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Evaluation of the safety effects of red light cameras: A case study

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Evaluation of the safety effects of red light cameras: A case study

by

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DISCLAIMER

This thesis represents the work of the researcher and does not reflect the views of the City of Cedar Rapids, Iowa nor does it reflect the views of Gatso USA.

ABSTRACT

Red light running results in approximately 260,000 crashes annually in the United States. These crashes have resulted in an average of 907 fatalities and 165,000 injuries annually from 2000-2008. Red light running crashes are a safety concern due to the increased likelihood of injury compared to other types of crashes. Automated enforcement in the form of red light camera systems has been found to be an effective way to reduce these crashes.

The city of Cedar Rapids installed red light cameras at eight intersections across the city starting in February of 2010. The following study looks at changes in various metrics in order to determine the effectiveness of the cameras in increasing safety at the intersections. These metrics included violation rates; the time vehicles entered the intersection into the red, time and percentage of vehicles which entered the intersection during the yellow phase and the headway between vehicles.

Most of the findings support the claim that the cameras are effective in increasing the safety at the intersections studied. The violation study saw decreases in the violation rate at approaches in the range of 6 to 91%. Vehicles entered into the intersection earlier during the yellow phase and appeared to give each other more space as they approached the intersection due to the decrease in the percentage of drivers traveling with headways in the 0-1 second bin. The findings of the percentage of the vehicles entering the intersection during the yellow phase as well as the red phase study were inconclusive with both increases and decreases being seen.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Red light running results in approximately 260,000 crashes annually in the United States (Retting et at., 1995). These crashes have resulted in an average of 907 fatalities and 165,000 injuries annually from 2000-2008 (FHWA, 2010). Red light running crashes are a safety concern due to the increased likelihood of injury compared to other types of crashes (Retting et al., 1999a). Automated enforcement in the form of red light camera systems has been found to be an effective way to reduce these crashes. Some states however, are pulling the red light cameras because they feel they have been installed as a revenue generator and not as a safety mechanism. Due to this backlash, studies on new camera installations provide useful evidence of the effectiveness of these programs.

In June of 2009 the City of Cedar Rapids passed an ordinance to install red light cameras at intersections across the city. A copy of this ordinance can be seen in Appendix A. The ordinance allowed for the violations to be issued as civil violation rather than a moving violation. A moving violation is given if the violation was witnessed and issued by a police officer without the use of automated enforcement. A civil violation is similar to a parking ticket. It is issued to the owner of the vehicle who may not necessarily be the driver. The civil violations did not gain one points against their license nor was it reported to insurance companies. It also allowed for increased privacy due to frontal photograph not being needed.

Upon examining 30 intersections that had high right angle crashes, eight intersections were chosen to have cameras installed. These intersections were chosen based on their crash rates as well as the ability for the cameras to be placed, appropriate intersection configurations and no future plans for intersection improvements. The cameras were placed starting in February of 2010 with the last becoming operational in December of 2010. A 30-day warning period preceding tickets being issued occurred after the first camera was put in place. An analysis of the cameras effect on safety at these intersections was determined prudent in helping to justify the installation and effectiveness of these cameras.

The cameras were installed and operated by a vendor. There was no cost to the city for the installation and operation of the cameras; however the vendor receives a share of each violation. The cost of a red light violation was set at $100 and the funds were distributed with the vendor receiving $30 of each citation while the city received the remaining $70.

1.2 RESEARCH OBJECTIVES

The objective of this research was to assess the safety effectiveness of the red light running program that has been implemented in Cedar Rapids, Iowa. This was accomplished by analyzing data to determine changes in the following metrics:

- Red light violation rates based on overall changes, time of day changes, and changes by lane.
- Time in which those running the red light enter the intersection.
- Percentage of those who enter the intersection during the yellow phase and the time into the yellow phase in which they enter.
- The average headway between vehicles entering the intersection.

These results were compared with previous research on red light running and further research was recommended.

1.3 THESIS ORGANIZATION

This thesis is organized into five chapters. It starts with this chapter which gives background into the problems associated with red light running and then lists the research goals. Chapter 2 contains information on previous research already completed on the topic. Chapter 3 provides information on the intersections used in the study as well as information on how the data were collected and reduced. This is followed by chapter 4 which discusses the studies performed. This includes background on each study, the methodology, analysis and results. Finally chapter 5 discusses overall findings and suggestions for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 BACKGROUND

In 2009 red light running resulted in 676 fatalities in the United States. This represented 10% of all intersection related fatalities as well as 2% of all roadway fatalities in 2009 (FHWA, 2011). Additionally, it is estimated that there were 130,000 people injured in crashes in 2009 due to red light running (IIHS, 2011). Over half of the fatalities due to red light running are not the driver of the vehicle which runs the red light, but passengers in that car, someone in the car they collide with or pedestrians (IIHS, 2007). Also, red light crashes are more likely than other crashes to result in injury (Retting et al., 1995). Red light running is a safety issue which 93% of respondents of the AAA 2010 Traffic Safety Culture Index consider unacceptable, yet over 30% of respondents admitted to running a red light in the last 30 days when they could have safely stopped (AAA, 2010).

Traditional enforcement while effective in reducing red light running requires extra officers in the field which most departments do not have the resources. Additionally, traditional enforcement often requires an officer to pursue a violator through the red signal creating more safety concerns (IIHS, 2011). Automated enforcement in the form of red light cameras has been found to be an effective substitute to traditional enforcement in reducing red light running. Red light cameras have been in place in the United States for the last 20 years and are estimated to be in use in approximately 538 cities as of May 2011 (IIHS, 2011a).

When evaluating the effectiveness of a red light camera program a crash analysis is often completed in order to determine if the presence of the cameras is causing a significant change in the number of crashes. Crash studies often look at changes to both right angle crashes (those associated most often with red light running) as well as rear end crashes. Rear end crashes are also studied due to the belief that the presence of the cameras causes more people to slam on their brakes resulting in more rear end crashes (IIHS, 2011b).

While crash studies are considered the most appropriate way to determine the effect red light cameras have on safety at an intersection they are not always possible. For instance in order to determine the true effectiveness of the cameras an extensive after period of data are required. This is anywhere from one to five years worth of crash data. In situations where the effectiveness of the cameras needs to be determined in the short term a violation study is often used.

A violation study looks at the direct impact the presence of red light cameras has on the number of red light violations committed. Since red light violations happen much more frequently than red light crashes, a shorter time period is able to be evaluated in order to determine significant changes.

A reduction in violations has been used as a surrogate for a reduction in red light crashes. This is due to the fact that as the number of violations decreases, the exposure of vehicles to the potential for a red light crash also decreases leading one to assume that there should be a reduction in crashes. This relationship is likely not a direct relationship due to the randomness of crashes.

Bonneson et al. (2002) developed a crash rate model to determine the relationship between red light violations and crash rates. Using three years worth of crash data from 20 approaches they extracted the crashes most associated with red light running, right angle and left turn related crashes. Using a non-linear regression analysis they were able to develop a model which took into account three year counts of red light related crashes, ADT of the intersecting streets and violation rates (per 1,000 entering vehicles). The model developed was then calibrated and found that as the red light violation rates increase (as well as increasing cross street traffic), so does the predicted approach crash frequency.

They also conducted a sensitivity analysis assuming constant ADT on the approaches and developed the trend seen in Figure 1. As can be seen the relationship is neither direct nor linear. For instance a 50% reduction in red light running would see a 25% reduction in crashes.

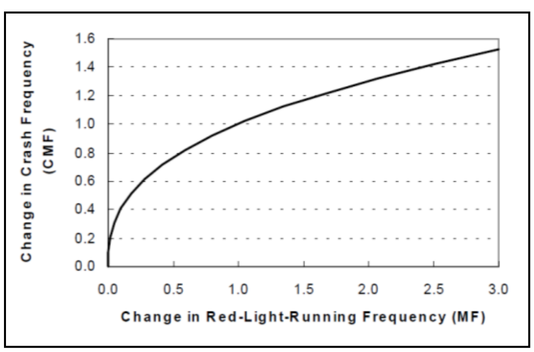

Figure 1: Effect of a Change in Red-Light-Running on Crash Frequency (Bonneson et al., 2002)

The following section contains more information on specific implementations of red light camera programs. It contains information on the effects the cameras had on changes in violations.

2.2 RED LIGHT PROGRAMS

Retting et al. (1999b) found around a 40% reduction in the violation rate at intersections in Oxnard, California three to four months after the red light cameras had been installed. They also found a spillover effect at other intersections across the city. Their "before/after quasi-experimental design" included collecting violation data at nine intersections across the city which had red light cameras installed and comparing the changes to three other intersections in the city without cameras as well as two control sites in nearby Santa Barbara.

The violation data used at the camera intersections were collected by the vendor while the data at the non camera and control intersections were collected by analyzing video collected at the sites by the investigators. Baseline data were collected prior to the 30 day warning period the city gave before the cameras started issuing citations while the after data were collected three to four months after the cameras became operational in July of 1997.

They defined a red light violation as one where the driver entered the intersection 0.4 or more seconds into the red while traveling at least 15 mph. This was done in order to eliminate those turning right on red and turning left. Citations cost $104 and were issued as moving violations which included one demerit point towards the driver's license. Citations were issued to the driver of the vehicle. The driver was identified using front photography and comparing the description of the driver to that of the registered owner of the vehicle.

They then analyzed the data using log-linear models which had variables including the period of data collection (before vs. after) as well as the site type (camera, non-camera, and control) which were then tested for statistical significance using an analysis of variance table. The results of the analysis of variance table showed no statistically significant difference between the reductions in violation rates seen at the camera and non camera sites, but did show a statistically significant difference between the camera and non camera sites and the control sites.

Retting et al. (1999c) conducted a similar study in Fairfax, VA to the one completed in Oxnard, CA. In this study only five camera sites were selected along with two non-camera sites in Fairfax and two control sites in nearby counties. All data in this case were collected by the investigators. They collected data right before the 30 day warning period and then collected data once the cameras had been operational for three months and then again after a year. They also defined a red light violation the same as in their other study, a vehicle entering the intersection at least 0.40 seconds into the red traveling at a minimum of 15 mph.

An analysis of variance table was again used to determine if changes seen were statistically significant. It was found that within the city of Fairfax that violation rates decreased by 9% three months after the cameras were installed and 40% after a year. Similar to the Oxnard study there were no statistically significant differences between the camera and non camera sites during both after time periods and a statistically significant difference was seen between the camera and non camera sites compared to the control sites one year after. At three months after however there was no statistically significant change between the control, camera and non camera sites.

Cunningham and Hummer (2004) performed an analysis where they studied the change in the violations which occurred greater than two seconds into the red. They chose to look at violations which occurred two seconds or more into the red after studying previous research which suggested this as the time when red light violations would most likely result in collisions. They obtained their data from the vendor for intersections in Chapel Hill and Raleigh. The before data were from a validation study the vendor conducted before placing the cameras.

This study involved taping the intersections from the side of the road for 16- 24 hours and then having an individual watch video for each intersection twice to determine the number of violations and the time into the red in which they occurred. After data were for four months to one year and were provided by the vendor. After data were reduced so only the same time of day was used. After data consisted of up to a week’s worth of observations in order to have a large enough sample size. A Chi Squared Test of Independence was used with a two by two contingency table. Results showed that there was a significant decrease in the frequency of violations which occurred two or more seconds after the red when the cameras were in place.

The authors of the study noted some limitations of their study which included the differences in the length of data collection periods for the before and after data, human error in coding violations in the before period, potential problems with the camera system malfunctioning, as well as left turn on red violations at some of the intersections which were made up of two one way streets.

Retting et al. (2008) completed an evaluation of the red light camera program in Philadelphia, PA. In addition to placing red light cameras the city also increased the length of the yellow signal prior to installing the cameras. The study looked at three approaches at two intersections which had cameras installed along with three control intersection approaches in Atlantic County, New Jersey which is located approximately 50 miles from Philadelphia. Table 1 below demonstrates the timeline the study followed. The cameras had a 120 day warning period once they were installed prior to citations being issued. Each approach had 24-48 hours of video collected during the three phases which were then viewed by one individual and violations were coded. A second individual verified the individuals coding by checking three of the approaches for three 24 hours periods.

Table 1: Study Timeline (Retting et al., 2008)

Date	Event
November 2004	Baseline data collection at experimental and comparison sites (phase 1)
December 2004	Implementation of yellow signal timing changes at experimental sites
January 2005	Data collection at experimental and comparison sites after yellow signal timing changes (phase 2)
February 2005	Implementation of 120-day warning period for red light running violations
June 2005	Implementation of red light camera enforcement at experimental sites
June-July 2006	Data collection at experimental and comparison sites after camera enforcement (phase 3)

Violation rates per 10,000 entering vehicles were determined using the violations found along with the exposure which was collected using road tubes. These rates were then analyzed using a logistic regression to estimate an odds ratio. Once taking into account the increase in violations seen at the control site the study sites saw a 36% decrease in the odds ratio due to the increase in the length of the yellow phase. The change seen post phase three once the cameras had been in place was an additional 96% reduction in the odds ratio. It should be noted that this change seen during phase three may also include residual decreases due to the increased yellow time.

Fitzsimmons et al. (2009) completed a cross sectional analysis to determine the effect of red light cameras on red light violations. A cross sectional analysis was completed in place of a before and after study due to a lack of before data being collected. Four study intersections composed of six approaches in Clive, Iowa were used as well as 15 control approaches at seven intersections in the Des Moines, Iowa metro area.

One day of video data were collected at the control intersections while data for the study intersections were obtained from the City of Clive. The video data were manually reduced to look at the peak hours. A red light violation was defined as " a vehicle located beyond the approach stop bar when the traffic signal indication is a red ball or arrow which then proceeds through the intersection for a through or left turn movement." An average violation rate per 1,000 entering vehicles was then found for the control intersections and study intersections by taking the total red light violations at the intersection (study or control) and dividing it by the total number of vehicles entering the intersection (study or control).

Then the generalized linear model was found in order to determine the statistical significance of the violation rates at the control and study intersections. Additionally, vehicle movements (i.e. left turn, right turn, through) were modeled separately for each approach and peak hour period. Results found that one expects 25 times more violations to occur at a non camera intersection compared to an intersection with a camera in place.

Additionally, Retting (2010) and Bochner & Walden (2010) conducted reviews of red light running programs across the United States. Both looked at the effects that programs across the country have had on reducing violations. Bochner and Walden found that programs across the country saw reductions anywhere from 18% to over 90%, while Retting mentioned programs seeing reductions in the range of 40% to over 90%. Bochner and Walden also mentioned that programs saw increasing reductions each month after implementation. Table 2 lists the studies mentioned in the two papers as well as the reductions in violations seen and the time period over which these reductions took place. This table does not list studies which were mentioned previously.

