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EVALUATION UPDATE OF RED LIGHT CAMERA PROGRAM IN FAIRFAX COUNTY, VIRGINIA

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Thesis submitted to the faculty of

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Civil and Environmental Engineering

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April 30, 2004

Blacksburg, Virginia

Keywords: Red Light Camera, Automated Photo Enforcement

Evaluation Update of Red Light Camera Program in Fairfax County, Virginia

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Abstract

The Red Light Camera program in Fairfax County has been in operation for more than 2 years. As of 2003, there are 13 cameras in operation. The camera takes 2 pictures of a vehicle while it illegally entered the intersection and after it entered the intersection. These photographs give evidence of the red light violation. The citation is mailed to the register owner of the vehicle. The penalty is $50.

This study has been conducted to evaluate the program. The violation and accident data at all of the study intersections were provided by Fairfax County Department of Transportation and Fairfax County Police Department. The traffic data in Fairfax County were provided by Virginia Department of Transportation. The results of the violation analysis indicate that the Red Light Camera program did reduce the violation rate by up to 58 percent in the 22^{nd} – 27^{th} month period of the operation. The study also shows that the increase of the amber-time interval produced a higher reduction in violation rate up to 70 percent. The reduction in violation was found to be statistically significant. The violation rate is reduced to 1-2 violations per 10,000 vehicles considering the effect of the RLC operation only. With the effect of both RLC and amber-time increase, the violation rate is reduced to 0-1 violation per 10,000 vehicles. The accident rate is reduced by 27 percent after 2 years of the RLC operation. The Red Light Camera is found to have an effect on the reduction in Property Damage Only accident. However, the reduction in accident was not found to be statistically significant. Therefore, there is no benefit accrued from the reduction in accidents. From this study, the Red Light Camera program increases safety at camera intersections in Fairfax County by reducing violation rates after 2 years of its operation.

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ACKNOWLEDGEMENTS

My work would not be complete without the assist from important people around me. First of all, I would like to thank my advisor, Dr. Hobeika, who has been supporting me on my study and thesis and giving me opportunities and valuable counsel throughout the years of graduate school. I would like to thank Bruce Taylor of Fairfax County Department of Transportation, Mike Uram of Fairfax County Police Department and Fouad Youssef of District Department of Transportation for providing me the information and data and never getting tired of answering my questions. I would like to thank Dr. Trani and Dr. Collura, my committee, who also support me during my study.

My accomplishment at Virginia Tech would not be exist without my family who always with me in every way. Dad and mom please know that I appreciate every minute being your daughter. And last, thank all of my friends who help me, encourage me and listen to me during all these years.

CHAPTER 1
INTRODUCTION

Red light running at intersections by motorists has caused a significant number of collisions and injuries around the world. Statistics from the National Highway Traffic Safety Administration (NHTSA) in 2002 show that the number of individuals who were killed on roadway intersections and in intersection related accidents is 22 percent of all death resulted from motor vehicle accidents. It also shows that 49 percent of all injuries from car crashes occurred at intersections.

Addressing the red light running behavior has been a major concern to the United States' government. As a result, the government introduced the Red Light Camera System (RLC) in order to increase traffic safety at intersections. The RLC discourages people from running the red light. The RLC has been widely used in European countries[1] since 1970s, and Australia has used the system for more than 20 years. Other countries that have been using the RLC include Canada, Israel, South Africa, Singapore and Taiwan. New York City is the first city in the United States that implemented the RLC program. This Chapter discusses the system design, RLC operation background, and RLC legislation. The system design, RLC operation background, and RLC legislation are discussed next.

BACKGROUND

1. 1 Red Light Camera Technology

The RLC system is composed of cameras, sensors and a traffic signal. The camera pole usually stands several feet back from the traffic signal. A camera is used to capture a photo of a vehicle violating the red signal at an intersection. The camera is activated when the traffic signal turns red. The picture is taken after a grace period, which is set by the program sponsor. The time span varies from one place to the other. At each intersection, detectors determine the speed of the vehicle; the minimum speed is preset to distinguish between the vehicle that stops or turns right and the vehicle that runs the red light. If the vehicle runs the red light, its image and speed are recorded and transferred to the central facility or collected at the end of the day

[1] Austria, Belgium, Germany, the Netherlands, Switzerland, and the United Kingdom.

depending on the type of the camera. Once the owner of the violating vehicle is determined from the recorded license plate, the notice of violation is issued and mailed to the owner. The functions and description of each RLC component are discussed as follows.

1.1.1 Camera

A red light camera is activated to take a picture of the violator only when the signal turns red. As mention earlier, the grace period is the time delay between the changing signal and the activation of the camera, which usually takes about 03-0.4 second. Normally, two photos are taken for each vehicle. The first one is taken when the vehicle enters the intersection and the traffic signal turns red, and the second picture when the vehicle is in the middle of the intersection. In some places, this information is also used to calculate the speed of the vehicle. Figure 1.1 and 1.2 are the sample first and second images taken by the RLC. A data bar or block is usually placed on the negative film of the picture at the same time it is exposed. This block provides the necessary information of the violation. An example of a data block used by New South Wales Police Department is shown in Figure 1.3. The sample data block describes the second photograph (Figure 1.2). It includes the date and time the photo was taken, the violation number, the speed of violating vehicle, the duration of red light at the violating time, and the interval time between the first and the second photo. It shows that the picture was taken on July 7, 1997 at 5:50 p.m. and was the eighth photo citation of the day at this intersection. The first photo was exposed 0.5 second prior to this shot, as shown in Figure 1.1. At the time of this photo, the light had been red for 0.9 second and the speed of the car is 58 miles per hour.

Figure 1.1 First photo taken by red light camera in New South Wales, Australia.

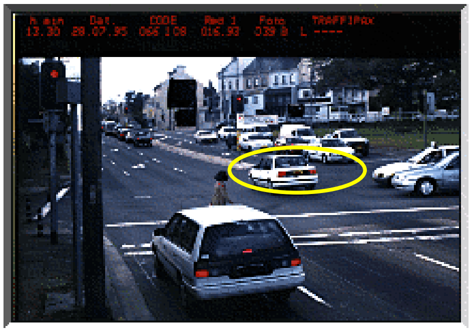

Figure 1.2 Second photo taken by red light camera in New South Wales, Australia.

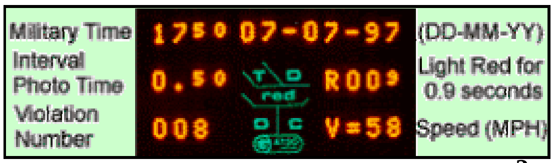

Figure 1.3 Data Bar of the second photo[2].

The automated enforcement technology depends a lot on the ability of the red light camera. The necessary information from the recorded images are a license plate, the driver, date, time of day, and time elapsed since the signal turns red. The red light camera technology has improved over the years; the number of lanes monitored by the camera expands and the quality of the pictures improves, which allow a better recognition of license plates and drivers. Moreover, the maintenance of these photographs is better. Three types of cameras that are widely used for the red light enforcement system are the followings.

- wet film/35-mm
- digital camera
- video

Each type of camera is discussed as follows.

Wet Film/35-mm

The 35-mm camera is the most common type of camera used for the red light camera enforcement. The photographs are in black and white as well as in color. The camera

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2 The data block shows that the second photo was taken on July 7, 1997 at 5:50 p.m. and was the eighth photo citation of the day at this intersection. The first photo was exposed 0.5 second prior to this shot, as shown in Figure 1.1. At the time of this photo, the light had been red for 0.9 second and the speed of the car is 58 miles per hour.

is installed at the intersection in a position that can capture the rear of the vehicle or both the front and the rear of the vehicle. The film is reloaded daily, which is a time consuming process (1).

The advantage of 35-mm camera or wet film is that it provides a film negative which is a better evidence in court than a digital product because the manipulation of the negative is almost impossible. The 35-mm camera is currently used in many states such as New York, San Francisco, CA, and Howard County, MD. The camera models that are used include Fujica FTIF, TC 1000 Traffic Cam, Traffiphot, obotmotorrecorder 36DCE, and Jacknau. The 35-mm red light camera used in Montgomery County, Maryland is shown in Figure 1.4.

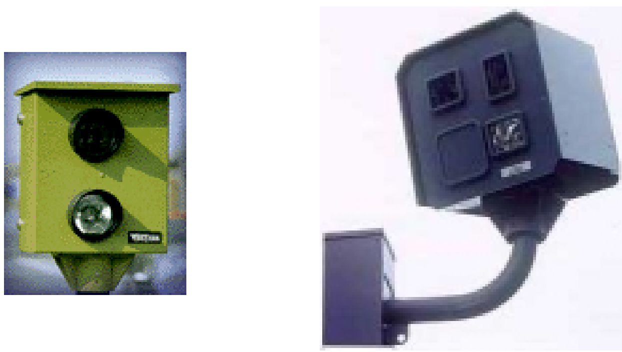

Figure 1.4 Wet Film/ 35 mm Red Light Cameras.

Digital Camera

Since the year 2000, a digital camera has become more and more popular. The application of a digital camera in the red light camera enforcement is very similar to the one described for the 35-mm cameras. However, the digital camera has one major advantage over the 35-mm that is a digital photo can be electrically recorded and transferred. Photographs from a digital camera are easily wired to the review facility. This advantage makes it easier and faster to collect and process the photos, and distribute the violation notices. Moreover, the use of digital camera reduces the cost of equipment and operation by eliminating the cost of films, the processing and personnel.

In spite of these advantages, there are fewer than 200 digital cameras out of more than 850 red light cameras installed in North America in 2003. Some places such as Nebraska, Maryland, Chicago, New York, and Charlotte, North Carolina are conducting studies of red light digital camera operation. They are planning to operate the RLC system by using the digital camera more in the future.

Video

In many states, the image from video camera has not been approved to be used as evidence in court. As a result, the video camera was rarely used to monitor traffic violations. However, the video camera technology has been significantly improved recently. It can now detect the speed of approaching vehicles, track the vehicle along the intersection and record a short video of the violation. Beside the use for the enforcement, the video camera provides surveillances of traffic including incident detects and response. In addition, video cameras are available in digital form. Like a digital camera, the video camera gives immediate picture transfer, and reduces film and handling cost. Even though the video camera can detect traffic violations, a still camera is usually required due to the location of the video camera, which is too high to capture the picture and a desire to use film instead of videotape as the evidentiary media.

1.1.2 Sensor System

A sensor system installed at the intersection, is used to determine if the vehicle has crossed the intersection when the traffic light is red. When the violation has occurred, it will activate the camera. A speed threshold is set to prevent the false triggering of vehicles, which sometime creep over a loop or a sensor. A vehicle with slow speed at an intersection either considered being a turning right or stopping; this speed is usually below a speed threshold, which is usually around 15-20 mph. The camera will not be triggered if the detected speed is less than the speed threshold. The sensor plays an essential role in reducing the number of mistaken pictures. By having the sensors used only for the automated enforcement system, interferences and conflicts with other detectors used for the traffic control system can be avoided.

A magnetic loop is the most common type of sensor applied for RLC system. They are embedded in the pavement as shown in Figures 1.4 and 1.5. It detects a vehicle and its speed. Other types of sensor are used such as coaxial sensor, piezoelectric sensor, roadway rubber tube sensor, radar, and laser sensors.

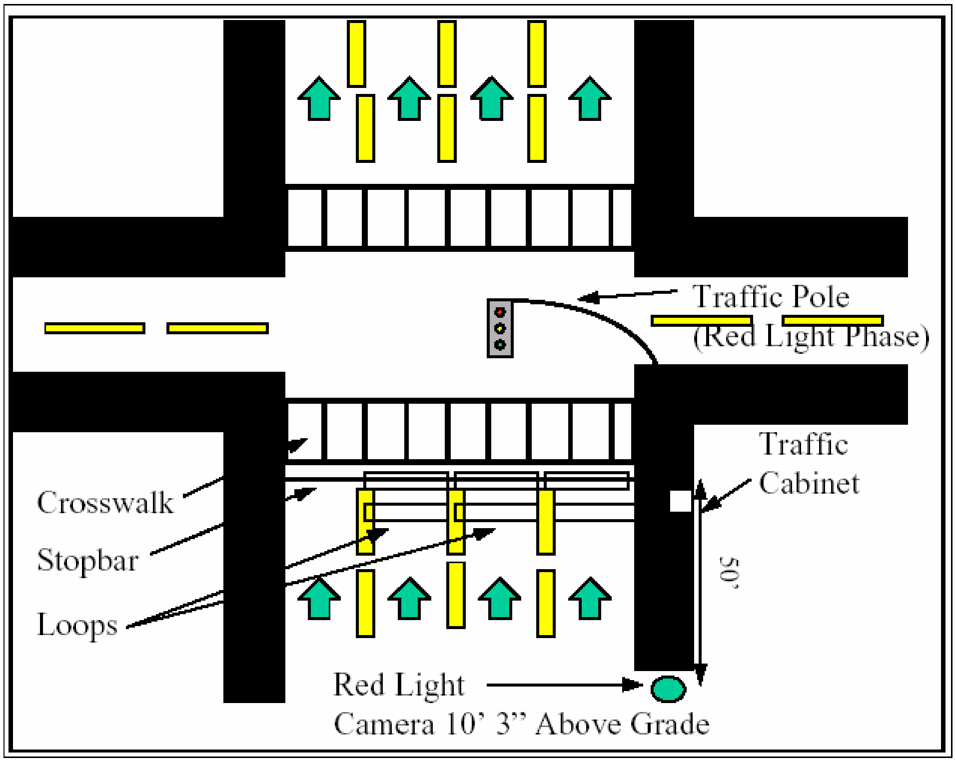

Figure 1.5 Loop detectors on the intersection.

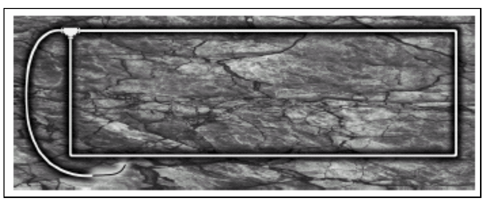

Figure 1.6 Magnetic loop detector.

Figures 1.7 and 1.8 show an intersection diagram which is equipped with two red light running cameras for through and left turn violations respectively. They also show the locations of loop detectors, which are used as sensors.

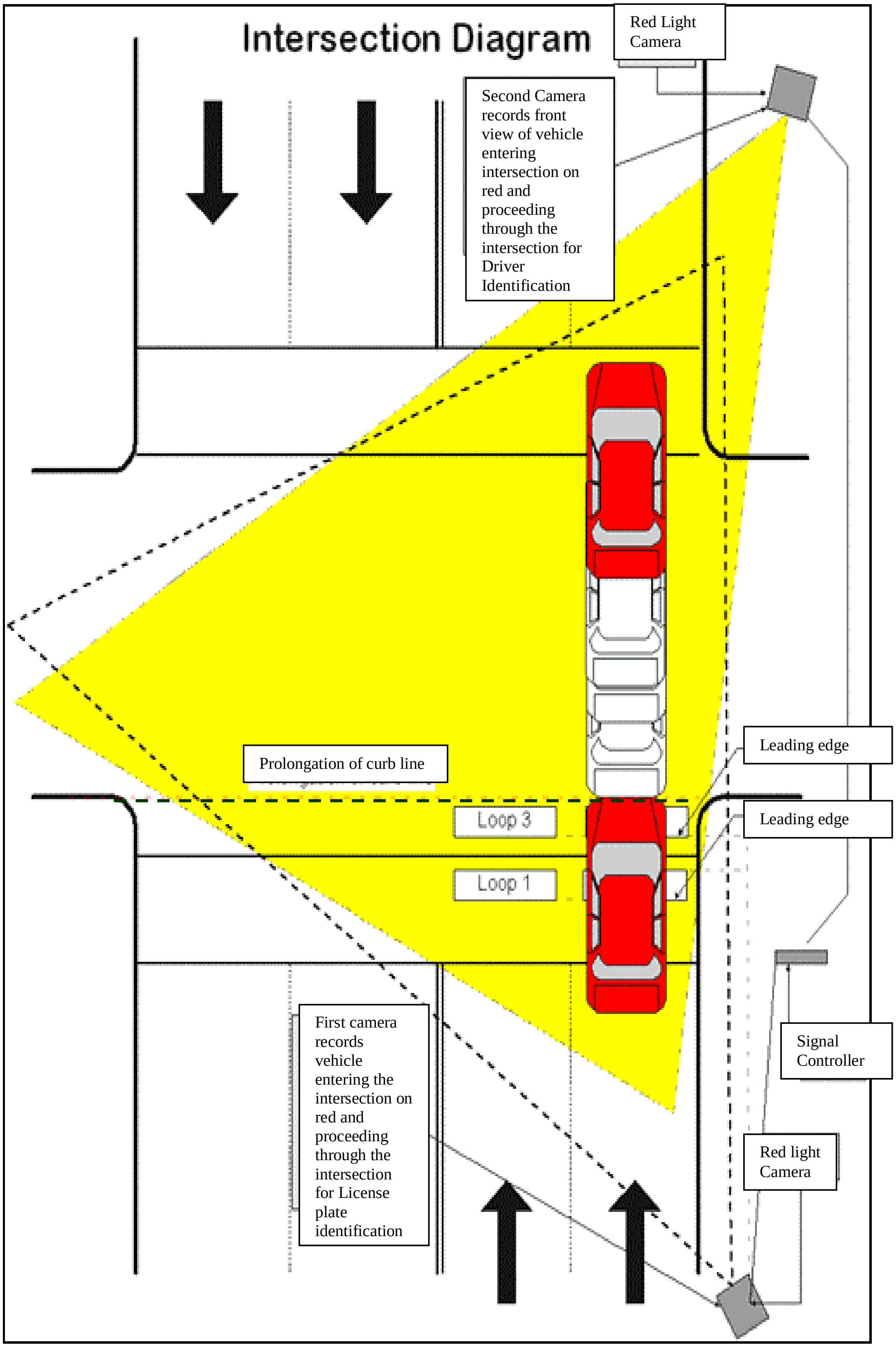

Figure 1.7 Red light camera diagram for through traffic.

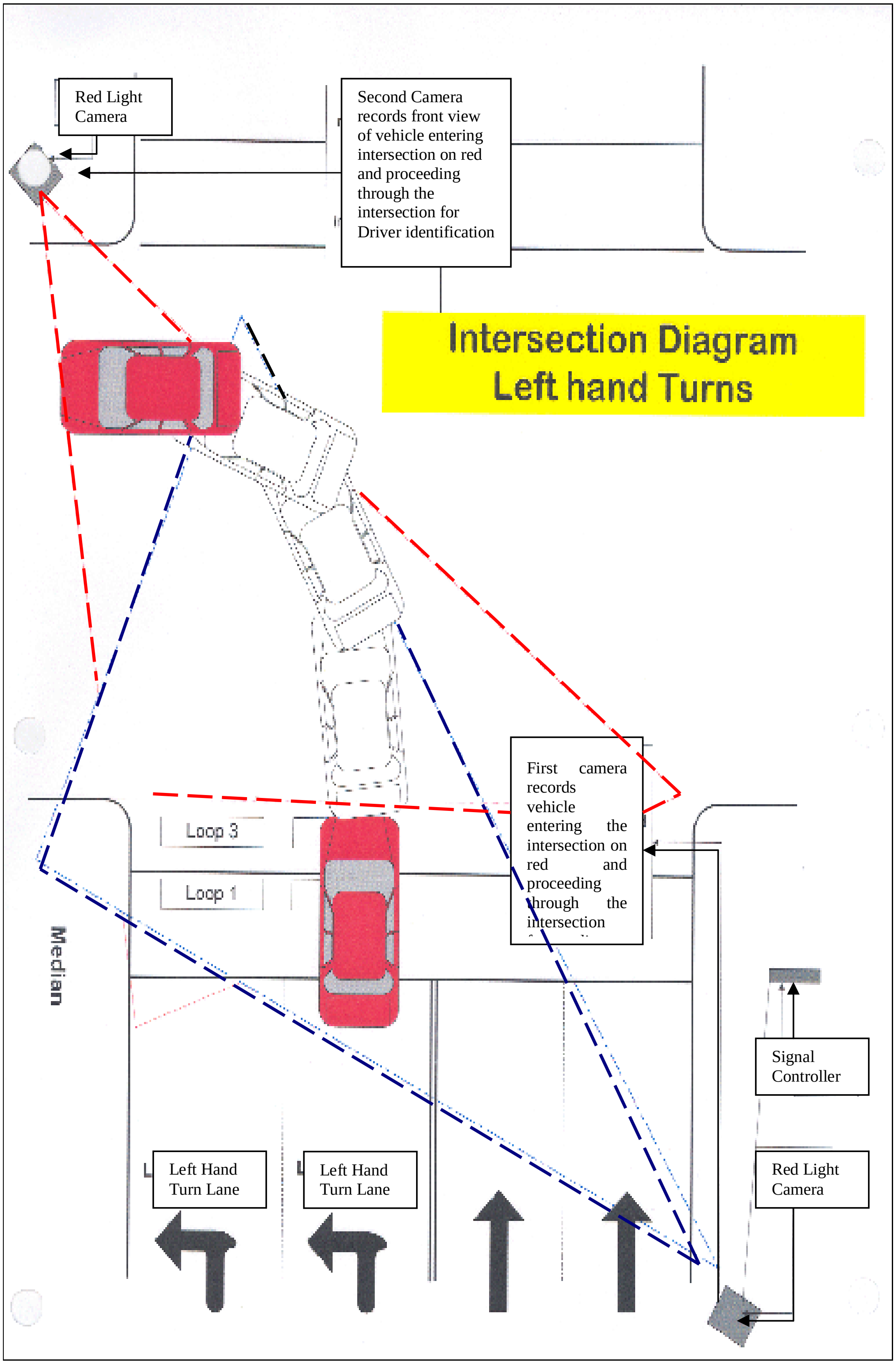

Figure 1.8 Red light camera diagram for left turn traffic.

1.2 Ticket Operation

Although the red light camera enforcement system is operated automatically by computers, the film development and the ticket processing are done manually.

1.2.1 Ticket Procedure

Photographs taken by the red light camera system are reviewed manually to determine if a driver or a registered owner will be ticketed or not. The decision is made using different criteria at different RLC jurisdiction. One of the criteria is photo matching; the citation is issued only if a photograph of the driver taken by a red light camera matches the driver’s license photograph of the vehicle’s registered owner. The camera on these sites takes pictures of both the license plate and the driver. However, a large number of the citations are rejected because the photographs do not match and the indistinct photograph of the driver. The cities that use this system are Paradise Valley, Arizona and San Francisco, California. The camera takes only the vehicle’s rear license plate. The notice of liability is issued to the registered owner of the vehicle no matter he or she is driving the vehicle at the time of violation. However, the registered owner is allowed to identify the driver who ran the red light at the monitored intersection in some states.

1.2.2 Ticket Processing Technology

The processing and the creation of tickets are conducted through computer software packages. For example, CITEWARE, a cost-effective program developed by U.S. Public Technology (1), prints and records a ticket or warning. An example of a warning notice used in Montgomery County, Maryland is shown in Figure 1.9.

INTERSECTION SAFETY SIGNAL WARNING NOTICE

This is only a warning notice. Please take notice as the registered owner(s) of the vehicle described and pictured herein, that the driver did not stop for the red traffic signal at the place, date and time specified. Therefore, as the registered owners(s) you are liable for a violation of Maryland State law (SS 21-202(H)). Maryland law imposes a civil penalty in the amount of $75.00, which normally must be paid by the date shown on this notice. No points are assessed against the registered owner(s) driving record and this violation is not reported to Motor Vehicle Administrations nor any insurance companies. Therefore, your insurance rates are not affected by this violation.

You owe nothing for this warning. However, normally if you fail to either remit payment or contest your liability by the date shown, then you would be deemed to have admitted liability and would be subject to an additional monetary penalty of $25 and a default judgement may be entered against you. In addition, failure to take timely action may result in the refusal or suspension of the motor vehicle registration.

This notice serves as a warning only. Do not pay the amount shown below.

DATE AND TIME OF VIOLATION	LOCATION OF VIOLATION	VEHICLE TAG
1/30/98 10:44:54 AM		[redacted]
VIOLATION NUMBER	AMOUNT DUE	DATE DUE
Red Light-TestSite-Disk - NOT EVID-24	$0.00	3/10/98

A Public Safety Program of the
Montgomery County Department of Police
Automated Enforcement Unit

I certify that I am a duly authorized employee of the Montgomery County Police and I have inspected the recorded images of the described vehicle, which was operated in violation of 21-202(H), as evidenced by the above images.

ID # 4808

Send Check or Money Order Payable to:
Director of Finance, Montgomery County
255 Hungerford Rd.
Rockville, Maryland 20850

NAME & ADDRESS OF REGISTERED OWNER OF VEHICLE

REMITTANCE ADVICE – RETURN WITH PAYMENT

VIOLATION NUMBER & DATE	FINE AMOUNT NOW DUE
Red Light-TestSite-Disk - NOT EVID-24 1/30/98	$0.00
	AMOUNT DUE AFTER 3/10/98 $0.00

Figure 1.9 Warning Notice.

1.3 Legislation

Many states and local governments in the United States enact laws and bills that allow the issuing of tickets and warning notices using the photograph as evidence.

1.3.1 Overview

In 2001, twenty-four states considered 68 bills regarding automated enforcement. Most of these bills allowed the establishment of red light camera or photo radar programs in cities and towns by enacting an enabling legislation. The enabling legislation establishes guidelines for local governments when setting up an automated enforcement program. These laws generally allow enforcement agencies to ticket violators through mail and usually make the vehicle owner accept his or her responsibility. Some bills proposed increasing penalties for red light runners.

As of June 2003, twenty-six states issue laws regarding automated enforcement. Washington, D.C. and 16 states pass enabling legislation, which allow the use of red light cameras or photo radar in photographing the violating driver. The 16 states include Arizona, California, Colorado, Delaware, Georgia, Hawaii, Illinois, Maryland, New York, North Carolina, Ohio, Oregon, Tennessee, Texas, Virginia, and Washington. Ten states pass laws that prohibit the use of photo technology in enforcing traffic laws. Those states include New Jersey, Alaska, Florida, Kentucky, Nevada, Nebraska, New Mexico, North Dakota, Utah, and Wisconsin. California and New York states enact laws that allow the use of photo technology at highway-rail crossings.

1.3.2 RLC enforcement legislations Comparison

This section compares the legislation of 13 states[1], which allow the use of photo-monitoring enforcement system. The content of automated red light enforcement legislation varies from one state to the other. Some of the differences are the amount of monetary penalty, form of evidence, the restriction of a contract between government agencies and vendors, and the requirement of warning signs or warning period.

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[3] Arizona, California, Colorado, Georgia, Hawaii, Illinois, Maryland, New York, North Carolina, Oregon, Texas, Virginia, Washington

The maximum charges of a civil penalty are different in each state. They range from $50 to $250. However, in some states, the fine is not specified by the state but by the local government.

The evidence required constitutes of photographs from a monitoring device. The type of camera is not specified. Some states recognize videotape as evidence. Such states are Virginia, New York, Maryland, Hawaii, among others. The information on recorded images differs from state to state. In some states, the driver's face is needed as well as the vehicle's license plate. The photograph of the driver is used to verify a person who committed the violation and offer an alternative of hearing request to the vehicle's registered owner. The owner can be dismissed from the case if he or she provides evidence that he or she does not operate the vehicle at the time of violation. This regulation is enforced in Arizona, California, Colorado and Hawaii. However, most states require only images of a license plate and a vehicle. Examples are New York, Texas, Georgia and Washington. In these states, a registered owner is subjected to the civil penalty whether he or she was operating the vehicle at the time of violation or not. However, The penalty can be avoided only if a vehicle that violated traffic signal is a rental vehicle or was reported to be stolen before the time of violation. Of all the states that require solely the license plate photo, only in a few states that the registered owner has a chance to stand in a court if the owner can prove that her or she was not operating the vehicle at the time of violation. Those states include Oregon, Virginia, Maryland and North Carolina.

Warning signs indicating the operation of the photo-enforcement system are required at a noticeable place in most states. However, the location of the sign differs in each state. In some states, the sign is required at the entrance of the city or municipality while in other states, it is required at the location of the camera or nearby. The sign is not mandatory in Arizona, Maryland and New York. In Hawaii, installing the warning sign is optional due to the frequent relocation of the photo-monitoring device.

The warning period is mandatory in California, Georgia and Hawaii. In these three states, the program that issues only warning notices must be implemented prior issuing citations. The period of warning is different in each state. The public information campaign shall be conducted in most states before the launch of the program or during the time the program is being used.

In 2003, some of the automated red light enforcement system legislation has been corrected because of the controversy surrounding the operating systems that are discussed later. One of the additional legislation is that the yellow time is directed to be established based on the recommended methodology that provides safety and appropriate traffic flow at an intersection. The states that have the yellow-time requirement include California, Georgia, North Carolina and Virginia. Another extension of the law that was influenced by the controversy is the restriction of the contract between governmental agencies and the vendor or equipment manufacturer. As of 2003, the local jurisdiction is not allowed to compensate the contractor as a specified percentage of or dollar amount from each civil penalty collected in some states such as California, Colorado, Georgia and Texas.

Several states require the program evaluation after a certain amount of time. The effectiveness and value of the program to a community are estimated in order to further develop and manage the RLC system.

Each state also creates its unique feature of the legislation. For example, Virginia state allow no more than 25 intersections to have the RLC enforcement system operated within each locality at any one time. Additionally, Texas forces the municipality to conduct a traffic engineering study of the approach before the implementation of the photographic traffic signal enforcement system to determine whether a design change to the approach or a change in the signalization of the intersection is likely to reduce the number of red light violations at the intersection. Other alternatives must also be considered before the photographic enforcement system is applied. The Colorado's bill regarding the first time violation says that the driver will not be imposed with penalty or fine. Hawaii prohibits the number plate cover that distorts a recorded image of a vehicle's license plate. Arizona state requires a red light runner to attend the Traffic Survival School (TSS) in addition to the monetary penalty. North Carolina limits the RLC enforcement system contract between governmental agency and private agency to 60 months.

In conclusion, the automated red light enforcement legislation differs from state to state. In spite of the same objective to reduce the number of accident ands injuries, the method varies according to the vision of each government as well as the individuality of each state or city. The average income of residents may influence the fine. Moreover, the argument about the application of the automated photo enforcement affects the law characteristic. Appendix B provides the summary of automated red light enforcement legislation of 10 states, and Table 1.1 illustrates a summary of the legislation in each state.

Table 1.1 Summary of Legislation.

State	Civil Penalty	Evidence	Warning Sign	Warning Period	Public Announcement	Yellow time analysis	Evaluation	Defense Option	Contract with Vendors
Arizona	minimum $250	images of license plate and driver identification	not required	not required	not required	not required	required after the end of the program	Yes	allow the payment based on the number of citations
California	not specified	images of license plate and driver identification	required	required for 30 days before the camera implementation	required for 30 days	Accordance with CALDOT Traffic Manual	not required	Yes	Prohibit the payment based on the number of citations
Colorado	maximum $75	images of the rear of vehicle, license plate and driver	required	not required	not required	not required	not required	Yes	Prohibit the payment based on the number of citations
Georgia	maximum $70	2 or more images showing rear of vehicle and license plate	required at the approach	required for 30 days before the camera implementation	not required	Accordance with ITE methodology	not required	Yes to the vehicle rental company	Prohibit the payment based on the number of citations
Hawaii	maximum $100	images of the rear of vehicle, license plate and driver	not required	required for the first year of operation	required for the first year of operation	not required	required after the end of the program	Yes	-
Illinois	not specified	images of vehicle and vehicle's license plate	-	-	-	-	-	-	-
Maryland	maximum $100	images of rear of a vehicle and license plate	not required	not required	not required	not required	not required	Yes	-

Table 1.1 (cont') Summary of Legislation.

State	Civil Penalty	Evidence	Warning Sign	Warning Period	Public Announcement	Yellow time analysis	Evaluation	Defense Option	Contract with Vendors
New York	maximum $50	images of violation	not required	not required	not required	not required	not required	Yes for rental car company	-
North Carolina	$50	images of violation	required at the approach	not required	not required	Accordance with NCDOT Design Manual	not required	Yes	Limit 60 months of contract
Oregon	same as a violation initiated by other means various by cities	images of violation	required	not required	required	not required	not required	Yes	-
Texas	maximum $75	images of license plate	required	not required	required for the first year of operation	not required	not required	Yes for rental car company	Prohibit the payment based on the number of citations
Virginia	maximum $50	images of a vehicle illegally entered and after entered the intersection	required	not required	required	Accordance with ITE methodology	required annually	Yes	-
Washington	not specified	images of vehicle and license plate	required	not required	required	not required	not required	Yes to the vehicle rental company	-

1.4 Controversies at Intersections

Several controversies regarding the application of the RLC system surfaced after the system was used by many cities in various states. The National Motorist Association (NMA) claims that the RLC system is not the best way to reduce the number of accidents; instead, it causes even more crashes. Moreover, commuters in certain areas such as Wilmington, DE and San Diego, CA say that the system is intentionally operated to make out money rather than helping people. Each topic of controversy is discussed as below.

1.4.1 Reducing Violations by Increasing Yellow Time

Two scenarios are considered regarding the red light running. The first one is the “intentional running” and the second one is the “unintentional running.” The problem arises in the latter case when the violator claims to be in the dilemma zone or in the zone that is impossible to stop after the signal turns red. As a result, a yellow time experiment was conducted to compare the number of cars crossing in conflict before and after extending the yellow time. The result shows that after increasing the yellow time from 4.6 to 6.1 seconds at off-peak traffic and dry pavement condition, the percentage of reduction in conflict rate was 91. The researchers concluded that the potential intersection conflict could be virtually eliminated if the duration of the yellow phase is increased (2). The results are used to support the extension of yellow time instead of the use of RLC in order to reduce red light running.

San Diego is one of the cities that have a controversy about the adoption of the automated red light enforcement system. Several studies are conducted to discredit the system. One of them studies the effect of yellow light interval on the frequency of apparent red light running violations (3). The data collected by the City of San Diego had shows that if the yellow time increases the number of violations will decrease. The summary stated that there is some evidence that in San Diego, the yellow light interval for red light camera intersections were set to be shorter than the recommended levels in order to raise revenue. It is also stated that the longer yellow interval will improve traffic safety.

This problem had occurred in other places as well. As a result certain, states such as Virginia and California have issued an amendment to the automated photo enforcement law. The amendment says that a yellow time interval at the intersection with camera must be set correspondingly to the methodology, which has been approved to provide appropriate and safe signal timing.

1.4.2 Revenue

The controversy over “Revenue or Safety” came along with the study about the yellow time. Drivers in San Diego as well as in San Francisco believe that a portion of their civil penalty is distributed to a contractor of red light camera system and not to the government. Another report by a professional law corporation (4) stated that one of the camera intersections in San Diego with a 3.0 second yellow light records an average of more than 3,000 alleged violations per month. In this case, potential revenues exceed of $400,000 per month for the RLC vendor alone. The report concluded that the RLC vender and the City of San Diego operate the program primarily to generate revenue rather than to increase public safety. Finally, in 2001, the Superior Court of The State of California County of San Diego did not approve the evidence of red light violation from the automated photo enforcement system because the court saw no difference between a contingent fee to a private corporation and a contingent fee paid to an individual.

Legislation is enacted to reduce this controversy. For example, the State of California, Colorado and Texas enact the law that prohibits the compensation of the red light camera operation to the contractor or private agency as a percentage of each civil penalty collected. The same controversy occurred in United Kingdom. As a result, Britain Government restricts the use of the monetary penalty to cover only the camera operation cost.

1.4.3 Safety

The main objective of the RLC system is to reduce the number of crashes and incidents at intersections from the red light running. However, some investigations show that the automated enforcement system have increased the number of crashes. For example, the Police Chief, David Bejarano gave a presentation informing that the San Diego Police Department found a few camera enforced intersections have few more accidents than prior to the red light photo enforcement. Other camera intersections have no change in the number of accidents at all.

Some studies claimed that while the RLC system reduces the number of right angle accident, it increases the number of rear-end accidents. For example, the city of Wilmington indicates an 8 percent increase in rear-end collisions at enforced intersections. Similarly, in Victoria, Australia, a long term study of red light camera and accident shows that the number of rear-end turning accidents increases by 28 percents (5). The accident data of South Australia and Sydney also indicates an increase of rear-end crashes at the camera intersections. Moreover, Senator Dick Armey files a report against the RLC system (6). It states that the previous reports of RLC evaluation present flaws in the rear-end accident estimation.

As of 2003, the trend of rear-end accident after the operation of the RLC system receives more attentions from each community, which already have installed the automated red light enforced system. Further studies and data collection are recommended in order to prove that the system does not increase the number of accidents.

1.4.4 Public Privacy

One of the most popular questions from road users in RLC areas is Does red light cameras violate their privacy? When the photograph with the location of driver, time of day, and day of week, is mailed to home, it can cause personal problems rather than the violation fee (7). Citizen claim that the system interferes their personal lives and restrict their citizen movements.

However, the RLC agencies respond that the purpose of the system is to protect public safety. They have no intention to violate public privacy. The agencies argue that after the necessary information is extracted from the system and used, the information is destroyed. The Insurance Institute for Highway safety (IIHS) comments that if the RLC violates public privacy, the traditional red light running enforcement dose too. When a police officer asks a violator to pull over, the officer inquires the same information as RLC records. According to the Fourth Amendment to the U.S. Constitution, the protection of citizen right to privacy from unreasonable intrusion by law-enforcement agents is specified. Katz v. United States, the U.S. Supreme Court establishes that the Fourth Amendment protects citizen’s right to privacy in those things that they actually keep private and those in which society generally regards as private. This may suggest that when people are driving their cars on streets, they knowingly expose to the public. Therefore, it cannot be counted as private.

In conclusion, the controversy still continues. If the RLC system is operated, the capture of the license plate is inevitable. One of the solutions is to make the system acceptable by drivers by showing them that the RLC can increase safety at intersections. The survey of public opinion should be conducted in the RLC area.

1.5 Conclusions

The purpose of red light camera is to reduce accidents resulted from running red light. The RLC system has been developing since it was first implemented. As of 2003, most of the RLC systems in the United States use 35-mm cameras. However, the digital camera is used in some states because of its capability to provide easier and faster picture transfer and more effective database. The magnetic loop has been used with the RLC system as a sensor since the beginning until now. However, in the past few years, radar and laser sensors have replaced the magnetic loop in many areas. While the RLC technology is developing, the legislation allowing the RLC operation is enacted across the country. As of June 2003, red light cameras are permitted in 17 states: Arizona, California, Colorado, Delaware, Georgia, Hawaii, Illinois, Maryland, New York, North Carolina, Ohio, Oregon, Pennsylvania, Tennessee, Texas, Virginia, and Washington; and the District of Columbia. The RLC system is named differently in each state. Some aspects of the legislation are different such as monetary penalty, form of evidence, the restriction of a contract between government agencies and vendors, and the requirement of warning signs or warning period. Some laws have been amended recently in order to reduce controversies arising from the RLC operation. The controversial topics include increasing of accidents by RLC, red light running reduction by higher yellow time, expense of revenue from citations, and privacy. Even though some actions have been taken to avoid the controversies, new problems still pile up. For example, in San Francisco, the RLC system is claimed to be unreliable and photographs are not clear enough to be used as court evidence. There is a request of red light signal to be included in a photograph. More legislation mending and system adjustment are suggested in the future.

The RLC system has been constantly improved and adjusted to suit each jurisdiction area and to satisfy road users and residents. The objective of this thesis and the content of the rest chapter are presented next.

Objective

The objectives of this thesis are to evaluate the RLC system in Fairfax County, Virginia, and to determine its effects on the violation and accident trend after more than 2 years of operation. The factors that affect the number of accidents and violations are studied. The thesis emphasizes on the impact of the RLC system on the accident number. The results are interpreted, and the benefit of the system to Fairfax County is determined.

Thesis Content

This report consists of 8 chapters.

Chapter 1 presents background and objectives of the thesis.

Chapter 2 presents the literature review of the RLC system in The United States and three other countries. The evaluation methodology and results of the application of the RLC system in each country are critically discussed.

Chapter 3 presents the evaluation method used in this thesis.

Chapter 4 summarizes the violation and accident data. The results are categorized and discussed.

Chapter 5 presents results of statistical tests. The effect of ADT and speed limit on violations and accidents are determined and discussed.

Chapter 6 presents the cost-benefit analysis of the RLC program for its 8-year life cycle.

Chapter 7 compares the RLC system performance between Fairfax County and Washington, D.C.

Chapter 8 summarizes the previous chapters and presents conclusions of the thesis.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the literature review of the Red Light Camera (RLC) system in the United States and three other countries. The overview of the system, effect of RLC on accident and violation number, and public opinion about the system are summarized. The literature review concentrates on the impact of the RLC system on the number of accidents and violations. Most of the reports on the performance of the RLC make a comparison of before and after the camera operation. Types of accidents included are different from one place to the other. The analysis methodology and the conclusions of each report are critically discussed. It should be recognized that the RLC system is named differently and has particular characteristic in each city. The review of the RLC system in foreign countries is discussed first.

