team that one intersection in each of the communities would be equipped with the confirmation light system. In Altoona the intersection of 8th Street and 34th Street and for Waterloo the intersection of University Avenue and Ansborough Avenue were selected. Along with determining treatment intersections, the research team identified spillover intersections next to the treatment intersections to determine if the confirmation lights affected RLR nearby. Also, control intersections were identified within both cities, but far from the treatment intersections or corridor under investigation. There were a total of 12 intersections studied, six in Waterloo and six in Altoona. In addition to the deployment site in Waterloo there were four intersections near University Avenue and Ansborough Avenue for possible spillover effects, and one control intersection. In Altoona there were two spillover sites and three control sites selected.

Blue confirmation lights were installed for the through and left turning movements, with exception to the southbound left turn movement, at University Avenue and Ansborough Avenue. The deployment site in Altoona (8th Street and 34th Street) had confirmation lights for all through movements and not the left turning movements. The reason only the through movements had confirmation lights in Altoona and all movements with the exception of the southbound left turning movement in Waterloo was that the intersections had protected and permitted left turning movements, so a green arrow and red light would be on at the same time.

Traditionally, effectiveness of a safety countermeasure is performed by investigating three years of before crash data and three years of after crash data. Since the research project was limited by time the research team performed a before-after RLR violation analysis. Confirmation light effectiveness would be determined by either a decrease or increase in RLR violations, which would equate to a possible reduction or increase in RLR crashes based on exposure. Video data were collected in the field prior to the confirmation light installation in July 2013, one month after installation, and three months after installation to determine short term and long term effectiveness.

Traffic was recorded during the morning peak hours of 7 a.m. to 9 a.m. and the afternoon peak hours of 4 p.m. to 6 p.m. Intersections were only recorded on Tuesday, Wednesday, or Thursday when traffic patterns were normal. Researchers recorded traffic in July, October, and December. The confirmation lights were installed on August 30, 2013. After traffic was recorded, the video was reduced and RLR violations were recorded. A vehicle was considered to be running a red light if it was behind the stop line when the light turned red and then traveled through the intersection. Only the through and left-turn movements were observed for red light violations. Researchers also counted turning movements, time into the red, and time of day of RLR occurrence. There were a total of 110 violations observed during this study, 75 in Altoona and 35 in Waterloo. In Altoona around 53 percent of violations were left turns and 47 percent were through movements. In Waterloo 69 percent were left turns and 31 percent were through movements. The control sites of Adventureland Drive and 1st Avenue, 8th Street and 1st Avenue, and E. San Marnan Drive and La Porte Road had the highest violations and violation rates.

The research team also investigated the changes in the time into red for both the left turning and through movements during each of the three study periods. Time into the red for violations ranged from 1 to 70 seconds. Eighty seven out of the 110 violations occurred within one second into red, 14 within two seconds, and nine over two seconds into the red. For violations that occurred over two seconds; five were left-turn movements and four were through movements. The deployment site of 8th Street and 34th Street had the highest volume count and the lowest violation rate out of the three most traveled intersections in Altoona. All violations occurred within one second of time into the red. This intersection did not see an increase or a decrease in the number of violations before and three months after deployment. The intersection did experience a slight decrease in RLR rate. The deployment intersection in Waterloo experienced an increase in violations and violation rate from before deployment to three months after deployment. At the three month period of the study however there was an increase observed at spillover and control sites. All violations at University Avenue and Ansborough Avenue occurred within one second into the red.

The results of this study indicated that the confirmation lights had little effect on changing driver behavior to not run red lights. No violations occurred within two seconds or over two seconds into the red after installment of the confirmation lights. It was determined from the time into the red analysis that motorists did not using the lights to cross intersections during the all-red phase. A statistical analysis showed that the change in violation rate experienced at the deployment sites was not significant 95 percent level of confidence. This implies that the confirmation light has little to no effect on driver behavior. It was also found the confirmation light did not encourage drivers to traverse the intersection during the all-red phase, and did not have an influence on the number of violations. This project focused on the effects of the confirmation lights on driver behavior. Further research is needed to further understand the effectiveness of confirmation lights as a law enforcement strategy.