Table 2: Summary of Studies Listed in Retting (2010) and Bochner & Walden (2010)

Location	Reduction seen	Time Frame
Los Angeles, California	92%	1 year
San Diego, California	32% & 54%	1 year & 2 years respectively
San Francisco, California	68%	1 year
Alpharetta, Georgia	64%	1 year
Rome, Georgia	32%	1 year
New Orleans, Louisiana	85%	7 months
Howard County, Maryland	18 to 67%	5 years
Charlotte, North Carolina	70%	1 year
Garland, Texas	56%	31 months
College Station, Texas	49%	1 year
Virginia Beach, Virginia	78%	Not listed
Seattle, Washington	44% & 59%	1 year & 2 years respectively
IIHS International Review	40% to 50%	Not listed

CHAPTER 3: SITE INFORMATION AND DATA PREPARATION

3.1 INTERSECTIONS

The City of Cedar Rapids examined 30 intersections that had high right angle crash rates and then selected eight intersections in which to have red light cameras installed. These intersections were chosen based on their crash rates as well as the ability for the cameras to be placed (i.e. adequate space for the cameras to be installed), appropriate intersection configurations and no future plans for intersection improvements. These cameras were put in place starting in February of 2010 with the last one installed in December of 2010. Although cameras were installed at eight sites, only four intersections were included in this study due to either late installation, lack of data for the before period, or bad data at the remaining four intersections.

1st & L Street was the intersection where there was an obvious problem with the before data which was removed from the analysis. The changes to the number of vehicles between the before period and June 2010, one month after installation were an approximate 25% increase. The traffic volumes were then similar for the after periods as well. Additionally in the before period a lane 4 was listed for the westbound approach that was not seen in the after data studied. For these reasons mentioned 1st & L Street was not included in the analysis.

Two approaches from these four intersections were looked at, except for 2nd & 6th Avenue which only included the northbound approach. The westbound approach was not studied due to a lack of before data. Listed below are the four intersections and approaches that were looked at as well as Figure 2 which illustrates where the sites are located across the city.

- 2nd Ave SW & 6th St SW -- northbound
- Edgewood & 42nd Ave – northbound and southbound
- 1st Ave &10th St -- eastbound and westbound
- 2nd Ave SW & 3rd St SW -- northbound and westbound

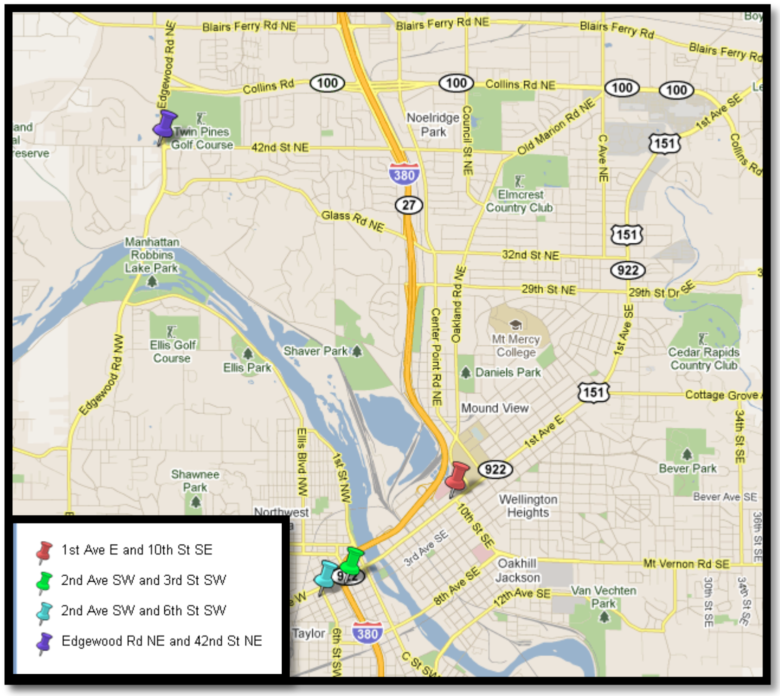

Figure 2 : Locations of Study Sites in Cedar Rapids, Iowa (Google Maps, 2011)

In the sections below more information will be included about each of the study intersections.

3.1.1 2nd & 6th Street

2nd Ave & 6th St SW is located west of downtown Cedar Rapids. 2nd Ave is a one way street with traffic traveling southwest through the intersection while 6th St SW is a two way street. The intersection configuration can be seen in Figure 3. This intersection reverts to flashing yellow/red during the hours of 2 am to 6 am daily; the flashing yellow is to 6th St and flashing red is to 2nd Ave. Cameras monitor the northbound 6th St approach as well as the westbound 2nd Ave approach. Due to before data not being collected the westbound approach will not be included in this study.

Figure 3: Aerial Photo of 2nd & 6th Ave (Google Earth, 2011)

3.1.2 Edgewood & 42nd Ave

Edgewood & 42nd Ave is located northwest of downtown Cedar Rapids. This intersection is made up of two, two way roads with right turn by-pass lanes as can be seen in Figure 4. The northbound and southbound approaches of Edgewood Rd are monitored by the cameras. Cameras started issuing citations in late April of 2010.

Figure 4: Aerial Photo of Edgewood & 42nd (Google Earth, 2011)

3.1.3 1st Ave & 10th St

This intersection is located in downtown Cedar Rapids just south east of St. Luke's Hospital. This intersection is made up of two, two way streets. Cameras are located on both approaches on 1st Ave E with cameras being operational starting with the warning period in February of 2010 followed by issuing citations in March of 2010. Figure 5 illustrates the approaches studied and labels the lanes.

Figure 5: Aerial Photo of 1st & 10th (Google Earth, 2011)

3.1.4 2nd & 3rd Street

2nd & 3rd Street is located east of I-380 and west of the river in downtown Cedar Rapids. This intersection is comprised of two one way streets. 2nd Ave SW is one-way with traffic moving westbound and 3rd St. SW is one way with traffic moving northbound. Both approaches are monitored as seen in Figure 6. This intersection also reverts to flashing yellow/red during the hours of 10 pm to 6 am each day. The flashing red is to 3rd St. SW and the flashing yellow is to 2nd Ave. Operations at this intersection started in April of 2010.

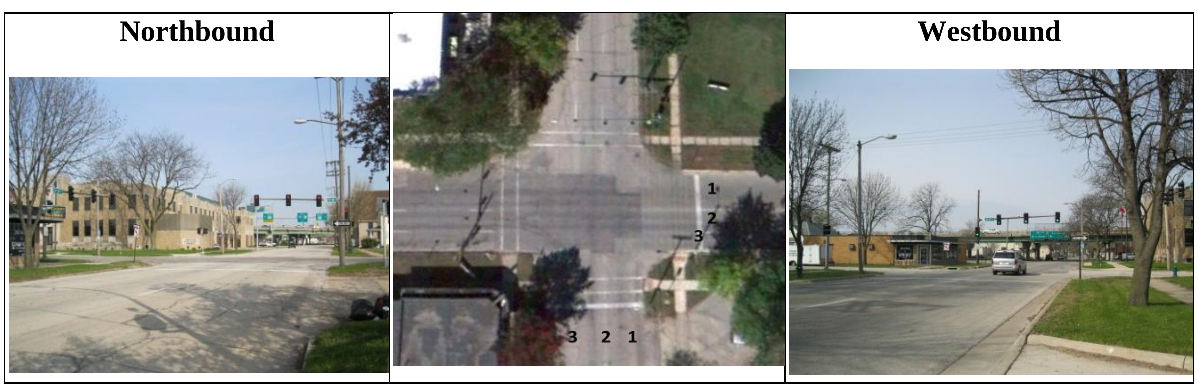

Figure 6: Aerial Photo of 2nd & 3rd Ave (Google Earth, 2011)

3.2 RED LIGHT CAMERA SYSTEM

The red camera system used was installed and operated by a vendor, Gatso USA. The systems that were installed included mast arms which held the RF antennas mounted over each lane. The mast arm and the RF antennas can be seen in Figure 7. According to Gatso (personal communication, March 4, 2010):

These (RF antennas) were installed by marking 20 feet from the stop bar, and aiming the antennas at that point in the road. When a car goes through the beam it triggers the radar. This is what you are seeing on the statistics. Each entry on the statistics is a trigger and the road conditions (lane #, red time, yellow time, etc…) during that trigger.

A valid (speed) measurement means that the vehicle was traveling within the limits of the radar (6 mph to 126 mph). Invalid triggers occur when the radar detected a speed less than 6 MPH or the return signature of the Doppler radar was not complete, or found inconsistencies in the Doppler shift. This was seen a lot with cars that slammed on their breaks just before the stop bar. These were reviewed by Cedar Rapids PD to ensure the offender did indeed run the red light.

Figure 7: Mast arm and RF Antenna Set up

If it is determined that the vehicle entered the intersection (i.e. crossed the stop bar before the signal turned red) while the signal is in the red phase, two photos are taken, one as the vehicle enters the intersection and another while the vehicle is traveling through the intersection. One of these photos is used to obtain a close up of the license plate of the vehicle. Video is also collected of the violations and sent to the Cedar Rapids Police Department where a sworn officer reviews the potential violation and decides if a violation occurred or if for instance the vehicle was attempting to get out of the way for an emergency vehicle. Figure 8 illustrates what the cameras look like at each intersection.

Figure 8: Camera Setup

3.2 DATA

Data were provided for this study by the vendor and were collected across the study. The vendor supplied a separate excel spreadsheet for each day of data collection at each approach. Figure 9 illustrates what the spreadsheet contained. The first column in each sheet is the date. Following that is the time listed in military format. Next to it that is the site code, the one shown is for 1^{st} & 10^{th} eastbound. Then is the offence type which is one of four possible offences: “no violation”, “red”, speed” or “speed + red”. Next is the lane number which is 1-4 depending on the approach. The lanes are numbered with 1 being the outer lane (i.e. right turn lane).

Speed valid and speed are the two columns following; these if considered to be valid will list “v” and if the system is not 100% positive it will be listed as “i”. If the speed is valid it will then be listed in mph in column F. Length validation and Length are the following columns and are used in finding the speed.

The last three columns are the Pardon time, Yellow time and Red time. These are in thousandths of a second and list the corresponding time in which each car enters into the intersection. The pardon time is 0.1 seconds. Yellow time ranges from 0 to 4.3 seconds. Appendix B contains definitions of the column headings and each descriptions of what each column entails.

A	B	C	D	E	F	G	H	I	J	K	L
Date	Time	Site code	Offence ty	Lane nr.	Spd valida	Speed	Length val	Length	Pardon tir	Yellow tin	Red time
8/16/2010	0:00:01	1STEB	no violatio	2	v	28	v	613	0	0	0
8/16/2010	0:00:16	1STEB	no violatio	2	v	31	v	613	0	0	0
8/16/2010	0:01:13	1STEB	no violatio	3	v	13	v	613	0	0	0
8/16/2010	0:01:30	1STEB	no violatio	2	v	34	v	613	0	0	0
8/16/2010	0:02:31	1STEB	no violatio	3	v	33	v	613	0	0	0
8/16/2010	0:03:43	1STEB	no violatio	2	v	30	v	613	0	0	0
8/16/2010	0:03:53	1STEB	no violatio	2	v	28	v	613	0	0	0
8/16/2010	0:06:07	1STEB	no violatio	3	v	28	v	613	0	0	0

Figure 9: Example of Data Spreadsheet

3.2.1 Data Collection Time Periods

Data were collected at various points in time across the study for comparison. The data that will be considered the "before" data were collected once the cameras were installed but not yet issuing tickets. This time period, which ranged from three days to a week, is also known as the "stealth period". Listed below in Table 3 are the dates in which the before data were collected for each intersection.

Table 3 : Collection Dates for Before Time Period

Intersection	Stealth Start Date	Stealth End Date
2nd Avenue & 6th Street SW	2/22/2010	2/28/2010
Edgewood Road & 42nd Street NE	4/16/2010	4/23/2010
1st Avenue & 10th Street E	2/06/2010	2/08/2010
2nd Avenue & 3rd Street SW	3/25/2010	3/31/2010

The vendor continuously collected data once the cameras became active. However there were time periods in which the data were not able to be backed up. Data from June – October were also collected and used as the after data. The time period corresponding closest to the before time period was then used as the after data for the months of June, August and

October. The dates used can be seen below in Table 4. Data were cleaned up to avoid things such as bad weather or low visibility. More information on dates and times removed can be seen in section 3.2.2 below.

Table 4: Collection Dates for After Time Periods

Intersection	June Dates	August Dates	October Dates
2nd Avenue & 6th Street SW	6/22/10 - 6/28/10	8/23/10 – 8/29/10	10/18/10 - 10/24/10
Edgewood Road & 42nd Street NE	6/4/10 - 6/10/10	8/13/10 – 8/19/10	10/22/10 - 10/28/10
1st Avenue & 10th Street E	6/5/10 - 6/6/10	8/21/10 – 8/22/10	10/09/10 - 10/10/10
2nd Avenue & 3rd Street SW	6/14/10 - 6/20/10	8/19/10 – 8/25/10	10/20/10 - 10/26/10

3.2.2 Data Reduction

After the data were gathered for each of the time periods, data were then "cleaned up". This involved making sure all time periods matched, therefore if data were not present from for example 0:00:00 am – 8:59:00 am in one of the time periods for a particular approach the same block of time was removed from all other time periods for that approach.

Also, when obvious problems with the data were present they were removed. For instance, one day the northbound approach of 2nd & 6th Street had longer than normal times listed for the length of the yellow signal (9.99 seconds) which indicated that there was something wrong with the signal or the data file. These data were therefore removed.

Next, the two intersections with flashing yellow/red overnight had the data removed for the time periods in which the flashing yellow/red was active. These two intersections were 2nd Avenue & 3rd Street and 2nd Ave & 6th Street. This was done due to the difference in intersection dynamic during these time periods.

Finally, weather effects were taken into account. Hourly weather data were obtained from the National Climatic Data Center (NCDC, 2011) for all the time periods where data were collected. Then if the precipitation or fog were considered heavy the data were then removed for these time periods. It was assumed that when there was accumulating snow, heavy rain (0.05+ in/hr) or dense fog (<0.5 miles of visibility) that traffic patterns would be effected.

Table 5 lists the dates and times not used for each approach. It also lists the reason why the data were removed.

Table 5: Data Reduction Dates and Reasons

Intersection Approach	Dates Removed [Time]	Reason why data were removed
2nd & 6th NB	• 6/23/10 [0:00-9:00] • 6/24/10 [7:15-9:45] • Each day [2:00-6:00]	• Heavy rain • Error with signal • Flashing red/yellow
Edgewood & 42nd NB	• No changes made	• N/A
Edgewood & 42nd SB	• 4/16/10 [0:00-12:00]	• Data collection did not start until 12:00
1st & 10th WB	• 2/8/10 [All day]	• Accumulating snow during this date
1st & 10th EB	• 2/8/10 [All day]	• Accumulating snow during this date
2nd & 3rd NB	• 6/18/10 [All day] • 3/25/10 [0:00-8:30] • Each night [22:00-6:00]	• Dense fog and heavy rain throughout the day • Data collection did not start until 8:30 • Flashing red/yellow
2nd & 3rd WB	• 6/18/10 [All day] • Each night [22:00-6:00]	• Dense fog and heavy rain throughout the day • Flashing red/yellow

3.2.3 Data limitations

The data used in this study were provided by the vendor. Therefore there are some limitations that go along with this. One of these limitations is that this is the raw data before a police officer is able to review the potential violation. Therefore it is assumed that all violations listed as “red” were in fact a red light violation. This was done in order to have equal comparisons from the before period where the violation was not reviewed to the after period where it was.

Other potential limitations are that the data are assumed valid and error free except for the aforementioned reasons. Since the data were provided by the vendor errors with collection methods or validation are not known and not taken into account.