2.1 Studies From Foreign Countries

United Kingdom

The automated photo enforcement system in the United Kingdom (UK) called "Safety Camera" includes speed cameras, and red light cameras. The speed camera captures 2 photographs of a vehicle running at speed higher than the speed limit. There are 2 types of speed camera: fixed and mobile. The mobile speed camera must be attended by a police officer to be enforced while the fixed camera is not. Hence, the fixed camera has an effect of 24 hours. The red light camera in UK works in the same way as the fixed speed camera. The safety camera system has been implemented in UK since 1991. Most of the systems are speed camera systems. The red light camera is operated in some cities such as Glasgow, Essex and Nottingham. In 2000, the Department of Transport, Local Government and The Regions (DTLR) of The United Kingdom launched the 2-year pilot program to study the safety camera. The period of this program is from April 2000 to March 2002. Eight DTLR partnerships: Cleveland, Lincolnshire, Nottingham, Northamptonshire, South Wales, Strathclyde, Essex, and Thames Valley participate in the DTRL pilot scheme. Both speed camera system and red light camera system in the UK are reviewed. Results from speed camera system study show how the photo enforcement effect drivers' behavior. The speed camera literature is presented next.

1) Speed Camera System in The United Kingdom

Department for Transport (DfT) published the evaluation of 2-year pilot program for 8 partnerships (8) in February 2003. Even though the red light camera is included in the pilot program, the report does not evaluate the red light camera impact due to the small number of the red light cameras. This report summarizes only the effects that speed cameras have on a vehicle speed and casualties. The criteria that the authors use to measure a success of the pilot program are:

- A significant reduction in speed and casualties in areas where cameras are operating.
- General public acceptance of the road safety benefits.
- Satisfactory working of the funding and partnership arrangements.

The effect of the speed camera on accidents is considered in term of changes in number of people killed and seriously injured (KSI) and personal injury accidents (PIA). In order to focus on changes attributable to the enforcement rather than some other general effects, the authors compare the percent reduction in accidents and casualties with the downward long-term trend prior to the start of the pilot program. The comparison is conducted between three years before and two years after the camera operation. The log-linear modeling exercise is used as an analysis method. The findings on the reduction in casualties are as following:

- At camera sites in six pilots[3], there was a 35 percent reduction in the number of KSIs, compared to the long-term trend or 280 fewer KSI casualties
- At camera sites in eight pilots, there was a 6 percent reduction in the number of PIAs compared to the long-term trend or 510 fewer accidents.

This report has a few points, which are unclear. First, all the accidents in this report are indicated as 'road accident'. This term implies all kind of accidents happened on the road while the RLC pilot can reduce only the accidents caused by speeding or running red light. Thus the accident reduction percent caused by the use of RLC pilot and the statistical test results should be different from what written in this report. Second, the effect of the increase in traffic from before until after the camera operation should be concerned when finding the accident reduction percent.

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[3] Cleveland, Lincolnshire, Nottingham, Northamptonshire, Strathclyde, and Essex. South Wales and Thames Valley are excluded because changes in reporting practices made the data incomparable with the other KSI data.

In this report, the KSI casualty number in the six pilot areas are compared to the number in other areas of the Great Britain (GB)[4]. The other areas beside the six pilot areas are referred as ‘the comparison areas’. The comparisons of the KSI casualty numbers are shown in Figures 2.1, 2.2, and 2.3. Figure 2.1 shows that the pilot areas have more reduction in casualties than the comparison areas. Figure 2.2 shows that the number of KSI casualties per quarter year in 6 pilot areas after the program is lower than those in other areas of the GB. Figure 2.3 presents that the number of KSI casualties per quarter year in the same 6 pilot areas but at the camera sites only after the program is lower than those in other areas of the GB. The conclusion are as following:

- In the 6 wider pilot areas, whole pilot areas not just at camera sites, the frequency of KSIs is by 5 percent below the long-term trend.
- In the same 6 pilot areas, at camera sites, the frequency of KSIs is 35 percent below the long-term trend.

The authors conclude that the pilot camera sites perform well compared to the rest of GB, and the safety camera produces beneficial effects in the wider partnership areas. However, the author did not include any other effects that may have happened during the program. Additionally, the comparison sites may have different characters that would affect the trend of accidents.

[4] The comparison areas are Shire PFA and Metropolitan PFA that did not bid for the pilot.

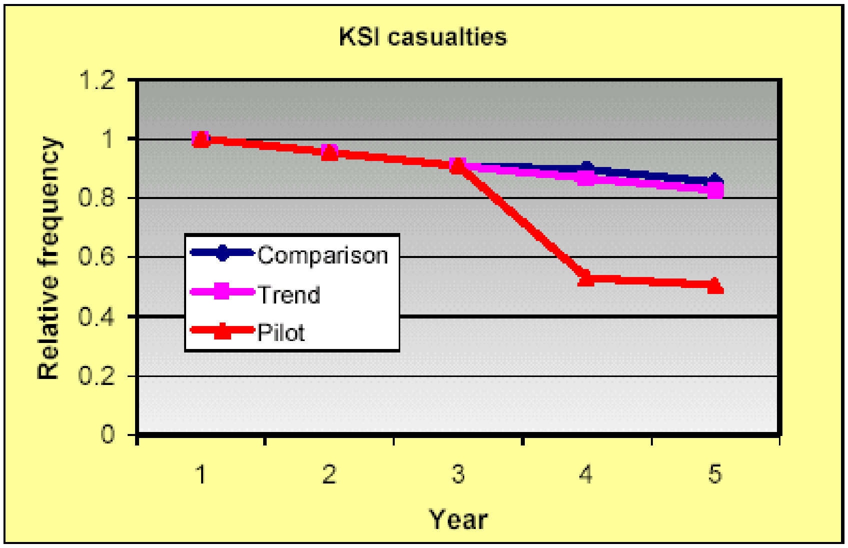

Figure 2.1 Trend in KSI Casualty Number

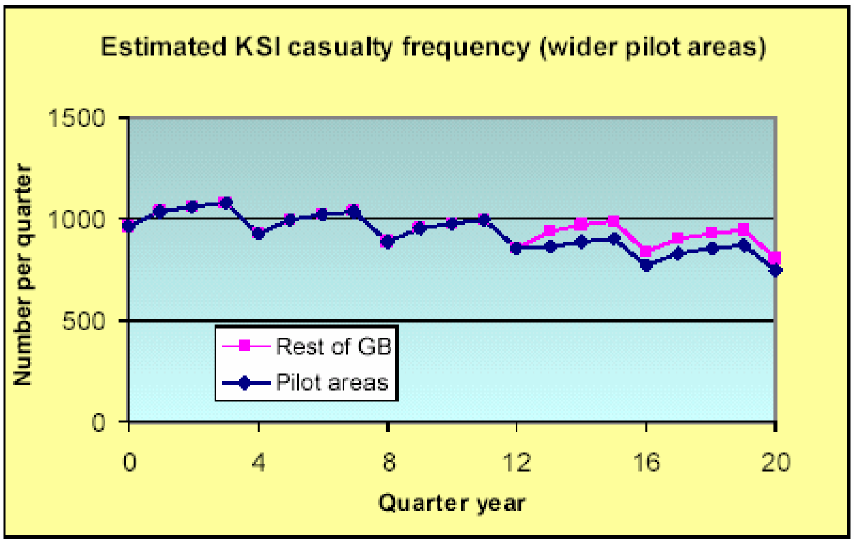

Figure 2.2 Change in KSI casualties in six pilot areas (whole area)

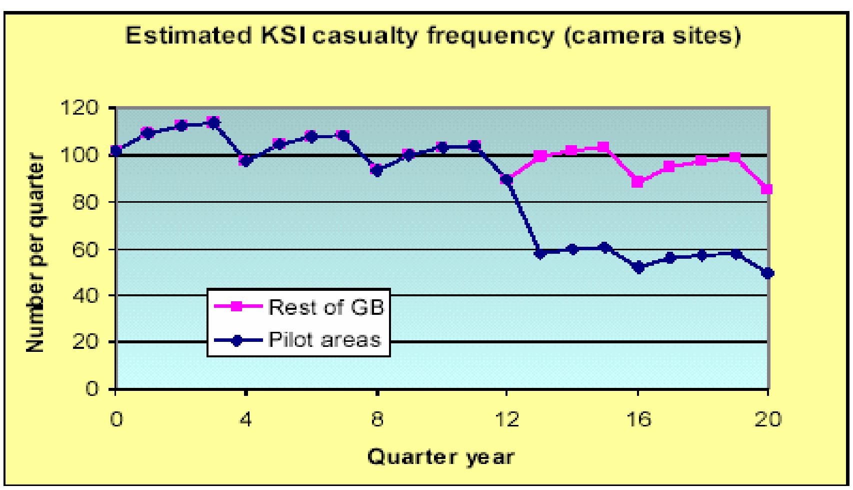

Figure 2.3 Change in KSI casualties at camera sites in six pilot areas

The impact of camera type on accidents is included in the report. The results are as following:

- At fixed camera sites, the number of KSIs fell by 65 percent
- At mobile camera sites, the number of KSIs fell by 28 percent

It is concluded that the fixed camera is the most effective. However, in some areas the number of PIAs is reduced more at the mobile camera sites than at the fixed camera sites. Therefore, the results are inconclusive. The explanation should have been furnished.

The impact by area and the effectiveness of the strategies are discussed in the report. The authors draw the following conclusions from their analysis in impact of the system on casualties.

- Some of the best strategies involved a combination of both fixed and mobile camera equipment.
- Fixed camera sites were approximately twice as effective as mobile cameras, although both reduce casualties significantly in certain conditions.
- Areas that focused predominantly on existing sites performed less well compared to areas that introduced new cameras.
- In general, the authors found some older sites were chosen on the basis of limited analysis of the accident history, which may have reduced their potential impact. The authors consider that the site analysis is the most critical element of the process.

According to the conclusion that 'fixed camera sites were twice as effective as mobile cameras', the data from the report does not support this conclusion. In some area that only the mobile camera sites are analyzed, the accident number still dramatically reduces more than those at some fixed camera sites. Therefore, there is no certainty that the fixed camera is more effective than the mobile camera. The authors also conclude that the existing sites perform less well compared to the new sites because of their lower percent reductions in casualties and accidents. However, these percent reductions are compared with the long term trend. The operation of safety cameras in the past may affect the long term trend of these experienced sites. The factors that effect these trends should have been considered.

In summary, the report draws some conclusions that are in conflict with the data. In addition, important control factors are missing such as traffic volume, and type of accidents.

After the 2-year pilot program, the UK Government establishes more criteria for the safety camera program. The new fixed camera locations must have an accident history and speeding problems. The required location is defined as where 4 people have been killed or seriously injured or where there have been 8 personal injury accidents in the previous three years together with 20 percent of vehicles exceed the speed limit. Other restrictions are that camera locations have to be more visible and the camera should be in a bright color. In addition, the location of camera should be made available to public. In 2003, there are 28 partnerships participating in safety camera scheme.

Examples of the safety camera pilot program partnerships are presented here.

Essex County

The speed and red light cameras have been used in Essex County since 1991. Essex County is one the partnerships that have a long history of camera enforcement. After the Essex partnership was selected to participate in the safety camera pilot scheme, the county receives the fund to extend the enforcement and to keep public informed about the scheme and the danger of inappropriate driving behaviors. There are two types of camera used in Essex County, a radar-based fixed unit and mobile camera. The fine is 60 pounds [1 pound = $1.83]. The penalty also includes the increase of 3 points to violators' license. Essex partnership believes that the well-communication strategy will bring the understanding in the use of safety camera to Essex residents and commuters. The theme 'More is Less' was used from 2000 to 2001. It means more cameras mean fewer accidents and fewer casualties. The message was changed in 2002 to 'They are Working'. It advises that safety camera is reducing accident and casualties and they are really working 24 hours at a fixed location. As of September 2003, there are 88 fixed speed cameras, 118 mobile speed cameras and 35 red light cameras being installed or due to be installed in Essex County.

After almost 2 years of the pilot program, the Essex Safety Camera Partnership carries out the report of accident estimation in March 2002. The results are as follows:

At fixed camera locations

- The number of speed-related accidents reduced by 44 percent.
- The number of overall accidents reduced by 21 percent.
- The number of fatal and serious accidents reduced by 8 percent.
- Average vehicle speeds reduced by 4.7 mph.
- The number of vehicles exceeding speed limit reduced by 81 percent
- The number of vehicles with ‘Excess Speed’[5] reduced by 97 percent.

At mobile camera locations

- The number of overall accidents reduced by 16 percent.
- The number of fatal and serious accidents reduced by 50 percent.
- Average vehicle speeds reduced by 1.2 mph.
- The number of vehicles exceeding speed limit reduced by 23 percent
- The number of vehicles with ‘Excess Speed’ reduced by 46 percent.

The report states that the camera is working (9). However, none of statistical test and control data is provided. In addition, the equivalent traffic volume between before and after the RLC operation is not considered. The conclusion should not be drawn from these simple results.

The percent changes in accidents in Essex County from the evaluation of 2-year pilot program by DfT (8) are analyzed differently from the previous report. The percent of accident changes is compared with the long term trend. The results are as follows.

- At camera sites, the number of killed and seriously injured casualties (KSI) increased by 15 percent.
- At camera sites, the number of personal injury accidents (PIA) decreased by 5 percent.
- In the wider areas, the number of killed and seriously injured casualties (KSI) increased by 4 percent.

The KSIs at the camera sites in Essex County increase while the average of KSIs in all partnerships reduces. From this result, the authors conclude that the safety camera system in Essex County is not as effective as other partnerships. However, since Essex County had been using the safety camera for a long time before the pilot

[5] The speed exceeding speed limit more than 15 mph

program initiated, the long-term trend can be different from those of the new sites. In this case, to better measure the effectiveness of the safety camera, the accident rate should be compared between before and after camera operating instead of between before and after the pilot program.

Several public opinion surveys and reports are conducted. In 1996, The Essex County Council released the report showing that the number of people requesting the use of camera in their areas was substantially more than the number of complaints about the camera operation. It was found that people will support cameras if they are visible and the reasons for their use are well addressed.

In October 2001, the consultant WS Atkins carried out a public opinion survey. The survey was conducted on a sample of 1,500 drivers in Chelmsford, Maldon, Thurrock and Southend on Sea. The results are as follows:

- 72 percent of the respondents agree with the statement ‘More should be done to reduce speed’.
- 72 percent of the respondents agree with the statement ‘fewer accidents are likely to happen on roads where cameras are installed’.
- 66 percent of the respondents agree with the statement ‘dangerous drivers are now more likely to get caught as a result of the safety camera’.
- 63 percent of the respondents agree with the statement ‘camera should be in a bright color to show drivers exactly where they are located’.

Essex Safety Camera Partnership conducted the annual driver survey in December 2002. The results show that:

- 81.7 percent of the respondents agree that ‘primary aim of safety camera is to save lives’.
- 86.7 percent of the respondents agree that ‘the use of safety cameras should be supported as a method of reducing casualties’.
- 70.3 percent of the respondents agree that ‘fewer accident are likely to happen on road where there are cameras installed’.
- 79.5 percent of the respondents agree that ‘the cameras meant to encourage driver to keep to speed limit not to punish them’.

The resident survey conducted in September 2003 found that:

- 75.7 percent of the respondents answered that they support the use of speed cameras in Essex.
- 63.1 percent of the respondents agree that more should be done in their area.

From the surveys, people agree that the safety camera reduces accidents. However, at the same time, people in Essex County thought that the safety camera is an easy way to make money from the commuters. However, the UK Government declares that the money raised through fines can only be used to cover the cost of the camera operation.

After the pilot period, more strategies are applied to the program. The new cameras are made more visible with the bright yellow color. More visible vans for mobile enforcement will be in operation. They will be larger and in brighter color than the currently used vans. The locations of the safety camera are available on the website www.essexsafetycameras.co.uk. The partnership plans to begin the six-month trial for frontal photography in 2003. The camera will take both front and rear of vehicle. The frontal photography will reduce problems when the registered owner of a vehicle did not operate the car at the time of violation. In addition, the unclear or broken license plate problem will be avoided. Another strategy is that new camera sites are graded by the number of casualties. The more casualties a site experienced, the more enforcement will be applied.

Cleveland

Cleveland Safety Camera Partnership is established under the operation of Cleveland Casualty Reduction Group. All of the cameras are mobile speed cameras. It photographs the rear of a vehicle. Cleveland is one of the partnerships that have not much experience of the safety camera before the pilot program started. There is report exclusively conducted to evaluate the safety camera program in Cleveland. However, the results of the program are available on the Cleveland Safety Camera Partnership website.

The results and findings (10) are as follows:

- The number of killed and seriously injured (KSI) casualties reduced by 17 percent.
- The number of personal injury accidents (PIA) reduced by 44 percent.
- The number of drivers exceeding speed limit reduced by 48 percent.
- The average speed is reduced by 4.5 mph.

This data is not statistically tested or compared with any control sites. Types of accidents included in the analysis are not specified. Therefore, it cannot be concluded that these reductions result from the safety camera only.

Results from The 2-year pilot program evaluation by DfT (8) are summarized as follows. The percents of accident reduction are compared with the 3-year long-term trend before the pilot program started.

- At camera sites, the number of KSIs statistically significantly decreased by 53 percent.
- At camera sites, the number of PIAs statistically significantly decreased by 45 percent.
- In the wider areas, the number of KSIs statistically insignificantly increased by 5 percent.

From the results, both casualties and crashes drop dramatically compared with those of other cities. However, the traffic volume, which affect safety at intersections are not adjusted to be in the same level between before and after the program. The comparison needs to be revised.

After 3 years of the camera operation, the Cleveland Safety Camera Partnership summarizes the number of injuries before and after the camera installation. The results are available on Cleveland Safety Camera Partnership website. Table 2.1 shows the summary of the data.

Table 2.1 The Number of Injuries before and after camera installation in Cleveland.

AREA	Number of Injuries			
	Yearly Average Before Cameras	Yearly Average Since Cameras	Actual No. prevented Over 3 years	Percent Changes Over 3 years
Redcar & Cleveland	72	48	72	-33.33%
Cleveland	51	21	90	-58.82%
Hartlepool	36	14	66	-61.11%
Stockton	71	25	138	-64.79%
Overall	230	108	366	-53.04%

The results indicate that 366 personal injury accidents are saved during the 3 years of camera operation. Even thought the results are encouraging, these accidents are not particularly related to speeding or red light running. The further analysis should be conducted for better evaluation of the program.

2) Red Light Camera System in The United Kingdom

Glasgow City

The red light camera (RLC) was initiated by the Strathclyde Police in the late 1980s. In 1990, the first red light camera was in operated in Glasgow District. In 2000, the City of Glasgow, which is a part of Strathclyde, participated in the safety camera pilot programs. As of 2003, there are 18 RLC intersections in Glasgow.

In 1996, the report "Accidents at Signal Controlled Junctions in Glasgow" (11) was released by Halcrow Fox from the Scottish Office. He investigates the benefit of RLC in Glasgow. Eight camera-equipped intersections and three camera-equipped pelican crossings[6] are studied. For the camera intersections, 6 cameras were installed in 1990 and 2 cameras were added in 1994. The period of study covered 3 years before and 3 years after the camera installation. The before period is from January 1989 to June 1991; and the after period is from April 1993 to November 1995. There is an interim period, which is when the RLC is in operation but only warning notices are issued. The interim period was from July 1991 to March 1993.

The number of accidents is compared in 'before/after' basis. The incidence of personal injury accidents of Glasgow during the study period is also compared with the national trend data, which is obtained from the annual data series of Road Accidents Scotland. There are 4 levels of accident severity: fatal, serious, slight, and non-injury.

The results are summarized as follows:

- The number of total accidents at all signalized intersections in Glasgow declined 25 percent.
- The number of total accidents at all pelican crossings in Glasgow declined 30 percent.
- The overall number of accidents in Scotland declined 20 percent.
- The number of PIAs at all signalized intersections in Glasgow declined 31 percents.
- The number of non-injury accidents at all signalized intersection in Glasgow declined 22 percents.

[6] Pedestrian crossing with traffic lights operated by pedestrians

The author concludes that there is a significant decline in accidents at all signalized intersections in Glasgow between the before and after periods studied. Moreover, the PIAs experience a greater decline than non-injury accidents do.

The PIAs are categorized by their primary causes into 5 groups:

- Red light running
- Crossing carelessly
- Unsafe right turn
- Fail to keep distance
- Other

The results, which are based on the primary cause of accidents, are as follows:

- There was 32 percent reduction in ‘red light running’ accidents.
- There was 54 percent reduction in ‘crossing carelessly’ accidents.
- There was 29 percent reduction in ‘unsafe right turn’ accidents.
- There was 8 percent reduction in ‘fail to keep distance’ accidents.

The author concludes that both injury and non-injury accidents caused by red light running fell by about a third. For the increase of accidents caused by failing to keep distance, the author comments that it reflects greater caution on the part of drivers approaching and driving through intersections. In addition, red light running accidents account for only 20 percent of the accidents decline while accidents occurred from other causes account for significantly more.

The analysis is also conducted based on the location. The results are:

- The PIAs caused by red light running fell by 25 percent at the first 6 sites
- The PIAs caused by red light running fell by 40 percent at the latest 2 sites.
- The PIAs caused by red light running fell by 21 percent at the adjacent sites.
- The PIAs caused by red light running fell by 30 percent at the area far from the camera sites.

Because of the reduction in PIAs at the adjacent sites, the author concludes that there are some wider area effects. The higher percent of reduction in accidents at sites far from camera sites than that of 6 camera sites suggests that factors such as junction improvement, traffic management and increased vigilance are also important. The traffic volume is observed during the study period. It increases at the camera areas.

The author concludes that the reduction in accidents cannot be attributed to the increase of traffic volume.

In conclusion, the author states that red light cameras appear to be only one of several factors contributing to the reduction of accidents at signalized junctions. However, from a cost-benefit analysis, the red light camera implementation brings benefit to Glasgow City.

This report is properly conducted with regard of accidents caused by running red light and comparison with national trend data. The study of different locations is very useful to determine the real effect of the red light camera. Statistical tests are recommended to support the results. In the same way, the further study on factors that affect the decline of accident at remote sites is suggested.

After the pilot period, the Strathclyde Police Department improves the location of the cameras to be more visible, including the signs notifying commuters of the safety camera. The notification signs are located within one kilometer of each site. A public opinion survey is also conducted. It is found that 89 percent of Scottish agree that safety cameras reduce accidents and save lives.

Nottingham

Nottingham is one of the DTLR partnerships that have both speed and red light cameras operating in their area. This city has less experience in camera enforcement comparing to other partnerships. As of 2003, there are 21 red light cameras. The effectiveness of the RLC is not evaluated separately from the speed camera. The average number of Personal Injury Collisions (PICs) and KSIs at the safety camera sites are released on the Nottingham Safety Camera website (12). The results at RLC sites are summarized as in Table 2.2. The results show that the total number of PICs and KSIs reduce after the operation of the RLC. Half of the RLC intersections have the number of PICs and KSIs reducing. Statistical analyses are recommended for this data in order to estimate the efficiency of the RLC.

Table 2.2 Crash and Casualty Results at Red Light Camera Intersection in Nottingham.

Intersection	PICs		KSIs		% Change	
	1997-1999	2002	1997-1999	2002	PCI	KSI
Kingsmill Way/Sutton Rd.	6.67	9.33	1	0	39.9%	-100.0%
Chesterfield Rd./Abbott Rd.	5.33	2.67	0.67	1.33	-49.9%	98.5%
Leeming Ln./ Old Mill Ln.	3.33	1.33	0.33	0	-60.1%	-100.0%
Nottingham Rd./Atkin Ln.	2.33	2.67	0	0	14.6%	0.0%
Mansfield Rd./Thackeray's Ln	6.67	6.67	0.67	1.33	0.0%	98.5%
Loughborough Rd./Kirk Ln	3.33	4	0.33	0	20.1%	-100.0%
Loughborough Rd./Radcliffe Rd.	2	5.33	0	0	166.5%	0.0%
Grantham Rd./Cropwell Rd.	1.33	8	0	0	501.5%	0.0%
Alfreton Rd/St. Helens St.	3.67	5.33	0.67	0	45.2%	-100.0%
Mansfield Rd./Fulforth St.	1	1.33	0.33	0	33.0%	-100.0%
Huntingdon St./Woodborough Rd.	7.67	4	1.33	0	-47.8%	-100.0%
Huntingdon St./King Edward St.	3	5.33	1.33	1.33	77.7%	0.0%
Lower Parliament St/ Barker Gate	2	5.33	0.67	4	166.5%	497.0%
Derby Rd./Lenton Blvd.	4.67	1.33	1.33	0	-71.5%	-100.0%
Ilkeston Rd./Radford Blvd.	3.67	2.67	0.33	0	-27.2%	-100.0%
Radford Rd/Bentinck Rd.	3.33	1.33	0.33	0	-60.1%	-100.0%
Radford Blvd./Harthley Rd.	6.33	0	0.67	0	-100.0%	-100.0%
Alfreton Rd./Hartley Rd.	1.67	5.33	0.67	2.67	219.2%	298.5%
Nuthall Rd./Stockhill Ln	8.67	8	0.67	0	-7.7%	-100.0%
Hucknall Rd./Haydn Rd.	4	1.33	0	0	-66.8%	0.0%
Valley Rd./Vernon Rd.	9	1.33	1.33	1.33	-85.2%	0.0%
Total	**89.67**	**82.64**	**12.66**	**11.99**	**-7.8%**	**-5.3%**

Australia

Victoria

The red light camera was implemented as a trial in Victoria, Australia in 1981 for 6 months. After that the Road and Traffic Authority purchased 10 red light cameras and the operation began in August 1983. As of 2003, 35 red light cameras are relocated among 132 sites within the Melbourne metropolitan region. The signs ‘Red Light Camera Ahead’ are installed on every approach of a camera intersection. The VicRoad and the Victoria police are responsible for the location of the camera.

The red light camera evaluation report was released by David Souths in 1988 (13). Souths selects 100 intersections. A half of them is camera sites and the other half is controlled sites. Souths concludes that:

- The use of automated enforcement technology reduced right angle accidents by more than 30 percent.

- There was 10.4 percent reduction in the number of casualties resulting from vehicle accidents.
- There was 35 to 60 percent reduction in the number of violation.

Andreassen who also conducts an analysis of the RLC program in Melbourne comments on Souths' report. He suggests that Souths makes a wrong conclusion that the right-angle crash reduction is statistically significant.

In 1995, David Andreassen released his study: a long-term study on red light camera and accident (5). He studies accident rates categorized by types of accident at 41 camera intersections in Melbourne. The study is based on the before data, from 1979 to 1983, and the after data, from 1985 to 1989. The year of installation, year 1984, is omitted. Andreassen analyzes the accident rates in 6 approaches. The methods and the results are discussed as follows:

<u>Approach 1: Comparison between the accident changes at 41 RLC intersections and at the non-camera intersections in Melbourne:</u>

The accidents are grouped into 4 types: hit pedestrians, vehicles from adjacent approaches, vehicles from opposing direction (right-thru) and vehicles in same lane (rear-end). The accident data at 41 RLC intersections is collected by the RLC itself. On the other hand, The accident data at non-camera intersections in Melbourne is obtained from VicRoad. The difference of the database type leads to the conclusion that the number of accidents obtained from RLC cannot be compared reliably with those provided from the VicRoad database.

<u>Approach 2: Analysis of each of 41 RLC intersections for changes over study period:</u>

The author uses Kornogorov-Smirnov goodness of fit test to determine if annual frequencies for each accident-type at the 41 sites are significantly different from a uniform distribution over the period. From this test, the adjacent approach, right-thru, and rear-end accident are found having the differences. However, the report does not clarify if the differences are that the annual frequencies were higher or lower than the uniform distributions. Another statistical test is Friedman 2 Way Analysis of Variance. From this test, there are differences in number of adjacent-approach and rear-end accident between before and after. The author concludes from his test that the number of both adjacent approach and rear-end accidents after the RLC operation period are higher than those the before the RLC operation period.

Approach 3: Analysis of the effect of RLC on the camera approach:

Since warning signs are installed on every approach of a camera intersection, the RLC may have the same effect on all approaches. The author compares the number of accidents on camera approaches and non-camera approaches of 41 RLC intersections between before and after camera operation and tests the differences with the Wilcoxon signed rank test. From the test results, he concludes that there is no clear evidence of an effect limited to the camera approach.

Approach 4: Analysis of the effect by initial frequency at 41 RLC sites:

The number of accidents after the RLC operation is compared with those at initial state. The results are summarized as in Table 2.3. The results are categorized based on the type of accidents and the number of accidents per year at initial state. In total, the number of accidents does not change after the camera operation.

Table 2.3 Summary of Accident results compared with initial accident frequency.

Type of Accidents	Results
Hit pedestrians	No significant change over time
Adjacent Approaches	Sites with >2 accidents/year had a decrease in accidents for the first 2 years but did not change afterwards Sites with 2 or less accidents/year had an increase in accident in after period.
Right-Thru	Sites with >3 accidents/year had no change over time Sites with 3 or less accidents/year had an increase in after period of >1.8 times of before period
Rear-End	There is an increase in after period of >2 times of before period.

Approach 5: Analysis of the effect by initial frequency on camera approach:

From the proportion of accidents in the after period to accidents frequency at initial state on camera approaches, the author concludes that all of the results have non significant difference in the proportion of accidents related to the camera approach.

Approach 6: Comparison between 41 RLC sites and signalized intersections:

From the comparison, the average number of annual accidents per site at the RLC sites is an average of 2.3 times of that at signalized intersections.

Andreassen concludes in his report that:

- The numbers of accidents at the RLC sites are above the average number of accidents per site before the cameras are installed and have remained above the average rate since then.
- The installation of the RLC at the 41 intersections does not provide reduction in accidents.
- There is an increase in rear end and adjacent approach accidents after the RLC operation and comparing to the accidents at signalized intersections.

However, according to the results from approach one analysis, the number of accidents obtained from RLC sites can not be compared reliably with those provided by the VicRoad database. Other conclusions from the other approaches are not reliable because of the undependable database. This report is also found having defects by overlooking the difference in roadway and traffic condition between before and after RLC operation.

Perth

The RLC program was initiated in Perth Metropolitan area in the early 1980s. The RLC were installed between 1984 and 1998. There are 30 cameras supporting 58 sites. Seventeen of these sites are permanent. The rest of the cameras are relocated during the operation period. Warning signs are placed at all approaches of each camera intersection.

The evaluation of effectiveness of RLC program (14) in Perth is conducted by Radalj T. from Main Roads Western Australia. All 58 intersections equipped with red light cameras between 1984 and 1988 are studied. The author determines the performance of the cameras from the cost and accident savings after the installation of the cameras. The evaluation is based on the “before/after” study design. The before period is 292.7 camera-years. The after period is set to be equal to the before period in order to eliminate the bias associated with variability between the sites related to crash history or traffic conflict exposures. The results are reported in 2 manners:

(a) Differences in number and cost of crashes involving vehicles that might have run red light by entering intersection from the approaching leg in the direction of red light camera, and

(b) Differences in number and cost of all crashes at the intersections.

The severity levels of crash include fatal, serious, minor, and property damage only (PDO). Types of crash include right turn against, right angle, rear end and, other type of crashes. The percent changes of crash between before and after the RLC operation are adjusted by annual percent change at a control sample of 477 non-camera intersections. The changes in accidents in direction of red light cameras are shown in Table 2.4.

The author concludes that the red light camera has a significant effect on a reduction in number of fatal crashes based on Poisson distribution. The chi-square tests accident changes based on type of crashes. The report states that there is a statistically significant change in types of crashes accounted for the decrease in number of right-angle and right-turn against crash and also the increase in rear-end crashes.

Table 2.4 Reductions in Number of Accident in Direction of Red Light Cameras.

Type of accidents	Reduction in number of accidents				Total Changes	%change after adjustment
	fatal	serious	minor	PDO		
Right Turn Against	-6	3	-34	-74	-111	-16.7%
Other	0	2	-20	-63	-81	-29.4%
Right Angle	-2	1	-17	-156	-174	-14.3%
Rear End	0	-2	34	204	236	18.0%
Total changes	-8	4	-37	-89	-130	3.3%
% Change	-72.7%	4.2%	-6.9%	-3.9%	-4.4%	

A hypothesis of this study is that most drivers are unaware of camera locations and their knowledge of its operation is limited. Therefore it is expected that red light cameras similarly affect the accident occurrence in each approach. The changes in total accidents at camera intersections under the above hypothesis are summarized in Table 2.5. The total number of crashes reduces from 6444 to 6153. The author concludes that there is no statistically significant change in crash severity pattern between the before and after RLC period. There is a significant reduction in fatal crashes. From chi-square test, there is a statistically significant association between the period and types of crash. Comparing accident reductions between on camera approach and all approaches, the author concludes that camera-warning signs have a similar effect to the effect arising from a red light camera. Table 2.6 presented the summary of the percent of changes in accidents.

Table 2.5 Reductions in All Accidents.

Type of accidents	Reduction in number of accidents				Total Changes	%change after adjustment
	Fatal	serious	minor	PDO		
Right Turn Against	-5	-2	-52	-176	-235	-21.0%
Other	-2	-5	-60	-187	-254	-18.0%
Right Angle	0	4	-54	-264	-314	-30.0%
Rear End	-1	4	111	428	542	17.0%
Total changes	-8	1	-55	-199	-261	-4.5%

Table 2.6 Summaries of Accident Changes.

Type of accidents	% Changes in accidents after camera installations		
	camera-direction crashes	non-camera direction crashes	all crashes
Right Turn Against	-16.7%	-28.0%	-21.0%
Other	-14.3%	-21.0%	-18.0%
Right Angle	-29.4%	-34.0%	-30.0%
Rear End	18.0%	16.0%	17.0%
Total changes	3.3%	-4.5%	-4.5%

The reductions in costs of crashes after the RLC operation are shown in Table 2.7. The cost of each type of crash are estimated as follows: AUD$1,810,874 per fatal accident; AUD$306,472 per serious accident; AUD$15,961 per minor injury accident; and AUD$10,202 per PDO accident [AUD$1 = US$0.76]. After the adjustment for the average of annual change in accidents, the estimated reduction cost is (AUD)$52,187.

Table 2.7 Differences in cost of all crashes between before and after period.

Nature	Severity				Total($M)	Annual Average Crash Cost Difference ($1000)/Red Light Camera Location	
	Fatal($M)	Serious Injury($M)	Minor Injury($M)	PDO($M)		Unadjusted	Adjusted
Right Turn Against	-9.054	-0.613	-0.830	1.796	-8.701	-41.994	-40.971
Other	-3.662	-1.532	-0.958	1.908	-4.244	-27.396	-23.527
Right Angle	0.000	1.226	-0.862	-2.693	-2.329	-7.957	-5.927
Rear End	-1.811	1.226	1.772	4.366	5.553	18.970	18.238
Total	-14.527	0.307	-0.878	5.377	-9.721	-58.377	-52.187

The author concludes that:

- There was a substantial reduction in number of fatal crashes and other less severe crashes, largely associated with right turn against, right angle crashes and crashes other than rear end crashes (Table 2.4).
- The benefit from the reduction in other types of crashes outweighs the loss resulting from the observed increase in rear end crashes (Table 2.7).
- The reduction in right turn against and right angle crashes, of over 50%, accounted for most of the economic benefits associated with red light cameras (Table 2.7).
- Reduction in crashes involving vehicles approaching an intersection from non-camera legs was found to be similar to those entering the intersection from the camera approach (Table 2.4 & Table 2.5).
- The installation of warning sing at all approaches is important.

The limitations of the study are also provided in the report. The author does not control or adjust for differences in number and characteristic of crashes associated with changes to intersection geometry and signalization or traffic exposure. In addition, he concludes that since the traffic exposure has an increasing trend over the study period, the effect of red light camera on the reduction in accidents is expected to be lower than the findings in the report.

In conclusion, this study is conducted properly with the statistical test and also the adjustment of the general reduction effect. However, other control factors are missing as mentioned in the limitation of the study. The results will be more accurate with further analysis.

Singapore

Singapore has installed the surveillance camera systems at more than 165 signalized intersections since 1990. In late 1997, the Traffic Police Department (TPD) of Singapore selected 10 intersections for installation of RLC. The RLC has been operated since 1998. A warning sign 'red light camera' is noticeably placed on the camera approach at an upstream distance. The penalty for running red light is S $200 [$1(U.S.)-S$1.74] for light vehicles or S$230 for heavy vehicles, and 12 demerit points.

Lum and Wong conducted the study of RLC system in Singapore in 2003 (15). The authors study the impact of RLC on violation characteristics. Three intersections are chosen for the study. Two of them are 'T' or three-leg intersections and the other one is a cross intersection. The data is collected by video cameras and categorized into before and after camera installation. The before periods are ranged from 2-7 days while the after periods are 1-3 months. The data is also categorized into camera and non-camera approach. Traffic in 3 types of lane are considered: median, middle, and curb lane. The data includes number of violations, after-red time, traffic volumes, speeds, timing and status of each signal phase.

The violation results are presented as per day and separated between weekdays and weekends. The difference between camera performance on weekdays and weekend is determined by comparing the reduction in violation rates. The ratio of the average number of daily violations volume for weekdays with respect to weekends in the after-RLC period is calculated.

The results are summarized as follows:

- There is 7 percent reduction in violations across all approaches.
- There is more than 40 percent reduction on the camera approaches.
- The reduction along the lanes on the camera approaches ranges from a low negative 80 percent to high positive 77 percent.
- All ratios of weekday to weekend violations except two cases are less than unity.

The authors study characteristics of the violations. They use the after-red time of a violation as a criterion and categorize violators into 3 types:

- Type 1 violators (Up to 2 s of After-Red Times)

- Type 2 violators (2-5s of after-red times)
- Type 3 Violators (>5 s of after-red times)

It is found that 69 to 96 percent of violators are Type 1. Type 2 violators are 2 to 15 percent while Type 3 violators are 1 to 17 percent. The report states that the RLC increases the share of violations of those having after-red times less than 0.5 seconds. This type of violation increases 13, 11 and 5 percent at the camera approach of 3 study intersections. The authors conclude that the RLC encourages violators to speed up and clear the intersection more speedily. For Type 2 violators, the share reduces by about 2-3 percent at all 3 intersections. The authors consider that some of the Type 2 violators indecisive drivers. The report states that the RLC might have helped these drivers to come to a stopping decision more quickly. For Type 3 violators, the overall result shows that the RLC was effective curbing this type of violations.

A linear model is set up comprising an after-red time as a dependent variable and 3 characteristics of intersections as independent categorical variables for the before and after RLC operation study. The equation is given as below:

$$y_{ijk} = \alpha_i + \beta_j + \delta_k + e_{ijk}$$

where y_{ijk} = after-red time

α_i = approach (intersection/ before or after/camera or non-camera approach)

β_j = lane (curb, middle, median)

δ_k = day (weekday or weekend)

e_{ijk} = error

The equation is tested using the SAS General Linear Model procedure. The results show that the after-red time in natural logarithmic forms is linearly related to 3 variables. The findings from the equation are as follows:

- The average of after-red times for each of camera approach after the RLC operation is significantly less than that before the RLC operation at 5% level for 2 intersections. The results are inconclusive for the non-camera approaches.
- The average of after-red times for weekdays is significantly less than that for weekends.
- The average of after-red times of the middle lane is significantly more than that of the median lane at 5 percent level. The middle lane, which has the highest violations in the before and after period of the RLC operation, has the largest average of after-red times.

The conclusions from the report are as follows:

- The RLC is more effective during weekends than weekdays at camera approaches.
- The RLC encourages violators to speed up and clear the intersection more speedily.
- Overall, the RLC is effective curbing the violation by Type 3 violators.
- The presence or absence of RLC significantly influences the after-red times and lower average of after-red times is observed for camera approaches.
- The larger the average of after red times is, the higher the degree of red light running violations is.

The results from this study can be inaccurate due to a small number of three study intersections. In addition, the before and after period of the RLC operation are too short. The comparison can be different with a longer period of study. Control intersections are suggested for the further analysis.

2.2 Studies From the United States

Howard County, Maryland

Overview

The red light running problem has been concerned in Howard County since 1990s. The Howard County Police Department (HCPD) was looking for a strategy to reduce the number of commuters killed or injured. In 1990s, the HCPD was responsible for providing the law enforcement service over Howard County which had an area of 251 square miles and more than 227,000 residents. They started using team enforcement method in 1993. This method basically uses 2 officers, one to observe and one to stop a violator. As a result, the number of violations reduced. However, the HCPD found this method was not cost effective. The personnel cost could be more than $360 for 3-hour enforcement. In 1994, the National Highway Traffic Safety Administration provided funding to the county for the red light running study. The violation and collision data was collected and 15 to 20 intersections were identified to be a majority of junctures where collisions were caused by red light violations. In 1996, Federal Highway Administration introduced the automated red light camera system (RLC) to Howard County. Funds were provided and a six-month trial of RLC was conducted. The HCPD was working with the Department of Public Works to test the RLC at two intersections with high collisions. Warning notices were sent to violators. The trial was considered effective so that the law allowing the use of RLC in Maryland state was enacted in October 1997.