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APPENDIX A

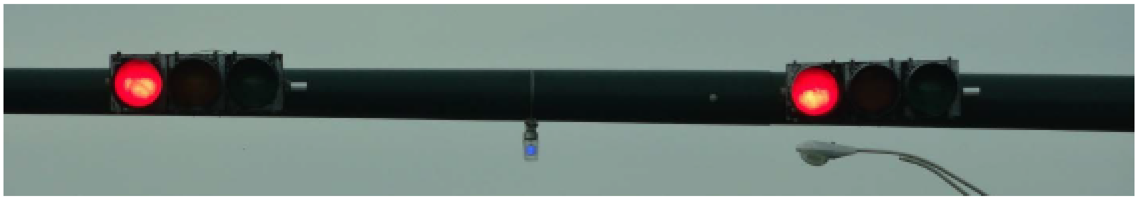
The University of Kansas
Department of Civil Engineering
2150 Learned Hall, 1530 West 15th Street
Lawrence, Kansas 66045

Iowa Department of Transportation
Research and Analytics Office
800 Lincoln Way
Ames, Iowa 50010

RE: Solicitation to Iowa Communities to Help with a Red Light Running Research Project

Dear Members of the Iowa Law Enforcement and Transportation Engineering Community:

The University of Kansas under the direction of the Iowa Highway Research Board is seeking medium and large communities in Iowa that are interested in participating in a one year research project aimed at reducing red light running violations at signalized intersections. As concluded by previous Iowa studies, red light running continues to be a serious safety concern for communities in Iowa and this research project is designed to reduce violations through a non-invasive low-cost countermeasure called a "confirmation light" as shown below.



Blue Confirmation Light Mounted to a Mast Arm in Naples, Florida

The confirmation light system consists of a low-wattage LED light housed in a blue Pelco globe that directly connects to the circuit for the red bulb of the traffic signal. If the signal in either the through or left turning movement shows red, an officer can verify a red light running violation at any location around the intersection without the need of additional officers present. This countermeasure has been widely deployed by the Florida Department of Transportation, however limited effectiveness data have been reported.

The research team plans to perform a before-after study using video data. Additionally, a 3 month after-study will be performed to investigate long-term effectiveness. A total of one or two intersections will be equipped with the confirmation light system and six to eight spillover and control intersections will also be studied. The research project will purchase all of the needed equipment. The research team requests technical assistance with identifying appropriate intersection and installation. Furthermore, the research team will work closely with law enforcement and public works departments to ensure ease of installation and understanding. Thank you for your time and consideration, please let us know if you're departments are interested in working with us or if you have further questions and comments.

Steven Schrock, Ph.D., P.E.
Associate Professor
University of Kansas
schrock@ku.edu
785-864-3418

Eric Fitzsimmons, Ph.D.
Post-Doctoral Researcher
University of Kansas
fitzsimmons@ku.edu
785-864-1921

Mark Dunn, P.E.
Operations Research Engineer
Iowa Department of Transportation
Mark.Dunn@dot.iowa.gov
515-239-1447

KU Engineering Researchers Study System to Improve Intersection Safety
Researchers at the University of Kansas School of Engineering have partnered with the cities of Altoona, Iowa and Waterloo, Iowa, to increase safety at two busy intersections by reducing red light running violations and simplifying law enforcement efforts to monitor potential infractions.

The project is funded by the Iowa Department of Transportation through the Iowa Highway Research Board 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 Iowa 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. Researchers have installed a blue light confirmation system at the following intersections and will be activated this Friday August, 30:

- 8th Street Southwest and 34th Avenue Southwest in Altoona
- University Avenue and Ansborough Avenue in Waterloo

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 Altoona and Waterloo 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."

Altoona Police Chief Jody Matherly quote, "The Altoona Police Department looks forward to participating in this very important study. Anytime officers can utilize low-cost technology to assist them in reducing traffic crashes, the effectiveness of their work day increases. Our goal of decreasing damage to property and injuries is an important one and confirmation lights may be a practical solution."