CHAPTER 4: A STUDY OF THE CEDAR RAPIDS RED LIGHT RUNNING PROGRAM

4.1 INTRODUCTION

The following sections contain a variety of studies conducted to evaluate the red light running program in Cedar Rapids, Iowa. Figure 10 outlines the organization of the studies completed. The first study conducted was the violation study which looked at changes to the violation rates to determine if the cameras had an effect on the rates. This was completed through first a general study, then a time of day study to determine if any patterns could be found when looking at day versus night and then finally a lane study to determine if patterns could be found for each movement.

Next, a time into the red analysis was conducted which looked at changes in the average time into the red in which vehicles entered the intersection before and after the cameras were put in place. This was conducted to determine which drivers, if any, the camera affected. This was completed by first looking at changes to the approach as a whole and then by breaking it down by lane to determine if changes occurred based on the movement of the vehicles.

After that a yellow time analysis was carried out. This analysis first looked at changes to the percentage which entered during the yellow phase which occurred between before and after the cameras were installed. After that changes to the average time into the yellow in which vehicles entered was also looked at to determine if vehicles were making more of an effort to stop the further into the yellow phase one got.

Finally a headway analysis was performed. This was done in order to determine if the cameras had an effect of the space between subsequent vehicles as they approached the intersection. This was done to test the theory that drivers would be worried the vehicle ahead of them would slam on their brakes if the light were to turn yellow and would therefore give each other more space than they had before the cameras were in place.

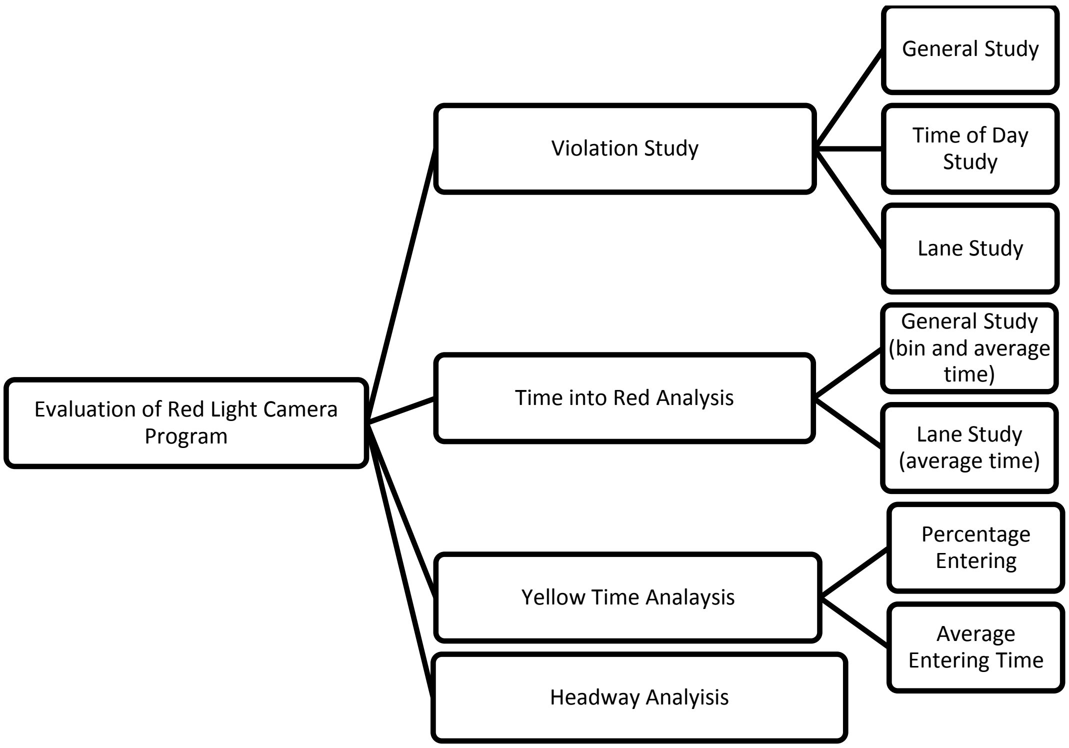

Figure 10: Study Layout

4.2 VIOLATION STUDIES

The following section evaluated the effectiveness of red light cameras at reducing violation rates at camera controlled intersection approaches through three approaches. These approaches included looking at changes to the approach as a whole, by time of day, and by lane. A violation study was chosen in place of a crash analysis due to the limited time since the cameras were installed. With less than a year's worth of data to use for the after period, a study of the change in crash rates was not plausible. Therefore the violation study was chosen in order to look at the cameras reduction of red light running. Reduction in red light running violations was used as a crash surrogate based on the assumption that there is a correlation between red light running violations and crashes. Ideally a comparison with a control group would have been looked at, but due to a lack of violation data being collected at non enforced intersections this could not be accomplished.

4.2.1 General Study

4.2.1.1 Introduction

This study looked at changes in violation rates over a 24 hour period at the seven camera controlled approaches. At times less than 24 hours of data were available, in that case as much data as were present were used. A general study was completed to determine the cameras overall effectiveness regardless of lane or time of day.

4.2.1.2 Methodology

A before and after study was conducted to measure the change in violation rates at the automated enforced intersections. This was done across the before period to the three after periods (June, August and October of 2010). Due to the range of installation dates the after data represents anywhere from one to nine months post camera installation.

The data were first reduced as described in chapter 3. Once the data were reduced the violation rate for each time period was calculated. This was completed by using Equation 4-1

$$\boldsymbol{violation\ rate} = \frac{\boldsymbol{Total\ Red\ Light\ Violations}}{\boldsymbol{Total\ Vehicles\ Entering\ the\ Intersection}} \times \mathbf{10,000} \quad \textbf{Equation 4-1}$$

Violation rate per 10,000 entering vehicles was calculated as opposed to the percentage in order to obtain numbers which were easier to interpret. Violation rates were calculated for each approach in each of the four time frames. The changes in rate between each after period and the before period were then found.

4.2.1.3 Analysis

A test of proportions was used to determine if the changes in violation rate were statistically significant. This test was performed using Equation 4-2 in order to calculate a Z test statistic. In this equation $\hat{\pi}_1$ represents the violation rate in the before period and n_1 represents the total number of observations during the before period. The other variables with subscript 2 represent the after rates and observations.

$$Z = \frac{(\hat{\pi}_1 - \hat{\pi}_2)}{\sqrt{\frac{\hat{\pi}_1(1-\hat{\pi}_1)}{n_1} + \frac{\hat{\pi}_2(1-\hat{\pi}_2)}{n_2}}} \quad \textbf{Equation 4-2}$$

This Z test statistic was then compared to a Z table using α=0.10 in order to determine significance at 90% confidence. Therefore if Z was greater than 1.28 the resulting decrease in violation rate was statistically significant and if Z was less than -1.28 then the increase in violation rate was statistically significant.

4.2.1.4 Results

Overall the cameras appeared to decrease the rate of violations at all intersections. Most changes were found to be statistically significant at the intersections expect for 2nd & 3rd where smaller sample sizes were present as well as smaller reductions were seen.

Results for each intersection can be seen in Tables 6 to 9 with statistically significant changes being bolded. Increases are numbers listed in red and decreases are listed in blue. This scheme and use of bold to illustrate statistical significance is used in tables throughout this chapter.

2nd Ave & 6th St saw consistently large decreases in violation rates once the cameras were installed and active. As can be seen in Table 6 the violation rates steadily decreased the longer the cameras had been in place. This is expected as more drivers become aware of the cameras and change their driving behavior. As of October 2010 a 90% decrease in the violation rate had been seen at this northbound approach.

Table 6: 2nd & 6th Street- Violation Rate Changes

		Before	June 2010	August 2010	October 2010
Northbound	Violation Rate (per 10,000 EV)	21.99	7.70	5.67	2.24
	Sample Size	21832	23383	22925	22367
	Change in Violation Rate	--	**-14.29**	**-16.32**	**-19.75**
	% Change in Violation Rate	-	-65%	-74%	-90%

Edgewood & 42nd Street saw large decreases in violation rates at its northbound approach as can be seen in Table 7. The southbound approach also saw decreases in violation rates; however they were smaller in magnitude. As with the 2nd & 6th Street's reductions, the largest decrease in violation rates seen at this intersection was in October, followed by

August and then June. Again this demonstrates the idea that the cameras are changing driver behavior the longer they are in effect.

Table 7: Edgewood & 42nd Street - Violation Rate Changes

		Before	June 2010	August 2010	October 2010
Northbound	Violation Rate (per 10,000 EV)	23.05	5.16	4.65	2.10
	Sample Size	71161	73645	70901	76244
	Change in Violation Rate	--	**-17.89**	**-18.40**	**-20.95**
	% Change in Violation Rate	--	-78%	-80%	-91%
Southbound	Violation Rate (per 10,000 EV)	5.10	4.26	3.17	2.42
	Sample Size	72618	68127	66302	65981
	Change in Violation Rate	--	-0.84	**-1.93**	**-2.68**
	% Change in Violation Rate	--	-16%	-38%	-53%

The westbound approach of 1st & 10th Street saw the largest numerical decreases in violation rates for all of the approaches as seen in Table 8. The largest drop was seen in August 2010 where the violation rate decreased by 47.69 red light violations per 10,000 entering vehicles. The eastbound approach also saw decreases in the violation rate however these were smaller in magnitude and not all were statistically significant.

Table 8 : 1st & 10th Street - Violation Rate Changes

		Before	June 2010	August 2010	October 2010
Westbound	Violation Rate (per 10,000 EV)	53.52	8.90	5.83	19.87
	Sample Size	18125	15739	13718	17113
	Change in Violation Rate	--	**-44.62**	**-47.69**	**-33.65**
	% Change in Violation Rate	--	-83%	-89%	-63%
Eastbound	Violation Rate (per 10,000 EV)	9.56	6.48	7.21	2.65
	Sample Size	14642	13886	13870	15079
	Change in Violation Rate	--	-3.08	-2.35	**-6.91**
	% Change in Violation Rate	--	-32%	-25%	-72%

2nd & 3rd Ave saw only one statistically significant change as can be seen in Table 9. Both approaches saw decreases in violation rates, but due to the smaller sample sizes these were not all significant at a 90% confidence level. The decreases seen in June for both approaches were close with Z values near 1.28.

Table 9: 2nd & 3rd Street - Violation Rate Changes

		Before	June 2010	August 2010	October 2010
Northbound	Violation Rate (per 10,000 EV)	34.81	22.76	32.69	19.73
	Sample Size	6033	6591	7036	7603
	Change in Violation Rate	--	-12.05	-2.12	**-15.08**
	% Change in Violation Rate	--	-35%	-6%	-43%
Westbound	Violation Rate (per 10,000 EV)	11.23	7.78	7.81	10.39
	Sample Size	18700	17984	17924	19246
	Change in Violation Rate	--	-3.45	-3.42	-0.84
	% Change in Violation Rate	--	-31%	-30%	-7%

4.2.2 Time of Day Study

4.2.2.1 Introduction

In addition to the general violation study performed earlier, a violation rate study based on time of day was also conducted. This was done in order to determine the changes in the rates based on whether it was daytime or nighttime. Daytime and nighttime hours were evaluated separately since visibility, traffic patterns, and driver behavior are different at night compared to during the day.

4.2.2.2 Methodology

Since two of the intersections go into flashing red/yellow overnight, only 1st & 10th Street and Edgewood & 42nd Street were studied for the time of day analysis. First data that had been reduced as mentioned previously were divided into daylight and darkness time periods. This was accomplished by first finding out the times the sun rose and set each day throughout the study using data tables from the U.S Naval Observatory. Next, the time period for daylight was found with the latest sunrise being used as the beginning of the period and the earliest sunset being used as the end of the period. For nighttime the latest sunset was used for the beginning and the earliest sunrise was used as the end of the time period. This was done in order to ensure that it was light during all times of the daylight period and dark during the entire nighttime period.

Tables 10 and 11 demonstrate the breakdown of the percentage of traffic entering the intersection during the two time periods. As can be seen the daytime group was around 60% of total AADT for each approach for both Edgewood & 42nd and 1st & 10th. Night traffic was around 7-10% of total AADT for each approach at Edgewood & 42nd and around 16-19% of total AADT for each approach at 1st &10th Street.

Table 10: Edgewood & 42nd Street - Percentage of Total Vehicles Based on Time of Day

		Before	June 2010	August 2010	October 2010
Northbound	Day	64.21%	63.23%	61.42%	64.31%
	Night	7.35%	8.90%	9.77%	7.51%
Southbound	Day	62.80%	62.21%	61.87%	62.66%
	Night	9.01%	10.10%	10.35%	9.27%

Table 11: 1st & 10th Street - Percentage of Total Vehicles Based on Time of Day

		Before	June 2010	August 2010	October 2010
Westbound	Day	62.97%	60.07%	58.61%	58.10%
	Night	16.74%	17.10%	17.19%	16.47%
Eastbound	Day	62.74%	59.82%	60.07%	59.89%
	Night	18.56%	19.24%	19.17%	17.81%

Once the daylight and night periods were found, data were disaggregated into these two times and then violation rates were calculated for each of the study stages. The violation rates from the after periods were compared to those from the before periods to find the change.

4.2.2.3 Analysis

The test of proportions was used to test the statistical significance of the changes. The same alpha value and approach as mentioned in section 4.2.1.3 were followed.

4.2.2.4 Results

Results showed that the largest decreases were seen during the daylight hours at these two intersections. 1st & 10th Street's westbound traffic reduced their violation rates by at least 75% during daylight hours while Edgewood & 42nd northbound saw decreases of 67-86% in red light violation rates. More changes can be seen for the daylight hours in Table 12.

Table 12:Changes in Violation Rates – Daylight Hours

			Before	June 2010	August 2010	October 2010
Edgewood & 42nd	Northbound	Violation Rate (per 10,000 EV)	20.71	6.87	5.51	2.86
		Sample Size	43453	46568	43547	49035
		Change in Violation Rate	--	**-13.84**	**-15.20**	**-17.86**
		% Change in Violation Rate	--	-67%	-73%	-86%
	Southbound	Violation Rate (per 10,000 EV)	4.97	3.54	3.41	2.42
		Sample Size	44252	42385	41019	41343
		Change in Violation Rate	--	-1.43	-1.56	**-2.55**
		% Change in Violation Rate	--	-29%	-31%	-51%
1st & 10th Street	Westbound	Violation Rate (per 10,000 EV)	56.08	4.23	3.73	13.08
		Sample Size	11413	9454	8040	9942
		Change in Violation Rate	--	**-51.85**	**-52.35**	**-43.00**
		% Change in Violation Rate	--	-92%	-93%	-77%
	Eastbound	Violation Rate (per 10,000 EV)	5.44	8.43	4.80	2.21
		Sample Size	9187	8307	8332	9031
		Change in Violation Rate	--	2.98	-0.64	-3.23
		% Change in Violation Rate	--	55%	-12%	-59%

During nighttime hours the only changes that were found which were statistically significant were the decreases seen in June and August at the Edgewood approaches and the westbound approach of 1st & 10th. This can be seen in Table 13. The lack of statistically significant changes seen in the night period can also be attributed to the smaller sample size of vehicles.