The RLC program began in February 1998 with 2 cameras in operation. It was the first time of using digital RLC in the United State. The county launched a public awareness campaign composed of distributing flyers and airing a thirty second public service announcement on the county's cable station and on Comcast Cable of Howard County. The citation is 75 dollars. The camera takes photographs of the rear end of a violation vehicle. The citation does not have an impact on driver license’s point or insurance. As of 2003, there are 25 camera intersections.

From the presentation document of Lt. Glenn Hansen (16), it shows that the numbers of collisions and violations at camera intersections in Howard County reduced for all 25 intersections in December 2000. The reduction in violations at each intersection is shown in Table 2.8. The results are summarized as follows:

- The reduction in collisions ranges from a negative 21 percent to a negative 44 percent or an average of negative 23 percent.
- The reduction in violations is an average of 66 percent.

The results are encouraging. However, a comparison of camera and non-camera intersection should be provided to prove that these reductions result from the use of RLC. Statistical tests are missing from the study. Other control factors such as traffic volume are not considered. Moreover, the type of accident included in the evaluation is not evidently account for those are related to red light running only. The effectiveness of the RLC in Howard County should be further evaluated.

Table 2.8 The Violation Reduction in Howard County, Maryland.

HOWARD COUNTY SITE	1ST MONTH OF OPERATION PER DAY AVERAGE NUMBER OF INCIDENTS		JUNE 2001 AVERAGE NUMBER OF INCIDENTS	PERCENTAGE OF CHANGE
600	40	MARCH 98	11	-73%
601	15	MARCH 98	3	-80%
602	15	MARCH 98	4	-74%
603	26	MARCH 98	3	-89%
604	21	MARCH 98	6	-72%
605	12	MARCH 98	3	-75%
606	11	APRIL 98	3	-73%
607	6	MAY 98	2	-67%
608	17	MAY 98	7	-59%
609	29	MAY 98	16	-45%
610	5	JULY 98	1	-80%
611	6	JULY 98	2	-67%
612	26	AUGUST 98	12	-54%
613	4	AUGUST 98	2	-50%
614	24	OCTOBER 98	3	-88%
615	8	OCTOBER 98	2	-75%
616	7	NOV 98	4	-43%
617	7	DEC 98	5	-29%
618	9	NOV 98	4	-56%
619	15	DEC 98	7	-54%
620	19	April 99	4	79%
621	3	APRIL 99	1	-67%
622	15	JULY 99	6	-60%
623	5	JULY 99	2	-60%
624	1	AUGUST 99	1	0%
625	1	AUGUST 00	4	PLUS 75%
626	1	AUGUST 00	1	0%
627	1	SEPT 00	SITE TERMINATED	N/A
628	3	NOV 00	3	0%
TOTALS	352		122	-66%

North Carolina

The RLC program in North Carolina is named “SafeLight”. It is first initiated in Charlotte. The bill authorizing the use of RLC system and allowing the issue of a citation for red light violation caught by automated camera system in Charlotte only was passed in 1997. This type of bill is passed for other cities in North Carolina after 1999. As of 2003, the SafeLight programs are implemented in 12 cities: Charlotte, High point, Wilmington, Greensboro, Rocky Mount, Fayetteville, Cary, Chapel Hill, Indian Trail, Marshville, Monroe and Raleigh. The citation is $50. There is no driver license point and insurance impact. Signs “Red Light Camera Enforced” are provided at each approach of intersection that has a camera monitoring. All red light cameras of SafeLight program are digital. The registered owner of a violation vehicle has an option to stand in court in case he or she is not driving the vehicle at the time of violation. The responsibility may be transferred to the person who is operating the vehicle at that time. Examples of SafeLight program are discussed next.

City of Charlotte

The City of Charlotte began the SafeLight program in August 1998. In 2003, there are twenty camera intersections. Seventeen of them are in operation for more than three years.

The accident statistics is collected and a study is conducted to determine percent changes in accidents. The comparison is between three years before and three years after camera installation. Types of crash are separated between rear-end and angle crashes. The angle crash is the most severe crash and a major cause of vehicle damages, injuries and deaths. The effect of the RLC on rear-end crashes is studied.

Table 2.10 shows the percent changes of the number of accidents at 17 intersections compared between 3 years before and 3 years after camera installation. The results are summarized as following:

- There is an average of 37 percent reduction in angle crashes at camera intersections on all approaches
- There is an average of 60 percent reduction in angle crashes at camera intersection on camera approach.
- Overall accidents reduced by 0.75 percent at camera intersections on all approaches.

- Overall accidents reduced by 19 percent at camera intersections on camera approaches.
- Crash severity reduced by 16 percent (per reduction in EPDO rate)
- Overall rear-end crashes increased 4 percent at camera intersection on camera approaches.
- 12 out of 17 intersections had a reduction in overall accident on the camera approach.
- The number of citations reduced by 34 percent comparing between in year 2000 and year 2002.

The results are very encouraging that the number of accidents reduces after using red light cameras. However, the control data is not provided. Other factors that affect the reduction in accidents are not concerned.

The public opinion survey is conducted by MarketWise, Inc. for the Charlotte Department of Transportation. The results are as in Table 2.9. Eighty-four percent of Charlotte residents believe that the red light camera program is beneficial to their communities.

Table 2.9 Public Opinion Survey in Charlotte, North Carolina.

Issue	Charlotte	State
Traffic violations are a problem	68%	62%
Running red lights is a problem	61%	57%
Awareness of operational *Safe*Light programs	98%	98%
Believe *Safe*Light is beneficial to the community	84%	82%
Support of *Safe*Light program	76%	74%

Table 2.10 Accident Rates in Charlotte, North Carolina.

	ALL APPROACH AT EACH INTERSECTION												CAMERA APPROACH ONLY AT EACH INTERSECTION								
	Accident Totals			Angle Accidents			Rear End Accidents			EPDO Rates			Accidents on Camera Approach			Angle Accidents on Camera Approach			Rear-End Accidents on Camera Approach		
INTERSECTION	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change
11th St @ Brevard St	60	30	-50.0%	21	6	-71.4%	12	14	16.7%	23.4	10.47	-55.3%	46	21	-54.4%	14	4	-71.4%	12	12	0.0%
Poplar St @4th St	32	29	-9.4%	27	19	-29.6%	2	16	700.0%	22.91	30.16	31.7%	25	20	-20.0%	22	18	-18.2%	2	2	0.0%
Albermarie Rd @ Harris Bv	215	225	4.7%	19	17	-10.5%	148	146	-1.4%	16.3	13.09	-19.7%	79	52	-34.2%	11	4	-63.6%	50	30	-40.0%
South Bv @ Arehdale Dr	105	131	24.8%	28	22	-21.4%	52	74	42.3%	12.71	14.25	12.1%	33	43	30.3%	7	5	-28.6%	18	24	33.3%
Arrowood Rd @ Nations Ford Rd	71	78	9.9%	24	19	-20.8%	20	26	30.0%	16.71	15.52	-7.1%	17	23	35.3%	7	2	-71.4%	2	12	500.0%
Beaties Ford Rd @ Hoskins Rd	14	13	-7.1%	1	1	0.0%	6	6	0.0%	4.08	3.32	-18.6%	5	2	-60.0%	0	0	-	4	2	-50.0%
Brookshire Bv @ Hovis Rd.	63	55	-12.7%	34	15	-55.9%	24	30	25.0%	12.97	12.6	-2.9%	45	33	-26.7%	30	10	-66.7%	14	18	28.6%
Sharon Amity Rd @ Central Av	205	242	18.1%	28	18	-35.7%	114	166	45.6%	20.88	20.17	-3.4%	47	56	19.2%	10	5	-50.0%	22	38	72.7%
Morehead St @ College St	52	21	-59.6%	34	2	-94.1%	14	12	-14.3%	20.08	6.33	-68.5%	27	10	-63.0%	23	0	-100.0%	6	10	66.7%
Eastway Dr @ Klborne Dr	75	80	6.7%	10	14	40.0%	46	48	4.4%	12.7	12.43	-2.1%	30	28	-6.7%	7	5	-28.6%	18	22	22.2%
Fairview Rd @ Sharon Rd	170	171	0.6%	12	17	41.7%	114	118	3.5%	11.75	9.31	-20.8%	39	40	2.6%	5	4	-20.0%	22	24	9.1%
Tryon St @ Harris Bv	155	152	-1.9%	18	11	-38.9%	104	100	-3.9%	12.94	7.44	-42.5%	50	55	10.0%	3	4	33.3%	40	42	5.0%

Table 2.9 Accident Rates in Charlotte, North Carolina (Con't).

	ALL APPROACH AT EACH INTERSECTION												CAMERA APPROACH ONLY AT EACH INTERSECTION								
	Accident Totals			Angle Accidents			Rear End Accidents			EPDO Rates			Accidents on Camera Approach			Angle Accidents on Camera Approach			Rear-End Accidents on Camera Approach		
INTERSECTION	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change	3 Yr Before	3 Yr After	% Change
Idlewild Rd @ Independence Bv	212	266	25.5%	35	30	-14.3%	132	192	45.5%	14.85	12.7	-14.5%	45	34	-24.4%	7	3	-57.1%	26	22	-15.4%
Morehead St @ McDowell St	64	39	-39.1%	10	8	-20.0%	26	14	-46.2%	9.93	7.86	-20.9%	28	17	-39.3%	2	0	-100.0%	16	10	-37.5%
Randolph Rd @ Sharon Amity Rd	84	77	-8.3%	17	22	29.4%	38	30	-21.1%	5.5	8.32	51.3%	21	18	-14.3%	4	6	50.0%	14	6	-57.1%
Westinghouse Bv @ Tryon Sq	115	79	-31.3%	31	9	-71.0%	50	48	-4.0%	19.41	12	-38.2%	28	12	-57.1%	19	5	-73.7%	4	6	50.0%
Tyvota Rd @ Wedgewood Av	34	25	-26.5%	20	1	-95.0%	10	18	80.0%	11.08	5.35	-51.7%	24	13	-45.8%	17	0	-100.0%	10	12	20.0%
Fairview Rd @ Sharon Rd	170	171	0.6%	12	17	41.7%	114	118	3.5%	11.75	9.31	-20.8%	39	40	2.6%	5	4	-20.0%	22	24	9.1%
Tryon St @ Harris Bv	155	152	-1.9%	18	11	-38.9%	104	100	-3.9%	12.94	7.44	-42.5%	50	55	10.0%	3	4	33.3%	40	42	5.0%
Total	233	181	-22.3%	68	32	-52.9%	98	96	-2.0%	35.99	25.67	-28.7%	73	43	-41.1%	40	11	-72.5%	28	24	-14.3%

Wilmington

The automated red light camera program was initiated in Wilmington in March 2000. The City has a 5-year contract with Peak Traffic, Inc. The program is deployed without any involvement at the federal level. There are 10 camera intersections. The results of the accident and violation rate at the camera intersections from March 2000 through March 2002 are summarized in the SafeLight Annual Report (17). Table 2.11 and 2.12 show the annual results. The accidents are categorized into 3 types: angle, rear end and other collisions. The yearly average numbers of accidents are compared between before and after camera operation. In conclusion, the total number of accidents reduces by 21 percent in Wilmington.

Table 2.11 Accident rate in Wilmington, North Carolina.

COLLISION TYPE	Before Cameras	After Cameras	Percent Difference
Angle collisions	73	23	-23%
Rear-end collisions	55	52	-5%
Other collisions	61	41	-32%
Totals	189	149	-21%

Table 2.12 Citation Statistics.

CITATION STATISTICS	
Number of citations issued	22,875
Revenue collected	$1,204,450
Number of citations appealed	383
Number of administrative dismissals	83

The statistical test is not found in this report as well as the comparison with control data. Traffic volume and other factors that may affect the number of accidents are not concerned.

The report includes the public opinion survey. About 85 percent of Wilmington citizens agree that the RLC reduces red light running at the intersections.

The RLC program in other cities of North Carolina has not yet to be evaluated. The information about the RLC program in North Carolina is summarized in Table 2.13.

Table 2.13 Safe Light program in North Carolina (2003).

City	Number of cameras	In operation month	Operated by
CHARLOTTE	20	August 1998	CDOT
Wilmington	10	March 2000	Peak Traffic, Inc.
Fayetteville	7	March 2000	City of Fayetteville
High Point	10	February 2001	Peak Traffic, Inc.
Greensboro	18	February 2001	Peak Traffic, Inc.
Rocky Mount	5	September 2002	Peak Traffic, Inc.
Raleigh	7(20)*	July 2003	RDOT
Chapel Hill	2	September 2003	The Town of Chapel Hill partnered with ACS, Inc.

* 20 cameras are planned to be installed

Virginia

City of Fairfax

The RLC enforcement has taken effect in city of Fairfax since July 1997 after a statewide law was put in force in July 1995. A 30-day warning period was provided before the program began. Fairfax Police Department collects $50 fine for a vehicle photographed by red light camera. Photo enforcement warning signs are installed on monitored approaches. The RLC program is publicized by a press release, local media and postcard mailed from City officials.

The evaluation of RLC enforcement in Fairfax was conducted by Richard A. Retting in 1999 (18). His report presents changes in number of violations resulting from the RLC. The violation data is categorized into before, three months after and one year after camera installation. The data is collected prior to the warning period and then three months after and one year after the enforcement. Nine intersections are observed. Five of them are camera intersections. Another two intersections referred as non-camera intersections are intersections located near camera intersections included for spill over effect study. The last two intersections are control intersections, which are located outside Fairfax City. The result is shown in Table 2.14.

Table 2.14 Violation Rate in Fairfax, Virginia.

INTERSECTION	Percent Changes in Violations /10,000 veh	
	Three months after	One year after
Camera (5)	-7 %	-44 %
Non-camera (2)	-14%	-34%
Control (2)	+1%	+5%

The report shows no statistically significant difference between the reduction in violation rates at the camera and non-camera sites for both three months and one year after the enforcement. There is also no statistically significant difference between the reduction in violation rates at camera and non-camera sites compared with the control sites for three months after the enforcement but there is for one year after the enforcement.

The author concludes that there is a significant reduction in number of violations after 1 year of camera operation at camera and non-camera intersections. In addition, the effect of the camera on violation reduction is not limited to at camera-equipped intersections but also at non-equipped intersections. The author noted that the presence of camera may promote a general readiness to stop for red light. The large number of camera-equipped intersections may promote the generalization to non-camera sites.

This report does not include the accident evaluation. Therefore, the benefit of the RLC cannot be completely concluded from this study. Further analysis of accident changes should be conducted.

Fairfax County

The RLC enforcement took effect in Fairfax County in October 2000. In 2001, there are ten cameras installed at the intersections with high traffic density and flow. A warning period is not provided. Commuters are assumed to be aware of the RLC by the similar system in nearby area. The warning sign, press release and information from local media are provided. All 10 cameras were put into use after the first camera has been installed for one year. The registered owner of the red light running vehicle is subjected to $50 citation.

The evaluation of RLC enforcement in Fairfax County is conducted by Daniel E. Ruby in 2001 (19). The evaluation method of this study is corresponding to that of Retting's study. The study period is at initial state, after 3 months, and after 6 months of camera installation. All 10 intersections are studied. The percent changes in number of violations and accidents are determined in this report. The results show that:

- There is an average of 36% reduction in violations per 10,000 vehicles after 3 months of operation
- There is an average of 69% reduction in violations per 10,000 vehicles after 6 months of operation

- There is an average 40% reduction in accidents after 3 months of operation

By the end of this study, three intersections cannot be evaluated because of their operation periods are less than three months. In addition, the accident data after the camera installation is available at four intersections. In addition, there are only 3 intersections from total 10 intersections that have data for more than 6 months. Therefore, the result may not be appropriate to present overall performance of the RLC due to the small sample size and short period of study. It may take a certain time for drivers to learn about the system and to adjust their behaviors.

The effect of Average Daily Traffic (ADT) on number of violations is studied. Three intersections, which had ADT lower than 58,000, are considered as low ADT intersection. Four intersections are considered having high ADT. The results are shown in Table 2.15.

Table 2.15 Average Daily Traffic Effect.

INTERSECTION	**% Change in Violations/10,000 vehicles**	
	3 month after	**6 month after**
High ADT	-55.5 %	-85.2 %
Low ADT	-9.9 %	-41.9 %

The effect of speed limit and speed tolerances on violations is also analyzed. Two intersections have speed limit of 55 mph, another three intersections have 45 mph and the other two intersections have 35 mph. The results are shown in Table 2.16.

Table 2.16 Speed Limit Effect.

INTERSECTION	**% Change in Violations/10,000 vehicles**	
	3 month after	**6 month after**
55 mph speed limit and 20 mph camera threshold	-5.0%	-41.9%
45 mph speed limit and 18 mph camera threshold	-30.5%	n/a
35 mph speed limit and 18 mph camera threshold	-53.6%	-85.2%

The conclusions of this report are as follows:

- The number of violations reduced after the camera installation.
- The red light camera worked more effectively on roadways with higher ADT.

- On lower speed limit roadways, there was higher reduction in violations.

However, the RLC performance in Fairfax, County should be further analyzed because of the short of the data in this study. For example, there is only one intersection that have 55-mph speed limit and have the data for 6 months.

The cost-benefit analysis is also conducted. It is concluded that the reduction of accidents saves $12.8 million over the eight-year life cycle of the system. The public opinion is obtained from 400 residents. Approximate 80% of the respondents approve the RLC being used in Fairfax County, their neighborhood and high commuter traffic areas.

2.3 Conclusion

From the previous literature reviews, the RLC program deployed in different places have different characteristics and also give various results. Several methods are used to evaluate the program. The comment on the method of evaluation, factors that affect RLC performance, and the effect of RLC on accident are discussed next.

Method of the evaluation

For most of the RLC studies, statistical tests proving the significant change in number of accident or violations are provided. The statistical test is important and required to ensure the reliability of a result. For several RLC studies, the type of studied accidents should be more exclusive. The accidents included in the study should be those involving red light running. Even though it is very complicated to identify what is the cause of each accident or to state that a certain accident is from the running red light only, the researcher should pay attention to screen those accident resulted from running red light from those resulted from other causes. The other flaw for most of the evaluation method of the RLC studies is the lack of control data. In order to determine the effectiveness of the RLC only on accident or violation change, the control data is important. Without control intersection, it would be unclear if the reduction in accidents or violations were from the RLC or from other factors.

In some cities, the performance of the RLC is reported on website by showing percent changes in accidents or violations at camera intersections. These percent changes are found encouraging. However, statistical test is missing in order to prove the positive result. The control site or other control factors are as well not provided. This information from the websites is not appropriate to be used to support the conclusion that the RLC is working and reduces accidents. More analysis should be conducted.

Factors effecting the RLC performance

In conclusion, the factor that affects the RLC performance still cannot be defined. In UK, the difference in types of cameras, fixed and mobile, results in the different effectiveness of the program. However, there are still questions that which type of cameras provides a better result or what combination of these two types of cameras effectively works. Moreover, it is still questionable if the effectiveness of the camera really involves with the type of camera. Another factor is an age of the program. In UK, the report indicates that the camera is more effective at the new site or the site that the program just begun. However, it is still unconvincing. For example, from the results of this report the reduction in accidents is higher when the program has been operated for 2 years compared with 1 year. The other factor such as the presence of warning sign or a warning period cannot be evaluated from this literature review. Despite most of RLC jurisdictions have warning sign and do not have warning period, they give different results. The factor that affects the accident change may various upon the characteristic of each intersection and also of each place. Economic and population factor should be additionally concerned.

The effect of red light camera on accident number

Even though most of the studies imply that the reduction in accidents results from the RLC. Their evaluation methods still have some flaws that lead to the difficulty to conclude that the reduction in accidents is only affected by RLC program. The lack of the control data makes it more difficult to draw a conclusion.

Table 2.17 shows the summary of the results in accident and violation changes at the reviewed RLC jurisdictions in this study. It is noticeable that the accident reduction rate in the UK is higher than those in Australia or the United States. However, it is incomparable because of the different method of evaluation and different criteria among countries. Moreover, the review of safety camera in the UK emphasized more on speed camera than on red light camera.

Table 2.17 Summarization of Violation and Accident Reduction.

Location	Accident Reduction	Death & Serious injury Reduction	Violation Reduction	Warning sign	Warning period	Fine	Driver license point
UK							
Glasgow	64%	67%	69%	Yes	No	60 pound	Yes
Essex	21%	8%	81%*	Yes	No	60 pound	Yes
Cleveland	44%	17%	48%*	Yes	No	60 pound	Yes
Nottingham	31%	1%	-	Yes	No	60 pound	Yes
Australia							
Victoria	30% right angle	10.4% casualties	35-60%	Yes	No		
Perth	30%righ angle	-	-	Yes	No		
Singapore	-	-	40%	Yes	No	S$200-230	Yes
USA							
Howard County, MD	23%	-	70%	No	No	$75	No
North Carolina							
Charlotte	60% right angle	-	34%	Yes	No	$50	No
Wilmington	23%	-	-	Yes	No	$50	No
Virginia							
City of Fairfax	-	-	44%	Yes	Yes	$50	No
Fairfax County	40%	-	69%	Yes	No	$50	No

CHAPTER 3

METHODOLOGICAL APPROACH

This chapter presents the evaluation approach of the thesis. The study emphasizes on how RLC affects accidents and violations. The measurement is mainly conducted using "before/after" methodology. The general trend of violation rate is also determined. The number of violations and accidents are collected at camera intersections monthly. The study takes into account the changes in traffic at different times and different traffic flows at each intersection. Therefore, the number of accidents and violations are measured by the ADT on monitored roadways.

The violation data is provided during the camera operation period. The accident data is available both before and after the camera operation and includes only the number of accidents that relate to red light running. The hypothesis is that accidents occur within 150 feet from the intersection are considered to involve red light running. The accidents involving pedestrians, animals and fixed object on the street are excluded. The severity of accidents are categorized into 3 levels: property damage only, injury, and fatal. Two types of accidents, rear-end and right-angle, are considered involving red light running. Since the number of right-angle accidents at the study intersections is very few, it is excluded from this study. As a result, the study emphasizes on the rear-end accident. The control intersections are compared with the camera intersections at the same period. Spillover effect is also studied by comparing camera intersections and non-camera intersections. The results summarize the general trend of accidents and violations.

After all, the results are statistically tested. The test involves a comparison of locations with and without camera and also a comparison of before and after camera operation.

3.1 Violation Data Analysis Approaches

For violation data, the results are analyzed using 3 approaches:

- Initial period and after period analysis at camera intersections
- Trend Analysis
- Statistical Analysis

3.1.1 Initial Period and After Period Analysis at Camera Intersections

This analysis is adjusted from the before-and-after analysis at camera intersections. A before-and-after analysis at camera intersection is a simple methodology. The performance of the RLC is measured by comparing the violation and accident number between before and after the operation. The comparison is conducted at the same location in order to eliminate the difference between locations.

Because the violation data is not available during the before period, the initial period is used instead for the comparison. The violation data after the camera operation is provided by Fairfax County Department of Transportation. The number of violations is provided monthly during the camera operation period. It is measured per 10,000 vehicles and is referred to as "violation rate." The violation rates in the first 3 months are averaged to be "initial violation rate."

The violation rates are categorized into 6 periods:

- Initial period of the RLC operation
- 4^{th} to 9^{th} month of the RLC operation
- 10^{th} to 15^{th} month of the RLC operation
- 16^{th} to 21^{st} month of the RLC operation
- 22^{nd} to 27^{th} month of the RLC operation
- After the 27^{th} month of the RLC operation

The violation rates in each period are averaged for each intersection. Out of 13 camera intersections, 10 of them have the camera installed for more than 27 months. The other 3 intersections have the RLC operated for only 9 months at the time of study. The averages of violation rates are compared at an initial period and after periods. The percent changes in violation rate are determined. Factors that affect the percent change in violation rates are discussed.

3.1.2 Trend Analysis

The trend analysis is an informal evaluation. Changes in accident or violation number at camera intersections are monitored over a period of time in order to generate a general trend of results.

For the purpose of this study, the general trend of violations after the RLC operation is created. A graph of monthly violation along with the RLC operation period is provided for each intersection. The camera intersections are grouped by their violation rate after the RLC operation. Factors that may affect the violation trend such as an amber time and ADT are considered. The results are discussed.

3.1.3 Statistical Analysis

The statistical tests are provided to ascertain a confidence in a magnitude of the difference observed. The t test and F test are used for the violation data.

The t test determines the significance in difference between 2 population means. For this study, the significant difference in means of violation rates between 2 periods of time is determined.

The F ratio tests the difference between variances of two data categories. It is used to determine the difference in variance of the violation rates between at initial period and after the period after the operation. Appendix C provides the detail of the statistical test.

3.2 Accident Data Analysis Approaches

For accident data, the results are analyzed using 3 approaches:

- Before-and-after analysis at camera intersections
- Comparison analysis between camera and control intersections
- Spillover analysis
- Statistical analysis

3.2.1 Before-and-After Analysis at Camera Intersections

The before-and after analysis of accident rates is a comparison of 2 years before and 2 years after the RLC operation. The accident data is provided by Fairfax County Police Department. The period of study is from January 1999 to May 2003, which covers the time period before and after camera operation. The accident data is also adjusted to be in “a number of accidents per 10,000 vehicles” or “accident rate”. Each year average accident rate for each intersection is determined and categorized into 4 groups:

- Average accident rate of 2 years before the RLC operation.
- Average accident rate of 1 year before the RLC operation.
- Average accident rate of 1 year after the RLC operation.

- Average accident rate of 2 years after the RLC operation.

The accidents are also grouped into 3 levels of severity: Property damage only (PDO), injury and fatal accident. From the accident data, all of the accidents are reported as rear-end accidents.

The comparison of accident rates is conducted for 4 pairs of data groups:

- 2 years before & 1 year after the RLC operation.
- 1 year before & 1 year after the RLC operation.
- 2 years before & 2 years after the RLC operation.
- 1 year before & 2 years after the RLC operation.

Percent changes of accident rates are determined and compared with the percent changes at non-camera and control intersections.

3.2.2 Comparison Analysis Between Camera and Control Intersections

The comparison of camera and control intersections is one of the most defensible methodologies. The changes of accident or violation at camera intersections are compared with those at intersections without the RLC.

Four control intersections are chosen from intersections that have high number of accident. They are located in Fairfax County and are far from camera intersections to avoid the spillover effect. These intersections have ADT in the ADT range of camera intersections. The number of accidents at these intersections is high compared to those at camera intersections. Since most of the cameras were installed in 2001, the estimated before period for these control intersection is from January 1999 to May 2001, and the after period is from June 2001 to May 2003. The percent changes in number of accidents at control intersections are compared with those at camera intersections. The results are discussed.

3.2.3 Spillover Analysis

At some locations, where the RLC operates, the changes in number of accidents or violations are not limited to only at camera intersections. Some reports show that intersections near camera intersections had been affected by the RLC as well. The spillover study is conducted to determine if the RLC has a general effect on drivers' behavior further beyond camera intersections.

In order to study the spillover effect on accident number, the chosen non-camera intersections are those locate near camera intersections. They have the same ADT as the nearby camera intersections. The before and after period of non-camera intersections are set to be the same as those of camera intersections. The percent changes in accidents of non-camera intersections are compared with those of camera intersections. The spillover effect is evaluated.

3.2.4 Statistical Analysis

The Chi-Square test is used in this study to test the consistency of the accident rates in different locations such as camera, non-camera, and control intersections after the RLC operation. The Chi-Square test is one of the most widely used nonparametric techniques. It is used when the type of data is frequencies rather than numerical value. The use of chi-square in this study is called testing for independence. The effect of types of intersections on accidents is determined. The detail of the Chi-Square test is provided in appendix C.

3.3 Evaluation

After applying the above approaches to the results, the effectiveness of the RLC is determined as follows:

- The RLC has an effect on the number of violations when the percent reduction of violation rates after the RLC operation is significant
- The RLC has an effect on the number of accidents when the percent reduction of accident rates after the RLC operation between camera and control intersections is significantly different.
- The RLC has a spillover effect on the number of accidents when the percent reduction of accidents between camera and non-camera intersections is not significantly different.
- The RLC program is considered to be an economical project if there is a benefit at the end of the project.

CHAPTER 4

RESULTS

The effect of the red light camera enforcement on the number of violations and accidents at the monitored sites is presented in this chapter. A total of 19 intersections were observed. Thirteen intersections are equipped with red light cameras. Two intersections, which are referred as ‘non-camera’ intersections, are included for the spillover study. They were selected based on their locations, which are nearby the camera sites. The last 4 intersections are control intersections, which are located far away from the camera intersections.

The number of observed violations and accidents are adjusted to reflect the vehicular volume passing through the intersections. They are measured per 10,000 vehicles in order to eliminate the bias from different traffic volumes. The Average Daily Traffic (ADT) on the primary street that is monitored by the red light camera is used to present the number of vehicles passing through the intersection. Periods of observation for the study intersections vary depending on the date of camera installation. The available violation data is only for the periods after a camera is being installed. The data is presented on a monthly basis. On the other hand, the accident data is available for both before and after operation period. The before period is 2 years as well as the after period. The number of accidents is presented on yearly basis. All accidents reported in this study occurred within 150 feet from the study intersections. The accidents involving pedestrians, animals, and fixed objects on the street were excluded. The ADT data is available from year 2000 to 2002. The 2000 ADT also represents 1999 ADT. The 2002 ADT represents 2003 ADT because at the study time, the 2003 ADT is still not available. The implementation time of each study intersection is shown in Table 4.1. The characteristic of each intersection and accident and violation results at each intersection are discussed next.

Table 4.1 Implementation Timetable Data of Study Intersections.

Type of intersection	Intersection	Name	Build Plan to VDOT	Permit issued	Construction Started	Construction Complete	Date in Operation	Date out of Operation
Camera	1	Leesburg Pike @ Towlston Rd.	01/06/00	08/24/00	09/11/00	09/22/00	10/01/00	03/14/03
	2	Lee Jackson @ Rugby Rd.	08/09/00	11/28/00	12/11/00	02/07/01	02/09/01	-
	3	Lee Jackson @ Fair Ridge Dr.	09/21/00	11/28/00	01/09/01	02/07/01	02/09/01	09/09/02
	4	Leesburg Pike @ Westpark Dr.	09/21/00	02/15/01	03/05/01	03/22/01	03/22/01	-
	5	Leesburg Pike @ Rt 66	09/21/00	03/21/01	04/19/01	05/01/01	05/02/01	-
	6	Arlington Blvd. @ Jaguar Trail	09/21/00	03/21/01	04/20/01	05/01/01	05/02/01	-
	7	Rt 28 @ Greens Trail Blvd.	01/29/01	04/16/01	05/08/01	06/15/01	06/15/01	3/19/03
	8	Leesburg Pike @ Dranesville Rd.	02/22/01	04/16/01	05/08/01	06/20/01	06/21/01	-
	9	Fairfax Cty Pkwy @ Popes Head rd.	02/22/01	04/11/01	05/08/01	05/29/01	07/10/01	-
	10	Fairfax Cty Pkwy @ Newington Rd.	09/21/00	02/02/01	02/26/01	09/16/01	10/16/01	-
	11	Rt 236 @ Heritage Rd.	04/23/02	07/12/02	07/30/02	08/08/02	09/09/02	-
	12	Telegraph Rd. @ Huntington Rd.	08/26/02	01/08/03	01/13/03	02/11/03	03/18/03	-
	13	Rt 7 @ Carlin Springs Rd.	08/26/02	01/08/03	01/13/03	02/11/03	03/24/03	-
Non- camera (spill over)	14	Rt 7 @ Lewinsville Rd.	-	-	-	-	-	-
	15	Rt 7 @ Beulah Rd.	-	-	-	-	-	-
Control	16	Rt 644 @ Rolling Rd.	-	-	-	-	-	-
	17	Richmond Hwy @ Telegraph Rd.	-	-	-	-	-	-
	18	Braddock Rd. @ Rolling Rd.	-	-	-	-	-	-
	19	S Van Dorn Rd. @ Franconia Rd.	-	-	-	-	-	-

4.1 Camera Intersection

Intersection # 1 Leesburg Pike @ Towlston Road

Yellow time:	4 seconds	10/01/00 - 6/30/01	
	4.5seconds	7/01/01 - 3/31/03	
	Seized Operation	4/01/03 – 5/31/03	
	5.5 seconds	6/01/03 - now	
RLR Camera Speed Tolerance:	20 mph	10/01/00 - now	
Leesburg Pike Speed Limit:	55 mph	10/01/00 - now	
Leesburg Pike ADT :	47,000	2000	
	44,000	2001	
	54,000	2002	

Violation Data

The RLC has been in operation at this intersection since October 2001. The camera operation was seized for 2 months, from April to May 2003. Figure 4.1 shows the numbers of violations from the first month of operation until the end of year 2003. Until before the increase of amber time, the monthly violation had been fluctuated. There was a major drop on the number of violations in July, after the increase of the amber time from 4 to 4.5 seconds. The number of violations remained almost flat after that month. After one year of the RLC operation, the average monthly violation was reduced by 69 percent and by 75 percent after two years.

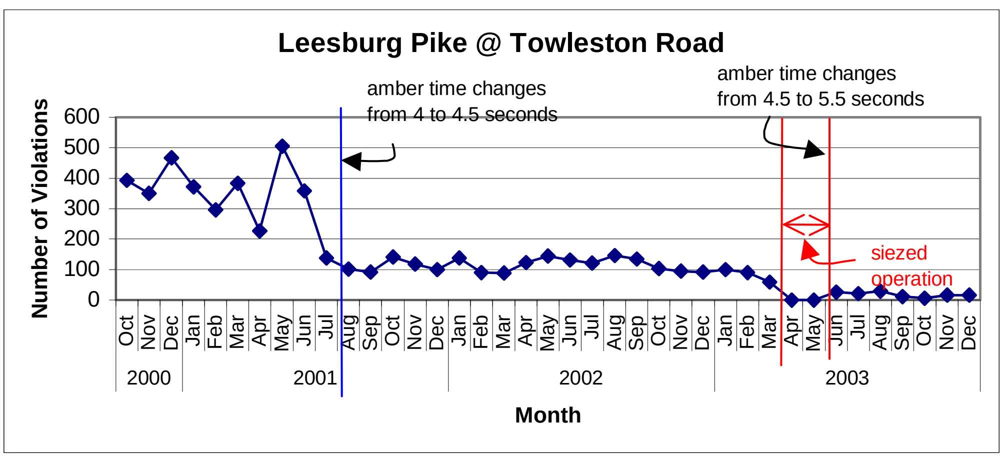

Figure 4.1 Number of Violations at Intersection # 1.

Figure 4.2 shows the numbers of violations per 10,000 vehicles, which had been decreased and had the same trend as Figure 4.1. The violation rate had decreased from

2-4 to 0.5-1.0 violations per 10,000 vehicles after the first amber-time increase. The violation rate decreased again to 0.04-0.2 violations per 10,000 vehicles after the second amber-time increase.

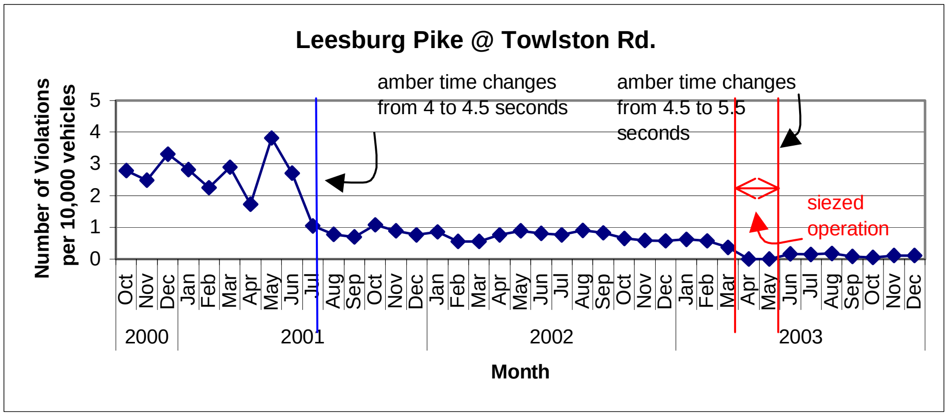

Figure 4.2 Number of Violations per 10,000 Vehicles at Intersection # 1.

Accident Data

The accident data is presented by year and by month as in Figures 4.3 and 4.4 respectively. From Figure 4.3, the total accident rate at intersection 1 increased after 1 year of the RLC operation. Then, in the second year of operation the accident rate was reduced by 18 percent compared with 2 years before the camera operation. The graph in Figure 4.3 shows that the increase in the total accident rate resulted from the increase in injury accident rates. The PDO accident rate had decreased after the RLC operation

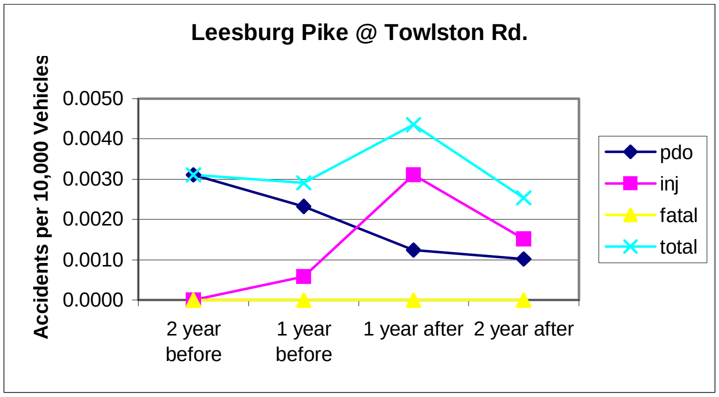

Figure 4.3 Accidents per 10,000 Vehicles at Intersection # 1.

From Figure 4.4, the frequency of accidents has increased after the RLC operation. There were more of injury accidents in the after period. In contrary, the number of PDO accidents has reduced.

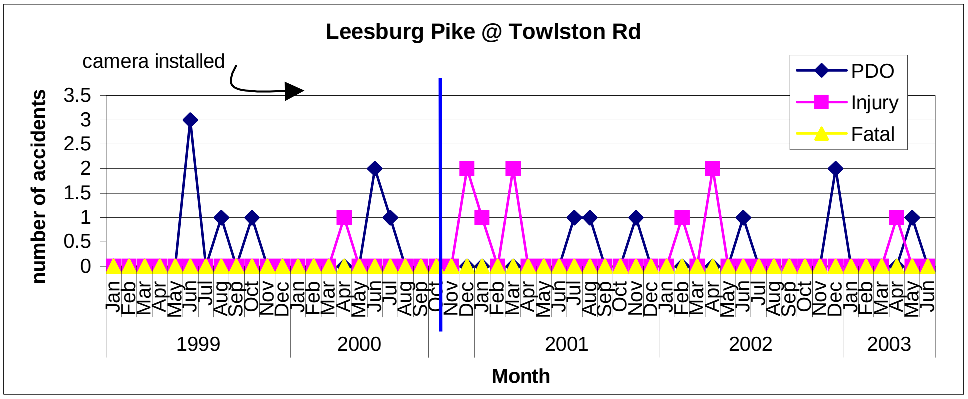

Figure 4.4 Accidents per Month at Intersection # 1.

Intersection # 2 Lee Jackson Memorial Highway(US50) @ Rugby Road.

Yellow time :	4 seconds	02/09/01 - 03/31/03	
	4.5seconds	4/01/03 - now	
RLR Camera Speed Tolerance :		18 mph 02/09/01 – 03/31/03	
		20 mph	04/01/03 - now
Lee Jackson Memorial Speed Limit :		45 mph	02/09/01 – now
Lee Jackson Memorial Hwy ADT :	74,000	2000	
	74,000	2001	
	76,000	2002	

Violation Data

The camera at this intersection has been in operation for the longest time for almost three years at the time of this study. The violation tendency at this intersection clearly shows that the red light camera resulted in the reduction of violation. The monthly violations were reduced by 72 percent after two years of the RLC operation. There was an increase in amber time from 4 to 4.5 seconds in March 2003. At the same time, there was also the increase of camera speed tolerance from 18 to 20 mph.