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Our lives are in your hands.

MEDIA INFORMATION

For more information, contact:
Mohammad Elahi – Traffic Engineer
mohammad.elahi@waterloo-ia.org
319-291-4440

FOR IMMEDIATE RELEASE

WATERLOO PARTICIPATES IN "BLUE LIGHT" TRAFFIC STUDY TO MAKE INTERSECTIONS SAFER

WATERLOO, IOWA (August 29, 2013) – Red light running at intersections with traffic signals continues to be a serious safety concern for drivers, pedestrians and bicyclists. Waterloo will soon be one of only two cities in Iowa experimenting with a new solution to this problem.

In 2011, the Federal Highway Administration reported that 676 fatalities – 10 percent of all signalized intersection crashes in the U.S. – were due to red light running.

Now, the City of Waterloo Traffic Operations Department has partnered with researchers at the University of Kansas School of Engineering on a study to increase safety at signalized intersections.

Starting Friday, the Ansborough Avenue and University Avenue intersection in Waterloo will utilize what's called a red light confirmation system. This intersection was selected based on recommendations from Traffic Operations and the University of Kansas research team.

"This initiative will surely assist the Waterloo Police Department with their goal to make the city safer," said Chief Daniel Trelka, director of safety services for Waterloo.

The system is a low-cost, non-invasive measure designed to reduce the number of officers needed to monitor an intersection and to reduce the need to interrupt traffic to pursue a violating vehicle.

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WATERLOO PARTICIPATES IN "BLUE LIGHT" TRAFFIC STUDY TO MAKE INTERSECTIONS SAFER / Page 2 of 3

Each traffic signal 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 light remains off. It comes on the moment the signal turns red. The blue light is visible from every angle, so officers and witnesses will know when a motorist has run a red light even if they cannot see the signal change colors.

Steve Walker, a Waterloo driver whose car was hit by a driver who ran a red light, looks forward to the changes that may come from the study.

"I was fortunate that I had a witness to the accident. The witness noticed I was the one who had the green light, so it was obvious that the other driver had a red light," he said. "It sounds like this blue light system will make it clearer for everyone at the intersection to see what's going on when there aren't officers or witnesses paying attention."

Researchers will evaluate the system over the next six months and report results to city and state officials. The system has shown promising results in Florida, Kentucky, Texas and Minnesota, and the City of Waterloo Traffic Operations Department expects the same.

"We are eager to participate in this study," said Mohammad Elahi, a Waterloo traffic engineer. "Traffic safety is obviously a top priority for us, and we always welcome new tools that could help reduce accidents."

The City of Altoona is currently the only other city in Iowa approved to participate in the study, where the intersection of 8th Street Southwest and 34th Avenue Southwest will be monitored.

The research project is funded by the Iowa Department of Transportation through the Iowa Highway Research Board, and is under the direction of Steven Schrock and Eric Fitzsimmons of the University of Kansas.

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Our lives are in your hands.

"The School of Engineering is excited to partner with the cities of Altoona and Waterloo in an effort to improve driver safety at these busy intersections," said Schrock, associate professor of civil, environmental and architectural engineering. "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."

For further traffic safety information and tips, visit www.DriveSafeCV.org.

About Drive Safe Cedar Valley

Drive Safe Cedar Valley, a 501(c)(25) in Waterloo, is a nonprofit that promotes traffic safety awareness. As the first public awareness program of its kind in Iowa, the goal of Drive Safe Cedar Valley is to change the culture of driving. All citizens – drivers, passengers, bikers and pedestrians – are encouraged to become accountable for safety.

This lifesaving program was initially funded by an Iowa Department of Transportation traffic safety grant. Now in its seventh year, Drive Safe Cedar Valley depends on gifts and in-kind contributions to keep it going and growing.

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VISUAL: A photo of the blue lights that will be installed at the intersection of Ansborough Avenue and University Avenue in Waterloo beginning August 30.

Please note: For other visuals, or to receive the image in another format, please contact Mohammad Elahi at 319-291-4440 or mohammad.elahi@waterloo-ia.org.