Table 13: Changes in Violation Rates - Night Hours

			Before	June 2010	August 2010	October 2010
Edgewood & 42nd	**Northbound**	Violation Rate (per 10,000 EV)	4.02	0.00	8.66	1.75
		Sample Size	4973	6556	6930	5725
		Change in Violation Rate	--	**-4.02**	4.64	-2.27
		% Change in Violation Rate	--	-100%	15%	-57%
	Southbound	Violation Rate (per 10,000 EV)	7.87	7.26	1.46	4.91
		Sample Size	6352	6884	6861	6114
		Change in Violation Rate	--	-0.61	**-6.41**	-2.96
		% Change in Violation Rate	--	-8%	-81%	-38%
1st & 10th Street	**Westbound**	Violation Rate (per 10,000 EV)	16.39	7.43	8.48	28.39
		Sample Size	7931	2692	2358	2818
		Change in Violation Rate	--	**-8.96**	-7.91	12.00
		% Change in Violation Rate	--	-55%	-48%	73%
	Eastbound	Violation Rate (per 10,000 EV)	11.04	7.49	22.56	3.70
		Sample Size	2718	2672	2659	2701
		Change in Violation Rate	--	-3.55	11.53	-7.34
		% Change in Violation Rate	--	-32%	104%	-66%

Overall these results help further support the safety benefits of these cameras in Cedar Rapids. The largest parts of the reductions seen are taking place during the daylight hours when the roads are most congested. Therefore the reduction in violations leads to a reduced chance of crashes occurring during these times when violators are more likely to encounter an opposing vehicle.

4.2.3 Violation Rate by Lane Study

4.2.3.1 Introduction

Violation rates were also analyzed by lane in order to provide information on violations based on the movement of traffic through the lanes. A reduction in violations at a through lane provides greater benefit than a reduction in a right turn only lane which allows right turn on red. This is due to the fact that crashes that occur due to violations in the through lane tend to be more severe right angle crashes than those crashes that occur due to a right turn on red violation.

4.2.3.2 Methodology

Data were first reduced as described in Chapter 3. Then they were disaggregated into each individual lane. Each approach had three lanes except for 2nd & 6th northbound where only two lanes were enforced.

Table 14 lists the movements in each lane at every approach. In Chapter 3 one can also see the lane configurations in Figures 3-6. In most cases lane 1 accommodates right turn only or right turn/through movements, lane 2 accommodates through traffic, except in the case of 2nd & 6th Ave where it is a left turn/through lane. Lane 3 houses left turn only or through movements.

Table 14: Traffic Movements by Lane

Intersection & Approach	Lane Number	Movement
2nd & 6th Ave Northbound	1	Through
	2	Left/Through
Edgewood & 42nd Ave Northbound	1	Through
	2	Through
	3	Left turn only
Edgewood & 42nd Ave Southbound	1	Through
	2	Through
	3	Left turn only
1st Ave & 10th St Westbound	1	Right/Through
	2	Through
	3	Left turn only
1st Ave & 10th St Eastbound	1	Right/Through
	2	Through
	3	Left turn only
2nd & 3rd Ave Northbound	1	Through
	2	Through
	3	Left/Through (left turn on red)
2nd & 3rd Ave Westbound	1	Right/Through
	2	Through
	3	Through

Once the lanes were broken down by approach the violation rates were calculated by lane for each time period. These were then compared across the time periods as in the previous sections.

4.2.3.3 Analysis

The test of proportions was again used to test the statistical significance of the changes including the use of an alpha value equal to 0.10. The same approach as mentioned in section 4.2.1.3 was followed. Refer to that section for further information.

4.2.3.4 Results

When analyzing the violation rates by lanes it was found that the greatest effects were seen in lanes 2 and 3 which are composed of the through, left turn/through, and left turn only lanes. Some of the largest increases were seen in lane 1 especially in lanes which had right turn as a movement and allowed for right turn on red. These increases therefore are not seen to be quite as troublesome as the increase seen in lane 3 for 2nd & 3rd westbound which also accommodated through movements.

Results for lane 1, seen in Table 15, indicate no clear conclusions on the cameras effect on violation rates. Both approaches of 1st & 10th Street saw statistically significant increases in violation rates; whereas 2nd & 6th Street northbound, Edgewood & 42nd Street northbound and 2nd & 3rd Street westbound all saw statistically significant increases. The changes based on movements are also non-conclusive with those with right turn on red are seeing both positive and negative changes based on approach. This non consistent improvement is also seen for lanes which just allow through movement.

Table 15: Changes in Violation Rates - Lane 1

Intersection	Direction	Time Period	Violation Rate (per 10,000 EV)	Sample Size	Change in Violation Rate	% Change in Violation rate
2nd & 6th	Northbound	Before	25.83	11227	--	--
		June	13.51	11847	**-12.33**	-48%
		August	9.62	11434	-16.21	-63%
		October	1.79	11172	**-24.04**	-93%
Edgewood & 42nd	Northbound	Before	146.28	5674	--	--
		June	0.00	3371	**-146.28**	-100%
		August	0.00	2879	**-146.28**	-100%
		October	0.00	6377	**-146.28**	-100%
	Southbound	Before	0.00	12801	--	--
		June	0.00	8576	0	n/a
		August	0.00	8143	0	n/a
		October	0.00	9792	0	n/a
1st & 10th	Westbound	Before	21.49	1861	--	--
		June	0.00	1312	-21.49	-100%
		August	27.55	726	**6.05**	28%
		October	147.29	1901	**125.80**	585%
	Eastbound	Before	0.00	200	--	--
		June	137.61	218	**137.61**	100%
		August	0.00	199	0	n/a
		October	0.00	234	0	n/a
2nd & 3rd	Northbound	Before	26.85	1490	--	--
		June	24.46	1635	-2.38	-9%
		August	42.49	1833	16.54	58%
		October	41.49	2410	14.65	55%
	Westbound	Before	21.75	2759	--	--
		June	9.05	2211	-12.70	-52%
		August	9.00	2222	-12.75	-59%
		October	5.40	3706	**-16.35**	**-75%**

Results for lane 2, which can be seen in Table 16, saw statistically significant decreases at the majority of the intersections. Decreases of at least 85% were seen at both 2nd & 6th Street northbound as well as 1st & 10th Street westbound. Lane 2 at all approaches except for 2nd & 6th Street northbound only allowed through movements; therefore the decreases seen here translate to notable increases in safety.

Table 17 indicates a trend towards a reduction in violation rates for lane 3 which accommodate through and left turn movements based on the approach. Notable exceptions to this trend include the increase seen in October at 2nd & 6th Street westbound where the violation rate increased. Large decreases in violation rates were seen at other approaches in October with 1st & 10th Street westbound seeing the violation rate drop by 90 violations per 10,000 entering vehicles and 2nd & 6th Street northbound as well as 1st & 10th Street westbound seeing no violations during the study period. These reductions occurred in through and left turn only lanes.

The results of the violation rate by lane study helped to further explain the findings of the general violation study by looking at changes based on the movement of vehicles in each lane. As was to be expected the largest increases were seen in lane 1, which at some approaches allowed right turn on red. Also lanes 2 and 3 saw statistically significant decreases over the majority of approaches which demonstrates that the cameras are working at diminishing the violations seen in those traveling through and turning left at the intersection.

Table 16: Changes in Violation Rates - Lane 2

		Time Period	Violation Rate (per 10,000 EV)	Sample Size	Change in Violation Rate	% Change in Violation rate
2nd & 6th	Northbound	Before	17.92	10605	--	--
		June	1.73	11536	**-16.18**	-90%
		August	1.74	11491	**-16.18**	-90%
		October	2.68	11195	**-15.24**	-85%
Edgewood & 42nd	Northbound	Before	14.46	23514	--	--
		June	6.49	26196	**-7.97**	-55%
		August	3.22	24823	**-11.24**	-78%
		October	3.34	26922	**-11.12**	-77%
	Southbound	Before	5.85	32505	--	--
		June	5.95	33601	0.11	2%
		August	3.03	32989	**-2.81**	-48%
		October	3.14	31835	**-2.70**	-46%
1st & 10th	Westbound	Before	16.39	7931	--	--
		June	1.27	7898	**-15.13**	-92%
		August	1.33	7495	**-15.06**	-92%
		October	2.51	7982	**-13.89**	-85%
	Eastbound	Before	7.26	8269	--	--
		June	6.60	7571	-0.65	-9%
		August	8.36	7179	1.10	15%
		October	4.74	8435	-2.51	-35%
2nd & 3rd	Northbound	Before	42.77	2572	--	--
		June	18.44	2712	**-24.33**	-57%
		August	48.28	2900	5.51	13%
		October	16.41	3047	**-26.36**	-62%
	Westbound	Before	7.53	7965	--	--
		June	4.00	7498	-3.53	-47%
		August	5.43	7368	-2.10	-28%
		October	3.23	9296	-4.31	-57%

Table 17: Changes in Violation Rates - Lane 3

		Time Period	Violation Rate (per 10,000 EV)	Sample Size	Change in Violation Rate	% Change in Violation rate
Edgewood & 42nd	Northbound	Before	10.13	38490	--	--
		June	4.76	44078	**-5.37**	-53%
		August	5.79	43199	**-4.35**	-43%
		October	1.33	42928	**-8.50**	-84%
	Southbound	Before	6.76	25156	--	--
		June	3.47	25950	**-3.29**	-49%
		August	4.37	25170	-2.39	-35%
		October	2.46	24354	**-4.29**	-64%
1st & 10th	Westbound	Before	96.02	8332	--	--
		June	19.91	6529	**-76.10**	-79%
		August	9.10	5497	**-86.92**	-91%
		October	5.53	7230	**-90.48**	-94%
	Eastbound	Before	12.96	6173	--	--
		June	1.64	6097	**-11.32**	-87%
		August	6.16	6492	-6.80	-52%
		October	0.00	6410	**-12.96**	-100%
2nd & 3rd	Northbound	Before	30.44	1971	--	--
		June	26.74	2244	-3.70	-12%
		August	4.44	2253	**-26.00**	-85%
		October	0.00	2146	**-30.44**	-100%
	Westbound	Before	11.28	7976	--	--
		June	10.88	8275	-0.41	-4%
		August	9.60	8334	-1.68	-15%
		October	24.02	6244	**12.74**	113%

4.3 TIME INTO RED ANALYSIS

The following two studies looked at changes in the time in which vehicles entered the intersection during the red phase. The first study evaluated the changes of the approach as a whole while the second study evaluated the changes based on lane. These were conducted in order to determine if the cameras were having an effect on those entering the intersection further into the red or those entering the intersection just as the light turned red. Drivers entering the intersection well into the red phase may pose a greater safety hazard than those who enter shortly after the red indication is given.

4.3.1 General Study

4.3.1.1 Introduction

In addition to a violation rates study, a study of the time into the red phase in which violators entered into the intersection was also conducted. This was completed in order to see how the cameras were also affecting those who continue to run the red light. Through the analysis it can be determined when drivers are entering the intersection during the red phase.

Those entering the intersection right as the signal enters the red phase could be those trapped in the dilemma zone and could possibly be taken care of with a longer yellow phase. These violations tend to be viewed as not as severe as those entering the intersection say 20 seconds into the red phase. This is due to the fact that as the other approaches light turns green that traffic will take longer to start up and will be more likely to anticipate someone running the red light and are more able to appropriately react to these violators. A vehicle driving through the intersection 20 seconds into the green phase is going to be less likely to anticipate a vehicle violating the signal.

4.3.1.2 Methodology

Data were reduced using the process stated in Chapter 3. Once that was complete all of the red light violations for each approach and study period were pulled. Next the times listed in the “red” column were averaged in order to find the average time into the red in which violators entered the intersections. This was found for the before period and then the three after periods. The change was then found by subtracting the average time of the after period from that of the before period for each of the three after periods.

In addition to looking at the average time vehicles entered into the intersection during the red phase each approach also had the time into the red broken up into bins in order to obtain more information on individual vehicles. The bin analysis proved to be helpful when there were few violations due to the ability of one violation to skew the average.

The number of violations occurring in each bin at each approach was tabulated and then the percentage of violations at each intersection in each bin was found. The bins used were 0-.49 seconds, 0.5-0.99 seconds, 1-1.99 seconds, 2-2.99 seconds, 3-3.99 seconds, 4-4.99 seconds, 5-9.99 seconds, 10-14.99 seconds, 15-29.99 seconds, and 30+ seconds and were chosen somewhat arbitrarily. The change in percent for each bin was then found by taking the percent in the after period and subtracting the percent in the before period.

4.3.1.3 Analysis

An approximate *t* test for independent samples with unequal variance was used to determine if the changes in average red time were statistically significant. Since the variances between time periods were largely different, the test for unequal variance was used. This test was performed using Equation 4-3 in order to calculate a test statistics, t'. In this equation $\boldsymbol{\bar{y}_1}$ represents the average red time in the before period and $\boldsymbol{n_1}$ represents the total number of observations during this before periods. $\boldsymbol{s_1^2}$ represents the variance of the before period. $\boldsymbol{D_0}$ is a specified value, in this case it is zero. The other variables with subscript 2 represent the after averages, observations and variances.

$$\boldsymbol{t' = \frac{(\bar{y}_1 - \bar{y}_2) - D_0}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}} \qquad \textbf{Equation 4-3}$$

This t' was then compared to a t table using α=0.10 in order to determine significance at 90% confidence. Degrees of freedom were calculated using Equation 4-4. If the value of degrees of freedom (df) was not an integer than it was rounded down to the nearest integer.

$$df = \frac{(n_1 - 1)(n_2 - 1)}{(1-c)^2(n_1 - 1) + c^2(n_2 - 1)} \quad with\ c = \frac{s_1^2/n_1}{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} \qquad \textbf{Equation 4-4}$$

Therefore if t' was greater than the t value found in the t-table the decrease in average red time was statistically significant and if t' was less than the t value found in the t-table then the increase in average red time was statistically significant.

In order to determine whether the changes in bin percentages were statistically significant the test of proportions was used. The procedure followed was outlined in section 4.2.1.3. An alpha value of 0.10 was again used.

4.3.1.4 Results

2nd & 6th Street results for the average time into the red in which those who ran the red light entered the intersection were mixed. As shown in Table 18, the approach saw a large increase in the average time into the red vehicles entered the intersection in June and saw a decrease in average time in October. An increase was also seen in August; however this result was not statistically significant.

Table 18: 2nd & 6th Street - Change in Average Red Time

		Before	June 2010	August 2010	October 2010
Northbound	Average Red Time (sec)	9.920	22.002	12.050	5.108
	Number of observations	48	18	13	5
	Variance	115.963	231.130	158.820	44.511
	Change in Average Red Time	--	**12.082**	2.130	**-4.812**

The results of the bin data analysis for changes in the time vehicles enter the intersection during the red showed statistically significant reductions in June and August for those entering the intersection just as the light turned red (0-0.49 seconds). This illustrates a possible change in behavior where vehicles which would have entered the intersection previously chose instead to stop. There was a large increase seen in those entering the intersection 30 plus seconds into the red in June. This helps explain the increase seen in average time. In October there were decreases in the percentage entering the intersection in the three bins representing the furthest times into the red phase (i.e. 20-24.99 seconds, 25-29.99 seconds and 30 plus seconds). These decreases, along with two other statically significant decreases seen in Table 19, give reason for the decrease seen in the average time in October.