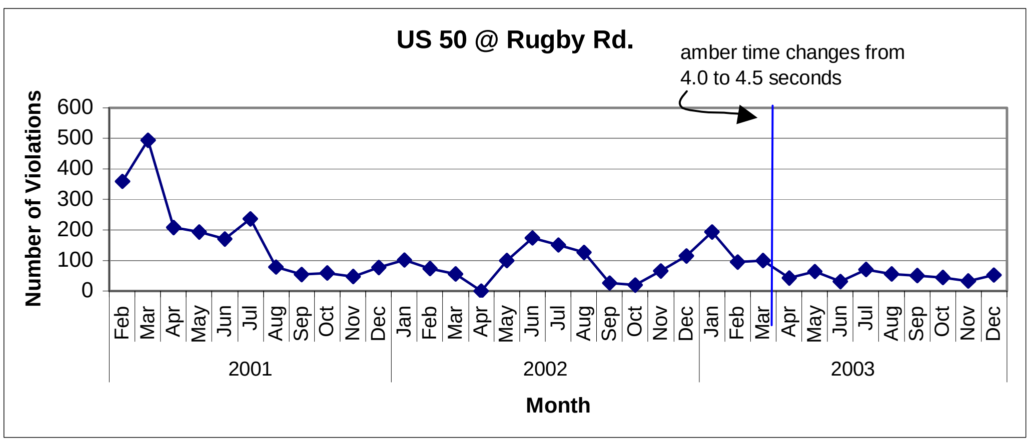

Figure 4.5 Number of Violations at Intersection # 2.

Figure 4.6 shows that after 6 months of the camera operation the violation rates reduced from 2 to 0-1 violations per 10,000 vehicles. After the increase of amber time, the violation rates have again reduced to 0.1-0.3 violations per 10,000 vehicles.

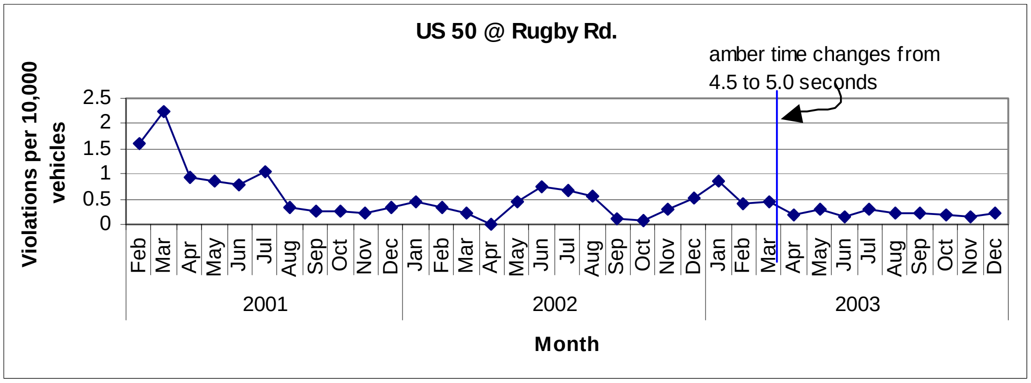

Figure 4.6 Number of Violations per 10,000 Vehicles at Intersection # 2.

Accident Data

At this intersection, the trends of the yearly and monthly accident after the installation period have been on the increase. From Figure 4.7, the increase in total accident rates resulted from the increase in PDO accidents. Considering the injury accident rate, it has decreased after the camera installation. The percent reduction in injury accident rates is 68 percent.

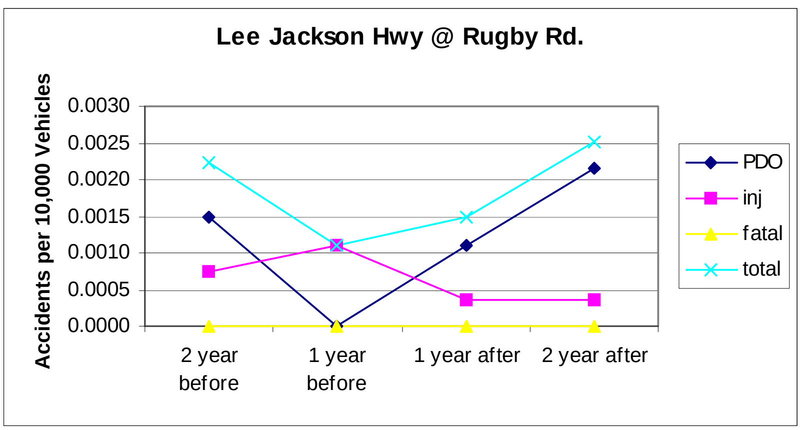

Figure 4.7 Accidents per 10,000 Vehicles at Intersection # 2.

Figure 4.8 shows the higher frequency of PDO accident after the RLC operation. At the same period, the average number of injury accidents was reduced by 54 percent compared with that of the before period.

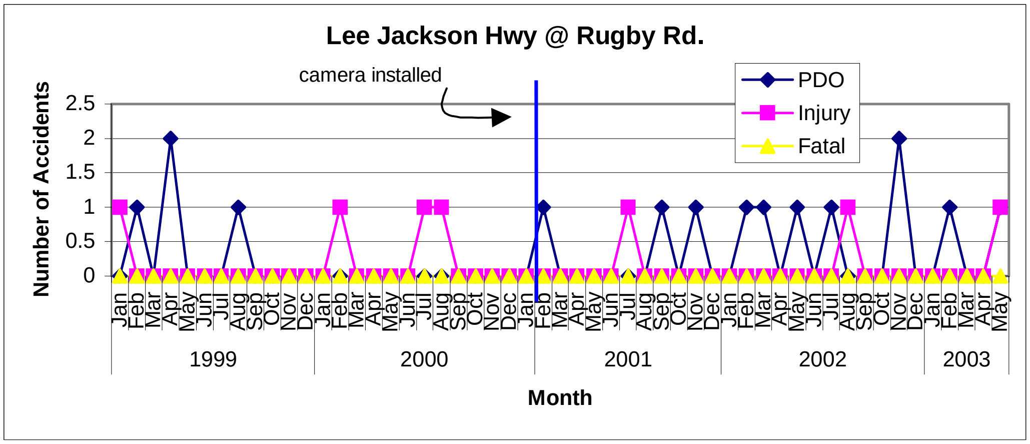

Figure 4.8 Accidents per month at Intersection # 2.

Intersection # 3 Lee Jackson Memorial Highway(US50) @ Fair Ridge Drive

Yellow time:	5.5 seconds	02/09/01 - 09/09/02
	Seized operation	09/10/02 - 05/31/03
	5.5 seconds	06/01/03 - now
RLR Camera Speed Tolerance:	18 mph	02/09/01 – 09/09/02
Lee Jackson Memorial Speed Limit :	45 mph	02/09/01 – now
Lee Jackson Memorial Hwy ADT :	108,000	2000
	108,000	2001
	110,000	2002

Violation Data

The ADT on the primary street of this intersection is high compared with those of other camera intersections. This intersection was equipped with a red light camera at the same time with intersection 2. The amber time at this intersection was increased from 4 to 5.5 seconds right before the camera installation. The camera operation had been seized for 8 months after 1 and half a year of the operation. It was re-operated again in June 2003. Figure 4.9 shows that the number of violations was dramatically reduced after the camera installation and the increase of the amber time. The significance of the reduction could be from both factors.

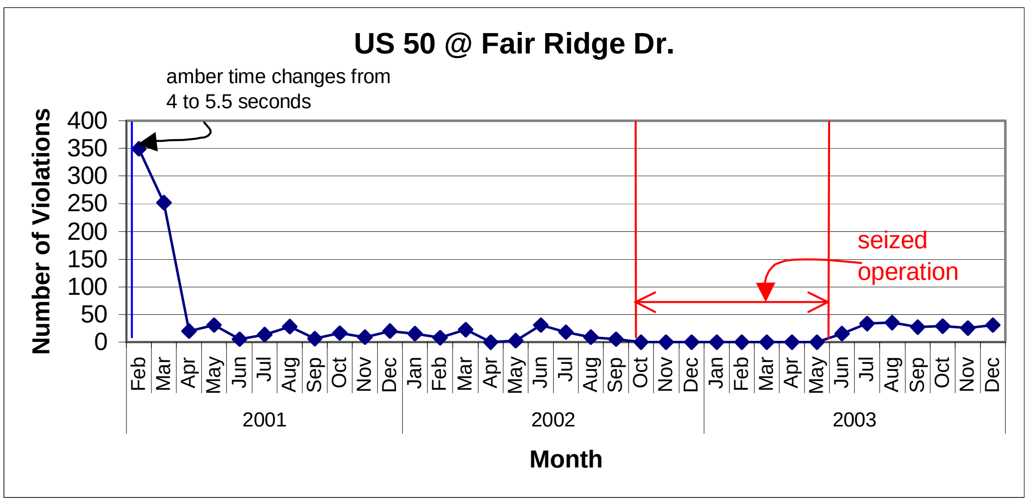

Figure 4.9 Number of Violations at Intersection # 3.

Figure 4.10 shows that the violation rate was reduced from the average of 0.6 violations per 10,000 vehicles in the initial period to be between 0-0.1 violation per 10,000 vehicles.

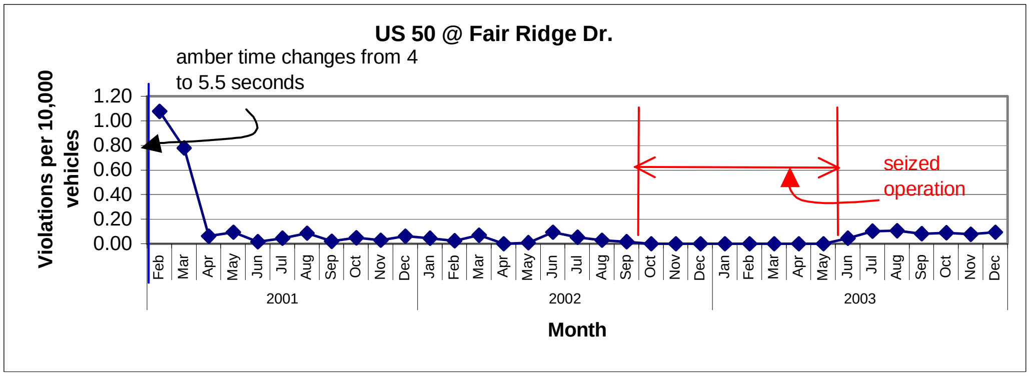

Figure 4.10 Number of Violations per 10,000 Vehicles at Intersection # 3.

Accident Data

At this intersection, both PDO and injury accidents have reduced in the after period. As shown in Figure 4.11, the accident rate has reduced by 71 percent in the second year of the RLC operation compared with that of one year before. The injury accidents reduced by 90 percent in the second of the RLC operation compared with that of two years before.

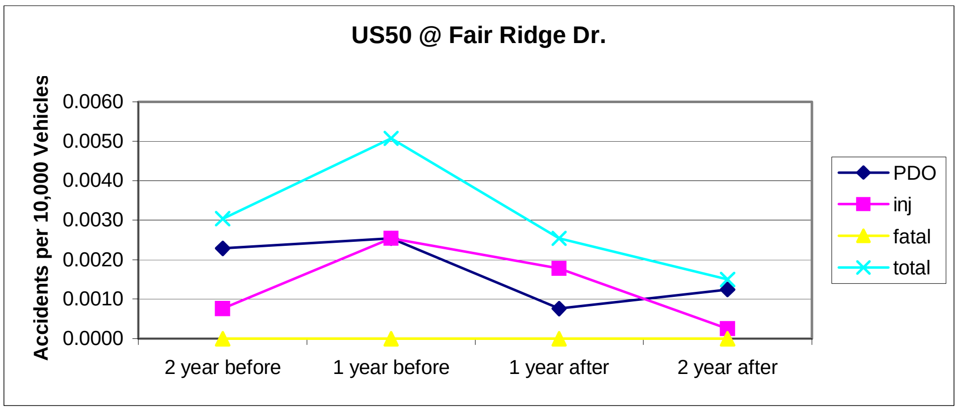

Figure 4.11 Accidents per 10,000 vehicles at Intersection # 3.

Figure 4.12 shows that the total number of accidents has reduced after the camera operation. There was a high reduction in both violation and accident rates at this intersection after the RLC operation. The reduction could result from RLC operation and the increase of amber time.

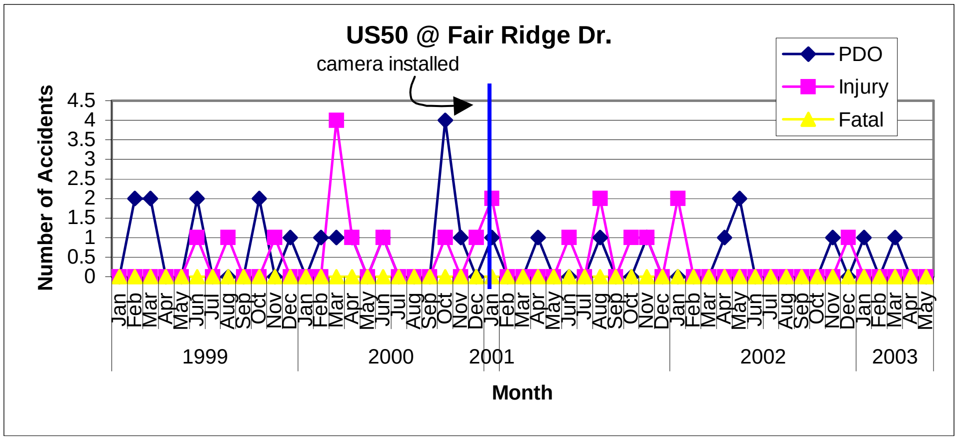

Figure 4.12 Accidents per Month at Intersection # 3.

<u>Intersection # 4 Lee Jackson Memorial Highway(US50) @ Westpark Drive</u>

Yellow time :	4 seconds	03/22/01 - now
RLR Camera Speed Tolerance :	18 mph	03/22/01 – 03/31/03
	20 mph	04/01/03 - now
Leesburg Pike Speed Limit :	35 mph	03/22/01 – now
Leesburg Pike ADT :	53,000	2000
	50,000	2001
	72,000	2002

Violation Data

This intersection has a camera installed three years at the time of this study. It has relatively low speed limit. The amber time is a constant of 4 seconds since before the RLC operation until present. From the results, after two years there was 56 percent of reduction in an average of monthly violations.

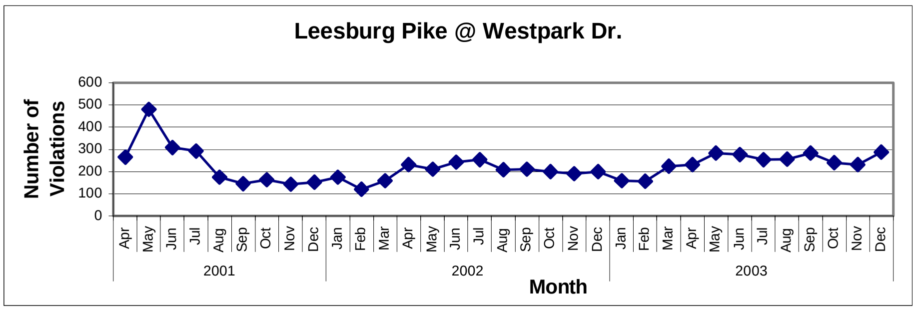

Figure 4.13 Number of Violations at Intersection # 4.

Figure 4.14 shows that after 4 months of camera operation, the violation rate reduced and remained in the range of 0.5 to 1.0 violations per 10,000 vehicle for 1 year and 9 months. It began to increase to 1.0-1.5 for the last 8 months of the study period.

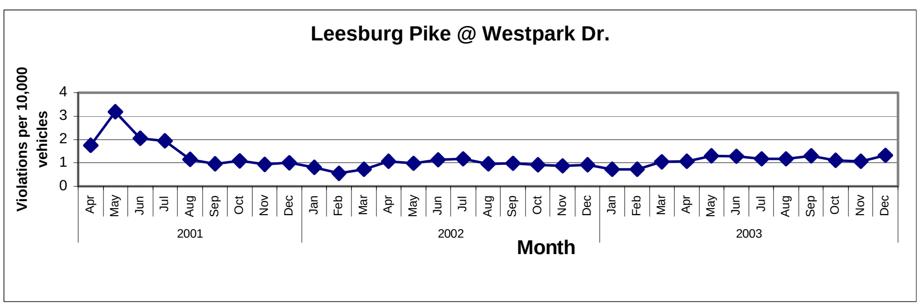

Figure 4.14 Number of Violations per 10,000 Vehicles at Intersection # 4.

Accident Data

After the RLC had been in operation for 1 year, the average of PDO accident rates had increased, which resulted in the higher total accident rate. Considering the injury accidents, it had reduced as it is shown in Figure 4.15.

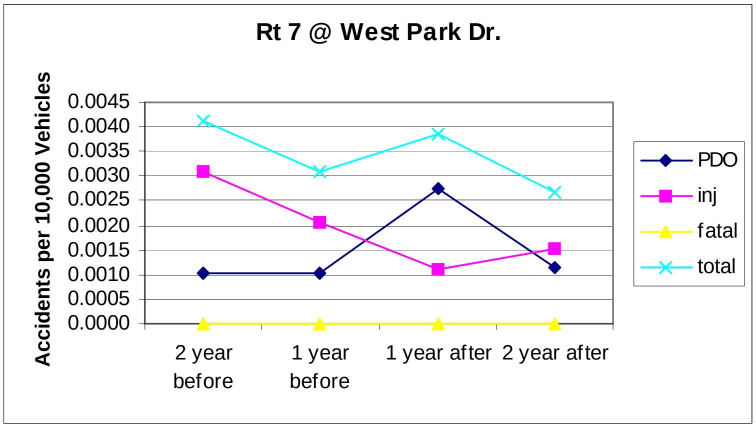

Figure 4.15 Accidents per 10,000 Vehicles at Intersection # 4.

Figure 4.16 shows that the frequency of accidents had reduced after the RLC operation. The graph also presents that the number of injury accidents in the after period is less than that of the before period.

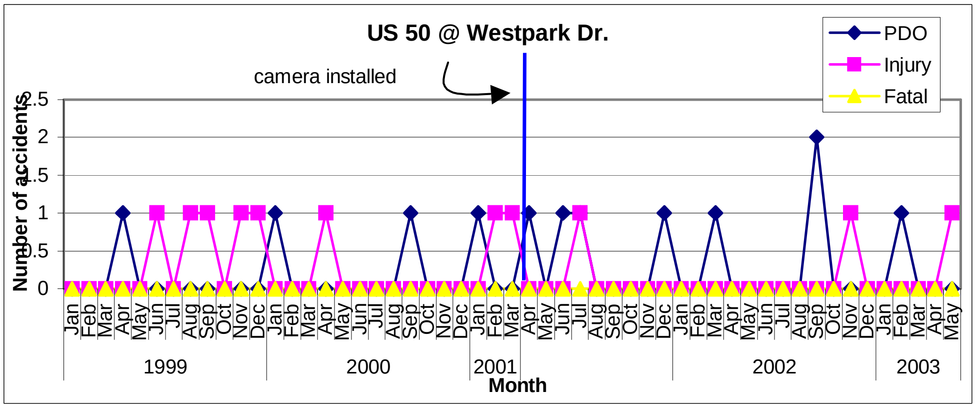

Figure 4.16 Accidents per Month at Intersection # 4.

Intersection # 5 Leesburg Pike (Rt 7) @ Route 66

Yellow time :	4 seconds	05/02/01 - now
RLR Camera Speed Tolerance :	18 mph	05/02/01 – 03/31/03
	20 mph	04/01/03 - now
Leesburg Pike Speed Limit :	35 mph	05/02/01 – now
Leesburg Pike ADT :	23,000	2000
	21,000	2001
	44,000	2002

Violation Data

This intersection is located at an off-ramp area. It is another low-speed limit intersection. The amber time is a constant of 4 seconds since before the installation until the end of study period. This intersection can be another good example of an intersection that was not affected by the amber-time increase. Figure 4.17 shows that after the camera operation, the violation numbers have decreased. The number of violations had reduced by 69 percent after 2 years of the camera operation.

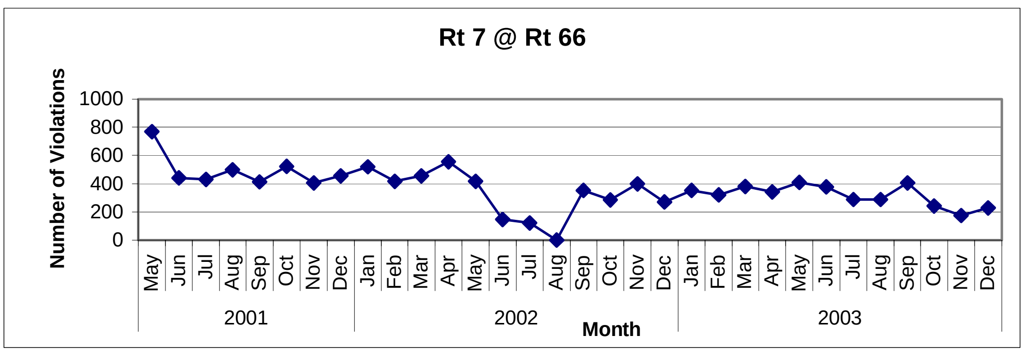

Figure 4.17 Number of Violations at Intersection # 5.

As shown in Figure 4.18, the initial violation rate was high at 12 violations per 10,000 vehicles compared with other intersections. After one year of RLC operation, the violation rate had reduced from average of 8.7 during the initial adoption to 1-3 violations per 10,000 vehicles.

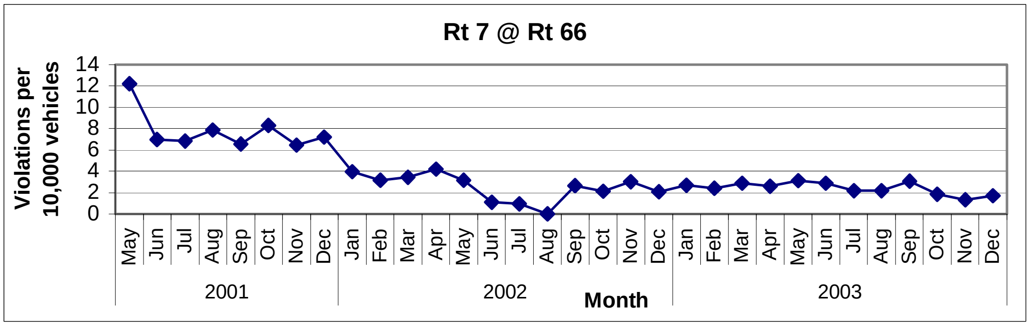

Figure 4.18 Number of Violations per 10,000 Vehicles at Intersection # 5.

Accident Data

At this intersection, considering the accident rate each year, both PDO and injury accident rates had a small increase in the first year of RLC operation. Then, they had dropped in the second year. The total accident rate reduced by 59 percent in the second year of the RLC operation compared with that of two years before the operation.

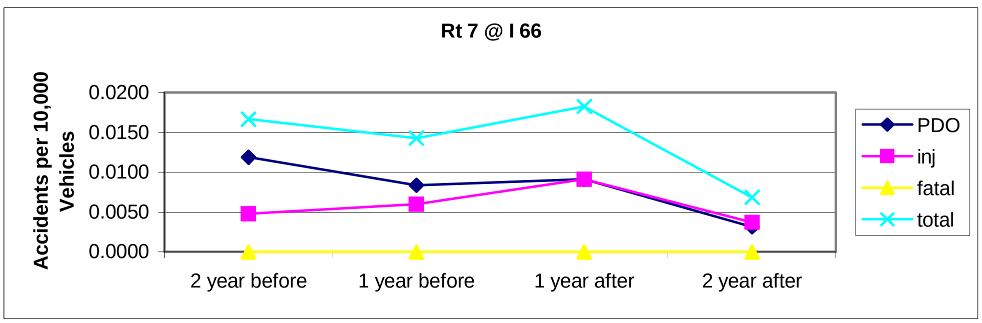

Figure 4.19 Accidents per 10,000 Vehicles at Intersection # 5.

Figure 4.20 shows that the number of injury accidents increased after the camera installation. It also shows that the number of PDO accident has decreased.

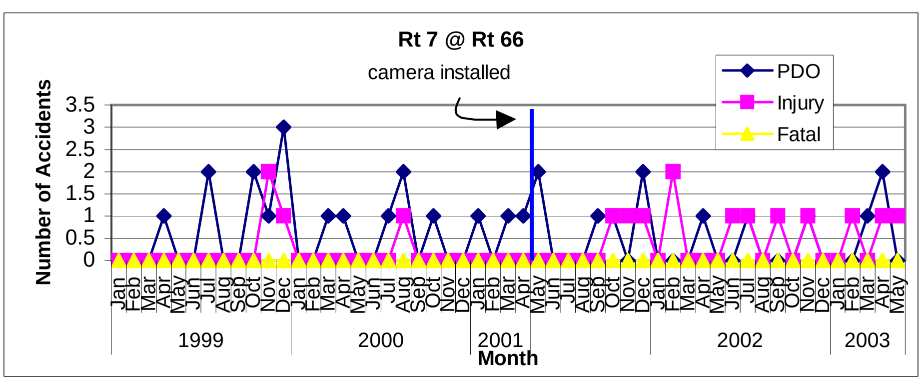

Figure 4.20 Accidents per Month at Intersection # 5

Intersection # 6 Arlington Blvd.(US50) @ Jaguar Trail

Yellow time :	4 seconds	05/02/01 – 03/31/03
	4.5 seconds	04/01/03 - now
RLR Camera Speed Tolerance :	18 mph	05/02/01 – 03/31/03
	20 mph	04/01/03 - now
Arlington Blvd. Speed Limit :	45 mph	05/02/01 – now
Arlington Blvd. ADT :	58,000	2000
	58,000	2001
	56,000	2002

Violation Data

This intersection had a constant of 4-second amber time for almost 2 years before it was increased to 4.5 seconds. At this intersection, the number of violations after the camera operation has a different trend from others. Figure 4.21 shows that the number of violations had not decrease until in the mid of 2002 that it began a downward tendency.

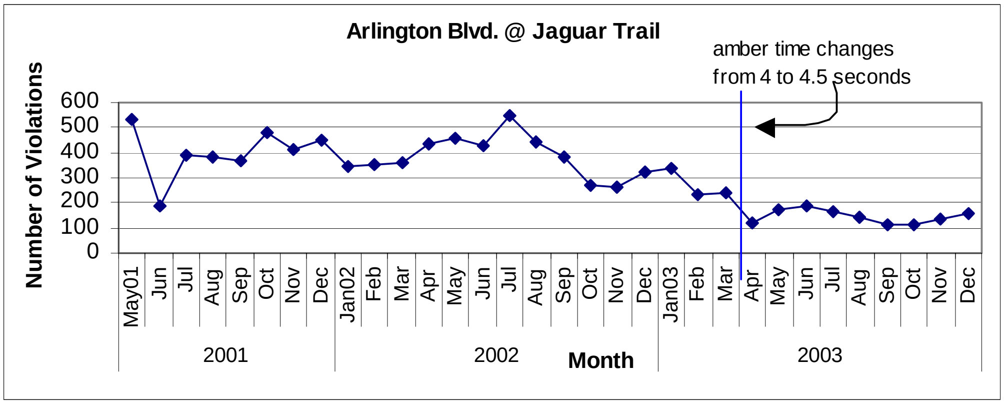

Figure 4.21 Number of Violations at Intersection # 6

From Figure 4.22, after the increase of amber time, the violation number has reduced from 1-3 to 0.6-1.0 violations per 10,000 vehicles. The average number of violations per 10,000 vehicles was reduced by 10 percent after one and a half year of RLC operation.

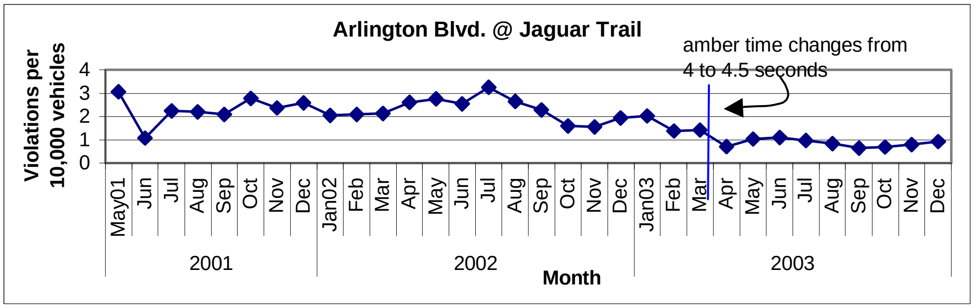

Figure 4.22 Number of Violations per 10,000 Vehicles at Intersection # 6.

Accident Data

From Figure 4.23, the total number of accidents per 10,000 vehicles increased in the first year of the RLC operation. The increase resulted from the increase of PDO accidents. The accident rate dropped in the second year of the operation, which is corresponding to the violation rate. Considering the injury accident rate, it had not changed before and after the analysis period.

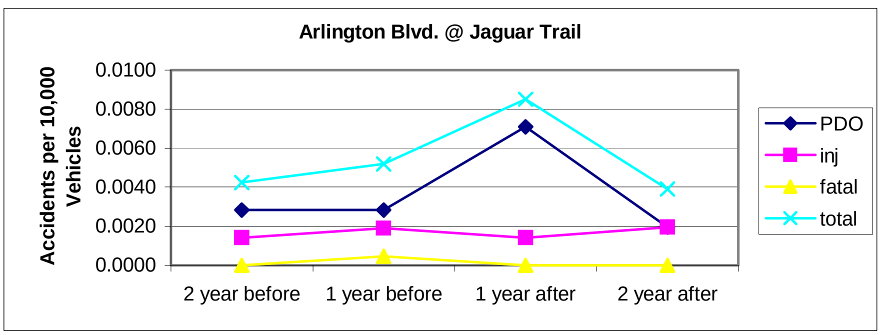

Figure 4.23 Accidents per 10,000 Vehicles at Intersection # 6.

Figure 4.24 shows that the number of PDO accidents increased after the camera installation. There was a small change in number of injury accidents.

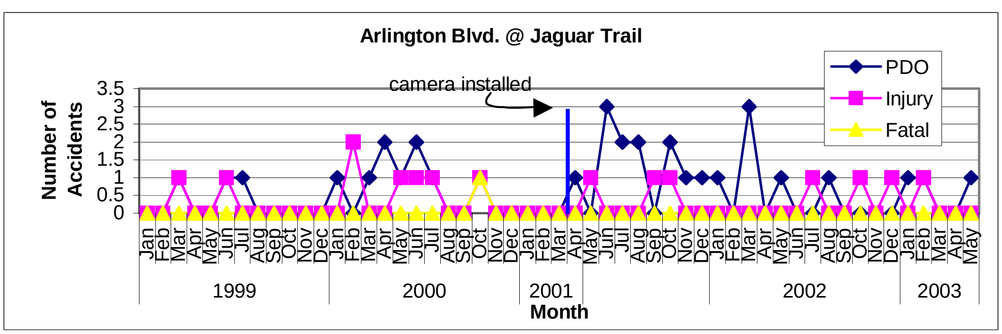

Figure 4.24 Accidents per Month at Intersection # 6.

Intersection # 7 Centreville Road (Rt 28) @ Greens Trail Blvd (Old Mill Road)

Yellow time:	4 seconds	06/15/01 – 11/30/01
	4.5 seconds	12/01/01 – 03/19/03
	Seized operation	03/20/03 - 05/31/03
	4.5 seconds	05/01/03 - now
RLR Camera Speed Tolerance:	20 mph	06/15/01 – 03/19/03
Centreville Rd. Speed Limit:	55 mph	06/15/01 – 03/19/03
Centreville Rd. ADT:	51,000	2000
	51,000	2001
	52,000	2002

Violation Data

After the operation had begun for 5 months, the amber time was increased from 4 to 4.5 seconds. From Figures 4.25 and 4.26, the number of violations did not increase after the camera operation but it began to decrease after the increase of the amber time.

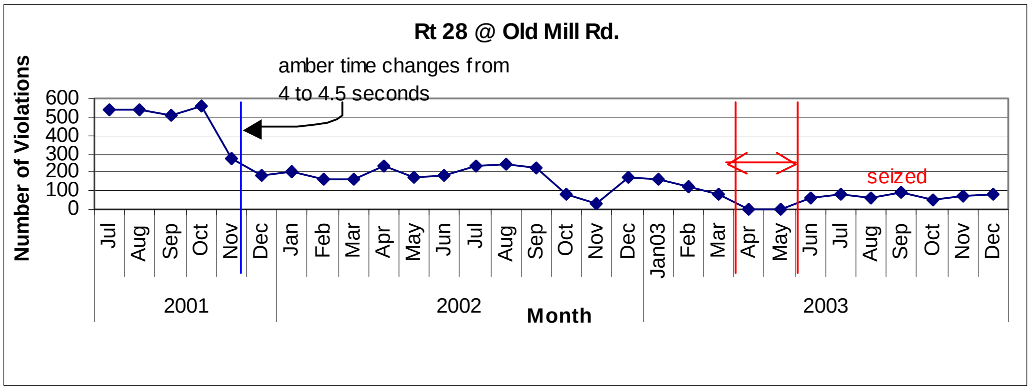

Figure 4.25 Number of Violations at Intersection # 7.

Figure 4.26 shows that after the increase of the amber time, the numbers of violations per 10,000 vehicles were in the range of 0.5 to 1.5 for almost one year. Then it decreased to 0.3-0.5 violations per 10,000 vehicles for the last 8 months of the study period.

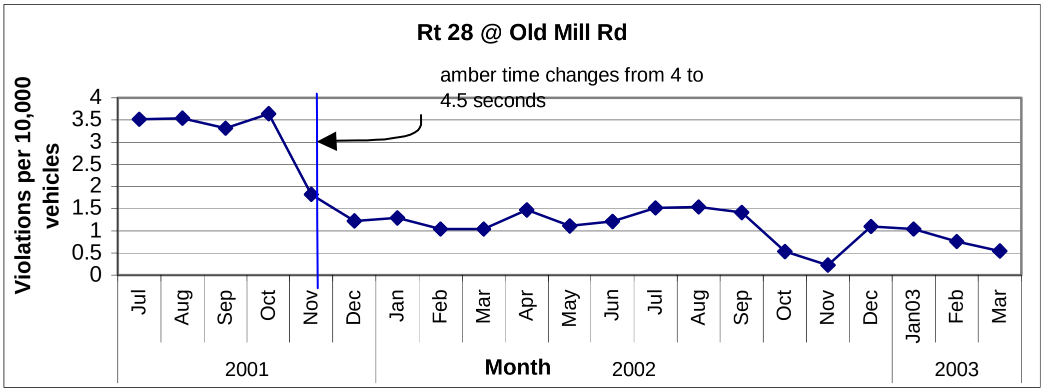

Figure 4.26 Number of Violations per 10,000 Vehicles at Intersection # 7.

Accident Data

Considering the accident rate in each year from Figure 4.27, there was a reduction in total accident in the second year of the camera operation for 18 percent compared with those of one and two years before. The injury accident rate significantly decreased for 61 percent compared between one years before and two years after the RLC operation. The PDO accident rate, on the other hand, increased in the first year of the RLC operation before it had a small drop in the second year.

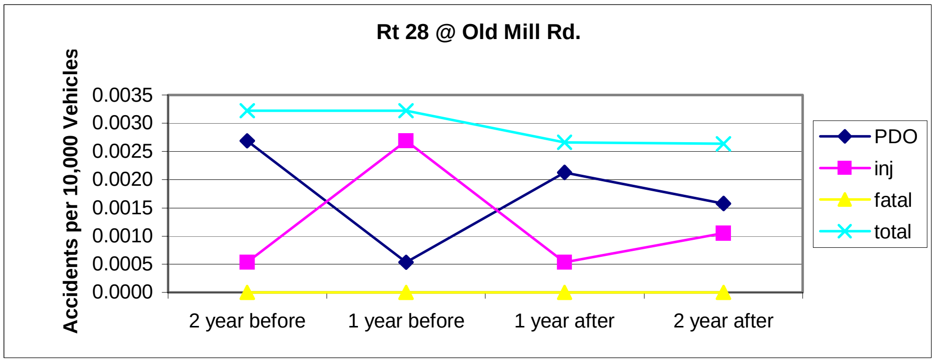

Figure 4.27 Accidents per 10,000 Vehicles at Intersection # 7.

From Figure 4.28, the frequency of accidents was reduced after the camera installation. There was also a small decrease in the average number of PDO accidents in the after period.

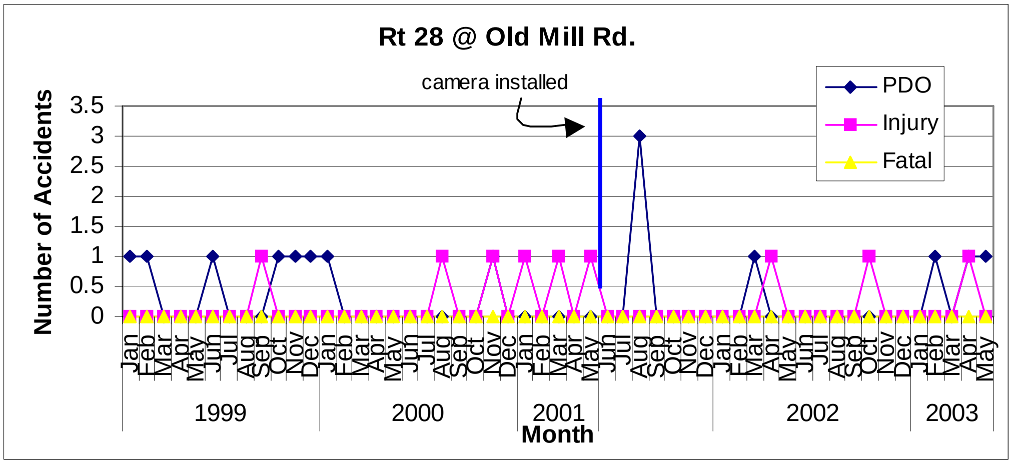

Figure 4.28 Accidents per Month at Intersection # 7.

Intersection # 8 Leesburg Pike (RT 7) @ Dranesville Road

Yellow time :	4 seconds	06/21/01 – 03/31/03
	4.5 seconds	04/01/03 – now
RLR Camera Speed Tolerance :	18 mph	06/21/01 – 03/31/03
	20 mph	04/01/03 - now
Leesburg Pike Speed Limit :	45 mph	06/21/01 – now
Leesburg Pike ADT :	47,000	2000
	44,000	2001
	59,000	2002

Violation Data

From Figures 4.29 and 4.30, the number of violations was not immediately reduced after the camera operation. However, since the mid of year 2002 the number of violations tended to decrease.

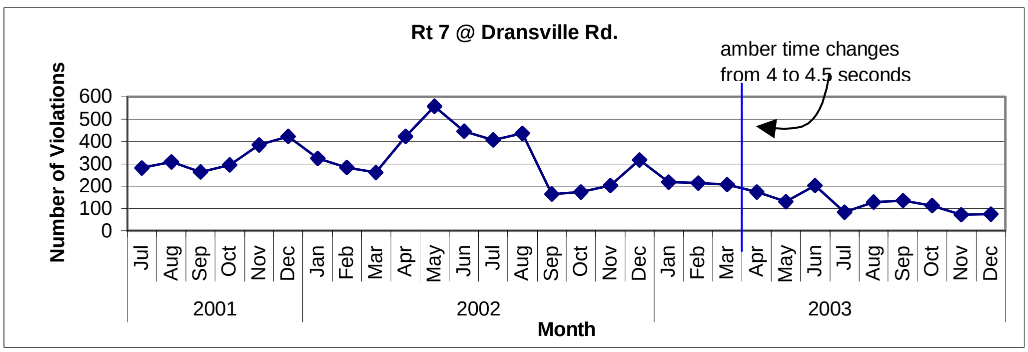

Figure 4.29 Number of Violations at Intersection # 8

Figure 4.30 shows that after the number of violations per 10,000 vehicles had reduced from an average of 2.4 in the initial period to 1.0-1.5 after August 2002. After the increase of amber time, the violation rate had reduced again to 0.4-1.0 violations per 10,0000 vehicles.

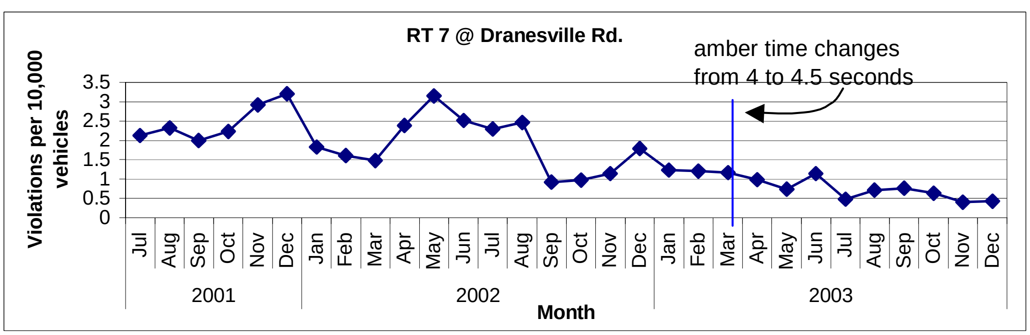

Figure 4.30 Number of Violations per 10,000 Vehicles at Intersection # 8.

Accident Data

At this intersection, after the RLC had been in operation for one year, there was a small decrease in the total accident rates. The injury accident rate had a downward trend after the RLC operation. The number of injury accidents per 10,000 vehicles reduced by 58 percent in the second year of the operation compared with one year before the operation. The PDO accident rate had not significantly changed after 2 years of the operation.