Table 19 :2nd & 6th Street Northbound - Change in Average Red Time Bin Data

	Before		June 2010			August 2010			October 2010		
Time in seconds	**#**	**%**	**#**	**%**	**Change**	**#**	**%**	**Change**	**#**	**%**	**Change**
0-.49	7	14.58%	0	0%	**-14.58%**	0	0%	**-14.58%**	1	20.00%	5.42%
.5-.99	4	8.33%	2	11.11%	2.78%	1	7.69%	-0.64%	0	0%	**-8.33%**
1-1.99	7	14.58%	0	0.00%	**-14.58%**	2	15.38%	0.80%	1	20.00%	5.42%
2-2.99	3	6.25%	1	5.56%	-0.69%	1	7.69%	1.44%	1	20.00%	13.75%
3-3.99	0	0%	0	0%	0%	1	7.69%	7.69%	0	0%	0%
4-4.99	3	6.25%	0	0%	**-6.25%**	0	0%	**-6.25%**	0	0%	**-6.25%**
5-9.99	8	16.67%	3	16.67%	0%	3	23.08%	6.41%	1	20.00%	3.33%
10-14.99	1	2.08%	1	5.56%	3.47%	1	7.69%	5.61%	0	0%	-2.08%
15-19.99	2	4.17%	1	5.56%	1.39%	0	0.00%	**-4.17%**	1	20.00%	15.83%
20 - 24.99	8	16.67%	2	11.11%	-5.56%	2	15.38%	-1.28%	0	0%	**-16.67%**
25 - 29.99	3	6.25%	1	5.56%	-0.69%	1	7.69%	1.44%	0	0%	**-6.25%**
30+	2	4.17%	7	38.89%	**34.72%**	1	7.69%	3.53%	0	0%	**-4.17%**

Table 20 illustrates the large decreases seen in the average time into the red in which vehicles entered the intersection at the northbound approach of Edgewood & 42nd Street in all three after periods. These decrease ranged from 13 to 20 seconds. The southbound approach did not see similar results however; it in fact saw a statistically significant increase in October of 2010.

Table 20: Edgewood & 42nd Street - Change in Average Red Time

		Before	June 2010	August 2010	October 2010
Northbound	Average Red Time (sec)	21.244	7.561	0.749	1.999
	Number of observations	156	38	33	16
	Variance	3024.698	400.282	0.652	30.411
	Change in Average Red Time	--	**-13.683**	**-20.495**	**-19.245**
Southbound	Average Red Time (sec)	3.626	6.677	1.700	13.496
	Number of observations	36	29	21	16
	Variance	105.874	343.310	21.668	544.972
	Change in Average Red Time	--	3.052	-1.926	**9.870**

The changes seen in Table 20 to the average time into the red can be further described by examining the results of the bin analysis seen in Tables 21 and 22. For the northbound approach the increases seen were within the first two seconds while the statistically significant decreases seen were from two seconds on with some of the largest decreases being seen in the 30 seconds and above bin. These changes help to better explain the large decreases seen to the average time.

The southbound approach saw very little change when examining the bin data. In fact only three statistically significant changes were seen in this bin analysis. In October there was a decrease in those entering the intersection 1-1.99 seconds into the red and an increase in those entering 30 plus seconds in. This increase seen at the 30 seconds and above bin more than likely skewed the average which describes the increase seen in the average time.

Table 21: Edgewood & 42nd Street Northbound - Change in Average Red Time Bin Data

	Before		June 2010			August 2010			October 2010		
Time in seconds	**#**	**%**	**#**	**%**	**Change**	**#**	**%**	**Change**	**#**	**%**	**Change**
0-.49	38	24.36%	16	42.11%	**17.75%**	15	45.45%	**21.10%**	7	43.75%	**19.39%**
.5-.99	26	16.67%	12	31.58%	**14.91%**	12	36.36%	**19.70%**	7	43.75%	**27.08%**
1-1.99	9	5.77%	5	13.16%	7.39%	5	15.15%	**9.38%**	1	6.25%	0.48%
2-2.99	3	1.92%	0	0%	**-1.92%**	0	0%	**-1.92%**	0	0%	**-1.92%**
3-3.99	1	0.64%	0	0%	-0.64%	0	0%	-0.64%	0	0%	-0.64%
4-4.99	1	0.64%	0	0%	-0.64%	1	3.03%	2.39%	0	0%	-0.64%
5-9.99	13	8.33%	1	2.63%	**-5.70%**	0	0%	**-8.33%**	0	0%	**-8.33%**
10-14.99	8	5.13%	0	0%	**-5.13%**	0	0%	**-5.13%**	0	0%	**-5.13%**
15-19.99	10	6.41%	0	0%	**-6.41%**	0	0%	**-6.41%**	0	0%	**-6.41%**
20 - 24.99	11	7.05%	0	0%	**-7.05%**	0	0%	**-7.05%**	1	6.25%	-0.80%
25 - 29.99	6	3.85%	0	0%	**-3.85%**	0	0%	**-3.85%**	0	0%	**-3.85%**
30+	30	19.23%	4	10.53%	**-8.70%**	0	0%	**-19.23%**	0	0%	**-19.23%**

Table 22: Edgewood & 42nd Street Southbound - Change in Average Red Time Bin Data

	Before		June 2010			August 2010			October 2010		
Time in seconds	**#**	**%**	**#**	**%**	**Change**	**#**	**%**	**Change**	**#**	**%**	**Change**
0-.49	18	50.00%	11	37.93%	-12.07%	7	33.33%	-16.67%	7	43.75%	-6.25%
.5-.99	9	25.00%	8	27.59%	2.59%	11	52.38%	**27.38%**	4	25.00%	0%
1-1.99	6	16.67%	6	20.69%	4.02%	2	9.52%	-7.14%	0	0%	**-16.67%**
2-2.99	0	0%	0	0%	0.00%	0	0%	0%	0	0%	0%
3-3.99	0	0%	1	3.45%	3.45%	0	0%	0%	0	0%	0%
4-4.99	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
5-9.99	0	0%	0	0%	0%	0	0%	0%	1	6.25%	6.25%
10-14.99	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
15-19.99	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
20 - 24.99	0	0%	0	0%	0%	1	4.76%	4.76%	0	0%	0%
25 - 29.99	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
30+	3	8.33%	3	10.34%	2.01%	0	0%	**-8.33%**	4	25.00%	**16.67%**

The only statistically significant changes seen for 1st & 10th Street with respect to the average time in which vehicles entered the intersection during the red phase occurred in October of 2010 for both approaches. Both approaches saw a decrease in the average time. Table 23 shows the decreases to be 3.155 seconds and 6.127 seconds for westbound and eastbound traffic respectively.

Table 23:1st & 10th Street - Change in Average Red Time

		Before	June 2010	August 2010	October 2010
Westbound	Average Red Time (sec)	14.141	11.127	12.441	10.986
	Number of observations	97	14	8	34
	Variance	66.760	74.642	116.215	53.778
	Change in Average Red Time	--	-3.014	-1.670	**-3.155**
Eastbound	Average Red Time (sec)	7.095	10.232	7.552	0.968
	Number of observations	14	9	10	4
	Variance	86.490	64.491	58.262	0.397
	Change in Average Red Time	--	3.137	0.457	**-6.127**

The bin analysis did not provide any clear patterns for changes seen in driver behavior. Detailed results are listed in Tables 24 and 25. The only conclusion that can be drawn from these results is that the decreases seen in the average times in October were mainly due to the decreases in the percentage entering the intersection during the later (i.e. 10-24.99 seconds into the red) bins.

Table 24: 1st & 10th Street Westbound - Change in Average Red Time Bin Data

	Before		June 2010			August 2010			October 2010		
Time in seconds	#	%	#	%	**Change**	#	%	**Change**	#	%	**Change**
0-0.49	3	3.09%	0	0%	**-3.09%**	2	25.00%	**21.91%**	1	2.94%	-0.15%
0.5-0.99	3	3.09%	2	14.29%	11.19%	1	12.50%	9.41%	2	5.88%	2.79%
1-1.99	9	9.28%	1	7.14%	-2.14%	0	0%	**-9.27%**	2	5.88%	-3.40%
2-2.99	5	5.15%	0	0%	**-5.15%**	0	0%	**-5.15%**	2	5.88%	0.73%
3-3.99	0	0%	2	14.29%	**14.29%**	0	0%	0%	2	5.88%	**5.88%**
4-4.99	2	2.06%	1	7.14%	5.08%	0	0%	**-2.06%**	0	0%	**-2.06%**
5-9.99	8	8.25%	0	0%	**-8.25%**	0	0%	**-8.25%**	7	20.59%	**12.34%**
10-14.99	8	8.25%	2	14.29%	6.04%	0	0%	**-8.25%**	7	20.59%	**12.34%**
15-19.99	31	31.96%	2	14.29%	**-17.67%**	3	37.50%	5.54%	7	20.59%	**-11.37%**
20-24.99	25	25.77%	4	28.57%	2.80%	1	12.50%	-13.27%	2	5.88%	**-19.89%**
25-29.99	3	3.09%	0	0%	**-3.09%**	1	12.50%	9.41%	2	5.88%	2.79%
30+	0	0%	0	0%	0%	0	0%	0%	0	0%	0%

Table 25:1st & 10th Street Eastbound - Change in Average Red Time Bin Data

	Before		June 2010			August 2010			October 2010		
Time in seconds	#	%	#	%	**Change**	#	%	**Change**	#	%	**Change**
0-0.49	3	21.43%	1	10.00%	-11.43%	1	10.00%	-11.43%	1	25.00%	3.57%
0.5-0.99	5	35.71%	0	0%	**-35.71%**	2	20.00%	-15.71%	2	50.00%	14.29%
1-1.99	1	7.14%	0	0%	-7.14%	2	20.00%	12.86%	1	25.00%	17.86%
2-2.99	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
3-3.99	0	0%	1	10.00%	10.00%	0	0%	0%	0	0%	0%
4-4.99	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
5-9.99	0	0%	4	40.00%	**40.00%**	1	10.00%	10.00%	0	0%	0%
10-14.99	2	14.29%	1	10.00%	-4.29%	1	10.00%	-4.29%	0	0%	**-14.29%**
15-19.99	2	14.29%	0	0%	**-14.29%**	3	30.00%	15.71%	0	0%	**-14.29%**
20-24.99	1	7.14%	3	30.00%	**22.86%**	0	0%	-7.14%	0	0%	-7.14%
25-29.99	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
30+	0	0 %	0	0%	0%	0	0%	0%	0%		0%

The last intersection studied, 2nd & 3rd Street, saw a statistically significant decrease for both approaches in June of 2010. Both approaches in June saw decreases of around 8 seconds to the average time in which vehicles entered the intersection during the red phase. Results for August and October were not found to be statistically significant as can be seen in Table 26.

Table 26: 2nd & 3rd Street - Change in Average Red Time

		Before	June 2010	August 2010	October 2010
Northbound	Average Red Time (sec)	41.070	32.363	38.339	37.661
	Number of observations	21	15	23	15
	Variance	275.145	304.409	306.119	312.825
	Change in Average Red Time	--	**-8.706**	-2.73	-3.409
Westbound	Average Red Time (sec)	13.934	5.539	14.421	12.889
	Number of observations	21	14	14	20
	Variance	87.634	68.504	114.522	120.593
	Change in Average Red Time	--	**-8.395**	0.488	-1.045

The analysis of the time into the red phase by bins yielded an apparent pattern for the westbound approach. This pattern shows an increase in those entering the intersection as the light is just turning red (i.e. 0-0.49 seconds). The decreases seen in the average time in June may be attributed to the decreases seen in those entering the intersection during the later bins as seen in Tables 27 and 28. For instance those entering the intersection 30 seconds or more into the red for the northbound approach decreased by over 25 percent and for the westbound approach large decreases were seen in the 10-14.99 second and 15-19.99 second bins.

Table 27: 2nd & 3rd Street Northbound - Change in Average Red Time Bin Data

	Before		June 2010			August 2010			October 2010		
Time in seconds	#	%	#	%	Change	#	%	Change	#	%	Change
0-.49	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
.5-.99	0	0%	0	0%	0%	1	4.35%	4.35%	0	0%	0%
1-1.99	0	0%	1	6.67%	6.67%	0	0%	0%	0	0%	0%
2-2.99	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
3-3.99	0	0%	0	0%	0%	0	0%	0%	0	0%	0%
4-4.99	0	0%	0	0%	0%	1	4.35%	4.35%	0	0%	0%
5-9.99	3	14.29%	0	0%	**-14.29%**	0	0%	**-14.29%**	0	0%	**-14.29%**
10-14.99	0	0%	1	6.67%	6.67%	1	4.35%	4.35%	4	26.67%	**26.67%**
15-19.99	0	0%	2	13.33%	**13.33%**	1	4.35%	4.35%	1	6.67%	6.67%
20 - 24.99	1	4.76%	3	20.00%	**15.24%**	3	13.04%	8.28%	0	0%	-4.76%
25 - 29.99	0	0%	0	0%	0%	1	4.35%	4.35%	0	0%	0%
30+	17	80.95%	8	53.33%	**-27.62%**	15	65.22%	-15.73%	10	66.67%	-14.29%

Table 28: 2nd & 3rd Street Westbound - Change in Average Red Time Bin Data

	Before		June 2010			August 2010			October 2010		
Time in seconds	#	%	#	%	Change	#	%	Change	#	%	Change
0-.49	0	0%	3	21.43%	**21.43%**	2	14.29%	**14.29%**	3	15.00%	**15.00%**
.5-.99	2	9.52%	4	28.57%	**19.05%**	0	0%	**-9.52%**	3	15.00%	5.48%
1-1.99	1	4.76%	1	7.14%	2.38%	0	0%	-4.76%	1	5.00%	0.24%
2-2.99	0	0%	1	7.14%	7.14%	0	0%	0%	0	0%	0%
3-3.99	0	0%	0	0%	0%	2	14.29%	**14.29%**	0	0%	0%
4-4.99	0	0%	1	7.14%	7.14%	1	7.14%	7.14%	1	5.00%	5.00%
5-9.99	4	19.05%	1	7.14%	-11.90%	0	0%	**-19.05%**	0	0%	**-19.05%**
10-14.99	6	28.57%	1	7.14%	**-21.43%**	3	21.43%	-7.14%	3	15.00%	-13.57%
15-19.99	2	9.52%	0	0%	**-9.52%**	1	7.14%	-2.38%	2	10.00%	0.48%
20 - 24.99	2	9.52%	1	7.14%	-2.38%	2	14.29%	4.76%	1	5.00%	-4.52%
25 - 29.99	3	14.29%	1	7.14%	-7.14%	3	21.43%	7.14%	4	20.00%	5.71%
30+	1	4.76%	0	0%	-4.76%	0	0%	-4.76%	2	10.00%	5.24%

4.3.2 Lane Study

4.3.2.1 Introduction

Further information can be gained by examining the time into the red in which vehicles entered the intersection by lane. By examining the average time by lane one can look at the time those traveling straight through enter the intersection separate from those turning right on red. This will allow for a better analysis of the safety effect the cameras have had at the intersection. This is due to the fact that crashes which occur when a vehicle runs a red light traveling straight tend to be right angle crashes which are more severe than the crashes which occur with a right turn on red.

4.3.2.2 Methodology

Data were first reduced as mentioned in Chapter 3. Next the reduced data were disaggregated by lane for each approach and time period and then all of the red light violations were extracted. Then the average time from the "red" column was found for each lane for all of the approaches. Finally the change in the average time was found by subtracting the average time found in the after period by the average time found for the before period.

4.3.2.3 Analysis

An approximate *t* test with assumed unequal variance was used to determine the statistical significance of the results. This was performed according to the process listed in section 4.3.1.3. Again an alpha value of 0.10 was used.

4.3.2.4 Results

When analyzing the changes in the average time in which vehicles entered the intersection during the red phase by lane, it was difficult to detect a pattern.
By looking at the tables below and combining it with the results found in section 4.3.1 however one is able to draw further conclusions on the changes seen. For example 2nd & 3rd Street northbound saw no statistically significant change in the average red time when looking at all lanes combined in August and October, however when analyzing by lane it is

apparent in Table 29 that lane one saw statistically significant decreases in August and October. This is also a through lane, which means people are driving straight through the intersection not as late into the red phase as they had previously.

Statistically significant results were not widely found for the approaches as evident in Tables 29 to 31. Two approaches saw opposing changes when studying the change by lane as opposed to looking at the approach as a whole. These included lane 2 of 1st & 10th Street westbound in October which saw an increase in average time for the lane while the approach saw a decrease, and lane 3 of Edgewood & 42nd Street northbound in June which also saw an increase for the lane by a decrease for the overall approach. These approaches are through moving traffic and left turning traffic respectively. Therefore these more detailed results demonstrate the safety effects found in section 4.3.1 were not as relevant as would have been thought otherwise.

Table 29: Change in Average Time into the Red Phase - Lane 1

Intersection	Direction	Time Period	Average Red Time (sec)	Number of observations	Variance	Change in Average Red Time
2nd & 6th	Northbound	Before	7.36	29	95.75	--
		June	23.94	16	221.57	**16.58**
		August	11.33	11	183.63	3.97
		October	1.32	2	2.38	**-6.04**
Edgewood & 42nd	Northbound	Before	38.80	83	5035.17	--
		June	0	0	0	-38.80
		August	0	0	0	-38.80
		October	0	0	0	-38.80
	Southbound	Before	0	0	0	--
		June	0	0	0	0
		August	0	0	0	0
		October	0	0	0	0
1st & 10th	Westbound	Before	12.90	4	139.43	--
		June	0	0	0	-12.90
		August	14.09	2	383.92	1.18
		October	10.13	28	46.59	-2.77
	Eastbound	Before	0	0	0	--
		June	10.56	3	131.15	10.56
		August	0	0	0	0
		October	0	0	0	0
2nd & 3rd	Northbound	Before	51.02	4	7.44	--
		June	36.99	4	347.14	-14.04
		August	44.21	8	146.52	**-6.82**
		October	35.42	10	362.12	**-15.60**
	Westbound	Before	16.97	6	91.74	--
		June	13.17	2	326.66	-3.80
		August	13.14	2	195.43	-3.83
		October	11.97	2	6.85	-5.00

Table 30: Change in Average Time into the Red Phase - Lane 2

		Time Period	Average Red Time (sec)	Number of observations	Variance	Change in Average Red Time
2nd & 6th	Northbound	Before	13.83	19	127.09	--
		June	6.49	2	64.30	-7.34
		August	16.02	2	32.32	2.19
		October	7.63	3	63.92	-6.20
Edgewood & 42nd	Northbound	Before	1.49	34	26.93	--
		June	1.13	17	3.47	-0.37
		August	0.61	8	0.08	-0.88
		October	3.00	9	54.33	1.51
	Southbound	Before	6.30	19	189.75	--
		June	9.39	20	480.86	3.10
		August	2.76	10	45.54	-3.53
		October	21.31	10	7.27	**15.01**
1st & 10th	Westbound	Before	10.81	13	91.76	--
		June	1.96	1	0	0.89
		August	15.14	1	0	4.33
		October	17.51	2	5.58	**6.70**
	Eastbound	Before	4.75	6	97.96	--
		June	10.52	5	61.75	5.77
		August	10.10	6	69.24	5.35
		October	0.97	4	0.40	-3.78
2nd & 3rd	Northbound	Before	40.74	11	318.27	--
		June	33.16	5	526.99	-7.58
		August	34.19	14	389.93	-6.55
		October	42.14	5	242.53	1.39
	Westbound	Before	12.85	6	85.04	--
		June	2.58	3	4.60	**-10.27**
		August	11.42	4	155.93	-1.42
		October	14.43	3	164.83	1.59

Table 31: Change in Average Time into the Red Phase - Lane 3

		Time Period	Average Red Time (sec)	Number of observations	Variance	Change in Average Red Time
Edgewood & 42nd	Northbound	Before	1.10	39	9.80	--
		June	12.77	21	674.04	**11.67**
		August	0.79	25	0.84	-0.30
		October	0.71	7	0.15	-0.39
	Southbound	Before	0.64	17	0.20	--
		June	0.64	9	0.08	0
		August	0.73	11	0.19	0.09
		October	0.48	6	0.08	-0.17
1st & 10th	Westbound	Before	14.74	80	59.62	--
		June	11.83	13	73.32	-2.91
		August	11.24	5	102.43	-3.50
		October	13.70	4	125.46	-1.05
	Eastbound	Before	8.86	8	82.39	--
		June	7.81	1	0	-1.05
		August	3.73	4	26.88	-5.13
		October	0	0	0	-8.86
2nd & 3rd	Northbound	Before	35.03	6	336.38	--
		June	28.62	6	187.88	-6.42
		August	49.47	1	0	14.44
		October	0	0	0	-35.03
	Westbound	Before	12.64	9	98.93	--
		June	4.83	9	50.92	**-7.81**
		August	16.24	8	108.54	3.60
		October	12.70	15	138.96	0.06

4.4 YELLOW PHASE ANALYSIS

Two studies of changes in the behavior of drivers entering the intersection during the yellow phase were also conducted. These studies looked at first the changes in the percentage of vehicles entering the intersection during the yellow phase and the second looked at the change to the average time into the yellow phase in which they entered. These were conducted in order to determine if the cameras were causing more vehicles to stop and not enter the intersection when they would have traveled through the intersection otherwise.

4.4.1 Percentage Vehicles Entering Intersection during Yellow Phase Study

4.4.1.1 Introduction

Determining the percentage of vehicles entering the intersection during the yellow phase is useful in determining the cameras effect on driver behavior as they approach the intersection. One might assume that as a driver approaches a signalized intersection with red light cameras they would be more likely to not enter the intersection during the yellow phase than a driver approaching the same intersection without automated enforcement. This is due to the risk of receiving a violation should the signal turn red while the driver enters the intersection.

4.4.1.2 Methodology

Data were first reduced as mentioned in Chapter 3. Next the number of vehicles entering the intersection during the yellow phase was found. This was completed by finding any vehicle which had a time greater than 0 entered into the “Yellow” column in the data spreadsheets and also had a time in the “Red” column equal to 0. This was done in order to extract only those entering the intersection during the yellow phase.

The number of vehicles entering the intersection during the yellow phase was then divided by the entire sample size in order to determine the percentage entering during the yellow phase. The percentage was found for each approach at each intersection during all four of the time periods. Then the percentage for each of the after periods had the percentage from the before period subtracted in order to calculate the change.

4.4.1.3 Analysis

A test of proportions was used to determine the statistical significance of the changes in the percentages found. The method described in section 4.2.1.3 was used except an alpha value of 0.05 was used.

4.4.1.4 Results

The results of the analysis of the changes in the percentage of drivers entering the intersection during the yellow phase gave no clear conclusions. As seen in Table 32 in June the majority of approaches saw a statistically significant increase in the percentage of drivers entering the intersection during the yellow phase. No statistically significant results were seen in August, while both increases and decreases were seen in October. No correlation between a change in the percentage of those entering during the yellow and changes in violation rates could be found. It can be determined that for the most part the cameras did not have an impact on drivers' decisions to stop or proceed through the intersection during the yellow phase.

Table 32: Change in Percentage of Drivers Entering the Intersection during the Yellow Phase

	Before	June		August		October	
	Percentage entering	**Percentage entering**	**Change**	**Percentage entering**	**Change**	**Percentage entering**	**Change**
2nd & 6th NB	2.03%	2.32%	**0.29%**	2.08%	0.05%	1.40%	**-0.63%**
Edgewood & 42nd NB	4.10%	4.31%	**0.21%**	4.13%	0.03%	3.65%	**-0.45%**
Edgewood & 42nd SB	2.68%	3.11%	**0.43%**	3.21%	0.56%	2.66%	-0.02%
1st & 10th WB	2.33%	2.15%	-0.18%	2.33%	0%	2.78%	**0.45%**
1st & 10th EB	2.34%	3.02%	**0.67%**	n/a	n/a	3.14%	**0.80%**
2nd & 3rd NB	1.49%	1.69%	0.20%	1.57%	0.08%	1.53%	0.04%
2nd & 3rd WB	3.58%	3.95%	**0.37%**	3.73%	0.15%	3.44%	-0.14%

4.4.2 Time into Yellow Phase Study

4.4.2.1 Introduction

The time in which vehicles are entering the intersection during the yellow phase can also be studied in an attempt to examine how the cameras are changing driver behavior. It can provide information on whether the presence of the cameras is causing drivers to stop rather than travel through the intersection when the signal is in the yellow phase especially as the time into the yellow phase increases.

4.4.2.2 Methodology

Those who were entering into the intersection during the yellow phase were extracted as mentioned in section 4.4.1.2. Next the average time in which vehicles entered into the intersection during the yellow phase was found by averaging all of the times listed in the "Yellow" column for each approach during each time period for those vehicles extracted. Finally the average time from the before period was subtracted from the average times found for each of the after periods.

4.4.2.3 Analysis

An approximate *t* test assuming equal variance was used. This was used as opposed to the unequal variance used in previous sections due to the small changes in variance (less than three times different). Equation 4-5 was used in order to find a test statistic t

$$\boldsymbol{t = \frac{(\bar{y}_1 - \bar{y}_2) - D_0}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}} \qquad \textbf{Equation 4-5}$$

In this equation the following variables stand for the following things:

- $\boldsymbol{\bar{y}_1, \bar{y}_2}$= Average time into the yellow phase vehicles entered the intersection
- $\boldsymbol{D_0}$= a specified variable (in this case it is equal to 0)
- $\boldsymbol{n_1, n_2}$= the number of observations
- $\boldsymbol{s_1^2, s_2^2}$= the variance of the sample

- In each of these equations variables with subscript 1 indicate the before period and subscript 2 indicated the after period

An alpha value of 0.05 was used to test the statistical significance. Therefore a result was statically significant if the test statistic t was greater than 1.645 and smaller than -1.645.

4.4.2.4 Results

When studying the change in the average time into the yellow phase in which drivers entered the intersection one was able to determine that at four of the approaches statistically significant decreases were seen in all three after time periods. The only statistically significant increases seen to the average time occurred at 1st & 10th westbound in June and October as displayed in Table 33. It should be noted that the average time for the before period for 1st &10th westbound was the lowest of all the approaches studied and that the largest average time for this approach was still lower than all but two of the other approaches average time in the before period.

The decreases seen to the average time into the yellow would appear to support the idea that the cameras are affecting driver behavior and causing them to come to a stop instead of entering the intersection the further one gets into the yellow phase. However when you couple this with the data found in the previous section (4.4.1.4) one finds that more drivers (as a percentage of total drivers) are entering the intersection during the yellow phase. Therefore by combing the results one could see a slight pattern where the percentage entering during the yellow phase increased while the time into the yellow decreased.

Table 33: Change in the Average Time into the Yellow in Which Drivers Enter the Intersection

	Before	June		August		October	
	Time into Yellow (sec)	**Time into Yellow (sec)**	**Change**	**Time into Yellow (sec)**	**Change**	**Time into Yellow (sec)**	**Change**
2nd & 6th NB	1.81	1.68	**-0.13**	1.67	**-0.14**	1.68	**-0.13**
Edgewood & 42nd NB	1.48	1.32	**-0.15**	1.26	**-0.22**	1.22	**-0.26**
Edgewood & 42nd SB	1.47	1.27	**-0.20**	1.22	**-0.25**	1.11	**-0.36**
1st & 10th WB	1.20	1.42	**0.22**	1.29	0.10	1.53	**0.33**
1st & 10th EB	1.84	1.44	**-0.40**	n/a	n/a	1.45	**-0.38**
2nd & 3rd NB	1.60	1.47	-0.13	1.41	-0.19	1.32	**-0.28**
2nd & 3rd WB	1.57	1.58	0.01	1.53	-0.04	1.60	0.03

4.5 HEADWAY ANALYSIS

4.5.1 Introduction

A headway analysis was completed in order to determine if the cameras had an effect on the amount of space between vehicles. It is often claimed that red light cameras increase rear end crashes since drivers are more likely to slam on their brakes when the light is in the yellow or red phase rather than travel through the intersection and risk receiving a citation. If this claim is true it is assumed drivers will give more space to the vehicle in front of them so they have adequate space to safely stop in the event the vehicle in front of them suddenly brakes. The following study tests that assumption for the four camera enforced intersections in Cedar Rapids.

4.5.2 Methodology

Data were first reduced following the process outlined in Chapter 3. Next data were sorted by lane and then into chronological order. Data needed to be sorted by lane to determine the gap between subsequent vehicles in the same lane. Then the gap between vehicles was found by taking the time listed in the "time" column and subtracting it from the time for the vehicle before it. These were found to the nearest second due to limitations with the data set.

Next the data were cleaned up by removing any values for gaps found when there was a break in data collection. It was also cleaned up to find the correct value when switching to a new day (i.e. time in the day before was 23:59:59 and next day was 0:00:01 value for gap originally calculated would have been 23:59:58 instead of 0:00:02). After data were cleaned up in this manner and then the spreadsheet was sorted by gap length.

Then, the lengths of gaps were placed into different bins and the percent in each bin were found. The bins used were 0-1 seconds, 1-2 seconds, 2-3 seconds, 3-4 seconds, 4-5 seconds, 5-10 seconds, 10-30 seconds, 30-60 seconds and 60 seconds and above with the lower limit being inclusive. More bins were used for the smaller gaps in order to better determine the cameras effects on these drivers. Finally the change in percentages for each bin were found by subtracting the percentage in the before period from the percentage in the after period.

4.5.3 Analysis

A test of proportions was used to determine statistical significance of the changes in percentages seen. A description of the test can be found in section 4.2.1.3. An alpha value of 0.05 was used so results were statistically significant if Z was greater than 1.645 or smaller than -1.645.

4.5.4 Results

2nd & 6th northbound saw decreases in all three time periods at the 0-1 second bin. Decreases were also seen at the 1 minute and above bin. Mixed results were seen by after time period for the rest of the results. October saw large decreases in the smaller bins and then large increases for the bin composed of 5-60 seconds. More detailed information can be found in Table 34.