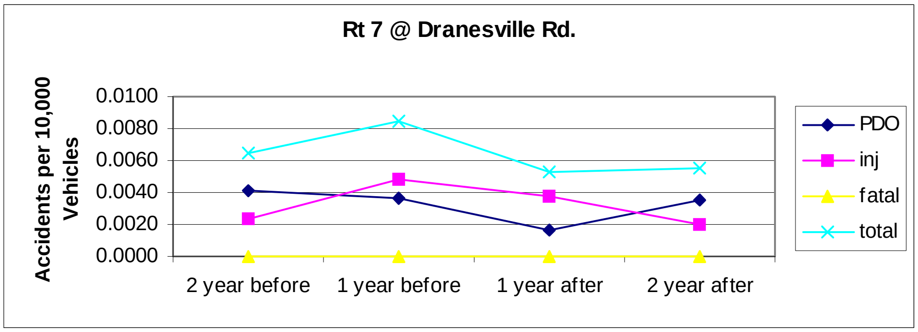

Figure 4.31 Accidents per 10,000 Vehicles at Intersection # 8.

Figure 4.32 shows that the numbers of injury and PDO accidents per month were approximately the same between before and after the camera operation.

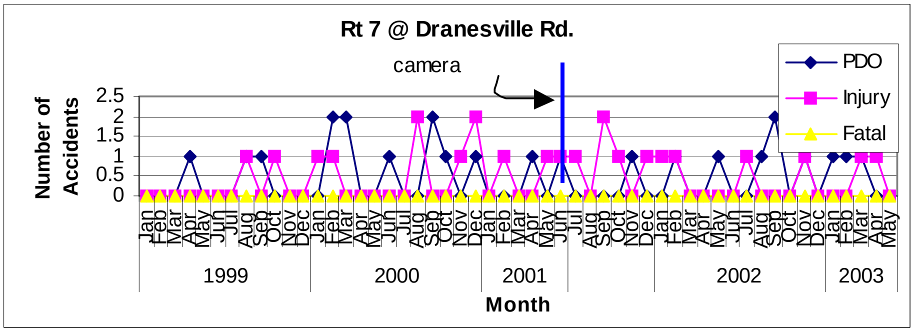

Figure 4.32 Accidents per Month at Intersection # 8.

Intersection # 9 Fairfax County Parkway @ Popes Head Road

Yellow time :	4 seconds	07/10/01 – 03/31/03
	5 seconds	04/01/03 – now
RLR Camera Speed Tolerance :	20 mph	07/10/01 – now
Fairfax County Pkwy Speed Limit :	50 mph	07/10/01 – now
Fairfax County Pkwy. ADT :	66,000	2001
	55,000	2002

Violation Data

The violation trend at this intersection is similar to those of intersection 6 and 7. From Figures 4.33 and 4.34, the number of violations had not immediately decreased after the camera installation but it had had a downward trend since the mid of 2002. After the increase of amber time, the number of violations had obviously reduced.

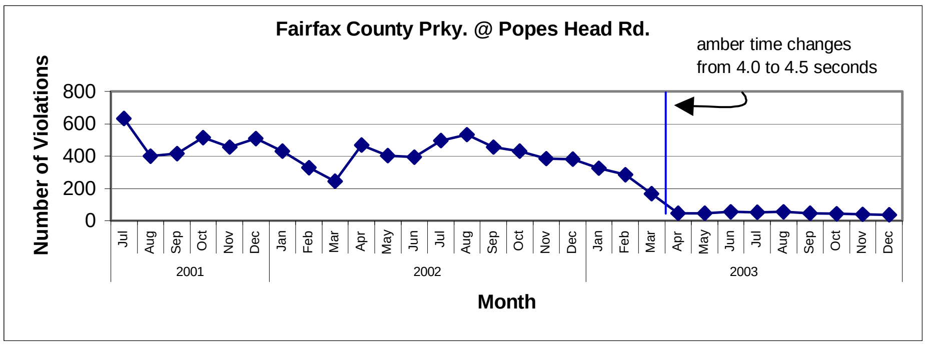

Figure 4.33 Number of Violations at Intersection # 9.

Figure 4.34 shows that after the amber-time increase, the violation rate has decreased to 0.2-0.3 violations per 10,000 vehicles.

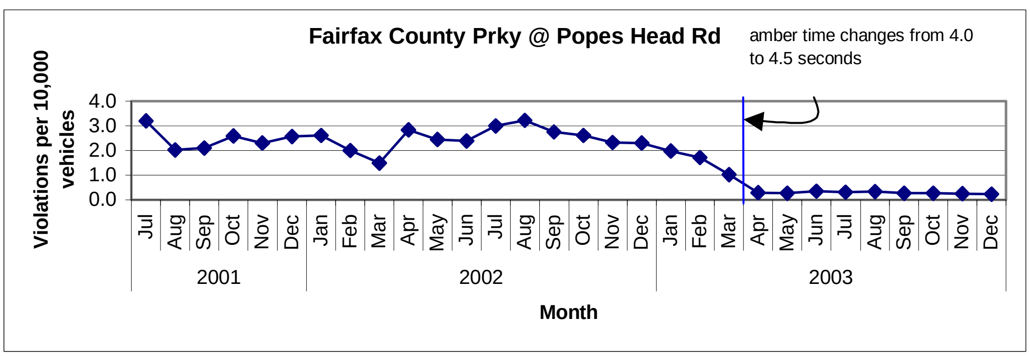

Figure 4.34 Number of Violations per 10,000 Vehicles at Intersection # 9.

Accident Data

From Figures 4.35 and 4.36, both yearly and monthly accident have been increased at this intersection after the camera installation. Other factors should be considered to be causes of this increasing trend in the after period. The trend of accident does not correspond to the trend of violation, which had a downward trend in the second year of the operation.

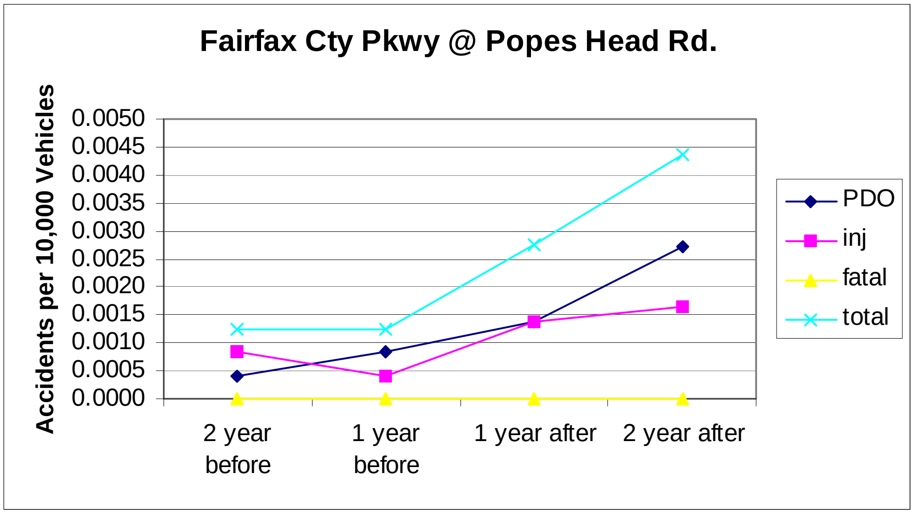

Figure 4.35 Accidents per 10,000 Vehicles at Intersection # 9.

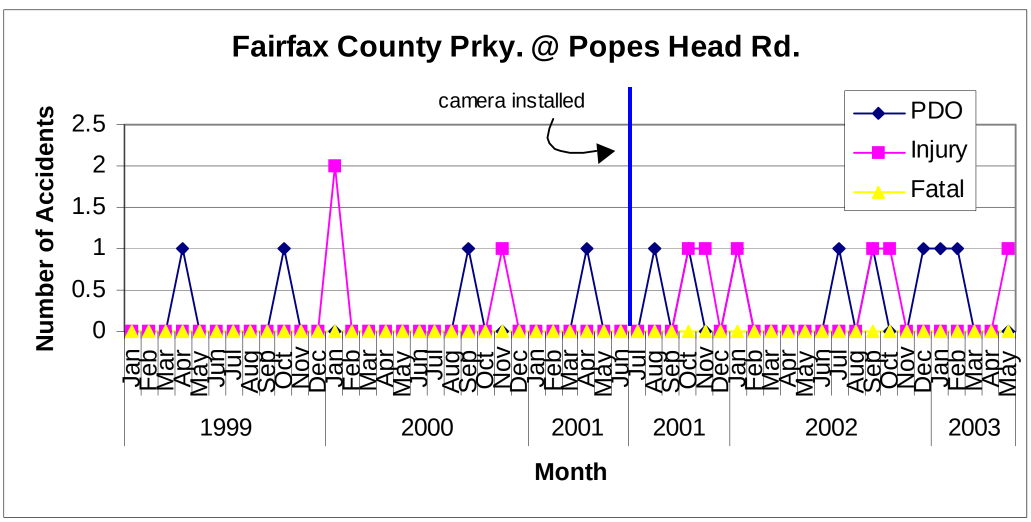

Figure 4.36 Accidents per Month at Intersection # 9.

Intersection # 10 Fairfax County Parkway @ Newington Road

Yellow time :	4 seconds	10/15/01 – 03/31/03
	4.5 seconds	04/01/03 – now
RLR Camera Speed Tolerance :	20 mph	10/15/01 – now
Fairfax County Pkwy Speed Limit :	50 mph	10/15/01 – now
Fairfax County Pkwy ADT :	66,000	2001
	55,000	2002

Violation Data

This intersection has the same characteristic with intersections 6 and 9. By having the same number of ADT, speed limit and amber time, the numbers of violations during the study period have the same trend with the fluctuation at the beginning and downward trend after the mid of 2002. The number of violations has further decreased after the increase of amber time.

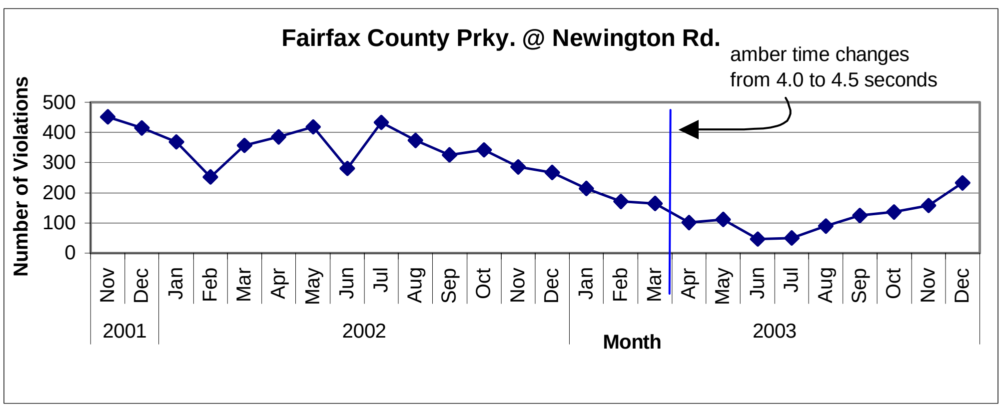

Figure 4.37 Number of Violations at Intersection # 10.

Figure 4.38 shows that after the increase of amber time, the violation rates had reduced from 2 to 0.3-1.0 violations per 10,000 vehicles. However, it had an upward trend in the last 6 months of the study period.

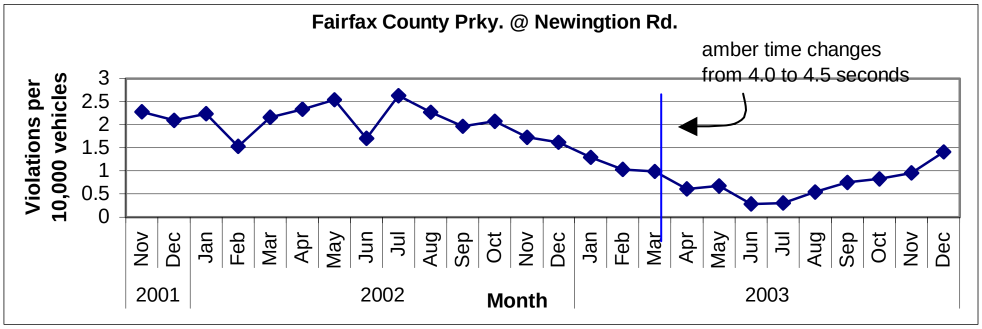

Figure 4.38 Number of Violations per 10,000 Vehicles at Intersection # 10.

Accident Data

At this intersection, the accident rates in Figure 4.39 show that the accident rate had a downward trend two years before the RLC operation. The downward trend continued after the RLC operation. The accident rate at this intersection is very low compared with those of other intersections.

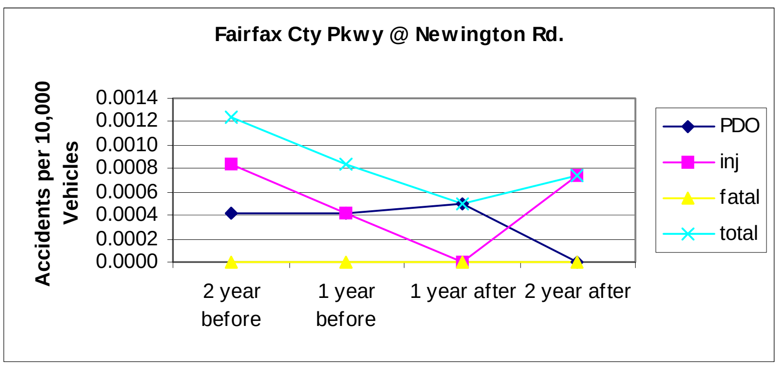

Figure 4.39 Accidents per 10,000 Vehicles at Intersection # 10.

Figure 4.40 shows that the number of PDO and injury accidents began to reduce since the mid of 2000, which is before the camera installation.

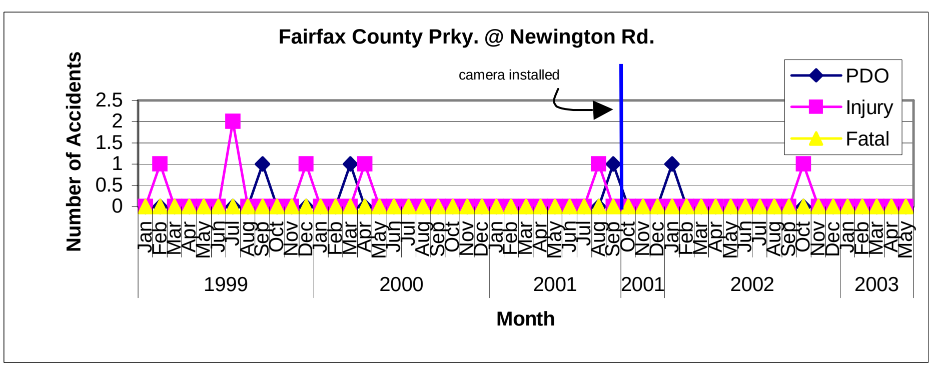

Figure 4.40 Accidents per Month at Intersection # 10.

Intersection # 11 Route 236 @ Heritage Drive

Yellow time :	4 seconds	09/09/02 – now
RLR Camera Speed Tolerance :	20 mph	09/09/02 – now
Fairfax County Pkwy Speed Limit :	35 mph	09/09/02 – now
Fairfax County Pkwy ADT :	51,000	2000
	51,000	2001
	52,000	2002

Violation Data

From Figures 4.41 and 4.42, it can be seen that the number of violations has not decreased after the camera installation.

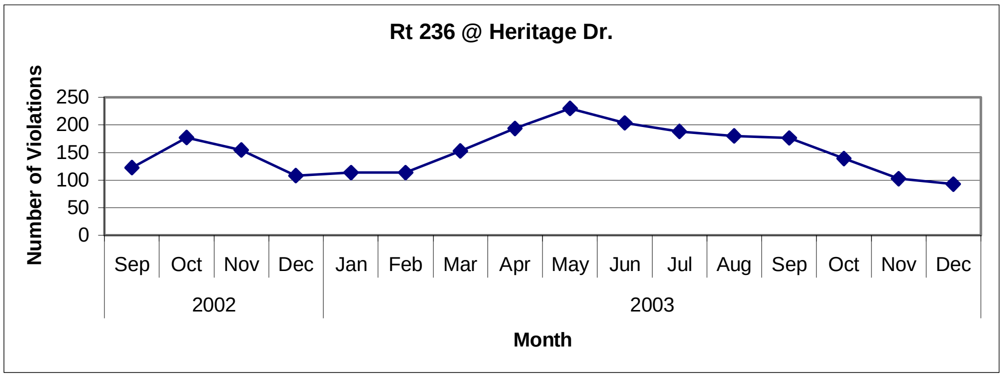

Figure 4.41 Number of Violations at Intersection # 11.

From Figure 4.42, the initial number of violations per 10,000 vehicles at this intersection is relatively low. During the study period, the violation rates were between 0.5 and 1.5 violations per 10,000 vehicles.

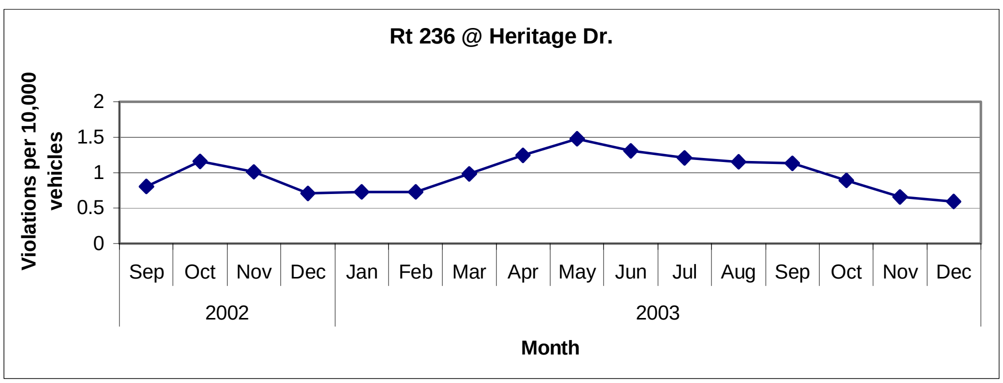

Figure 4.42 Number of Violations per 10,000 Vehicles at Intersection # 11.

Accident Data

At this intersection, as shown in Figure 4.43, the accident results are presented by year instead of before and after basis because of the deficiency of the post-installation data. The post-installation data is available for only 8 months at the time of study.

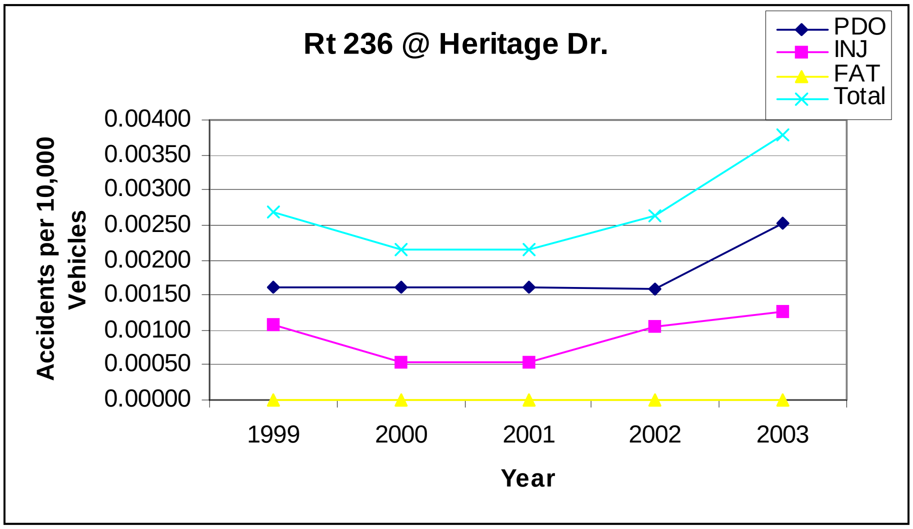

Figure 4.43 Accidents per 10,000 Vehicles at Intersection # 11.

Considering before and after monthly accident, the period of data after the installation is too short. The evaluation will be more accurate with further data in the future.

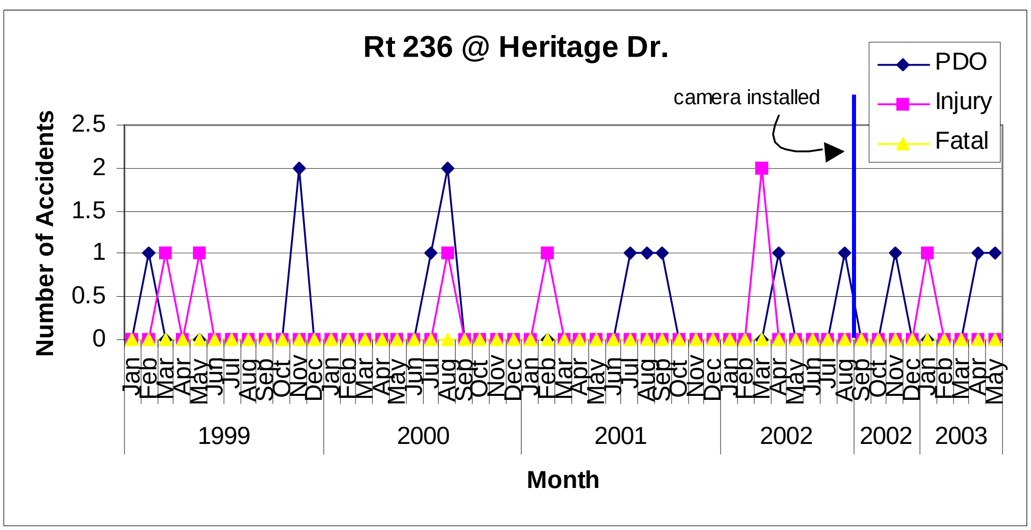

Figure 4.44 Accidents per Month at Intersection # 11.

Intersection # 12 Telegraph Road@ Huntington Avenue

Yellow time :	4 seconds	03/18/03 – now
RLR Camera Speed Tolerance :	20 mph	03/18/03 – now
Fairfax County Pkwy Speed Limit :	35 mph	03/18/03 – now
Fairfax County Pkwy ADT :	30,000	2001
	31,000	2002

Violation Data

This intersection has had a camera installed for ten months at the time of the study. In the 4th to 9th month of the operation, the number of violations per 10,000 vehicles has reduced by 16 percent compared with that of the initial period. However, more data is needed for the better evaluation.

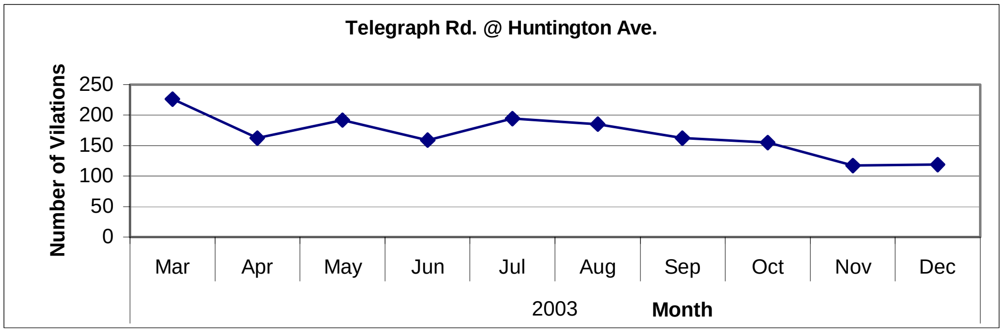

Figure 4.45 Number of Violations at Intersection # 12.

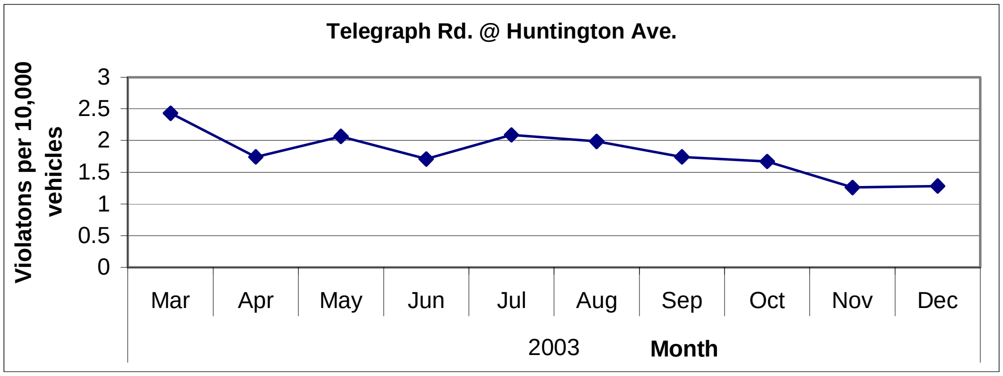

Figure 4.46 Number of Violations per 10,000 Vehicles at Intersection # 12.

Accident Data

This intersection has a high accident rate compared with other intersections. From Figure 4.47, the accident tends to decrease since 2001. More of the post-installation data is needed for the evaluation.

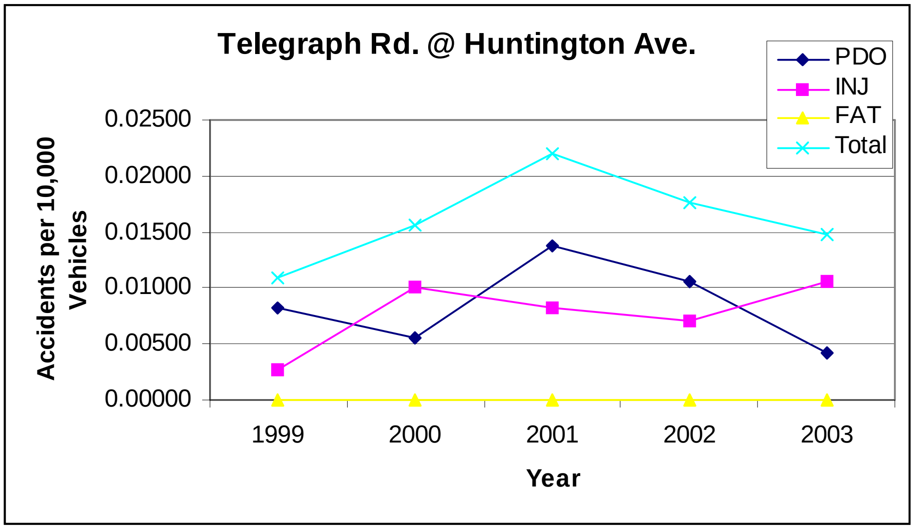

Figure 4.47 Accidents per 10,000 vehicles at Intersection # 12.

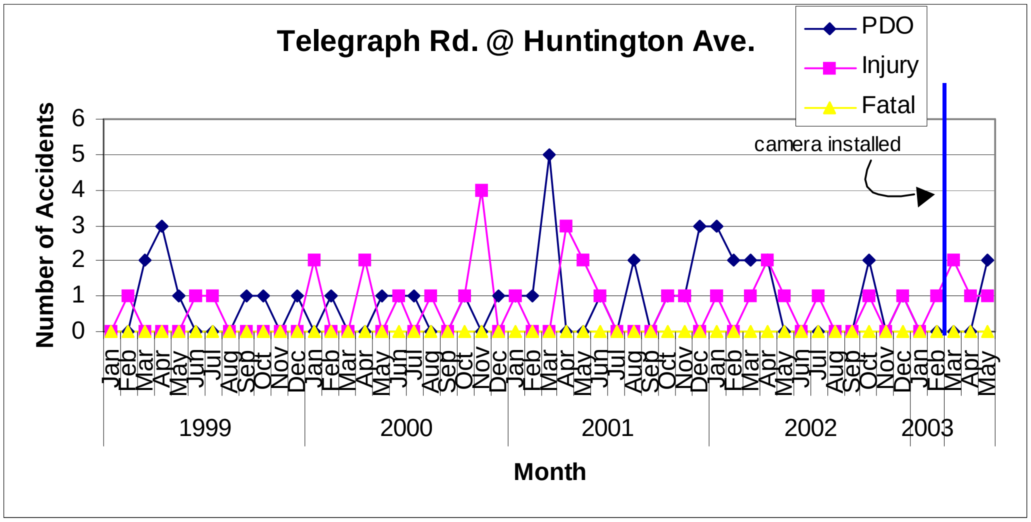

Figure 4.48 Accidents per month at Intersection # 12.

Intersection # 13 Route 7 @ Carlin Springs Road

Yellow time :	4 seconds	03/24/03 – now
RLR Camera Speed Tolerance :	20 mph	03/24/03 – now
Fairfax County Pkwy Speed Limit :	35 mph	03/24/03 – now
Fairfax County Pkwy ADT :	41,000	2000
	38,000	2001
	46,000	2002

Violation Data

This intersection is the latest location of the red light camera in Fairfax County. In the 4th to 9th month of RLC operation, the average number of violations per 10,000 vehicles increased 8.4 percent compared with the initial period. However, the further analysis should be conducted in the future.

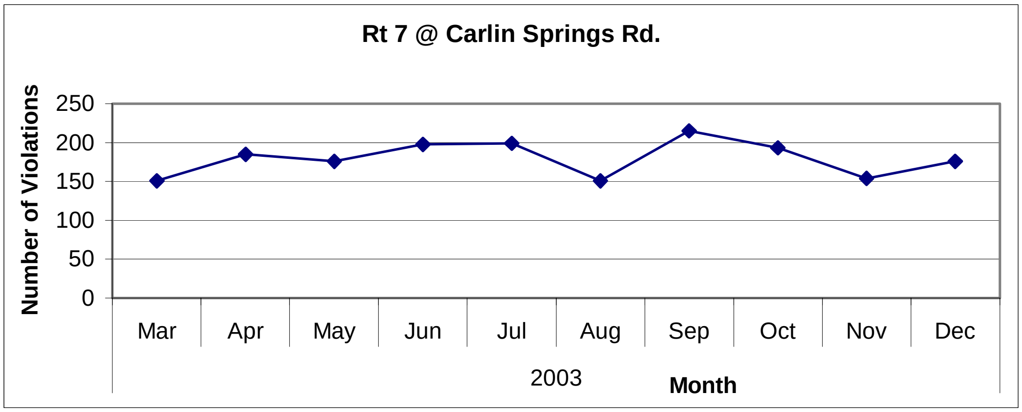

Figure 4.49 Number of Violations at Intersection # 13.

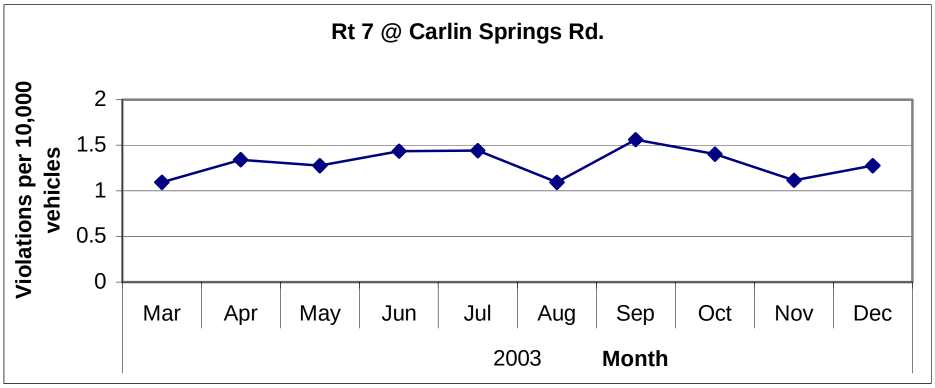

Figure 4.50 Number of Violations per 10,000 Vehicles at Intersection # 13.

Accident Data

As well as intersection 12, it is too soon to evaluate the effect of the RLC on this intersection.

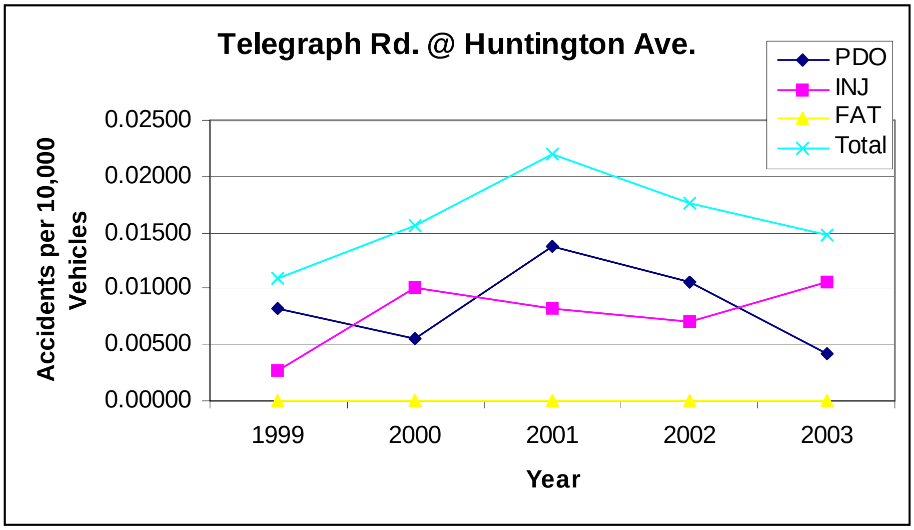

Figure 4.51 Accidents per 10,000 Vehicles at Intersection # 13.

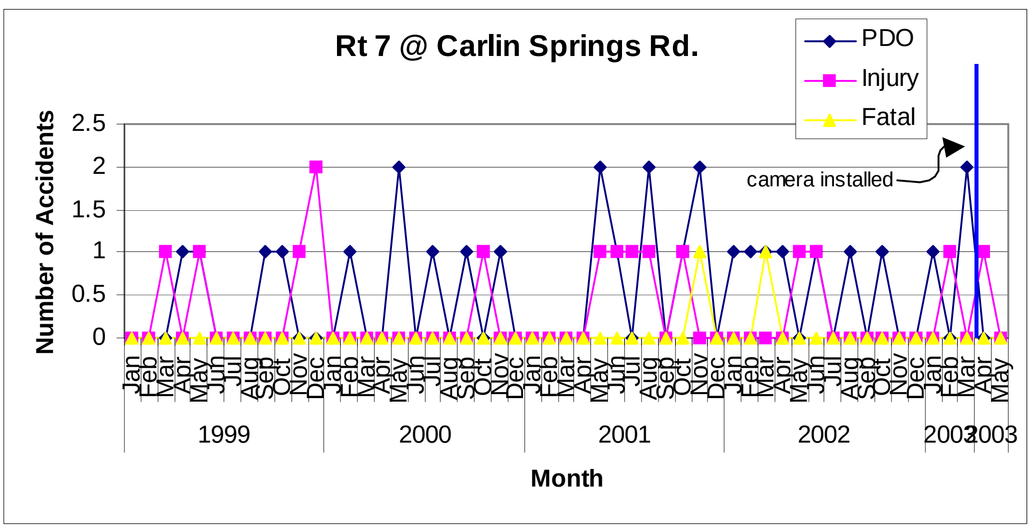

Figure 4.52 Accidents per Month at Intersection # 13.

4.2 Non–Camera Intersection (Spill Over effect)

Two intersections were selected for the spillover effect study. At these intersections, only the accident data was available. Since there is no monitoring camera at these sites, the violation data is not available.

<u>Intersection # 14 Leesburg Pike @ Lewinsville Road</u>

Leesburg Pike ADT :	47,000	2000
	44,000	2001
	54,000	2002

Intersection 14 is a three-leg intersection. It is located far from intersection 1 approximately one mile to the south. It has the same ADT as intersection 1. The before and after camera installation period are corresponding with the installation date of intersection 1 which is October 2000.

Accident Data

As it is shown in Figure 4.53, the total accident rate increased in the first year of the operation and then decreased in the second year compared with that of one year before camera installation. However, the increase in accidents in the first year is due to the increase in PDO accidents, which is different from intersection 1. At intersection 1, the increase in accident rates resulted from the increase in injury accident rates. The injury accident rate at this intersection, on the other hand, reduced in the after period.

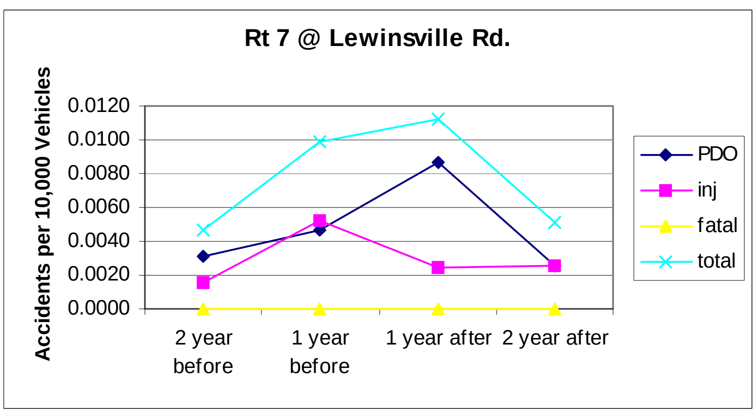

Figure 4.53 Accidents per 10,000 Vehicles at Intersection # 14

From Figure 4.54, the total frequency of accident reduced in the after period. The number of injury accidents was decreasing while the number of PDO accidents was increasing.

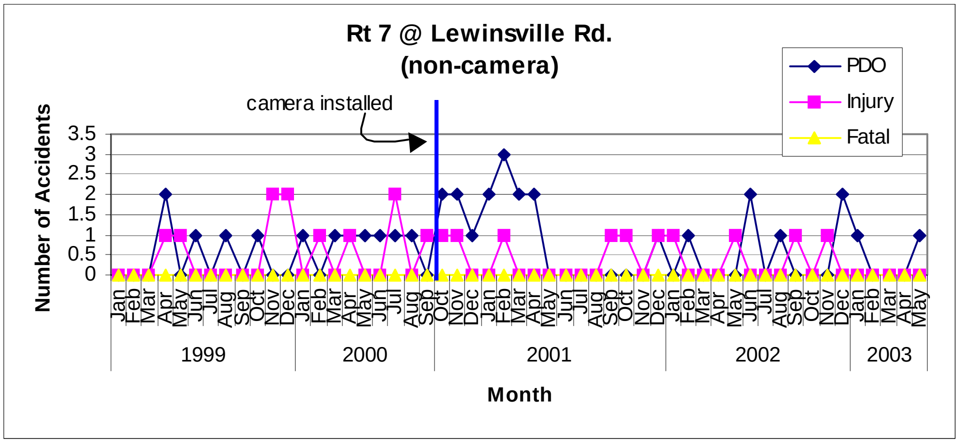

Figure 4.54 Accidents per 10,000 Vehicles at Intersection # 14.

Intersection#15 Rt 7 @ Beulah Road

Leesburg Pike ADT :	47,000	2000
	44,000	2001
	54,000	2002

This intersection is a three-leg intersection located approximately one mile from intersection 1 to the north. It has the same ADT as those of intersections 1 and 14. The before and after period are set to be the same as those of intersection 1.

Accident Data

At this intersection the trend of accident rate is different from intersections 1 and 14. From Figure 4.55, the total yearly accident decreased in the first year of the RLC operation at intersection 1 and then increased in the second year. The PDO and injury accident rate had the same trend with those of intersection 1. While the injury accident rate increased in the first year, the PDO accident rate was decreasing.

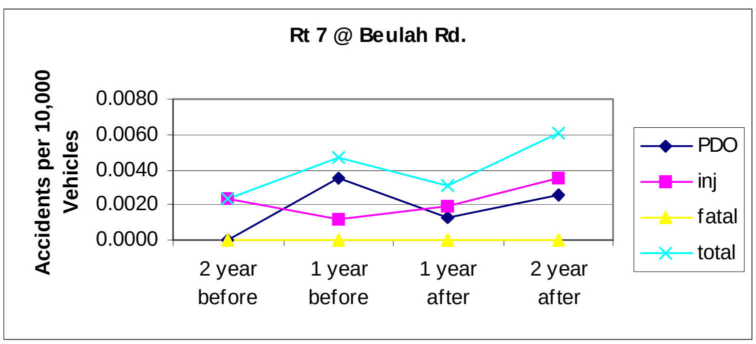

Figure 4.55 Accidents per 10,000 vehicles at Intersection # 15

From Figure 4.56, the frequency of injury accident has increased while that of PDO accidents has a small decrease.