Table 34: 2nd & 6th Street Northbound – Headway Analysis

Bin (sec)	Before		June			August			October		
	#	%	#	%	Change	#	%	Change	#	%	Change
0 -1	829	3.80%	607	2.60%	**-1.20%**	667	2.91%	**-0.89%**	545	2.44%	**-1.36%**
1-2	1016	4.66%	1119	4.79%	0.13%	1185	5.17%	**0.52%**	833	3.73%	**-0.93%**
2-3	2703	12.39%	3188	13.64%	**1.25%**	3071	13.41%	**1.02%**	1940	8.68%	**-3.71%**
3-4	2309	10.58%	2742	11.73%	**1.15%**	2581	11.27%	**0.68%**	1758	7.87%	**-2.72%**
4-5	1388	6.36%	1433	6.13%	-0.23%	1432	6.25%	-0.11%	1067	4.77%	**-1.59%**
5-10	2179	9.99%	2474	10.59%	**0.60%**	2377	10.38%	0.39%	2561	11.46%	**1.47%**
10 - 30	2021	9.26%	2194	9.39%	0.12%	2085	9.10%	-0.16%	4318	19.32%	**10.06%**
30 - 60	2594	11.89%	2539	10.86%	**-1.03%**	2503	10.93%	**-0.96%**	3690	16.51%	**4.62%**
60+	6775	31.06%	7074	30.27%	**-0.79%**	7006	30.58%	-0.47%	5638	25.23%	**-5.83%**

Edgewood & 42nd northbound saw statistically significant decreases across all time periods for the 1 minute and above bin. Increases were seen in June and August for the 2-3 second and 3-4 second bins and then for the 10-30 second and 30-60 second bins in October. More information on the other decreases seen can be found in Table 35. Edgewood & 42nd Street southbound saw statistically significant decreases in both the 0-1 second and 1-2 second bins. Statistically significant increases were seen at the 1+ minute bins. More detailed information on the changes seen in the other bins can be found in Table 36.

Table 35: Edgewood & 42nd Street Northbound – Headway Analysis

Bin (sec)	Before		June			August			October		
	#	%	#	%	Change	#	%	Change	#	%	Change
0 -1	1274	1.88%	1362	1.85%	-0.03%	1216	1.72%	**-0.17%**	1492	1.96%	0.07%
1-2	6855	10.13%	7586	10.30%	0.17%	6734	9.50%	**-0.63%**	7757	10.17%	0.05%
2-3	18420	27.22%	21747	29.53%	**2.31%**	20254	28.57%	**1.35%**	21125	27.71%	0.49%
3-4	8925	13.19%	10657	14.47%	**1.28%**	10111	14.26%	**1.07%**	10037	13.16%	-0.02%
4-5	3476	5.14%	3773	5.12%	-0.01%	3741	5.28%	0.14%	3744	4.91%	**-0.23%**
5-10	6066	8.96%	6169	8.38%	**-0.59%**	6398	9.02%	0.06%	6534	8.57%	**-0.39%**
10 - 30	7815	11.55%	7275	9.88%	**-1.67%**	7454	10.51%	**-1.03%**	9238	12.12%	**0.57%**
30 - 60	8003	11.83%	8016	10.89%	**-0.94%**	8132	11.47%	**-0.36%**	9424	12.36%	**0.54%**
60+	6841	10.11%	7057	9.58%	**-0.53%**	6858	9.67%	**-0.44%**	6890	9.04%	**-1.07%**

Table 36: Edgewood & 42nd Street Southbound – Headway Analysis

Bin (sec)	Before		June			August			October		
	#	%	#	%	Change	#	%	Change	#	%	Change
0 -1	856	1.21%	542	0.80%	**-0.42%**	536	0.81%	**-0.41%**	660	1.00%	**-0.21%**
1-2	5495	7.80%	5281	7.75%	-0.05%	4697	7.08%	**-0.71%**	4743	7.19%	**-0.61%**
2-3	16952	24.06%	17020	24.98%	**0.92%**	16197	24.43%	0.37%	15127	22.93%	**-1.13%**
3-4	9491	13.47%	9776	14.35%	**0.88%**	9295	14.02%	**0.55%**	8712	13.20%	-0.27%
4-5	4228	6.00%	4437	6.51%	**0.51%**	4297	6.48%	**0.48%**	4019	6.09%	0.09%
5-10	8233	11.68%	7979	11.71%	0.03%	7867	11.87%	0.18%	7568	11.47%	-0.21%
10 - 30	9367	13.29%	7623	11.19%	**-2.10%**	8053	12.15%	**-1.15%**	9407	14.26%	**0.96%**
30 - 60	8537	12.12%	7407	10.87%	**-1.24%**	7359	11.10%	**-1.02%**	8510	12.90%	**0.78%**
60+	7300	10.36%	8059	11.83%	**1.47%**	7998	12.06%	**1.70%**	7232	10.96%	**0.60%**

1st & 10th Street saw statistically significant decreases at both approaches in August for the 0-1 second bin. Other decreases during at least two months were seen at the westbound approach for the 2-3 second bin, 3-4 second bin and 10-30 second bin and for the eastbound approach in the 3-4 and 4-5 second bins. Increases were seen in the 1 minute and above bin for the westbound approach and for the eastbound approach increases were seen at the 1-2 second and the 30-60 second bins. Detailed results can be seen in Tables 37 and 38.

Table 37: 1st & 10th Street Westbound – Headway Analysis

Bin (sec)	Before		June			August			October		
	#	%	#	%	Change	#	%	Change	#	%	Change
0 -1	142	0.78%	129	0.82%	0.04%	85	0.62%	**-0.16%**	118	0.69%	-0.09%
1-2	673	3.71%	616	3.91%	0.20%	537	3.92%	0.20%	662	3.87%	0.16%
2-3	3384	18.67%	2827	17.97%	**-0.71%**	2310	16.84%	**-1.83%**	2963	17.32%	**-1.36%**
3-4	2823	15.58%	2464	15.66%	0.08%	1993	14.53%	**-1.05%**	2360	13.79%	**-1.78%**
4-5	1199	6.62%	1089	6.92%	0.30%	935	6.82%	0.20%	1159	6.77%	0.16%
5-10	2202	12.15%	1809	11.50%	**-0.66%**	1747	12.74%	0.59%	2150	12.57%	0.41%
10 - 30	2739	15.11%	1971	12.53%	**-2.59%**	1772	12.92%	**-2.19%**	2660	15.55%	0.43%
30 - 60	2245	12.39%	1927	12.25%	-0.14%	1689	12.31%	-0.07%	2254	13.17%	**0.79%**
60+	2715	14.98%	2904	18.45%	**3.47%**	2647	19.30%	**4.32%**	2784	16.27%	**1.29%**

Table 38: 1st & 10th Street Eastbound – Headway Analysis

Bin (sec)	Before		June			August			October		
	#	%	#	%	Change	#	%	Change	#	%	Change
0 -1	50	0.34%	41	0.30%	-0.05%	33	0.24%	**-0.10%**	53	0.35%	0.01%
1-2	458	3.13%	494	3.56%	**0.43%**	452	3.26%	0.13%	546	3.62%	**0.49%**
2-3	2401	16.40%	2223	16.01%	-0.39%	2198	15.85%	-0.55%	2430	16.12%	-0.28%
3-4	1961	13.40%	1766	12.72%	**-0.68%**	1708	12.32%	**-1.08%**	1893	12.56%	**-0.84%**
4-5	901	6.15%	0-	5.19%	**-0.97%**	764	5.51%	**-0.65%**	853	5.66%	**-0.50%**
5-10	1766	12.06%	1585	11.42%	**-0.65%**	1621	11.69%	-0.37%	1827	12.12%	0.05%
10 - 30	3203	21.88%	3008	21.67%	-0.21%	3048	21.98%	0.10%	3388	22.47%	0.59%
30 - 60	2291	15.65%	2362	17.01%	**1.36%**	2507	18.08%	**2.43%**	2538	16.83%	**1.18%**
60+	1608	10.98%	1684	12.13%	**1.15%**	1536	11.08%	0.09%	1548	10.27%	**-0.72%**

At the northbound approach of 2nd & 3rd Street the only statistically significant decreases were seen in October for the 0-1 second bin and during all three after periods in the 1 minute and above time period. Detailed results relating the magnitude of the decreases and information on the increases can be seen in Table 39. The westbound approach of 2nd & 3rd Street saw the only statistically significant increase of all the approaches in the 0-1 bin in October. Decreases were seen in August in the bins ranging from 0-4 seconds. Detailed results on the magnitude and existence of other significant changes can be found in Table 40.

Table 39: 2nd & 3rd Street Northbound – Headway Analysis

Bin (sec)	Before		June			August			October		
	#	%	#	%	Change	#	%	Change	#	%	Change
0 -1	100	1.66%	112	1.71%	0.05%	117	1.67%	0.01%	81	1.07%	**-0.59%**
1-2	124	2.06%	137	2.09%	0.03%	181	2.58%	**0.52%**	137	1.81%	-0.25%
2-3	136	2.26%	172	2.62%	**0.36%**	195	2.78%	**0.52%**	195	2.57%	0.31%
3-4	179	2.98%	214	3.26%	0.29%	221	3.15%	0.17%	233	3.07%	0.10%
4-5	98	1.63%	127	1.94%	**0.31%**	114	1.63%	0.00%	148	1.95%	0.32%
5-10	316	5.25%	336	5.13%	-0.13%	442	6.30%	**1.05%**	481	6.34%	**1.09%**
10 - 30	411	6.83%	523	7.98%	**1.15%**	484	6.90%	0.07%	589	7.77%	**0.94%**
30 - 60	752	12.50%	880	13.42%	**0.92%**	936	13.34%	0.84%	1139	15.02%	**2.52%**
60+	3900	64.83%	4054	61.85%	**-2.98%**	4325	61.65%	**-3.17%**	4579	60.39%	**-4.43%**

Table 40: 2nd & 3rd Street Westbound – Headway Analysis

Bin (sec)	Before		June			August			October		
	#	%	#	%	Change	#	%	Change	#	%	Change
0 -1	189	1.01%	173	0.96%	-0.05%	138	0.77%	**-0.24%**	246	1.28%	**0.27%**
1-2	566	3.03%	444	2.47%	**-0.56%**	459	2.56%	**-0.47%**	635	3.30%	0.27%
2-3	1513	8.10%	1391	7.74%	-0.36%	1339	7.48%	**-0.62%**	1611	8.38%	0.28%
3-4	1330	7.12%	1226	6.82%	-0.30%	1108	6.19%	**-0.93%**	1406	7.31%	0.19%
4-5	856	4.58%	893	4.97%	0.39%	843	4.71%	0.13%	986	5.13%	**0.55%**
5-10	2681	14.35%	2463	13.71%	**-0.64%**	2605	14.55%	0.20%	2684	13.96%	-0.39%
10 - 30	3379	18.09%	3422	19.05%	**0.96%**	3462	19.33%	**1.25%**	3663	19.05%	**0.96%**
30 - 60	2487	13.31%	2364	13.16%	-0.15%	2357	13.16%	-0.15%	2589	13.46%	0.15%
60+	5681	30.41%	5590	31.11%	0.71%	5595	31.25%	**0.84%**	5409	28.13%	**-2.28%**

Overall the majority of approaches saw statistically significant decreases in the 0-1 second bin which could suggest that drivers were giving each other more space anticipating that some drivers would slam on their brakes. Inconsistent results were seen for the other bins and therefore no conclusions could be made. Looking at larger samples of data and trying to remove possible seasonal driving effects may help to obtain more conclusive results.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL CONCLUSIONS

This thesis evaluated the red light running program in the City of Cedar Rapids, Iowa which was implemented starting in February of 2010. While a crash analysis is the preferred method used to evaluate the effectiveness of the cameras it cannot be reliably completed in the short term. Therefore other metrics must be looked at and used to determine the safety effects of the program.

In this instance a violations study was completed with the understanding that a decrease in violations is a surrogate for a decrease in red light crashes. Additionally changes in vehicles entering the intersection into the red phase and yellow phase along with a headway analysis were completed in order to determine if the cameras were having the desired effect on safety. These analyses were completed across four phases of data collection (before period, June 2010, August 2010, and October 2010).

The general violation study saw decreases in the violation rate at approaches in the range of 6 to 91% with an average of around a 50% decrease. These findings are similar to those found by Retting et al. (1999b, 1999c) in Oxnard, CA and Fairfax, VA as well as the general findings from the studies mentioned in both Retting (2010) and Bochner & Walden (2010).

The findings from the violation rates by time of day study and lane study further support the effectiveness of the cameras. The majority of reductions in violations are occurring during the day when the traffic is heaviest. The decrease seen during the times when traffic is heaviest leads to a reduction in potential crashes as found in the model by Bonneson et al. (2002). The lane study found that the largest increases were seen in lane 1 where right turn on red was allowed at most approaches. The decreases seen in lanes 2 and 3 (the through and left turn movements) help to provide evidence of the cameras effectiveness in reducing the potential for right angle and left turn related crashes.

The findings of the yellow phase and headway studies help to support the positive effect on safety that occurred once the cameras were in place. The yellow phase study saw vehicles entering the intersection not as far into the yellow phase, while the headway analysis saw a decrease in the percentage of vehicles traveling with headways in the 0-1 second bin. These findings suggest that drivers are making more of an effort to give each space while they approach the intersections as well as attempting to not enter the intersection when the signal has been yellow for awhile.

The findings of the red phase study were inconclusive. Both increases and decreases to the average time into the red phase in which vehicles were entering the intersections were seen. The bin data helped in some cases to explain these changes.

Overall, the main findings of the research conducted as a part of this thesis support the idea that the cameras have had a positive effect on safety at the intersections. This is especially supported by the decreases in violation rates seen at all of the intersections.

5.2 FUTURE RESEARCH

5.2.1 Additional Violation Studies

The violations studies in this thesis occurred one to nine months (depending on approach) after operations began. A violation study one year after the cameras have been operational is recommended. A study one year later is helpful in order to see the longer term effects of the cameras on violations as well as to avoid any seasonal variation that may be present in the current research

5.2.2 Crash Analysis

It is suggested that if the cameras stay in place for an extended period of time that a crash analysis be completed in order to quantify the cameras effect on crashes at the intersection. It is recommended that it be completed using the Empirical Bayes technique which appears to be the most widely accepted method to date. This analysis should look at changes to red light crashes (i.e. right angle and left turn related) as well as the changes to rear end crashes. It could also be used to determine if a spillover effect is seen at other intersections across the city.

5.2.3 Braking Study

A large complaint of drivers upon the installation of red light cameras is that rear end crashes will increase due to drivers braking hard and at the last minute to avoid receiving a citation. Studies show mixed results on whether increases in rear end crashes occur or not. It is suggested that a study be completed to examine the actual effect on braking that occurs at intersections which have red light cameras as vehicles brake during the yellow and red phases.

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APPENDIX A: CEDAR RAPIDS AUTOMATED ENFORCEMENT ORDINANCE

61.138 - AUTOMATED TRAFFIC ENFORCEMENT.