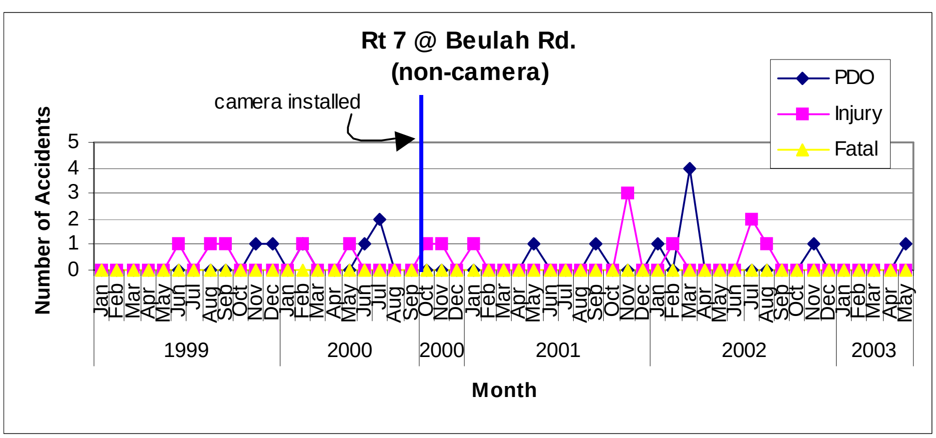

Figure 4.56 Accidents per month at Intersection # 15

4.3 Control intersection

Four intersections were selected as control intersections. They are located far from most of the camera intersections. These control intersections, like non-camera intersections, have only accident data available. Since most of the cameras were installed in 2001, the estimated time of the camera installation is June 2001. The estimated before period for these control intersection is from January 1999 to May 2001. The after period is from June 2001 to May 2003.

<u>Intersection # 16 Route 644 @ Rolling Road</u>

Route 644 ADT :	36,000	2001
	36,000	2002

Accident Data

The accident rates in Figure 4.57 shows the increase in PDO accident rates in the after period. The injury rate, on the other hand, reduced. As a result, the total accident rate in the after period had not changed much compared with that of 2 years before the RLC operation.

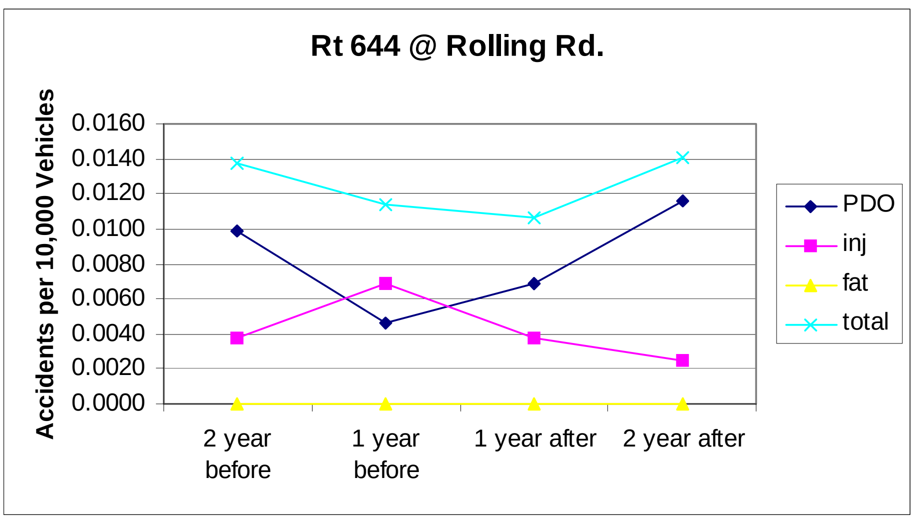

Figure 4.57 Accidents per 10,000 vehicles at Intersection # 16

Figure 4.58 shows the high frequency of accident in both before and after period. The number of PDO accidents was higher in the after period while that of injury accidents number was lower.

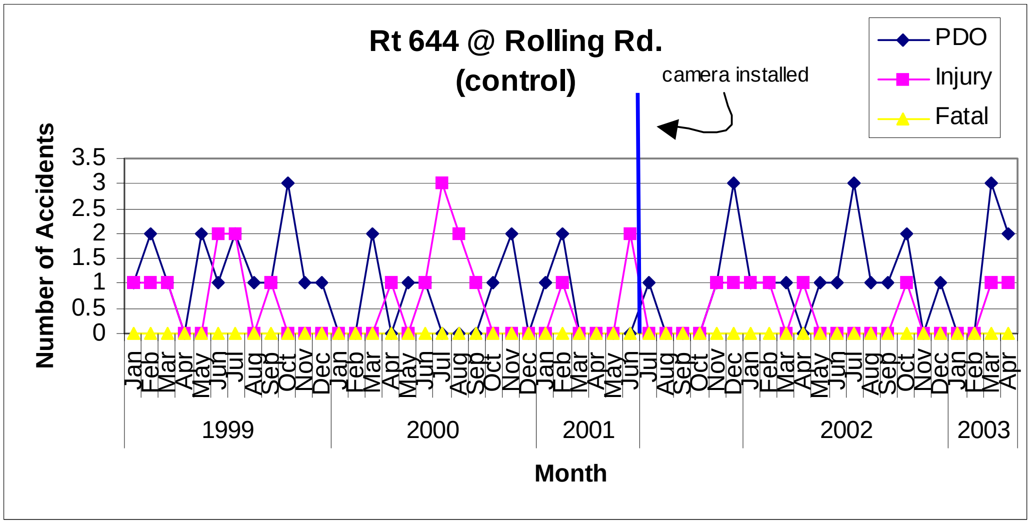

Figure 4.58 Accidents per month at Intersection # 16

Intersection # 17 Richmond Highway @ Telegraph Road

Richmond Highway ADT :	32,000	2000
	32,000	2001
	38,000	2002

Accident Data

The trend of accidents at this intersection is similar to that of intersection 16. The PDO accident rate was increasing while the injury accident rate was decreasing. Overall, the total accident rate had not changed much in the after period.

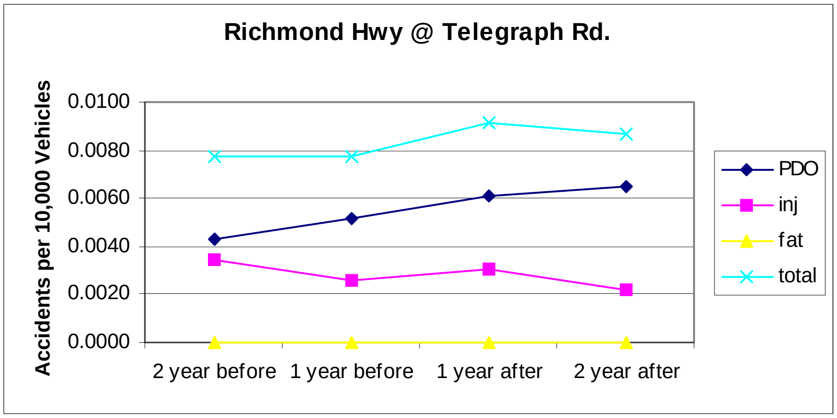

Figure 4.59 Accidents per 10,000 vehicles at Intersection # 17

Considering numbers of accidents by month from Figure 4.60, the frequency of the PDO accidents increased in the after period. On the other hand, the frequency of injury accidents had declined in the after period.

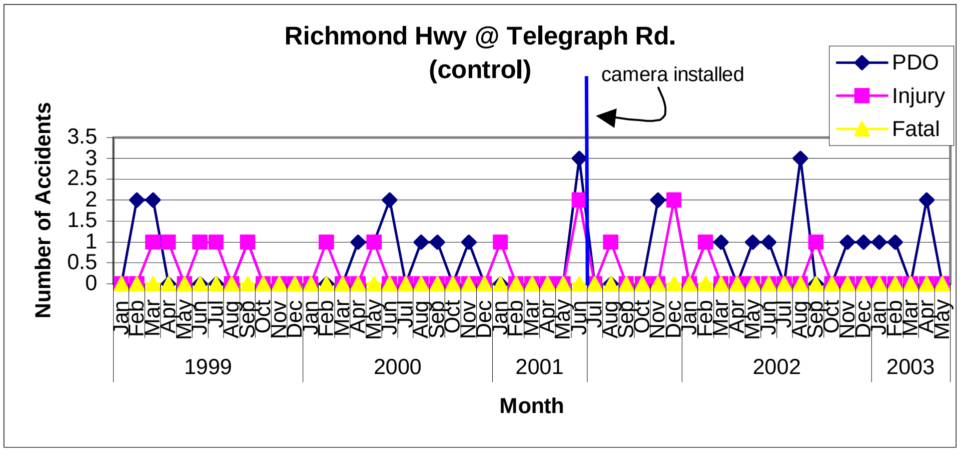

Figure 4.60 Accidents per month at Intersection # 17

Intersection # 18 Braddock Road & Rolling Road

Braddock Road ADT : 63,000 2001

64,000 2002

Accident Data

At this intersection, the trend of accident was different from other the previous intersections. Figures 4.61 and 4.62 show that both PDO and injury accident rate have been decreased after the estimated time of camera installation.

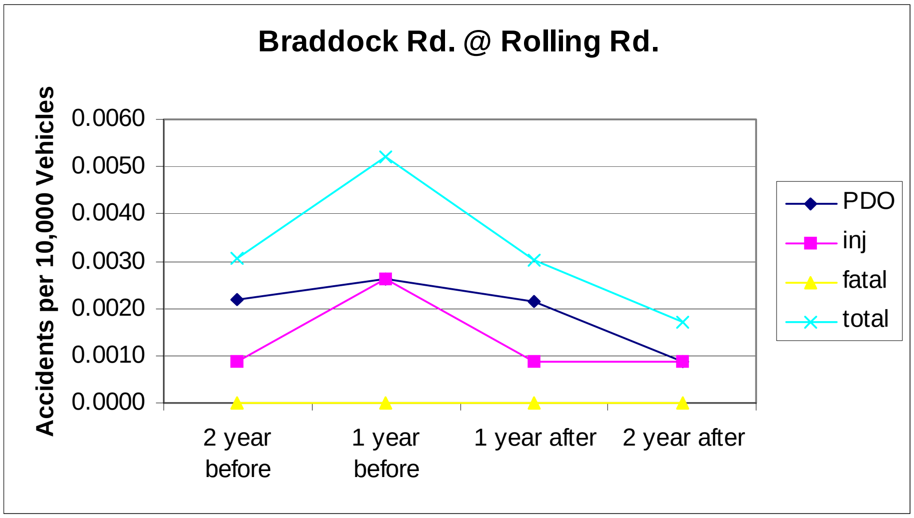

Figure 4.61 Accidents per 10,000 vehicles at Intersection # 18

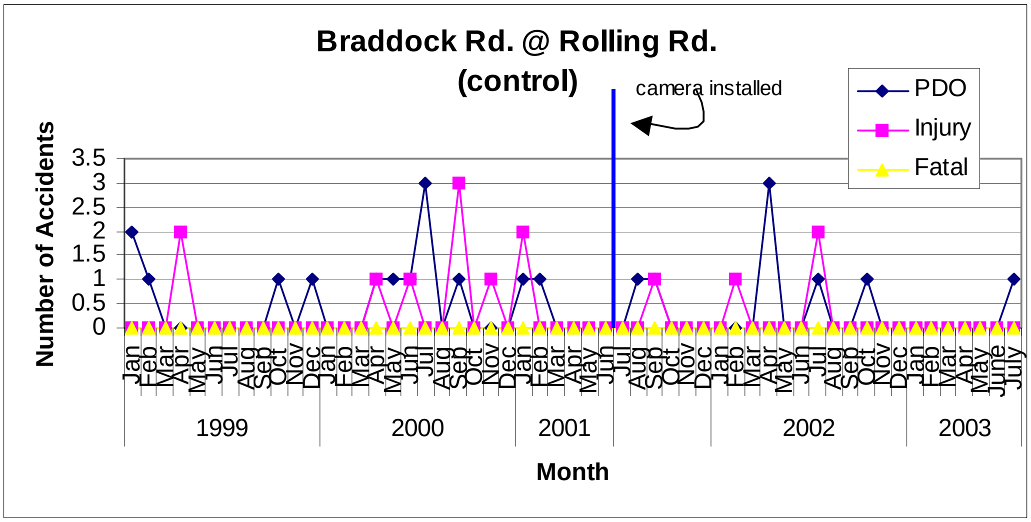

Figure 4.62 Accidents per month at Intersection # 18

Intersection # 19 S Van Dorn Road (Rt 613) & Franconia Road (Rt 644)

S Van Dorn ADT : 53,000 2001

54,000 2002

Accident Data

Figure 4.63 shows that in the after period, the PDO accident rate had begun a downward trend. On the other hand, the injury accident rate had a small increase. In total, the accident rate had not changed much compared between before and after period.

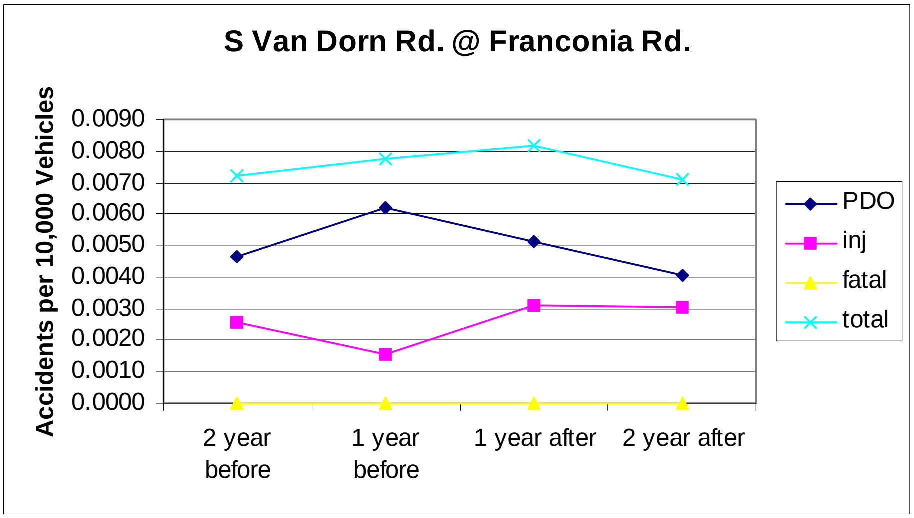

Figure 4.63 Accidents per 10,000 vehicles at Intersection # 19

Figure 4.64 shows that the frequency of PDO accidents slightly reduced while the frequency of injury accidents increased in the after period.

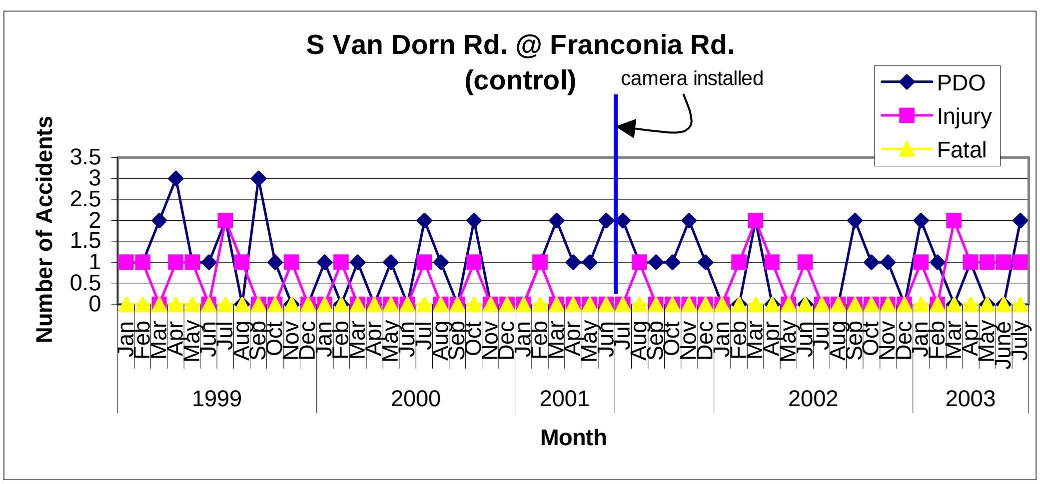

Figure 4.64 Accidents per month at Intersection # 19

4.4 Violation Data Analysis

The violation data of intersection 1 to intersection 10 during the camera operation is analyzed to determine the effect of RLC on violation rate. Intersection 11, 12 and 13 are excluded from the analysis because they have a short period of study compared with other intersections. The violation results are analyzed by 2 approaches:

- Initial period and after period at camera intersections analysis
- Trend analysis

The method of each approach is discussed in chapter 3.

4.4.1 Initial Period and After Period Analysis at Camera Intersection

In this analysis, the numbers of violations at the camera intersections are measured per 10,000 vehicles and then compared between initial period and after RLC operation period. The average of violation rates in the first 3 months of RLC operation is referred as the initial violation rate. At camera intersections, both of RLC and the increase of amber time during the operation period had an effect on changes in violation rates. The changes in violation rates affected from the RLC operation is compared with those affected from the amber-time increase. Effects of Average Daily Traffic (ADT) and speed limit, on the change in violation rates are also studied. This analysis is conducted in 3 groups:

- Comparison between with and without the effect of amber-time increase.
- Comparison between low and high ADT intersections.
- Comparison between low, medium and high speed limit intersections.

<u>Comparison between with and without amber-time increase effect</u>

1) With Amber-Time Increase Effect

The intersections that were affected by the increase of amber time include intersections 1, 2, 3, 6, 7, 8, 9 and 10. Table 4.2 shows percent changes in violations per 10,000 vehicles with the effect of the change of amber time. The number of violations per 10,000 vehicles has been reduced in an average of:

- 22 percent in the 4^{th} to 9^{th} month of RLC operation
- 37 percent in the 10^{th} to 15^{th} month of RLC operation
- 59 percent in the 16^{th} to 21^{st} month of RLC operation and
- 70 percent in the 22^{nd} to 27^{th} month of RLC operation
- 76 percent after the 27^{th} month of RLC operation

With the effect of the increase of amber time, the violation rate had reduced during the RLC operation. From Table 4.2, 10 from 13 intersections, had the violation rate decreasing in the 4th to 9th month of the RLC operation. Every intersection had the reduction in violation rates in the 22nd to 27th month of the RLC operation. The significant reduction of violation rates at the camera intersections after the 22nd month of the RLC operation should be attributed to the increase of the amber time, since most of the camera intersections had the amber time increasing after 22 months of the RLC operation.

Table 4.2 Violation Data with Amber-Time Increase Effect.

camera inter-section	**Average Number of Violations/10,000 vehicles**						**% Changes in Violations per 10,000 vehicles**				
	Initial Period (3 mo)	4-9 mo	10-15 mo	16-21 mo	22-27 mo	>27 mo	4-9 mo after	10-15 mo after	16-21mo after	22-27mo after	>27 mo after
1	2.86	2.70	0.88	0.74	0.72	0.34	-5.5%	-69.4%	-74.2%	-75.0%	-88.2%
2	1.59	0.59	0.26	0.44	0.45	0.23	-62.8%	-83.6%	-72.6%	-72.0%	-85.5%
3	0.64	0.05	0.04	0.04	0.09	-	-91.9%	-94.0%	-93.6%	-85.7%	-
4	2.33	1.19	0.88	0.97	1.03	1.20	-49.1%	-62.4%	-58.3%	-56.1%	-48.7%
5	8.68	6.73	2.67	2.09	2.67	2.03	-22.5%	-69.3%	-75.9%	-69.2%	-76.6%
6	2.13	2.34	2.56	2.01	1.11	0.78	10.1%	20.5%	-5.7%	-48.0%	-63.5%
7	3.45	1.67	1.38	0.70	0.45	-	-51.5%	-60.2%	-79.8%	-87.0%	-
8	2.15	2.21	2.29	1.25	0.80	0.49	2.7%	6.5%	-41.8%	-62.6%	-77.2%
9	2.44	2.26	2.78	2.00	0.31	0.24	-7.2%	14.0%	-18.1%	-87.5%	-90.0%
10	2.21	2.15	1.83	0.65	0.90	-	-2.4%	-17.2%	-70.5%	-59.4%	-
11	0.99	0.98	1.06	-	-	-	-1.4%	6.7%	-	-	-
12	2.08	1.74	-	-	-	-	-16.2%	-	-	-	-
13	1.24	1.34	-	-	-	-	8.4%	-	-	-	-
Average	2.5	2.0	1.5	1.1	0.9	0.8	-22.3%	-37.1%	-59.0%	-70.2%	-75.7%

2) Without Amber-Time Increase Effect

To evaluate percent changes in violation rates without the amber-time increase effect, the violation rates after the change of amber time are predicted from the trend of the violation rates before the change. The linear regression method is applied to predict the violation rate in the period that the amber time has changed. Intersections 3 and 7 cannot be analyzed without the amber-time effect because the amber times at these intersections were increased in the early of the RLC operation; right before and 5 months after the RLC operation respectively. Figures 4.65, 4.66, 4.67, 4.68, 4.69 and 4.70 show the predicted violation rates at intersections 1, 2, 6, 8, 9 and 10 respectively.

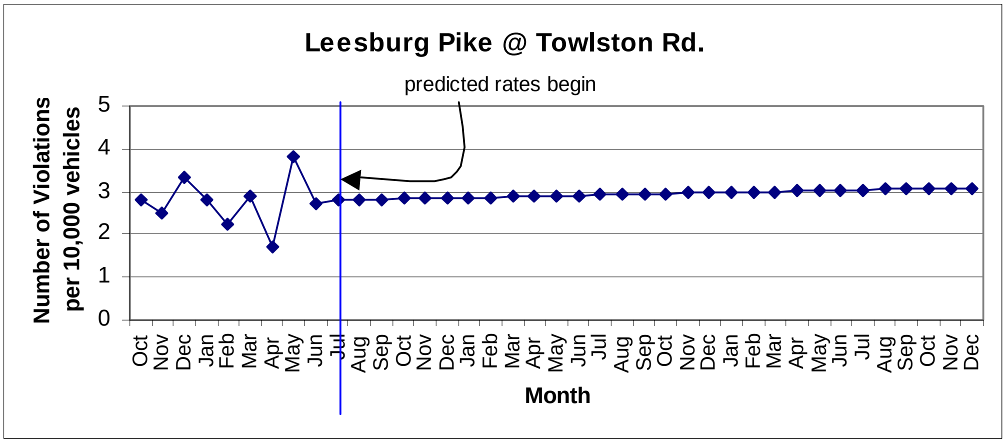

Figure 4.65 Predicted Violation Rates at Intersection 1

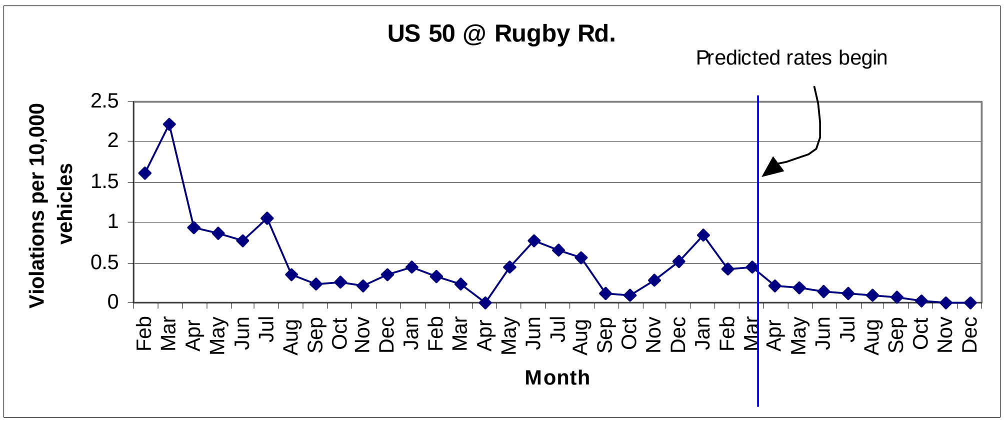

Figure 4.66 Predicted Violation Rates at Intersection 2

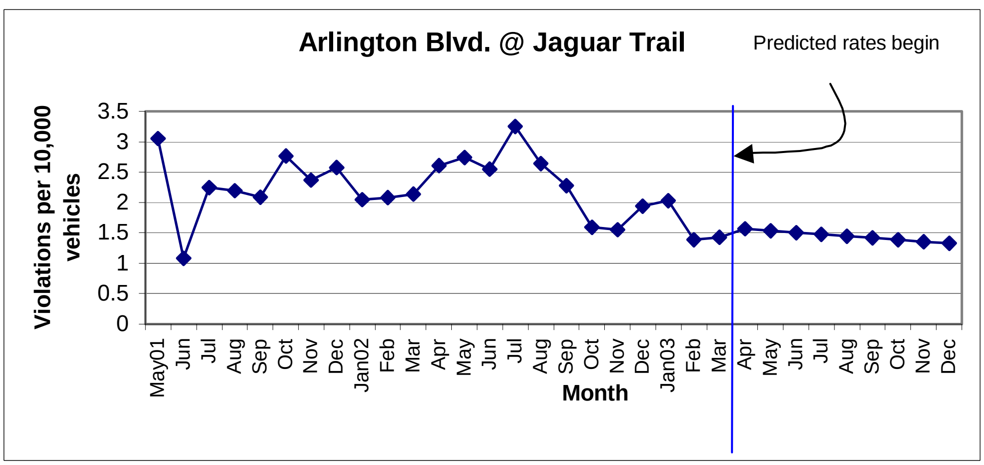

Figure 4.67 Predicted Violation Rates at Intersection 6

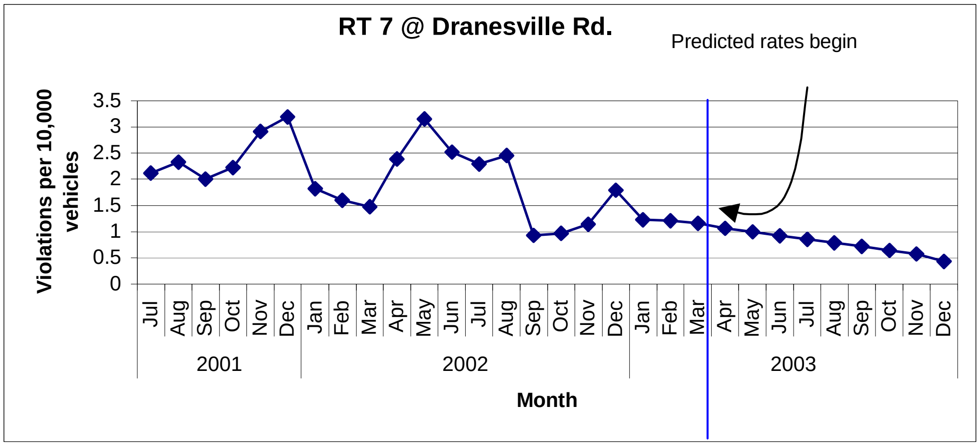

Figure 4.68 Predicted Violation Rates at Intersection 8

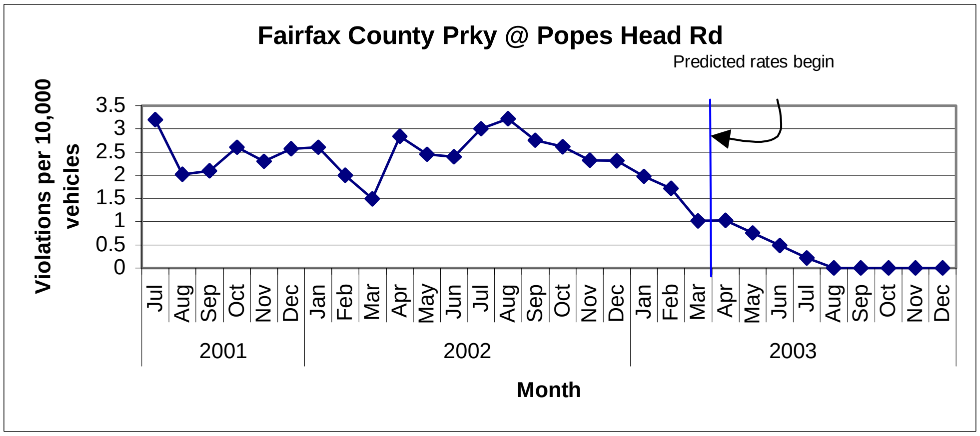

Figure 4.69 Predicted Violation Rates at Intersection 9

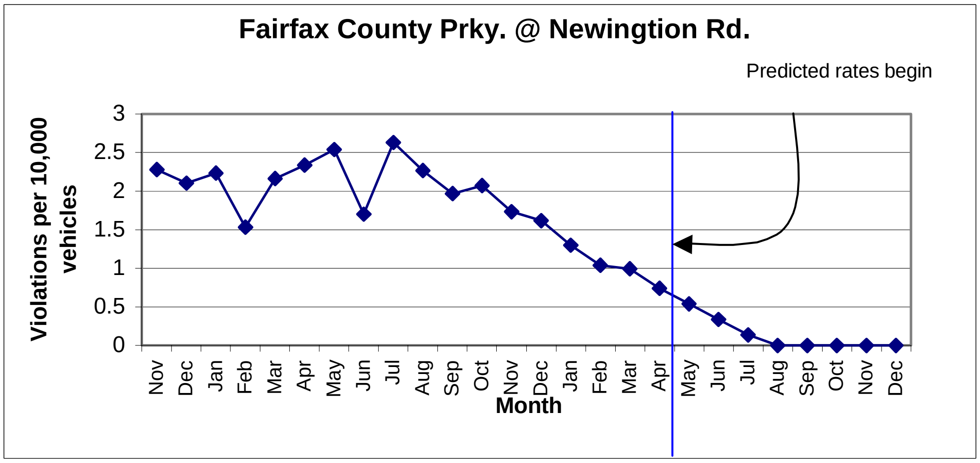

Figure 4.70 Predicted Violation Rates at Intersection 9

The results are adjusted as shown in Table 4.3. Without the amber-time increase effect, the number of violations per 10,000 vehicles has been reduced in an average of:

- 13 percent in the 4th to 9th month of RLC operation
- 21 percent in the 10th to 15th month of RLC operation
- 43 percent in the 16th to 21st month of RLC operation and
- 58 percent in the 22nd to 27th month of RLC operation
- 60 percent after the 27th month of RLC operation

From Table 4.3, 7 from 11 intersections had the reduction in violation rates in the 4th – 9th month of the RLC operation. Only intersection 6 had an upward trend of violation rate in the 4th to 15th month of the RLC operation. Intersection 1 is the only intersection that is predicted to have an upward trend after the 22nd month of the RLC operation. Overall, with effect of the RLC operation only, the violation rate had reduced. The RLC is one of the factors that had an effect on the violation reduction.

Table 4.3 Violation Data Without Amber-Time Increase Effect.

camera inter-section	Average Number of Violations/10,000 vehicles						% Changes in Violations per 10,000 vehicles				
	Initial Period (3 mo)	4-9 mo	10-15 mo	16-21 mo	22-27 mo	>27 mo	4-9 mo after	10-15 mo after	16-21mo after	22-27mo after	>27 mo after
1	2.86	2.86	2.70	2.83	2.89	2.95	3.02	-5.5%	-1.2%	0.9%	3.0%
2	1.59	0.59	0.26	0.44	0.45	0.11	-62.8%	-83.6%	-72.6%	-71.8%	-93.1%
3	-	-	-	-	-	-	-	-	-	-	-
4	2.33	1.19	0.88	0.97	1.03	1.20	-49.1%	-62.4%	-58.3%	-56.1%	-48.7%
5	8.68	6.73	2.67	2.09	2.67	2.03	-22.5%	-69.3%	-75.9%	-69.2%	-76.6%
6	2.13	2.34	2.56	2.01	1.48	1.39	10.1%	20.5%	-5.7%	-30.4%	-34.6%
7	-	-	-	-	-	-	-	-	-	-	-
8	2.15	2.21	2.29	1.25	0.89	0.55	2.7%	6.5%	-41.8%	-58.6%	-74.3%
9	2.44	2.26	2.78	2.00	0.41	0.00	-7.2%	14.0%	-18.1%	-83.2%	-100.0%
10	2.21	2.15	1.83	0.63	0.00	-	-2.4%	-17.2%	-71.4%	-100.0%	-
11	0.99	0.98	1.06	-	-	-	-1.4%	6.7%	-	-	-
12	2.08	1.74	-	-	-	-	-16.2%	-	-	-	-
13	1.24	1.34	-	-	-	-	8.4%	-	-	-	-
Average	2.6	2.2	1.9	1.5	1.2	1.2	-13.3%	-20.7%	-42.9%	-58.3%	-60.3%

Compare between with and without amber-time increase effect, the results evidently show that with the increase of amber time, there was a greater reduction in number of violations per 10,000 vehicles. From the study of the amber time duration effect on driver responses conducted by Stimpson (10), the results show that the longer is the amber time, the lower is the violation number. This is because drivers in the dilemma zone can pass the intersection before the signal turns red. The optimal amber-time interval that would reduce violation number varies from one intersection to another intersection depending upon its geometry and traffic characteristic.

Comparison between low and high ADT intersection

The intersections are categorized by their ADT. An intersection with the ADT of more than 60,000 is considered to be in the high ADT group. The rest of the intersections are in the low ADT group. Three intersections are in the high ADT group while seven intersections are in the low ADT group. Table 4.4 presents percent changes in violation rates for the two groups.

From Table 4.4, for the high ADT group, all 3 intersections had percent reductions more than 60 percent in the 10^{th} to 15^{th} month period of the RLC operation. On the other hand, for the low ADT group, only 3 from 7 intersections had a percent reduction more than 60 percent in the same period. The results show that during the first 21 months of the study period, the average of percent reductions in violation rates on the high ADT intersections are higher than those on the low ADT intersections. For the high ADT intersections, the averages of percent reductions are 68, 80 and 75 percent in the 9^{th}-15^{th}, 16^{th}-21^{st} and 22^{nd}-27^{th} month period respectively. For the low ADT group, the averages of percent reductions are lower at 11, 25 and 52 percent in the 9^{th}-15^{th}, 16^{th}-21^{st} and 22^{nd}-27^{th} month period respectively. However, after the 27^{th} month period of the RLC operation, the average of percent reductions is higher in the low ADT intersection group. The average of percent reductions at the low ADT intersection is 79 percent. The average of percent reductions at the high ADT intersections is lower at 67 percent. In conclusion, the intersections with higher ADT exhibit greater effectiveness of the RLC program than the intersections with lower ADT.

Table 4.4 Comparisons of Percent Changes in Violation Rates by ADT.

Camera inter-section	ADT (primary street)	Violations/10,000 vehicles						% Changes in Violations per 10,000 vehicles				
		Initial Period (3 mo)	4-9 mo	10-15 mo	16-21 mo	22-27 mo	>27 mo	After 4-9 mo	After 10-15 mo	After 16-21mo	After 22-27mo	After 27 mo
High ADT												
2	76000	1.59	0.59	0.26	0.44	0.45	0.23	-62.8%	-83.6%	-72.6%	-72.0%	-85.5%
3	110000	0.64	0.05	0.04	0.04	0.09	-	-91.9%	-94.0%	-93.6%	-85.7%	-
4	72000	2.33	1.19	0.88	0.97	1.03	1.20	-49.1%	-62.4%	-58.3%	-56.1%	-48.7%
Average		1.52	0.61	0.39	0.48	0.52	0.71	-68.0%	-80.0%	-74.8%	-71.2%	-67.1%
Low ADT												
1	54000	2.86	2.70	0.88	0.74	0.72	0.34	-5.5%	-69.4%	-74.2%	-75.0%	-88.2%
5	44000	8.68	6.73	2.67	2.09	2.67	2.03	-22.5%	-69.3%	-75.9%	-69.2%	-76.6%
6	56000	2.13	2.34	2.56	2.01	1.11	0.78	10.1%	20.5%	-5.7%	-48.0%	-63.5%
7	52000	3.45	1.67	1.38	0.70	0.45	-	-51.5%	-60.2%	-79.8%	-87.0%	-
8	59000	2.15	2.21	2.29	1.25	0.80	0.49	2.7%	6.5%	-41.8%	-62.6%	-77.2%
9	55000	2.44	2.26	2.78	2.00	0.31	0.24	-7.2%	14.0%	-18.1%	-87.5%	-90.0%
10	55000	2.21	2.15	1.83	0.65	0.90	-	-2.4%	-17.2%	-70.5%	-59.4%	-
Average		3.42	2.87	2.05	1.35	0.99	0.78	-10.9%	-25.0%	-52.3%	-69.8%	-79.1%

Comparison between low, medium, and high speed limit intersection

For this comparison, the intersections are grouped by the speed limit. The speed limits are grouped into 3 levels: low, medium, and high. The high-speed-limit group includes the intersections that have speed limit of 55 mph while the medium-speed-limit group includes those that have speed limit of 45 and 50 mph. The low-speed-limit group is intersections with speed limit of 35 mph. Table 4.5 presents percent changes in violation rates categorized by different speed-limit level. The results show that overall; the high-speed limit and low-speed limit intersections had approximately the same percent reduction in violation rates during the study period. All intersections that have a speed limit of 35 and 55 mph had more than 60 percent reduction in violation rates in the 10^{th}-15^{th} month period of the RLC operation. Considering the medium-speed-limit group, an average of reduction in violation rates was 14 percent in the 10^{th} to 15^{th} month period of the RLC operation.

In conclusion, the intersections with high and low speed limit exhibit greater effectiveness of the RLC than those with medium speed limit. From this study, the medium speed limit refers to the speed of 45 and 50 mph.

Table 4.5 Comparisons of Percent Changes in Violation Rates by Speed Limit

Camera inter-section	Speed Limit (MPH)	Violations/10,000 vehicles						% Changes in Violations per 10,000 vehicles				
		Initial Period (3 mo)	4-9 mo	10-15 mo	16-21 mo	22-27 mo	>27 mo	after 4-9 mo	after 10-15 mo	after 16-21 mo	after 22-27 mo	after >27 mo
High Speed Limit												
1	55	2.86	2.70	0.88	0.74	0.72	0.34	-5.5%	-69.4%	-74.2%	-75.0%	-88.2%
2	55	1.59	0.59	0.26	0.44	0.45	0.23	-62.8%	-83.6%	-72.6%	-72.0%	-85.5%
7	55	3.45	1.67	1.38	0.70	0.45	-	-51.5%	-60.2%	-79.8%	-87.0%	-
Average		2.64	1.66	0.84	0.62	0.54	0.28	-39.9%	-71.1%	-75.6%	-78.0%	-86.9%
Medium Speed Limit												
3	45	0.64	0.05	0.04	0.04	0.09	-	-91.9%	-94.0%	-93.6%	-85.7%	-
6	45	2.13	2.34	2.56	2.01	1.11	0.78	10.1%	20.5%	-5.7%	-48.0%	-63.5%
8	45	2.15	2.21	2.29	1.25	0.80	0.49	2.7%	6.5%	-41.8%	-62.6%	-77.2%
9	50	2.44	2.26	2.78	2.00	0.31	0.24	-7.2%	14.0%	-18.1%	-87.5%	-90.0%
10	50	2.21	2.15	1.83	0.65	0.90	-	-2.4%	-17.2%	-70.5%	-59.4%	-
Average		1.91	1.80	1.90	1.19	0.64	0.50	-17.8%	-14.0%	-45.9%	-68.6%	-76.9%
Low Speed Limit												
4	35	2.33	1.19	0.88	0.97	1.03	1.20	-49.1%	-62.4%	-58.3%	-56.1%	-48.7%
5	35	8.68	6.73	2.67	2.09	2.67	2.03	-22.5%	-69.3%	-75.9%	-69.2%	-76.6%
Average		5.51	3.96	1.77	1.53	1.85	1.61	-35.8%	-65.9%	-67.1%	-62.6%	-62.7%

4.4.2 Trend Analysis

Violation rates at camera intersections during the RLC operation period are monitored for the trend analysis. This analysis is conducted to anticipate violation rates after the operation of the RLC. The analysis is conducted in 2 conditions: with and without the amber-time increase effect. For the 'without amber-time increase effect' analysis, the number of violations per 10,000 vehicles at each intersection is monitored until before the increase of the amber time. On the other hand, for the 'with amber-time increase effect' analysis, the violation rates are monitored during the RLC operation period without concerning about the change of the amber time. The camera intersections are categorized into several groups based on their range of violation rates after the RLC operation. The analysis with each condition is discussed below.

1) With Amber-Time Increase Effects

After the amber time has increased at some of the camera intersections, the violation rate has reduced to a certain range. The intersections are categorized into 2 groups. The first group includes the intersections that have the number of violations per 10,000 vehicles reducing to the range of 0 to 0.3. The second group includes the intersections that have the number of violations per 10,000 vehicles reducing to the range of 0.3 and 1.0. Intersections 4 and 5 are excluded from this analysis because during the study period, there is no change of amber time at these two intersections.

1.1) The number of violations per 10,000 vehicles reduced to less than 0.3

This group includes intersection 1, 2, 3 and 9. After the amber time changes, the numbers of violations per 10,000 vehicles at these intersections have reduced and remained to the range of 0.04 to 0.3 for 9 months to more than 1 year. Table 4.6 presents the range of violation rate of each intersection after an increase of the amber time. The average of the reduced violation rate of 4 intersections is 0.18 violations per 10,000 vehicles. The percent reductions in violation rates are high compared to other intersections. The amber times at these intersections are 5.0 and 5.5 seconds. Both of the RLC operation and the amber-time increase cause the reduction in violations at the intersections in this group.

Table 4.6 Group of Intersections with Violation Rates Less Than 0.3.

Intersection	Reduced Rate Range (Violations per 10,000 vehicles)	Average of Reduced Rate (Violations per 10,000 veh)	Percent Changes After 27 months	Amber Time Interval (seconds)
1	0.04-0.2	0.12	-75%	5.5
2	0.1-0.3	0.22	-72%	5.0
3	0.04-0.1	0.08	-85.7%	5.5
9	0.2-0.3	0.28	-87.5%	5
Average	0.04-0.3	0.18	-80%	5.25

1.2) The number of violations per 10,000 vehicles reduced to 0.3-1.0

This group includes intersection 6, 7, 8 and 10. The ranges of violation rates after the amber time changed are shown in Table 4.7. The violation rates reduce to a higher level than those of the first group while the percent reductions in the 22nd – 27th are lower. The amber times at all intersections in this group are 4.5 seconds, which are lower than those in the first group.

Table 4.7 Group of Intersections with Violation Rates from 0.3-1.0

Intersection	Number of Violations/10,000 vehicles	Average of Reduced Rate (Violations per 10,000 veh)	Percent Changes After 27 months	Amber Time Interval (seconds)
6	0.6-1.0	0.86	-48.0%	4.5
7	0.3-0.5	0.46	-87.0%	4.5
8	0.4-1.0	0.70	-62.6%	4.5
10	0.3-1.0	0.71	-59.4%	4.5
Average	0.3-1.0	0.68	-64.3%	4.5

With the effect from both of the amber-time increase and the RLC operation, the violation rates have dramatically decreased from 0.6-3.4 violations per 10,000 vehicles or 7-18 vehicles per day to 0.04-1.0 violations per 10,000 vehicles or 0-6 vehicles per day. The amber-time interval is one of the important factors that indicate what level of the violation rate would reduce to. The results evidently show that a longer amber time results in a lower violation rates and also a higher percent of reduction.

2) Without Amber-Time Increase Effects

To study the trend of violation rates without the amber-time increase effect, only violation rates at before the amber time was changed are analyzed. The trends of violations are categorized into 2 groups. The first group includes the intersections that have no decrease in violation rates after the RLC operation. The second group includes the intersections that have a decrease in violations rates. Only intersection 3 is excluded from this analysis because the amber-time interval at this intersection was increased right before the RLC operation.

2.1) No Decrease in Violation Rates

This group includes intersections 1 and 7. Figures 4.71 and 4.72 show the violation rates before they are affected by the increase of amber time at intersection 1 and 7 respectively. After the RLC installation, the numbers of violations per 10,000 vehicles have not decreased at these intersections. Instead, they are fluctuating and then decreasing after the increase of the amber time. However, compared with the 'violation rate decreased' group, which is discussed later, these 2 intersections have a shorter period of operation that is not affected by the amber-time increase. Hence, at these two intersections, it is more complicated to study about the effect of the RLC only in the long-term period.

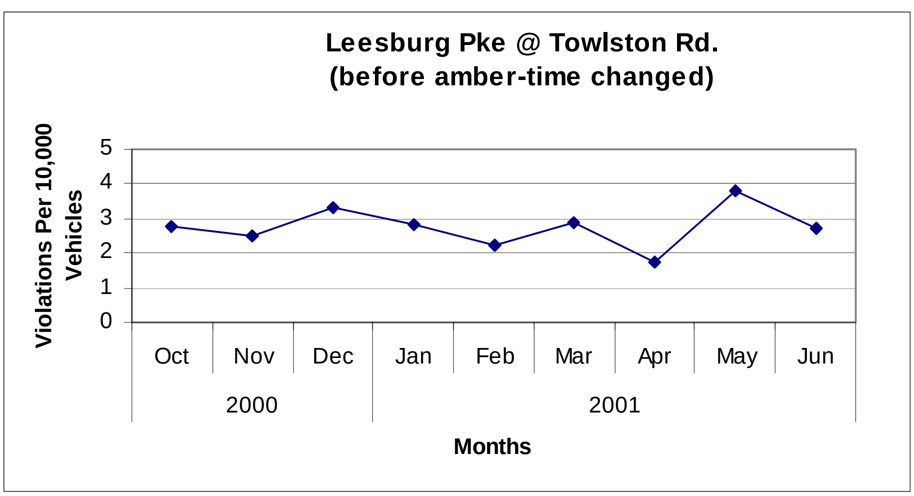

Figure 4.71 Violation Rates at Intersection 1 Before The Amber-time Changed

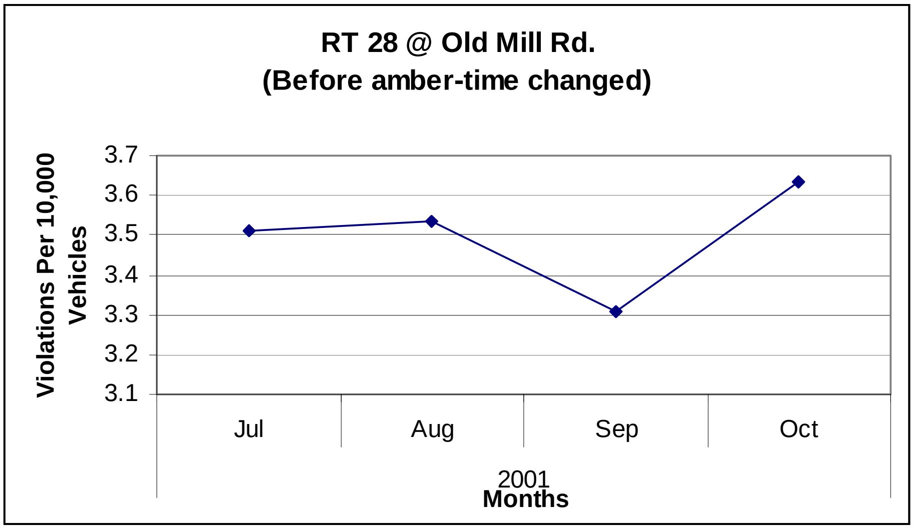

Figure 4.72 Violation Rates at Intersection 1 Before The Amber-time Changed

2.2) Violation Rates Decreased

Seven camera intersections, intersections 2, 4, 5, 6, 8, 9, and 10, have violation rates decreasing after the RLC had been in operation. Several of them took more than one year before the violation rates reduce. On the other hand, at some intersections, the violation rates reduce within 6 months of the RLC operation. The camera intersections are divided into 3 types based on the range of violation rates after the RLC operation. Each group is discussed below.

2.2.1) Violation Rates decreased to Average of 0-1 Violation per 10,000 vehicles

Intersection 2 is the only site that has the violation rate reducing to lower than one violation per 10,000 vehicles without the effect from the increase of amber time. This intersection has a speed limit of 55 mph. The ADT on the primary street is high compared to other intersections. Figure 4.73 shows the violation rates at intersection 2 before the amber time is increased. The initial violation rate is as low as 1.6 violations per 10,000 vehicles. After 6 months of the RLC operation, the violation rates reduce to the range of 0.1-0.8 violations per 10,000 vehicles with an average of 0.4 violations per 10,000 vehicles. The percent reduction in violation rate is 73 percent in the 18th to 21st month of the RLC operation.

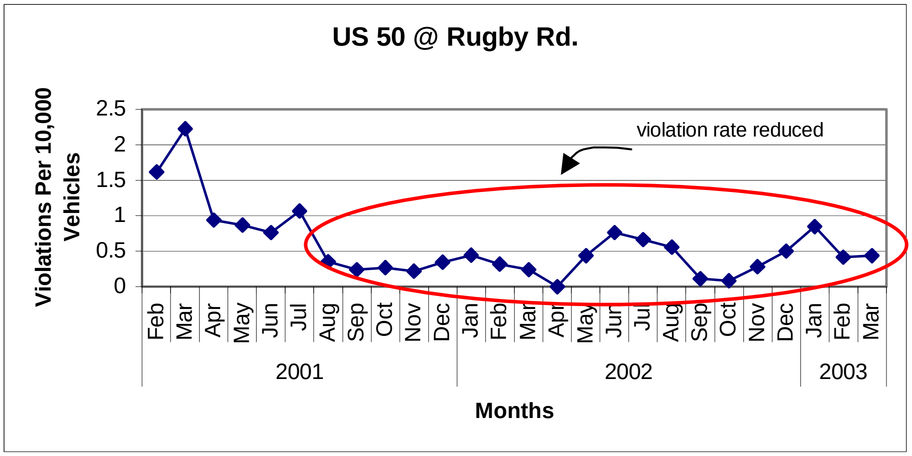

Figure 4.73 Violation Rates at Intersection 2 Before The Amber-time Changed

2.2.2) Violation Rates decreased to Average of 1.0-2.0 Violations per 10,000 vehicles

Intersection 4, 6, 8, 9 and 10 are in this group. The initial rate and reduced rate of each intersection are summarized in Table 4.8. The initial violation rates among these intersections are very close. It is in the range of 2.1-2.4 violations per 10,000 vehicles. Table 4.8 also shows that both speed limits and ADT of the intersections in this group vary from low to high. Therefore, the speed limit and ADT is not the factors that indicate the level of final violation rates.

Table 4.8 Group of Intersections with Average Violation Rate from 1.0-2.0.

Intersection	Initial Rate (Violations per 10,000 veh)	Period before the violation rates reduced (months)	Reduced Rate Range (Violations per 10,000 veh)	Average of Reduced Rate (Violations per 10,000 veh)	Speed Limit (mph)	2002 ADT
4	2.3	4	0.5-1.3	1.02	35	72000
6	2.13	17	1.5-2.0	1.65	45	56000
8	2.15	14	0.9-1.8	1.21	45	59000
9	2.4	18	1.0-2.0	1.60	50	55000
10	2.2	13	1.0-1.6	1.24	50	55000
Average	2.24	13	0.5-2.0	1.34	45	59400

Figures 4.74, 4.75, 4.76, 4.77 and 4.78 show the violation rates before the change of the amber time at intersections 4, 6, 8, 9 and 10 respectively. At intersection 4,

the percent reduction of violation rate is high of 49 percent after the 27th month of RLC operation. The violation rate at intersection 4 reduces faster compared with those of other intersections in this group. The violation trends at intersections 6, 8, 9 and 10 are similar. After the installation of RLC, the violation rates did not immediately decrease but they had fluctuated for more than one year before began the downward trend. The violation rates at intersection 6, 8, 9 and 10 reduce by 5.7, 42, 18 and 17 percent respectively before the amber time has changed.

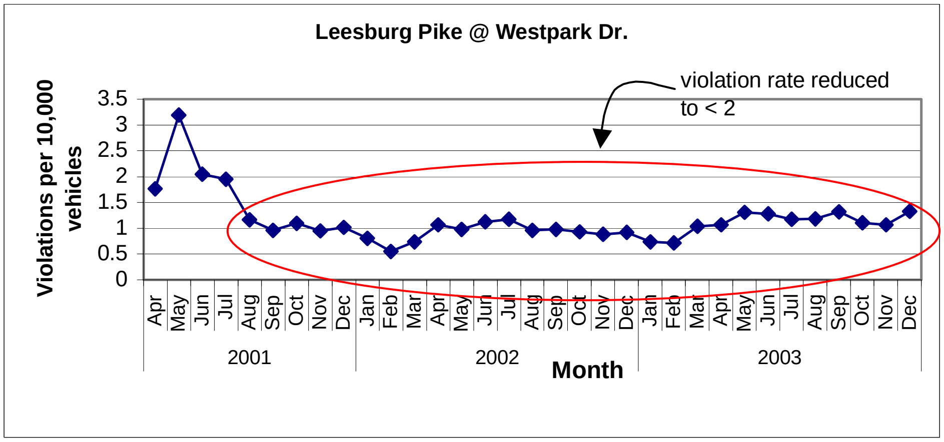

Figure 4.74 Violation Rates at Intersection 4 Before The Amber-time Change

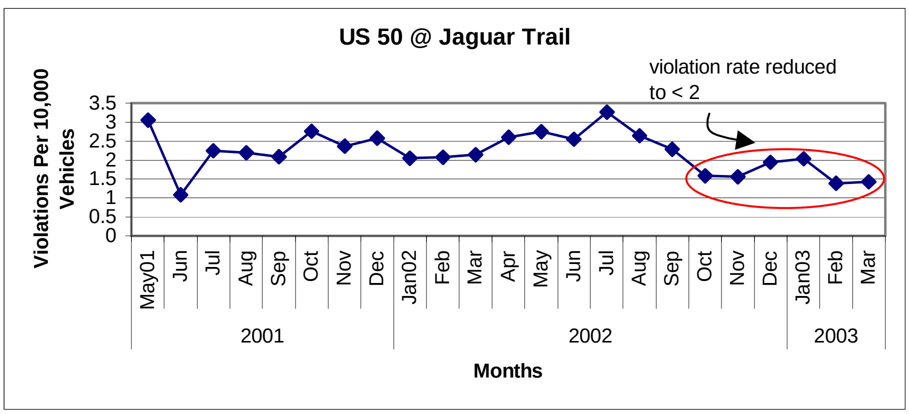

Figure 4.75 Violation Rates at Intersection 6 Before The Amber-time Change

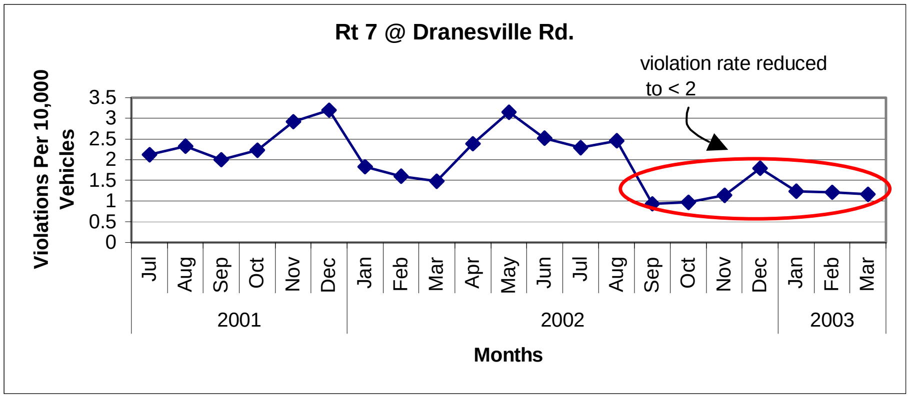

Figure 4.76 Violation Rates at Intersection 8 Before The Amber-time Change

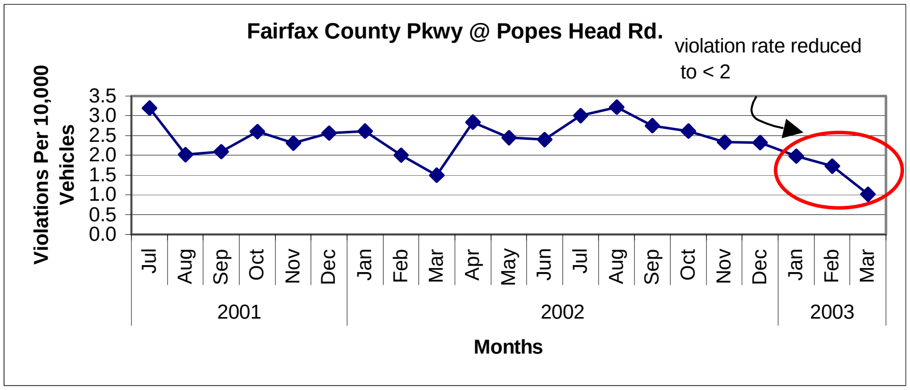

Figure 4.77 Violation Rates at Intersection 9 Before The Amber-time Change

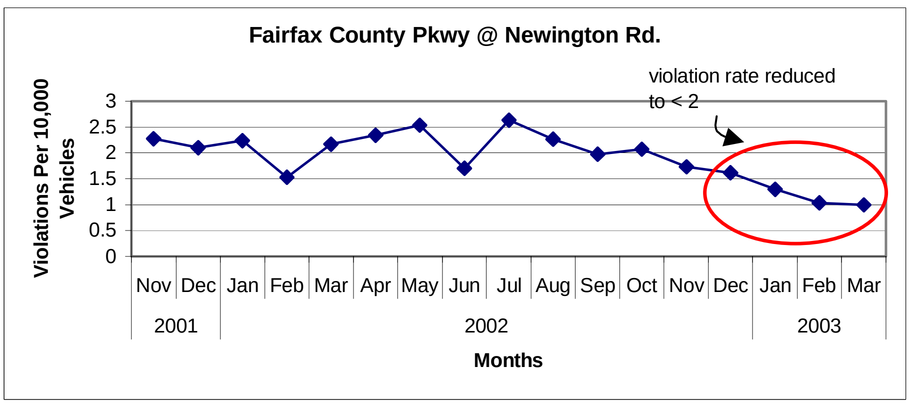

Figure 4.78 Violation Rates at Intersection 10 Before The Amber-time Change

The violation trends at intersections 6, 8, 9 and 10 are affected by the increase of amber time before the trends can be continuingly analyzed.

2.2.3) Violation Rates decreased to Average of > 2 Violations per 10,000 vehicles

Intersection 5 is the only intersection that has the violation rates reducing to the range of 1-3 violations per 10,000 vehicles with an average of 2.15, which is high compared to other intersections. However, with the initial violation rate of 8.7 violations per 10,000 vehicles, the percent reduction is high at 77 percent after the 27th month of RLC operation. As it is shown in Figure 4.79, the violations have significantly reduced within 8 months, which is relatively fast. This intersection has a speed limit of 35 mph and a low ADT of 44000 in 2002. The high initial violation rate can be one of the reasons why the violation rate is still high after 2 years of the RLC operation. It may take longer time to reduce the violation rate at this intersection to lower than 2 violations per 10,000 vehicles. The different geometry of this intersection can be another factor that affects the higher violation rate. This intersection is an only three-leg camera intersection, which located on an off-ramp area. The further analysis should be conducted to evaluate the effect of the intersection geometry on RLC operation and drivers' behavior.

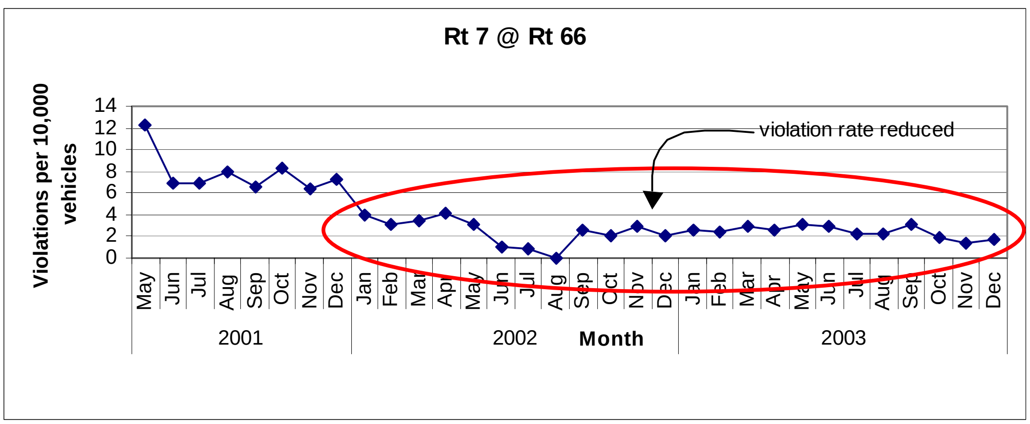

Figure 4.79 Violation Rates at Intersection 5 Before the Amber-Time Change.

Without the amber-time effect, in other words, with the RLC effect only, the violation rate does not instantly reduce but they had fluctuated for more than one year before the downward trend began. The average violation rates are reduced from the range of 1.6-8.7 violations per 10,000 vehicles or 12-38 violations per day to the range of 0.4-2.1 violations per 10,000 vehicles or 3-9 violations per day. Compare these violation rates with those affected by the amber-time increase, they are higher and take longer time to decrease.

4.4.3 Conclusion

From the trend analysis, the results are discussed in different topics as follows:

What Violation Rates are likely to be after the RLC operation?

From the results, it is found that the red light running can be reduced to the lowest rate of 0.08 violations per 10,000 vehicles or 0.88 violations per day. However, this low rate results from the increase of the amber time together with the operation of the RLC. With both factors, the violation rate has reduced and remained in the range of 0-1 violations per 10,000 vehicles. The average of the violation rates is 0.43 violations per 10,000 vehicles. The increase of the amber time to 5 or 5.5 seconds results in the lower violation rate.

Without the increase of amber time during the RLC operation, the violation can be reduced to the lowest rate of 0.4 violations per 10,000 vehicles or 3 violations per day. Most of the camera intersections have the violation rates reducing to the range of 1-2 violations per 10,000 vehicles. The average of the violation rates is 1.32 violations per 10,000 vehicles or 7.9 violations per day. However, these rates are not stable. The violation trend is interrupted by the increase of amber time. The further analysis should be conducted to determine the trend of violation rates without the affect from the change in amber time.

What are factors that affect the difference in final violation rate?

After the RLC installation or the increase of the amber time, the violation rate at each intersection reduces to a certain range, which is different from one intersection to another intersection. Many traffic characteristics such as ADT, speed limit, and initial violation rate are studied and determined if it can cause the variation in levels of final violation rate.

Considering the relationship between an initial and final violation rate, if the initial rate is very high, it will take longer time to reduce the red light violations. Intersection 5 is an example of intersection that has a high initial violation rate and also has a high final violation rate. The violation rate at intersection 5 has dramatically reduced after 8 months of the RLC operation. Even though the percent reduction is high, the final violation rate is still high compared with those of other intersections. On the other hand, the low initial rate does not result in the low final violation rate after the RLC operation. Intersections 2, 11 and 13 have low initial rates compared with those of other intersections. However, the violation results of these intersections are different. After a short time of RLC operation, intersection 2 has a decrease in violation rates, while intersection 11 shows an increase in violation rates. Intersection 13 shows a small increase in violation rates in the 4^{th} to 9^{th} month of camera operation. Hence, the low initial rate does not guarantee the high reduction in violations or the low violation rate after the RLC operation.

The results present that the speed limit and ADT does not affect the final violation rates. The final violation rates at camera intersections can be approximately the same even though they have different speed limits and ADT levels.

What are factors that affect the learning duration?

The RLC operation becomes effective after different periods of time. Each intersection takes different time durations to reduce violation rates. With the RLC operation only, three intersections require less than one year to reduce the violation rate to a saturation level while other four intersections require one to one and half a year. The difference of traffic characteristics between the first and the second group of intersections is the ADT level. Two of three intersections of the first group have a high ADT of 72000 and 76000. In contrary, every intersection in the second group has a lower ADT in the range of 55000 to 59000. This result is corresponding with the result from before-and-after at camera intersection analysis; the intersection with higher ADT exhibits effectiveness of the RLC faster. This analysis brings the conclusion that intersections with higher ADT have a greater and faster reduction in violation rates than those with lower ADT.

From the violation data analysis, the results show that the introduction of RLC and the increase in amber time reduce violations. The variation of speed limit and ADT level of each intersection also induce the different effectiveness of the RLC. From the analysis, the following conclusions are established.

- After the RLC operation, most of the camera intersections have a reduction in violation rates.
- The RLC operation has an effect on the reduction in violation rates.
- The increase in amber times does further reduce the violation rates.
- The intersections with higher ADT exhibit greater effectiveness of the RLC program.

- The intersection with medium speed limit of 45 and 50 mph exhibit less effectiveness of the RLC program than other intersections.
- The operation of RLC only can reduce the violation rate to 1-2 violations per 10,000 vehicles.
- The operation of RLC together with the amber time increase can reduce the violation rate to 0-1 violations per 10,000 vehicles.
- The increase of the amber time to 5 or 5.5 seconds results in the lower of the violation rate in the after period.
- With the RLC operation only, it will take longer time to reduce the violation rate to lower than 2 violations per 10,000 vehicles at the intersection with very high initial violation rate.
- There is no effect of low initial violation on the level of violation rate after the RLC operation.
- The ADT and speed limit at camera intersections have no effect on the level of violation rate after the RLC operation.
- An intersection with higher ADT has a greater and faster reduction in violation rates than those with lower ADT.

The general violation trend from this study may or may not apply to RLC operation in other cities. The difference in characteristics of an intersection, traffic, population and photo enforcement legislation can cause differences in a trend of violations.

4.5 Accident Data Preliminary Analysis

The analysis of accident data in this chapter is only a preliminary analysis. The results are referred as preliminary findings from accident data. The statistical analysis is provided in next chapter. For this analysis, the accident data is summarized on yearly basis as shown in Table 4.9. The number of accidents and the number of violations are measured per 10,000 vehicles. The data in Table 4.9 represents the average accident rate at each intersection 2 years before and 2 years after camera installation. The accident data is categorized by severity level. The data is used to determine the effect of the RLC on accidents. There are 3 approaches using to find the accident data.

- Before and after analysis at camera intersections
- Comparison analysis between camera and control intersections
- Spill Over Analysis

Table 4.9 Yearly Accident Data.

Intersection		Number of Accidents Per 10,000 vehicles (10^{-3})															
		2 years before				1 year before				1 year after				2 year after			
		pdo	inj	fat	total	pdo	inj	fat	total	pdo	inj	fat	total	pdo	inj	fat	total
Camera	**1***	3.1	0.0	0.0	3.1	2.3	0.6	0.0	2.9	1.2	3.1	0.0	4.4	1.0	1.5	0.0	2.5
	2	1.5	0.7	0.0	2.2	0.0	1.1	0.0	1.1	1.1	0.4	0.0	1.5	2.2	0.4	0.0	2.5
	3	2.3	0.8	0.0	3.0	2.5	2.5	0.0	5.1	0.8	1.8	0.0	2.5	1.2	0.2	0.0	1.5
	4	1.0	3.1	0.0	4.1	1.0	2.1	0.0	3.1	2.7	1.1	0.0	3.8	1.1	1.5	0.0	2.7
	5	11.9	4.8	0.0	16.7	8.3	6.0	0.0	14.3	9.1	9.1	0.0	18.3	3.1	3.7	0.0	6.8
	6	2.8	1.4	0.0	4.3	2.8	1.9	0.5	5.2	7.1	1.4	0.0	8.5	2.0	2.0	0.0	3.9
	7	2.7	0.5	0.0	3.2	0.5	2.7	0.0	3.2	2.1	0.5	0.0	2.7	1.6	1.1	0.0	2.6
	8	4.1	2.3	0.0	6.4	3.6	4.8	0.0	8.4	1.6	3.7	0.0	5.3	3.5	2.0	0.0	5.6
	9*	0.4	0.8	0.0	1.2	0.8	0.4	0.0	1.2	1.4	1.4	0.0	2.7	2.7	1.6	0.0	4.3
	10*	0.4	0.8	0.0	1.2	0.4	0.4	0.0	0.8	0.5	0.0	0.0	0.5	0.0	0.7	0.0	0.7
Total		30.2	15.3	0.0	45.6	22.5	22.5	0.5	45.4	27.7	22.5	0.0	50.2	18.5	14.8	0.0	33.3
Non-Camera	**14***	3.1	1.6	0.0	4.7	4.7	5.2	0.0	9.9	8.7	2.5	0.0	11.2	2.5	2.5	0.0	5.1
	15*	0.0	2.3	0.0	2.3	3.5	1.2	0.0	4.7	1.2	1.9	0.0	3.1	2.5	3.6	0.0	6.1
Total		3.1	3.9	0.0	7.0	8.2	6.4	0.0	14.6	10.0	4.4	0.0	14.3	5.1	6.1	0.0	11.2
Control	**16**	9.9	3.8	0.0	13.7	4.6	6.8	0.0	11.4	6.8	3.8	0.0	10.7	11.6	2.5	0.0	14.1
	17	4.3	3.4	0.0	7.7	5.1	2.6	0.0	7.7	6.1	3.0	0.0	9.1	6.5	2.2	0.0	8.7
	18	2.2	0.9	0.0	3.0	2.6	2.6	0.0	5.2	2.2	0.9	0.0	3.0	0.9	0.9	0.0	1.7
	19	4.7	2.6	0.0	7.2	6.2	1.6	0.0	7.8	5.1	3.1	0.0	8.2	4.1	3.0	0.0	7.1
Total		21.0	10.7	0.0	31.7	18.5	13.6	0.0	32.1	20.2	10.8	0.0	31.0	23.0	8.6	0.0	31.6

4.5.1 Before-and-After Analysis at Camera Intersections

The before-and-after analysis at camera intersections is conducted to compare the accident rate at the same place. The change in accident rate after the RLC operation is determined. The study intersections include intersection 1 to intersection 10. The comparison is conducted between 4 pairs of data groups:

- Between 1 year after and 2 years before
- Between 1 year after and 1 year before
- Between 2 years after and 1 year before
- Between 2 years after and 2 years before

The percent changes in accident rates are shown in Table 4.10. Overall, after 1 year the accident rate has increased by approximately 10 percent. Compare the accident rate between in 1 year before and in 1 year after the RLC operation, only 4 of 10 camera intersections have the total accident rates reducing. After 2 years of the RLC operation, the total accident rate has reduced by 27 percent compared with those of 1 and 2 years before. Most of the camera intersections have the reduction in accident rate after 2 years.

Considering PDO accidents from Figure 4.80, the overall PDO accident rate has increased in the first year of the RLC operation. However, in the second year of the operation, the PDO accident rate has decreased to lower than those of 1 and 2 years before the operation.

Considering injury accidents from Figure 4.80, it has an upward trend in the 2-year-before period. After the RLC operation, the upward trend stops in the first year of the operation. In the second year, the injury accident decreases to approximately the same level as those of 2-year-before period.

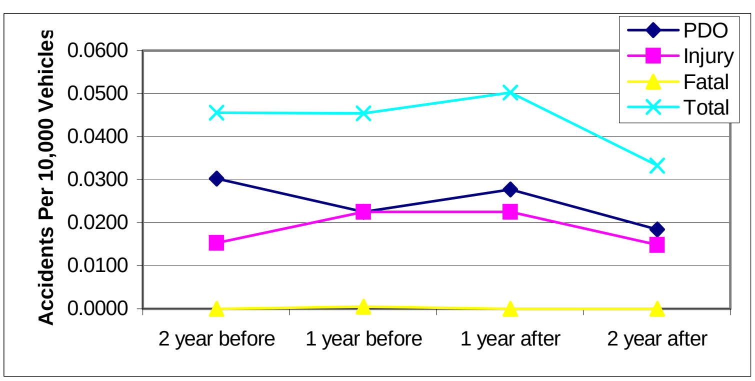

Figure 4.80 Total Accident Rate at Camera Intersections

Table 4.10 Percent Change in Number of Accidents per 10,000 Vehicles at Camera Intersections

Intersection		% Change in Number of Accidents per 10,000 vehicles															
		1 year after VS 2 Years before				**1 year after VS 1 Year before**				**2 years after VS 2 Years before**				**2 years after VS 1 Year before**			
		PDO	**Inj**	**Fat**	**Total**	**PDO**	**Inj**	**Fat**	**Total**	**PDO**	**Inj**	**Fat**	**Total**	**PDO**	**Inj**	**Fat**	**Total**
Camera	1*	-60%	+	0%	**40%**	114%	434%	0%	**50%**	-67%	+	0%	**-18%**	-56%	161%	0%	**-13%**
	2	-25%	-50%	0%	**-33%**	0%	-67%	0%	**33%**	46%	-51%	0%	**14%**	+	-68%	0%	**127%**
	3	-67%	133%	0%	**-17%**	-70%	-30%	0%	**-50%**	-45%	-67%	0%	**-51%**	-51%	-90%	0%	**-71%**
	4	165%	-65%	0%	**-7%**	33%	-47%	0%	**24%**	10%	-51%	0%	**-36%**	10%	-26%	0%	**-14%**
	5	-23%	92%	0%	**10%**	53%	53%	0%	**28%**	-74%	-22%	0%	**-59%**	-63%	-37%	0%	**-52%**
	6	150%	0%	0%	**100%**	275%	-25%	-100%	**64%**	-31%	38%	0%	**-8%**	-31%	4%	0%	**-25%**
	7	-21%	-1%	0%	**-17%**	-21%	-80%	0%	**-17%**	-41%	96%	0%	**-18%**	194%	-61%	0%	**-18%**
	8	-61%	60%	0%	**-17%**	-67%	-23%	0%	**-37%**	-13%	-13%	0%	**-13%**	-2%	-58%	0%	**-34%**
	9*	230%	65%	0%	**120%**	230%	230%	0%	**120%**	555%	96%	0%	**249%**	227%	293%	0%	**249%**
	10*	20%	-100%	0%	**-60%**	20%	-100%	0%	**-40%**	-100%	-10%	0%	**-40%**	-100%	80%	0%	**-10%**
Total		-9%	47%	0%	**10%**	23%	0%	-100%	**11%**	-39%	-3%	0%	**-27%**	-18%	-34%	0%	**-27%**

In summary, at camera intersections, the total accident rate, which is the sum of the number of injury and PDO accidents, is increasing during the first year after the camera is installed, but it is decreasing during the second year. The total accident rate after 2 years of the camera operation is less than the rate before the operation.

In the following analysis, the accident data at the camera intersections is compared with that of the control intersections to determine whether the reduction in accident rate is affected from the RLC operation or not.

4.5.2 Comparison Analysis Between Camera and Control Intersections Analysis

This analysis is conducted by comparing the accident rates of camera intersections with those of control intersections. The control intersections were selected from intersections located far away from the RLC zone and have high number of accidents. This analysis has a purpose to observe the accident trend without any effect from RLC and compare it with those with effect from the RLC. The effectiveness of the RLC is evaluated from the comparison. The control intersections include intersection 16 to intersection 19. The comparison is conducted between 4 pairs of data groups:

- Between 1 year after and 2 years before
- Between 1 year after and 1 year before
- Between 2 years after and 1 year before
- Between 2 years after and 2 years before

The percent changes in accidents at control intersections are shown in Table 4.11. From Table 4.11, after the RLC operation, two of for control intersections have the reduction in total accidents. Considering only injury accidents, in the second year of the RLC operation, they reduce at most of the control intersections.

A detailed analysis of the accidents by accident types for both control and camera intersections are shown in Figure 4.81, 4.82 and 4.83. This may provide a better comparison of the accident results. From Figure 4.82, the injury accident rates in the after period at the control intersections have a lower downward trend than those of the camera intersection. From this result, it may conclude that the reduction in injury accident rates at camera intersections did not result from the RLC effect only. At the control intersections, which do not have RLC installed, the injury accident rate have also reduced. Other factors such as traffic management and intersection improvement could cause reduction in injury accidents. From Figure 4.83, PDO accident trends at camera and control intersections are the same in the before period and also in the 1-year-after period. The average PDO accident rate has dropped in the second year of the RLC operation at the camera intersections while at control intersections, it still continuingly increases. The reduction in PDO accident rates at the camera intersections could result from the RLC operation. Overall, from Figure 4.81 the total accident rate at camera intersections has reduced after 2 years of the RLC operation while at control intersections, the rate is not significantly different along the 4-year observation. The RLC may have an effect on the accident reduction in the long term.

Table 4.11 Percent Change in Number of Accidents per 10,000 vehicles at Control Intersections

		% Change in Number of Accidents per 10,000 vehicles															
Intersection		1 year after vs 2 Years before				1 year after vs 1 Year before				2 years after vs 2 Years before				2 years after vs 1 Year before			
		PDO	Inj	Fat	Total	PDO	Inj	Fat	Total	PDO	Inj	Fat	Total	PDO	Inj	Fat	Total
Control	16	-31%	0%	0%	**-22%**	0%	-44%	0%	**-7%**	17%	-35%	0%	**3%**	155%	-64%	0%	**24%**
	17	42%	-11%	0%	**19%**	137%	19%	0%	**19%**	52%	-37%	0%	**12%**	26%	-16%	0%	**12%**
	18	-1%	-1%	0%	**-1%**	-17%	-67%	0%	**-42%**	-61%	-2%	0%	**-44%**	-67%	-67%	0%	**-67%**
	19	10%	19%	0%	**13%**	230%	98%	0%	**6%**	-13%	18%	0%	**-2%**	-35%	96%	0%	**-8%**
Total		-4%	1%	0%	**-2%**	49%	-21%	0%	**-3%**	10%	-20%	0%	**0%**	24%	-37%	0%	**-2%**

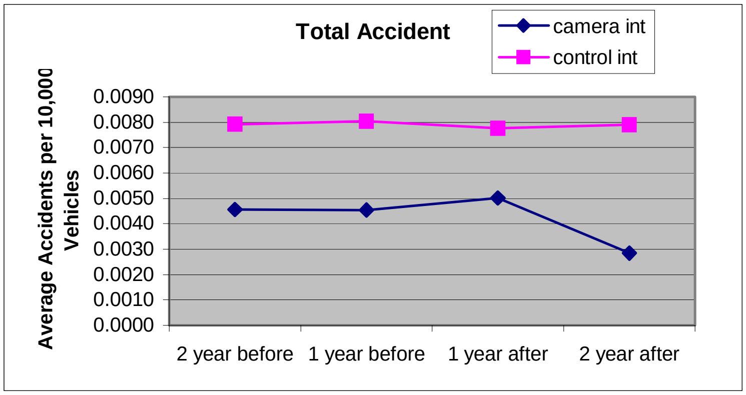

Figure 4.81 Comparison of Total Accident Rates between camera and control intersections

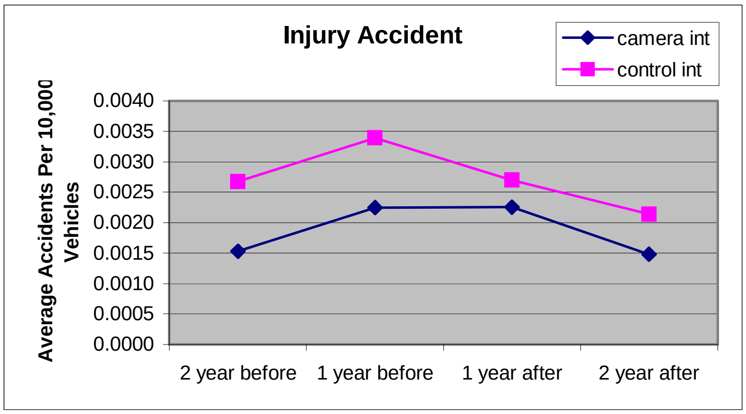

Figure 4.82 Comparison of Total Accident Rates between camera and control intersections

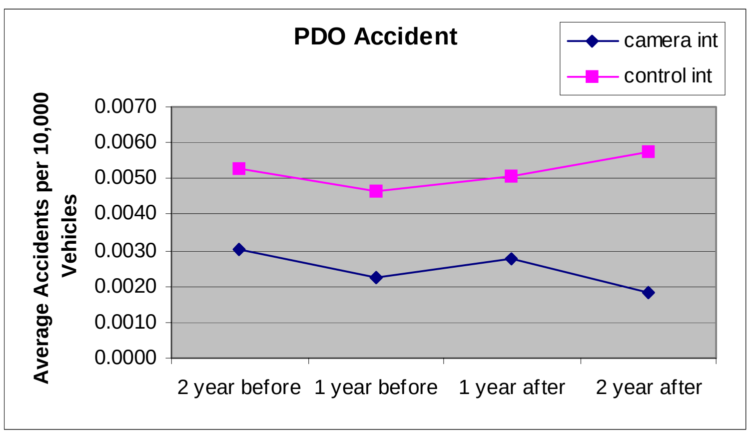

Figure 4.83 Comparison of Total Accident Rates between camera and control intersections

4.5.3 Spillover Effect Analysis

There is an assumption that the RLC can widely change drivers' behavior, not limited to those at camera intersections. The RLC study in Oxnard, California concludes that the reduction in accidents at intersections nearby camera intersections was attributed to the spillover. However, the spillover effect did not occur in every RLC site.

The spillover effect analysis is conducted by comparing accident rates at camera intersections with those at non-camera intersections. Two non-camera intersections, intersections 14 and 15, are observed. They are located nearby one of the camera intersections. Trends of accident at these intersections are determined for the spillover effect. The percent changes in accidents per 10,000 vehicles are shown in Table 4.12.

The data in Table 4.12 shows that trends of accidents between two non-camera intersections are completely different during the 4-year study period. Considering injury accident rates of intersection 14, they have reduced in the first and second year of the RLC operation, while those of intersection 15 have increased after the RLC operation. Considering PDO accident rates of intersection 14, they have increased in the first year of the RLC operation and then reduced in the second year. On the other hand, at intersection 15, the PDO accident rates have reduced in the first year and then increased in the second year of the RLC operation. The average of accident rates at camera intersections and non-camera intersection are plotted in Figures 4.84, 4.85 and 4.86.

Figure 4.85 shows that the injury accident trends of camera and non-camera intersections are different. While the injury accidents at non-camera intersections have increased in the second year of the RLC operation, those at camera intersections have decreased. From Figure 4.86, the PDO accident trends at camera and non-camera intersection are the same after the RLC operation. Considering the total accident rate in Figure 4.84, the accident rates at both sites had the same reduction trend in the second year of the RLC operation.