(a)
General. The City of Cedar Rapids, in accordance with its police powers, may deploy, erect or cause to have erected an automated traffic enforcement system for making video images of vehicles that fail to obey red light traffic signals at intersections designated by the city manager, or his designee, or fail to obey speed regulations at other locations in the city. The systems may be managed by the private contractor that owns and operates the requisite equipment with supervisory control vested in the city's police department. Video images shall be provided to the police department by the contractor for review. The police department will determine which vehicle owners are in violation of the city's traffic control ordinances and are to receive a notice of violation for the offense.
(b)
Definitions.
1.
Automated Traffic Citation shall mean a notice of fine generated in connection with the automated traffic enforcement system.
2.
Automated Traffic Enforcement Contractor shall mean the company or entity, if any, with which the City of Cedar Rapids contracts to provide equipment and/or services in connection with the Automated Traffic Enforcement System.
3.
Automated Traffic Enforcement System shall mean an electronic system consisting of a photographic, video, or electronic camera and a vehicle sensor installed to work in conjunction with an official traffic controller or police department employee to automatically produce photographs, video or digital images of each vehicle violating a standard traffic control device or speed restriction.
4.
Vehicle Owner shall mean the person or entity identified by the Iowa Department of Transportation, or registered with any other state vehicle registration office, as the registered owner of a vehicle.
(c)
Vehicle Owner's Civil Liability for Certain Traffic Offenses.
1.
The Vehicle Owner shall be liable for a fine as imposed below if such a vehicle crosses a marked stop line or the intersection plane at a system location when the traffic signal for that vehicle's direction is emitting a steady red light or arrow.
2.
The Vehicle Owner shall be liable for a fine as imposed below if such vehicle travels at a speed above the posted limit.
3.

The violation may be exempted from liability as outlined below in subsection (f.) of this section, and other defenses may be considered in connection with the appeal process.
4.
In no event will an Automated Traffic Citation be sent or reported to the Iowa Department of Transportation or similar department of any other state for the purpose of being added to the Vehicle Owner's driving record.
(d)
Notice of Violation; Fine.
1.
Notice of the violation will be mailed to the Vehicle Owner for each violation recorded by an Automated Traffic Enforcement System or traffic control signal monitoring device. The Automated Traffic Enforcement Contractor shall mail the notice within 30 days after receiving information about the Vehicle Owner. The notice shall include the name and address of the Vehicle Owner; the vehicle make, if available and readily discernable, and registration number; the violation charged; the time; the date; and the location of the alleged violation; the applicable fine and monetary penalty which shall be assessed for late payment; information as to the availability of an administrative hearing in which the notice may be contested on its merits; and that the basis of the notice is a photographic record obtained by an Automated Traffic Enforcement System.
2.
Any violation of subsequent section (c.)(1). above shall be subject to a civil fine of one hundred dollars, payable to the City of Cedar Rapids.
3.
Any violation of subsection (c.)(2). above shall be subject to a civil fine as listed in the table below, and the fine for any violation committed in a designated construction zone (as provided by Iowa Code), shall be doubled, as reflected below, subject in any event to the limit on fines sought in municipal infractions. All civil fines shall be payable to the City of Cedar Rapids.

Speed over the limit	Civil Fine	If in Construction Zone
1 through 5 MPH	$25	$50
6 through 10 MPH	$50	$100
11 through 20 MPH	$75	$150
21 through 25 MPH	$100	$200
25 through 30 MPH	$250	$500
Over 30 MPH	$500	$750

(e)
Contesting an Automated Traffic Citation. A Vehicle Owner who has been issued an Automated Traffic Citation may contest the citation as follows:
1.

By submitting in a form specified by the City a request for an administrative hearing to be held at the Cedar Rapids Police Department before an administrative appeals board (the "Board") consisting of one or more impartial fact finders. Such a request must be filed within 30 days from the date on which Notice of the violation is sent to the Vehicle Owner. After a hearing, the Board may either uphold or dismiss the Automated Traffic Citation, and shall mail its written decision within 10 days after the hearing, to the address provided on the request for hearing. If the citation is upheld, then the Board shall include in its written decision a date by which the fine must be paid, and on or before that date, the Vehicle Owner shall either pay the fine or submit a request pursuant to the next paragraph, (e.)(2.).

2.

By submitting in a form specified by the City a request that in lieu of the Automated Traffic Citation, a municipal infraction citation be issued and filed with the Small Claims Division of the Iowa District Court in Linn County. Such a request must be filed within 30 days from the date on which Notice of the violation is sent to the Vehicle Owner. Such a request will result in a court order requiring the Vehicle Owner to file an answer and appearance with the Clerk of Court, as well as setting the matter for trial before a judge or magistrate. If the Court finds the Vehicle Owner guilty of the municipal infraction, state mandated court costs will be added to the amount of the fine imposed by this section.

(f)

Exceptions to Owner Liability. There shall be no liability pursuant to this section if:

1.

The operator of the vehicle in question was issued a uniform traffic citation for the violation in question pursuant to Cedar Rapids Code Chapter 61 or Iowa Code Chapter 321 (2008); or

2.

The violation occurred at any time after the vehicle in question or its state registration plates were reported to a law enforcement agency as having been stolen, provided, however, the vehicle or its plates had not been recovered by the Vehicle Owner at the time of the alleged violation; or

3.

The vehicle in question was an authorized emergency vehicle; or

4.

The officer inspecting the recorded image determines that the vehicle in question was lawfully participating in a funeral procession; or

5.

The officer inspecting the recorded image determines that the vehicle in question entered the intersection in order to yield the right-of-way to an emergency vehicle.

(g)

Failure to Timely Pay or Appeal. If the recipient of an Automated Traffic Citation does not either pay the fine by the due date stated in the citation or appeal the citation as provided herein, a municipal infraction citation may be filed by the Cedar Rapids Police Department and a fine may be sought in accordance with Cedar Rapids Code section 1.12 rather than subsection (d.) above. If the Court finds the Vehicle Owner guilty of the municipal infraction, state mandated court costs will be added to the amount of the fine imposed by this section.

APPENDIX B: DATA DICTIONARY

Heading	Explanation
Date	The day in which the data were collected listed in month/day/year format
Time	This is the time during the day in which a vehicle enters the intersection. It is listed in hour: minute: second format using military time.
Site Code	This column lists the intersection and approach in which the data were collected for. Below are the site codes and which intersection and approach they stand for. • 6THNB – 2nd & 6th Street northbound • EDGNB – Edgewood & 42nd Street northbound • EDGSB – Edgewood & 42nd Street Southbound • 1STWB – 1st & 10th Street westbound • 1STEB – 1st & 10th Street eastbound • 3RDNB – 2nd & 3rd Street northbound • 3RDWB – 2nd & 3rd Street westbound
Offence Type	This column lists whether a violation took place for that vehicle. One of four thing will be listed in this column: • no violation: In this case no violation occurred and the vehicle proceeded through the intersection without speed or running the red light • red: In this case the vehicle entered the intersection after the light had been red for at least 0.1 seconds. In this case the vehicle was not speeding. • speed: In this case the vehicle entered the intersection traveling at least 12 mph over the posted speed limit. • speed + red: In this case the vehicle entered the intersection after the light had been red for at least 0.1 seconds and was traveling at least 7 mph over the posted speed limit.
Speed Validation	This column lists whether a valid length could be determined. If the length is valid and the vehicle enters the intersection the potential violation is reviewed by Cedar Rapids PD to ensure the offender did indeed run the red light.

Heading	Explanation
Speed	This column lists the speed in which a vehicle is traveling when it enters the intersection. If the speed validation column has an “i" listed for a vehicle the speed column will be 0. Speeds are listed in mph.
Length Validation	This column lists whether a valid speed could be determined. According to the vendor A valid speed measurement means that the vehicle was traveling within the limits of the radar (6MPH to 126MPH). Invalid triggers occur when the radar detected a speed less than 6 MPH or the return signature of the Doppler radar was not complete, or found inconsistencies in the Doppler shift. This is seen a lot with cars that slam on their breaks just before the stop bar. These are reviewed by Cedar Rapids PD to ensure the offender did indeed run the red light.
Length	This is the length used for the length validation. If the length is valid it will list the length (usually 613) and if invalid it will list 0.
Pardon Time	This is a length of time into the red before citations are issued. At the intersections in the study this is 0.1 seconds. The column will list 0 if the vehicle enters the intersection in the green or yellow phase. The column will list 100 (time is listed in thousandths of a second) if the vehicle enters the intersection in the red phase.
Yellow Time	This lists the time into the yellow phase a vehicle entered the intersection. If the signal was green it is listed as 0. If the signal was yellow it lists how far into the yellow that was. If the signal was red it lists the length of the yellow cycle. This time is listed in thousandths of a second.
Red Time	This lists the time into the red phase a vehicle entered the intersection. If the signal was green or yellow the time listed is 0. If the signal was red it lists the length of time into the red phase that the vehicle entered. This time is listed in thousandths of a second.

APPENDIX C: CORRESPONDENCE

George Jennings to Shauna, me, Rich, Sgt show details 3/4/10

Shauna/Nicole,

Please find the answers to your questions below. I also attached the statistics for the intersection of NB 2nd Ave & 6th St. This camera has been in quiet mode gathering data since the 20th of February.

What configuration is used for lane number, For instance is lane 1 the lane farthest to the left or right?

At most locations lane numbers are from right to left. At 2nd Ave. and 6th St. WB lane 1 is the farthest to the right. We did this because there are four lanes on this road and we are enforcing three (RT turn, Thru, Thru).

- Do V and I in speed and length validation stand for valid/invalid (if so how was valid/invalid determined)?

  Valid/invalid speeds are generated within the camera. A valid speed measurement means that the vehicle was traveling within the limits of the radar (6MPH to 126MPH) . Invalid triggers occur when the radar detected a speed less than 6 MPH or the return signature of the Doppler radar was not complete, or found inconsistencies in the Doppler shift. We see this a lot with cars that slam on their breaks just before the stop bar. These are reviewed by Cedar Rapids PD to ensure the offender did indeed run the red light.

- Will the offense type be listed differently if it is a speed violation?

  Yes, it will read "speed"

- What is pardon time and what are the units? Seconds?

  Pardon time is the grace time for the red light. After the light turns red, we can specify a grace or pardon time. We typically set this at .1 second. The units are hundredths of a second.

- Is the speed measurement taken at the camera location? How is speed being determined (i.e. is there a radar unit present?)

  The speed measurement is taken from RF antennas mounted over each lane. When we install, we mark 20 ft. from the stop bar, and aim our antennas at that point in the road. When a car goes through the beam it triggers the radar. This is what you are seeing on the statistics. Each entry on the statistics is a trigger and the road conditions (lane #, red time, yellow time, etc…) during that trigger.

- Why are there no yellow time or short (0.15 seconds) yellow time showing for some violations?

  This was a technical issue involving our relays. For some reason we were getting erroneous yellow readings at 1STWB (lane1). These would not have been processed as violations due to the erroneous yellow times.

- Is there an all red phase at the intersection?

  Yes

- Is there any way to tell right turn on red from other movements?

  Not with the statistics. Well, you could look at the lane # typically right turns will be in Lane 3 or 4 depending on the road. If there is a dedicated RHT lane the answer is yes, all triggers in that lane will be right turns. At this intersection there are no dedicated right turns.

- How were red time, yellow time measured? (i.e. does a red time of 3.5 seconds mean the vehicle crossed the stopline 3.5 seconds into the red?)

  Red and yellow times are measured from when the car goes through the radar trigger point. When the traffic signal turns on we begin measuring the signal. At the point a vehicle runs the light, we measure how long the traffic light had been red and use that time period. For the yellow, we merely measure how long the light is yellow for each cycle.

- Is the speed metric MPH? time is in seconds?

  Speed in MPH. Time is in seconds.

George Jennings

Systems Engineer

Cell: 602.284.4160

Office: 480.315.1386

g.jennings@gatso.com

FW: Cedar Rapids Red Light Running Cameras Request for Information

1 message

Hart, Leslie <L.Hart@cedar-rapids.org> **Wed, Mar 3, 2010 at 2:45 PM**
To: "noneyear@gmail.com" <noneyear@gmail.com>

Nicole –

The attached document has the yellow (change) intervals. For the other items, see below.

Let me know what else is needed.

Leslie Hart, P.E., PTOE
Associate Traffic Engineer
1201 6th Street SW
Cedar Rapids, IA 52404
Phone: 319-286-5802

In order to enhance the quality of our service, please take a moment to complete a survey…Public Works Customer Service Survey

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From: Griffith, Ron
Sent: Wednesday, March 03, 2010 2:23 PM
To: Hart, Leslie
Subject: FW: Cedar Rapids Red Light Running Cameras Request for Information

Leslie,

Can you respond to Nicole.

From: Nicole Oneyear [mailto:noneyear@gmail.com]
Sent: Wednesday, March 03, 2010 11:24 AM
To: Griffith, Ron

Subject: Cedar Rapids Red Light Running Cameras Request for Information

Hello,

I am Nicole Oneyear, a graduate student at Iowa State University, working on the red light cameras project with Dr. Hallmark and Tom McDonald at InTrans. I was wondering if I could get some information on the intersection configurations as well as information on the signal timing plans? Some of the information I am interested in includes:

- what is the sight distance approaching the intersection?

>> we do not have measurements, but none have sight distance restrictions. The Center Point Road intersection is half of a tight diamond.

- What is the length of the yellow phase?

>>see attached

- Is there an all red phase and if so, how long?

>>yes, but I don't have that compiled. Will send later.

- Do the signals have hoods?

>>by "hoods", do you mean "visors"? if so, yes.

- What size are the signal heads?

>>all of the City's signal heads are 12".

Type of backlight?

>>not sure what this refers to. If "backplate", then, all signal heads have 6" black backplates.

Any of this information you could provide would be greatly appreciated.

Thank you,

Nicole Oneyear
Graduate Research Assistant
Civil Engineering Masters Candidate
Iowa State University

APPENDIX D: YELLOW TIME AND SPEED LIMITS

MEMORANDUM

TO: Jo Ellen Carter, IDOT, Cedar Rapids office, Kirkwood Blvd SW
Steve Wilson, IDOT, Cedar Rapids office, 16th Avenue SW
Tim Crouch, IDOT, Ames office

FROM: Leslie Hart
Public Works-Traffic Engineering Division

DATE: January 19, 2010

RE: Change Intervals: Proposed Automated Enforcement Sites
Non-CIP Project No. 60-10-023

Per Iowa DOT's request, the following information is provided.

Monitored Route	Approach Direction	At	Posted Speed Limit	Grade	Change Interval
1st Avenue	Eastbound	10th St E	30 mph	-1	4.1 sec
1st Avenue	Westbound	10th St E	35 mph*	+1	4.1 sec
1st Avenue	Eastbound	L St W	35 mph	0	4.2 sec
1st Avenue	Westbound	L St W	35 mph	0	4.2 sec
Williams Blvd	NE-bound	16th Ave SW	35 mph**	-1	4.3 sec
Williams Blvd	SW-bound	16th Ave SW	35 mph	-1	4.3 sec
3rd Street	Northbound	2nd Ave SW	30 mph	0	4.0 sec

*Speed limit changes from 35 mph to 30 mph at a point 50 feet NW of intersection
**Speed limit changes from 40 mph to 35 mph at a point 100 feet past the previous signalized intersection (Trent Street SW)

The City's draft Policy & Procedure for Clearance Intervals (October 2007) is attached for reference.

Please contact me if further information or clarification is needed.

LH/krs

Enclosure

cc: Steve O'Konek, Cedar Rapids Police Department (w/o enclosure)
Ron Griffith, Cedar Rapids Public Works-Traffic Engineering (w/o enclosure)