According to the results from this analysis, the RLC does not have an effect on injury accident rates in Fairfax County. Therefore, the spillover effect on injury accident is rather insignificant, which is consistent with the earlier conclusion that. The injury accident rate is affected by other factors rather than the operation of the RLC.

Considering the same trends of PDO accident between camera and non-camera intersections after the RLC operation, it can be concluded that there is an RLC-spillover effect on the PDO accidents. In addition, the PDO accident trends at camera and non-camera intersections are different from that of control intersections.

Table 4.12 Percent Change in Number of Accidents per 10,000 Vehicles at Non-Camera Intersections

Intersection		% Change in Number of Accidents per 10,000 vehicles															
		1 year after vs 2 Years before				**1 year after vs 1 Year before**				**2 years after vs 2 Years before**				**2 years after vs 1 Year before**			
		PDO	**Inj**	**Fat**	**Total**	**PDO**	**Inj**	**Fat**	**Total**	**PDO**	**Inj**	**Fat**	**Total**	**PDO**	**Inj**	**Fat**	**Total**
Non-	14*	180%	60%	0%	**140%**	66%	-53%	0%	**13%**	-18%	63%	0%	**9%**	-46%	-52%	0%	**-49%**
Camera	15*	+	-20%	0%	**34%**	7%	60%	0%	**-33%**	+	52%	0%	**161%**	-27%	205%	0%	**31%**
Total		220%	12%	0%	**105%**	55%	-32%	0%	**-2%**	63%	57%	0%	**60%**	-38%	-5%	0%	**-23%**

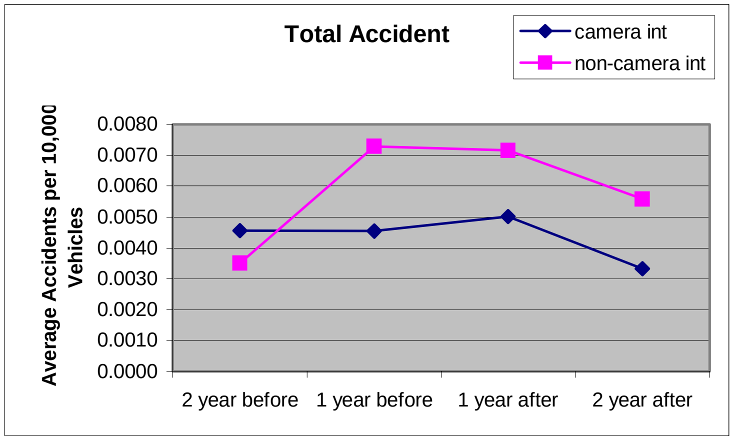

Figure 4.84 Comparison of Total Accident Rates between camera and non-camera intersections

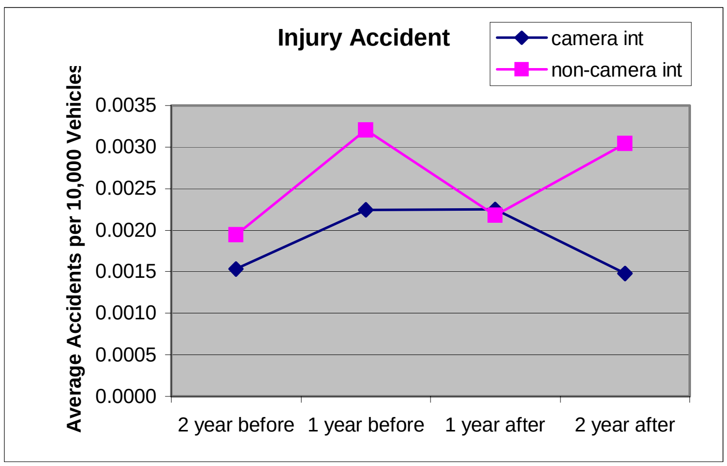

Figure 4.85 Comparison of Injury Accident Rates between camera and non-camera intersections

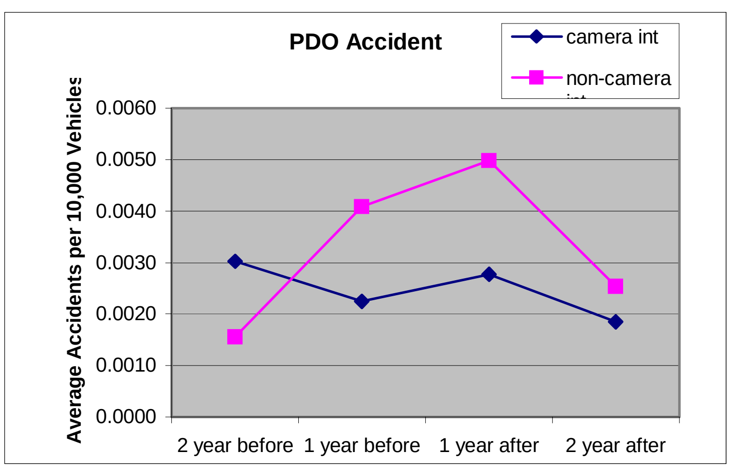

Figure 4.86 Comparison of PDO Accident Rates between camera and non-camera intersections

4.5.4 Preliminary Conclusions

From the preliminary analysis of accident data, the conclusions are summarized as follows:

- The accident rates at the camera intersections increase in the first year and then decrease in the second year of the RLC operation.
- The reduction in PDO accidents at the camera intersections results from the RLC operation.
- The reduction in injury accidents at the camera intersections results from other factors rather than the RLC operation.
- The RLC has an effect on the reduction of PDO accidents in the long term.
- The RLC has a spillover effect on the reduction of PDO accidents.

The statistical analysis of the violation and accident data is presented in the next chapter.

4.6 Comparison of the RLC in Fairfax County with other cities

The RLC system in Fairfax County is compared with those in other regions to determine how characteristics of the society affect the system. Populations, population densities and median household incomes are factors to be considered for this study.

Table 4.13 presents the comparison of violation and accident reduction between Fairfax County and other cities. RLC jurisdictions are categorized into 3 groups based on the violation reduction rate. Cities in the first group have a high reduction in violation rates of more than 50 percent. The second group includes cities that have a medium reduction in violation rates of between 30 and 50 percent. The last group includes those cities that have low reduction in violation rates of less than 30 percent. the low violation reduction rate group. The percent reduction in violations of this group is less than 30 percent. The average of percent reductions of the high reduction rate group is 66 percent while that of the medium reduction rate group is 37 percent. The low reduction rate group has an average of 20 percent reduction.

The results show that the group that has higher reduction rate has an average of income lower. The results also show that the RLC program is more successful in medium-size cities rather than those cities with too high or too low populations an population densities.

Fairfax County is one of the jurisdictions that have a medium size of populations and low population density. In addition, it has a very high median household income compared with other cities. From these characteristics of Fairfax County, the performance of the RLC should be in the low or medium reduction rate. However, Fairfax County is in the high reduction rate group with 66 percent of reduction. The technique of increasing amber time is considered enhancing the performance of the RLC.

In conclusion, generally, it seems that the RLC system is more effective in a city that has medium size and low income. However, other factors that applied with the RLC operation are also important and significantly influence on the effectiveness of the RLC.

Table 4.13 Violation and Accident rate comparison with other cities.

Site	Violation Reduction	Crash Reduction	Source Type(s)	Source(s)	Populations	Density per Mile Square	Median Household Income (US Dollar)
Fairfax, VA	66%(after 18 mon)	27% reduction rear end crash	Report	Yaungyai, 2004	969,749	2,455	$85,310
High violation reduction sites							
Jackson, MI	83%	-	Synthesis Report	ITE, 1999	36,316	3,275	31,294
Los Angeles, CA	75%	-	Conference Paper	Rocchi, 1999	3,694,820	7,877	36,687
Victoria, BC, Canada	73%	-	Conference Paper	Rocchi, 1999	74,125	8,217	18,375
Queensland, Australia	70%	-	Agency Website	"Technology versus the Lawbreakers.", *undated*	3,774,292	-	12,312
Glasgow, Scotland, UK	69%	62% reduction in injury accidents	Independent Evaluation	Winn, 1995	612,000	9,000	-
Howard County, MD	62%	21-44% at individual intersections	Agency Data	"Maryland House of Delegates…", 2001	247,842	983	27,782
Scottsdale, AZ	62%	-	Trade Press Article	"Applications Increase…", 2000	202,705	1,100	57,484
Nottinghamshire, UK	60%	-	-	Rocchi, 1999	600,000	719	-
Washington, DC	56%	-	Newspaper Article	"Red-light Cameras.", 2001	572,059	9,316	40,127
Fort Meade, FL	50%	-	Conference Paper	Rocchi, 1999	5,691	1,144	32,984
Average	66%	-	-	-	981,985	4,626	32,131

Table 4.13 (cont') Violation and Accident rate comparison with other cities.

Site	Violation Reduction	Crash Reduction	Source Type(s)	Source(s)	Populations	Density per Mile Square	Median Household Income (US Dollar)
Medium violation reduction sites							
Wilmington, NC	40-60%	26% reduction in right-angle and 8% increase in rear end, 22% decline in total collisions	Agency Brochure	"Safelight Wilmington: First Year in Review.", 2001	75,838	1,850	31,099
Oxnard, CA	42%[1]	29% reduction injury crashes, 32% reduction right-angle crashes[2]	Insurance Institute for Highway Safety (IIHS) Studies	Retting, 19992 Retting, 2001	170,358	6,730	48,603
San Francisco, CA	42%	-	Conference Paper	Fleck and Smith, 1999	776,733	16,634	55,221
Hong Kong	40%	-	Conference Paper	Rocchi, 1999	1407600	45,401	-
Singapore	40%	-	Conference Paper	Rocchi, 1999	2,705,000	22,542	-
Boulder, CO	37%	57%	Newspaper Article	"Speeders may be…", 2001	94,673	3,884	44,748
New York, NY	34%	60-70% reduction in angle crashes at one site	FHWA Website	FHWA, *undated*	8,008,278	26,403	38,293
Victoria, Australia	30%	-	Synthesis Report	ITE, 1999	3,488,750	1,014	12,312
Average	37%	-	-	-	2,090,904	15,557	38,379

Table 4.13 (cont') Violation and Accident rate comparison with other cities.

Site	Violation Reduction	Crash Reduction	Source Type(s)	Source(s)	Populations	Density per Mile Square	Median Household Income (US Dollar)
Low violation reduction sites							
Charlotte, NC	20%	24% reduction at enforced intersections, 20% reduction in crashes caused by RLR	Agency Report	"Safelight Charlotte: First-Year Report.", *undated*	540,828	2,232	46,975
Greensboro, NC	20-25%	-	Newspaper Article	"Cameras curb red…", 2001	223,891	2,138	39,661
High Point, NC	20%	-	Newspaper Article	"City Shoots for…", 2001	85,839	1,750	40,137
Average	20%	-	-	-	283,519	2,040	42,258

CHAPTER 5

STATISTICAL ANALYSIS AND EVALUATION

From the previous chapter, the violation and accident data at 19 signal intersections in Fairfax County are collected and summarized. The violation data is available in the period of RLC operation. It is analyzed on the 'initial period and after period at camera intersection' basis. The percent changes in violation rate and violation trend are determined. The results from the analysis show that the violation rate had significantly reduced after the RLC operation.

The accident data is available for both before and after RLC operation period. It is, therefore, analyzed on the 'before-and-after' basis. The accident data is also provided at non-camera intersections for the comparison purpose. The results show that overall; the accident rate had increase in the first year and reduced in the second year of the RLC operation. Compare with the accident data at control intersections, the accident data at camera intersection had shown a different trend in the second year of the operation.

In this chapter the violation and accident data are tested by statistical methods. In order to prove that there is a reliable significant difference in the violation and accident rates after the camera operation compared with before period, a statistic test is necessary. T test, F test and Chi-Square test are chosen for this study. They are simple and appropriate for the collected data. The results of the test are presented and discussed next.

5.1 Statistical Analysis

Many statistical methods are applied to test the performance of the RLC at various sites in the United States and foreign countries. The statistical test has the purpose to test the difference in the performance of the violation or accident rates after the photo enforcement begin. The selected statistical tests for this study are the T test, F test and the Chi-square test.

T Test

The t-test has a purpose to determine the significance of difference between two means. Several t techniques can be applied for different types of data. Before applying the t-test, a problem should be examined to find an appropriate technique. Three questions should be answered in order to select the t-technique as follows:

- Is there a positive correlation between data contained in the two groups?
- Is there a significant difference between the variances of the two groups?
- Are the two groups equal in size?

Different types of t technique are available for different problems. The detail of how to select the t test is provided in appendix C. For this study, the t test is applied to determine the difference in violation rates between 2 periods of time.

F-Test

The purpose of F test is to determine the significant difference between 2 variances. The limitation of this test is that two populations should both follow normal distribution. However, it is not necessary that they should have the same means. The F test is used in this study to determine the difference in variances of violation rates between different periods of RLC operation.

Chi-Square Test (X^2)

The Chi-Square test is one of the most widely used nonparametric techniques. The nonparametric statistics are a group of techniques designed to analyze data that fail to meet the assumption for parametric techniques, i.e., distribution and variance assumptions. The nonparametric techniques do not make numerous or stringent assumptions about parameters. They result in conclusions, which require fewer qualifications than when using parametric technique.

The Chi-Square test can be of the goodness-of-fit type in that it may be used to test whether a significant difference exists between an 'observed' number of objects or responses falling in each category and an 'expected' number. It is also used to determine the significance of the differences between 2 independent groups or more.

The Chi-Square test applied for this study is the latter case. It is applied to test for independence in a p x q table, when p and q is equal or greater than 2. The objective of applying the Chi-Square test is to investigate the difference in frequency when classified by one attribute after classification by a second attribute.

5.2 Statistical Test of Violation Data

The violation results are tested by the T test and F test. Both tests are used to test the difference in violation rates between different periods of time. The violation rates are tested between 6 pairs of violation data as follows:

The number of violations per 10,000 vehicles between

- Initial period VS 4^{th} to 9^{th} month period
- Initial period VS 10^{th} to 15^{th} month period
- Initial period VS 16^{th} to 21^{st} month period
- Initial period VS 22^{nd} to 27^{th} month period
- Initial period VS after the 27^{th} month period
- 10^{th} to 15^{th} month period VS 22^{nd} to 27^{th} month period

F test

To find the difference of the data by F test, the F ratio of each pair of data is determined. After that, compare the F ratio with the critical F value, which can be obtained from table C6 in appendix C. The critical F value depends on the degree of freedom of the data. After the comparison, if the F ratio is less than the critical F value from the table, the two population variances are not significantly different from each other. The detail of how to find the F ratio, critical F value and degree of freedom and how to test a pair of data by F test are presented in appendix C.

Table 5.1 shows the F ratio and the critical F value for the 6 pairs of violation rate. The results show that there is no significant difference in variances of violation rates between at initial period and 4^{th}-9^{th} month period (F ratio=1.54 < F value= 2.6). On the other hand, there is a significant difference in variances of violation rates between at initial period and after 10^{th} to 15^{th}, 16^{th} to 21^{st}, 22^{nd} to 27^{th} and after 27^{th} month (F ratio= 4.2, 7.64, 7.74, 9.21 > F value = 2.91, 3.07, 3.07, 4.0). From the statistical results, the violation rates do not significantly reduce until the 10^{th}–15^{th} month period after the RLC operation. Comparing the violation rates between the 10^{th}-15^{th} months period and after 27^{th} month period, there is no significant difference between two variances (F ratio = 1.54 < F value = 2.69). As a result, the violation rates after the 10^{th}–15^{th} month period do not any longer significantly reduce.

Table 5.1 F ratio and Critical F value of violation rate comparison.

Effect	F ratio	Critical F value
Initial period VS 4^{th} –9^{th} month period	1.54	2.69
Initial period VS 10^{th} –15^{th} month period	**4.20**	2.91
Initial period VS 16^{th} – 21^{st} month period	**7.64**	3.07
Initial period VS 22^{nd} –27^{th} month period	**7.74**	3.07
Initial period VS after the 27^{th} month period	**9.21**	4.0
10^{th} –15^{th} month period VS 22^{nd} –27^{th} month period	1.54	2.69

T Test

To find differences in means of violation data by t test, the t value of each pair of data is determined. After that, compare the computed t value with the t value from the table. The t value from the table varies by degree of freedom of each pair of data. If the computed t value is less than the t value from the table, there is no significant difference in means of the 2 data categories. The detail of how to compute t value, and how to test a pair of data by t test are presented in appendix C.

Table 5.2 shows the computed t value and the t value from the statistical t table for each pair of violation rate data. From Table 5.2, the mean of violation rates at initial period is not significantly different from those in the 4^{th}-9^{th} month period and 10^{th}–15^{th} month period (t value = 0.74, 1.61 < t table = 2.06, 2.07). From this result, the violation rate, therefore, does not significantly decrease in the 4^{th}-15^{th} month period of the RLC operation. The violation rates significantly decrease in the 16^{th}-21^{st} month and 22^{nd} –27^{th} month period compared with those at initial period (t value = 2.39, 2.79> t table = 2.08).

Comparing the mean between 2 periods, 9^{th}–15^{th} month and 22^{nd}– 27^{th} month, there is no significant difference between 2 means (t value = 1.75 < t table = 2.09).

From the statistical results, the violation rates significantly reduce when the RLC had been operated longer than 15 months. After that, it had not decreased as much as it did in the beginning.

Table 5.2 t value of violation rate comparison

Effect	t value	t value from table ($\alpha = 0.05$)
Initial period VS 4^{th} –9^{th} month period	0.74	2.06
Initial period VS 10^{th} –15^{th} month period	1.61	2.07
Initial period VS 16^{th} – 21^{st} month period	**2.39**	2.08
Initial period VS 22^{nd} –27^{th} month period	**2.79**	2.08
Initial period VS after the 27^{th} month period	**2.90**	2.1
10^{th} –15^{th} month period VS 22^{nd} –27^{th} month period	1.75	2.09

Conclusion

From the statistical test of violation data, the conclusions are drawn as follows:

- There are statistically significant reductions in violation rates after the RLC operation.
- Violation Rates statistically significantly reduce in the 9^{th} –15^{th} month of the RLC operation.
- After the 15^{th} month of the RLC operation, the RLC no longer significantly reduced the violation rate.

5.3 Statistical Test of Accident Data

The accident data is tested by the Chi-Square test. The difference of accident data between different types of intersections are determined if they are statistically significant. The accident data is categorized into 5 groups based on the type of intersection as follows:

- Camera intersection
- Control intersection
- Non-camera intersection
- Non-camera plus control intersection
- Camera plus non-camera intersection

The Chi-Square test determines if there is significant difference in the proportion of the accident rates of different types of intersections between before and after RLC operation. Five comparisons of accident rates are tested by the Chi-Square test as follows:

- Camera VS non-camera VS control intersections
- Camera VS control intersections
- Camera VS non-camera intersections
- Camera VS non-camera plus control intersections
- Camera plus non-camera VS control intersections

To test the difference of data by Chi-Square test, the X^2 value is calculated and then compared with the X^2 value from the statistical table. If the computed X^2 value is less than the X^2 from the table, there is no significant difference in the proportion of accident rate between before and after period. The detail of how to test the difference by X^2 is provided in the Appendix C.

Table 5.6 shows that all comparisons have X^2values less than the X^2 value from the table. As a result, there is no significant difference in the proportion of accident rate between before and after period for different type of intersection.

Table 5.3 X^2 values of accident rate comparison

Effect	**X^2 value**	**X^2 value from table**
Camera VS Non-camera VS Control	1.27	5.99
Camera VS Non-camera	1.22	3.84
Camera VS Control	0.22	3.84
Camera VS (Non-camera plus Control)	0.43	3.84
(Camera plus Non-camera) VS Control	0.05	3.84

<u>Conclusion</u>

From the statistical test of accident data, there is no significant difference in the proportion of accident rates at different types of intersection between before and after periods. The accident rates at camera intersection do not statistically decrease after the RLC operation. In the after period, the accident rates at camera intersection still maintain the same proportion with control intersections and non-camera intersections as before the operation of RLC. From the statistical test, the accident rates at camera intersection do not perform differently from intersections without the camera.

CHAPTER 6

COMPARISON OF RLC PROGRAM BETWEEN FAIRFAX COUNTY AND WASHINGTON, D.C.

The Red Light Camera program in Washington, D.C. was initiated and operated by Affiliated Computer Services (ACS) since 1999. The first camera was installed in August 1999. By June 2000, 40 red light cameras had been in operation. Thirty-one cameras are fixed at intersections while the rest of them are rotated among 9 intersections. Warning signs are installed at the camera intersections. A violator is subjected to $75 citation. If the registered owner of a violating vehicle did not operate the vehicle at the time of violation, he or she can avoid the penalty by providing the name and address of the person who responsible for the violation.

Washington, D.C. has a smaller area and smaller size of populations compared with Fairfax County. However, the population density of Washington, D.C. is almost four times of Fairfax County. Differences in city characteristic between Fairfax County and Washington, D.C. are shown in Table 7.1. The RLC locations in Washington, D.C. are shown in Table 7.2 and Figure 7.1.

6.1 Comparison of Violation Results

Violation and accident data at the camera intersections in Washington, D.C. are provided by District Department of Transportation. Violation data is available after the camera installation. The data is grouped corresponding to the data of Fairfax County. It is grouped into 6 periods of time: initial period, 4^{th} to 9^{th} month, 10^{th} to 15^{th} month, 16^{th} to 21^{st} month, 22^{nd} to 27^{th} month, and after the 27^{th} month of the RLC operation. Overall, the number of violations per 10,000 vehicles has been reduced by 63 percent in the 22^{nd} to 27^{th} month of the RLC operation. The summary of percent changes in violation rates in Washington, D.C. is presented in Table 7.3 as well as those of Fairfax County. The percent changes of violation rates at each camera intersection in Washington, D.C. are provided in Appendix A.

Table 6.1 Fairfax and Washington, D.C. Characteristics.

Locations	Land Area (square miles)	Populations	Density per square miles	Median Household Income ($)
Fairfax	**395**	**969,749**	**2,455**	**$85,310**
Washington, D.C.	**68.2**	**572,059**	**9,316**	**$40,127**

Table 6.2 Washington, D.C. Red Light Camera locations and Date in Operation

No.	Intersection	Date in Operation	No.	Intersection	Date in Operation
1	Benning @ Minnesota	12/22/99	21	N. Capital @ Gallatin	10/27/99
2	Bladensburg @ NY NB	10/08/99	22	New York @ Bladensburg EB	10/01/99
3	Branch @ Alabama	02/15/00	23	New York @ Bladensburg WB	10/01/99
4	Connecticut @ Military	02/14/00	24	New York @ 4th	08/01/99
5	Connecticut @ Nebraska	02/16/00	25	Penn @ Southern	09/01/00
6	Constitution @ 15th	01/05/00	26	Penn @ Minnesota	09/24/99
7	E. Capital @ Texas	09/13/99	27	Rhode Island @ Reed	01/12/00
8	E. Capital @ Benning	09/10/99	28	Rhode Island @ 1st	02/07/00
9	E. Capital @ Southern	12/21/99	29	S Capital @ I	12/01/99
10	Georgia @ Missouri	12/10/99	30	S Dakota @ Bladensburg	11/03/99
11	Independence @ Washington	01/01/00	31	Suitland @ Firth Sterling	12/01/99
12	Independence @ 3rd	12/24/99	32	Suitland @ Stanton	12/10/99
13	K St @ 27	02/14/00	33	N. Capital @ H	10/14/99
14	K St @ 25	11/04/99	34	Wisconsin @ Brandywine	06/09/00
15	M St @ Whitehurst	02/14/00	35	12th @ Constitution	12/21/99
16	Mt Olivet @ West Virginia	11/11/99	36	14th @ C St	09/01/00
17	N. Capital @ Riggs	11/18/99	37	14th @ U St	08/01/99
18	New York Ave @ New Jersey	02/14/00	38	16th @ Oak	12/01/99
19	New York Ave @ Florida	03/30/00	39	16th @ Colorado	12/01/99
20	North Capital @ Harewood	10/26/99	40	16th @ Irving	12/01/99

Table 6.3 Comparison of Violation Reduction between Fairfax and Washington, D.C.

Location	% Changes in number of accident/10,000 vehicles per month				
	after 4-9 mo	after 10-15 mo	after 16-21mo	after 22-27mo	after >27 mo
Fairfax County	-20.8%	-40.1%	-56.8%	-66.2%	-69.9%
Washington DC	-43.0%	-59.6%	-61.9%	-62.5%	-58.2%

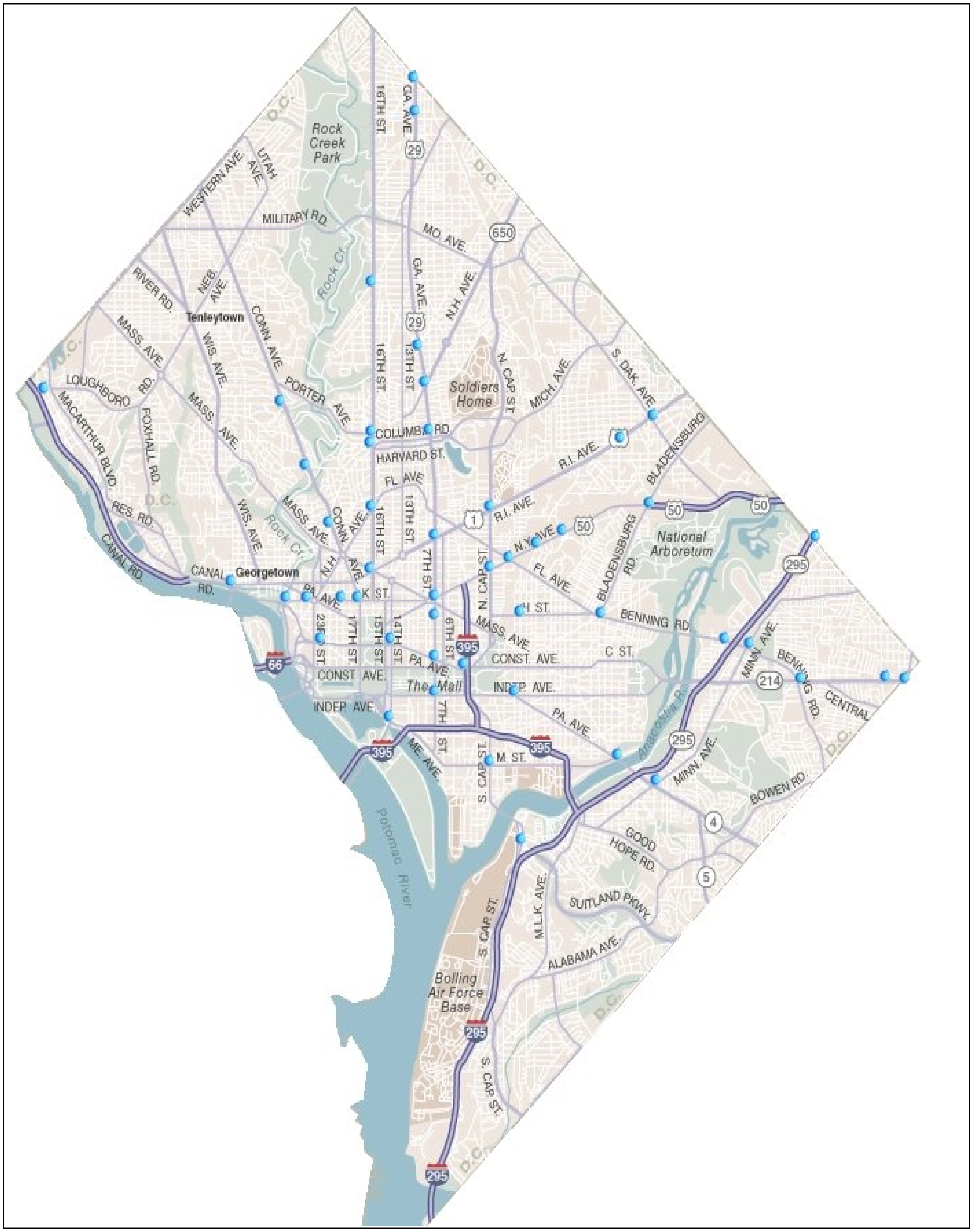

Figure 6.1 Traffic Camera Location in Washington, D.C.

Conclusion

As in Table 7.3, the violation rates in Washington, D.C. more rapidly reduce than those in Fairfax County. The lower household income in Washington D.C. could be one of the reasons that the RLC become effective in a shorter time. In addition, the Metropolitan Police Department states that one tip that makes the Red Light Camera program in Washington, D.C. successful is the placement of a large number of cameras in a short period of time. Thirty-nine cameras are installed in Washington, D.C. within 8 months while 10 cameras are consecutively installed in Fairfax County in one year. It is claimed that people are better educated about the camera by putting a large number of cameras at once. The higher density of cameras in Washington, D.C. is one of the factors that change driver's behavior readily.

6.2 Comparison of Accident Results

The injury, right-angle, and rear-end accident rate in Washington, D.C. are compared with the accident rates in Fairfax County. The comparison of percent changes in accidents is shown in Table 7.4. The results show that after either 1 or 2 years of operation, the numbers of every type of accidents per 10,000 vehicles in Washington, D.C. significantly increase. The percent increase of total accidents is 87% compared between 2 years before and 2 years after the RLC operation. The percent changes in accidents at each camera intersection are presented in Appendix A.

Table 6.4 Comparison of Accident Reduction between Fairfax and Washington, D.C.

Location	% change in accidents per 10,000 vehicles															
	1 year after VS 2 Year before				1 Year after VS 1 Year before				2 year after VS 2 Year before				2 Year after VS 1 Year before			
	Total	Inj	RA	RE	Total	Inj	RA	RE	Total	Inj	RA	RE	Total	Inj	RA	RE
Fairfax County	+10	+47	-	-	+11	0	-	-	-27	-39	-	-	-27	-34	-	-
Washington, D.C.	+62	+95	+21	+114	+48	+78	-2	+77	+87	+76	+28	+121	+71	+61	+6	+3

* Inj = injury, RA = right angle, RE = rear end

Considering intersection by intersection, the results show that:

After 1 year of operation:

Washington, D.C.:

- 8 of 33 intersections or 24% of intersections have a reduction or no change in total accidents
- 9 of 33 intersections or 27% of intersections have a reduction or no change in injury accidents

Fairfax County:

- 6 of 10 intersections or 60% of intersections have a reduction or no change in total accidents
- 7 of 10 intersections or 70% of intersections have a reduction or no change in injury accidents

After 2 year of operation:

Washington, D.C.:

- 4 of 33 intersections or 12% of intersections have a reduction or no change in total accidents
- 17 of 33 intersections or 51% of intersections have a reduction or no change in injury accidents

Fairfax County:

- 7 of 10 intersections or 70% of intersections have a reduction or no change in total accidents
- 6 of 10 intersections or 60% of intersections have a reduction or no change in injury accidents

The higher proportions of effective camera intersections to total camera intersections in Fairfax County show that the RLC program is more effective in Fairfax County than in Washington, D.C.

Conclusion

The reduction in accident rates in Fairfax County is much higher than in Washington, D.C. In average, the number of total, injury, right angle, and rear end accident in D.C. is getting higher after the camera operation while in Fairfax County, the number of total and injury accidents reduces after 2 years of operation. The characteristic of the city is an important factor that influences the effectiveness of the RLC. The characteristic of the traffic and intersections in Washington, D.C. is different from those in Fairfax County. Moreover, driving behaviors of people in the city must be different from those in suburban. These factors effect the performance of RLC. The accident trend does not follow the violation trend, as a result, running red light may not a major cause of accidents at intersection. The control intersections are recommended for the further study.

CHAPTER 7

CONCLUSIONS

This thesis is conducted with the purpose to evaluate the Red Light Camera program in Fairfax County. Several approaches are applied to determine the difference in accident rate and violation rates at the camera intersections after the RLC operation. The change of drivers' behavior by RLC is measured from the reduction of violation rate at the camera intersection. The reduction in violation rates evidence that the RLC discourages drivers from running red light. The reduction in accidents is expected from the lower number of red light running. A large proportion of roadway accidents are found occurring at or near intersections each year. These accidents cost a lot of lives and money. The use of RLC to reduce accidents at intersections, therefore, would bring a significant benefit to a community.

The performance of the RLC program varies from one place to the other. Many factors have an effect on the change in violation or accident rates after the camera operation. From this study, the effect of several factors are studied and discussed.

Limitations of the study

This study has the limitation in data. The violation data before the camera operation is not provided. The violation data in the initial period is used instead that of the before period of the camera installation. Therefore, the result can be different if the violation rates after the RLC operation are compared with those when there is no RLC operation at all. There is also a limitation in accident data. The criterion of selecting the accident is the distance from an intersection not the cause of accident. Therefore, not all of accidents are occurred due to red light running. The percent changes in accident can be different if only accidents involving red light running are included.

There are also limitations of the evaluation approach. The study applies the before-and-after analysis at camera intersections. Even though this methodology is simple and the difference of location can be discarded, factors other than RLC may affect the result. For the accident analysis, the accident data at camera intersections is compared with that at control intersections. This methodology requires the camera intersections and control intersections to be very similar. Even though the control intersections in this study have the ADT close to that of the camera intersections, they still have some other different aspects such as accident rates and geometry. The comparison can be more accurate if the control intersections are more similar to the camera intersections.

These limitations can bring the inaccurate result to this study. However, apart from these difficulties, some valuable conclusions supported by the available data are summarized next.

Effect of the RLC on violation rate

<u>Results</u>

From the before-and-after and statistical analysis of violation data, the results are summarized as follows:

- The RLC operation and increase of the amber time to 5.0 seconds result in 70 percent reduction in violation rates at camera intersections in the 22^{nd} to 27^{th} month period of the RLC operation.
- The RLC operation only results in 58 percent reduction in violation rate at camera intersections in the 22^{nd} to 27^{th} month period of the RLC operation.
- The camera intersections with high ADT of greater than 60000, have an average of 80 percent reduction in violation rates in the 10^{th} –15^{th} month period of the RLC operation.
- The camera intersections with low ADT of lower than 60000, have 25 percent reduction in violation rates in the 10^{th} –15^{th} month period of the RLC operation.
- The camera intersections with low and high speed limit of 35 and 55 mph, have an average of 66 and 71 percent reduction in violation rate in the 10^{th} –15^{th} month period of the RLC operation.
- The camera intersections with medium limit of between 35 and 55 mph, have an average of 14 percent reduction in violation rates in the 10^{th} –15^{th} month of the RLC operation.
- With the RLC operation and increase of the amber time to 5.0 seconds, the violation rates at camera intersections reduce to 0-1 violation per 10,000 vehicles

- With the RLC operation only, most of the camera intersections have violation rates reducing to 1-2 violations per 10,000 vehicles.
- The violation rates at camera intersections statistically significantly reduce after the RLC operation.
- Violation rates statistically significantly reduce in the 9th –15th month of the RLC operation.
- After the 15th month of the RLC operation, the RLC no longer significantly reduce the violation rate.

<u>Conclusions</u>

From the results, following conclusions are drawn.

- After the RLC operation, most of the camera intersections in Fairfax County have a reduction in violation rates.
- The RLC operation has an effect on the reduction in violation rates.
- The increase in amber time from 4.0 to 4.5 seconds and from 4.5 to 5.0 or 5.5 seconds does further reduce the violation rate.
- The intersections with higher ADT exhibit greater effectiveness of the RLC program.
- The intersections with medium speed limit exhibit less effectiveness of the RLC program than those with high or low speed limit.

  The RLC evidently has a positive effect on reducing violation rate at camera intersections in Fairfax County. However, further analysis of violation rates at control intersections should be conducted to ascertain the effectiveness of the RLC.

Effect of the RLC on accident rate

From the accident data analysis, the results are summarized as follows:

<u>Preliminary Findings</u>

At the camera intersections,

- The total accident rate reduces by 27 percent after 1 and 2 years of the RLC operation compared with those of 1 and 2 years before.

- The PDO accident rate reduces by 18 percent after 2 years of the RLC operation compared with those of 1 year before.
- The injury accident rate reduces by 34 percent after 2 years of the RLC operation compared with those of 1 year before.

At the control intersections,

- The total accident rate reduces by 2 percent after 2 years of the RLC operation compared with those of 1 year before.
- The PDO accident rate reduces by 24 percent after 2 years of the RLC operation compared with those of 1 year before.
- The injury accident rate reduces by 37 percent after 2 years of the RLC operation compared with those of 1 year before.

At non-camera intersections,

- The total accident rate reduces in an average of 23 percent after 2 years of the RLC operation compared with those of 1 and 2 years before.
- The PDO accident rate reduces in an average 38 percent after 2 years of the RLC operation compared with those of 1 year before.
- The injury accident rate reduces in an average 5 percent after 2 years of the RLC operation compared with those of 1 year before.

Overall,

- The total accident rate at camera intersections increases in the first year and then decreases in the second year of the RLC operation.
- The injury accident at camera and control intersections both have a downward trend in the second year of the RLC operation.
- The PDO accidents at camera intersection have an upward trend in the second year of the RLC operation while those at control intersections have an upward trend.
- The camera and non-camera intersections both have the same PDO accident trend after the RLC operation.

Statistical Results

There is no statistically significant difference in the proportion of accident rates at different types of intersection between before and after periods.

Conclusions

From the results, following conclusions are drawn.

From preliminary findings,

- The RLC has an effect on the reduction of PDO accidents in the long term.
- The reduction in injury accidents at the camera intersections results from other factors rather than the RLC operation.
- The RLC is considered to have a spillover effect on the reduction of PDO accidents.

From statistical analysis,

- The operation of RLC does not have an effect on the reduction in accident at camera intersection or non-camera intersection.

Even though, the accident rates show a downward trend after the RLC operation, the statistical test did not support the results. Based on the statistics, the RLC does no help reducing accidents at camera intersections. Therefore, there is no benefit accrued from the reduction in accidents.

The results from this thesis show that the red light camera reduces violation rates at intersections equipped with cameras in Fairfax County. In contrast, the red light camera does not reduce accident rates at the camera intersections. The results are draw from the obtainable data. Further number of control intersections and non-camera intersections are recommended to substantiate the future analysis. The selection of the control intersection is very important to justify the result.

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APPENDIX A

Data

Table A1 Violation Data at Study Intersections

Camera inter-section	Average Number of Violations per Month						Violations/10,000 vehicles						% Changes in Violations per 10,000 vehicles			
	Initial Period (3 mo)	4-9 mo	10-15 mo	16-21 mo	22-27 mo	>27 mo	Initial Period (3 mo)	4-9 mo	10-15 mo	16-21 mo	22-27 mo	>27 mo	after 9 mo	aftrer 15 mo	after 21mo	after 27mo
1	403	357	116	119	116	55	2.86	2.70	0.88	0.74	0.72	0.34	-5.5%	-69.4%	-74.2%	-75.0%
2	354	132	59	100	102	54	1.59	0.59	0.26	0.44	0.45	0.23	-62.8%	-83.6%	-72.6%	-72.0%
3	207	17	13	11	28	-	0.64	0.05	0.04	0.04	0.09	-	-91.9%	-94.0%	-93.6%	-85.7%
4	350	178	189	210	222	253	2.33	1.19	0.88	0.97	1.03	1.20	-49.1%	-62.4%	-58.3%	-56.1%
5	547	469	352	276	353	268	8.68	6.73	2.67	2.09	2.67	2.03	-22.5%	-69.3%	-75.9%	-69.2%
6	370	405	430	337	186	130	2.13	2.34	2.56	2.01	1.11	0.78	10.1%	20.5%	-5.7%	-48.0%
7	528	258	215	109	70	-	3.45	1.67	1.38	0.70	0.45	-	-51.5%	-60.2%	-79.8%	-87.0%
8	284	328	405	222	142	87	2.15	2.21	2.29	1.25	0.80	0.49	2.7%	6.5%	-41.8%	-62.6%
9	482	414	458	329	50	40	2.44	2.26	2.78	2.00	0.31	0.24	-7.2%	14.0%	-18.1%	-87.5%
10	412	355	301	108	148	-	2.21	2.15	1.83	0.65	0.90	-	-2.4%	-17.2%	-70.5%	-59.4%
11	152	152	165	-	-	-	0.99	0.98	1.06	-	-	-	-1.4%	6.7%	-	-
12	193	162	-	-	-	-	2.08	1.74	-	-	-	-	-16.2%	-	-	-
13	171	185	-	-	-	-	1.24	1.34	-	-	-	-	8.4%	-	-	-
Total	4453	3412	2703	1820	1416	887	32.8	26.0	16.6	10.9	8.5	5.3	-20.8%	-40.1%	-56.8%	-66.2%
Average	342.51	262.44	245.73	182.02	141.56	126.70	2.52	2.00	1.51	1.09	0.85	0.76	-22.26%	-37.13%	-59.04%	-70.24%
Variance	17928	18400	23598	11978	9086	9222	3.99	2.60	0.95	0.52	0.52	0.4336	0.10	0.19	0.08	0.02

Table A2 Yearly Accident Data at Study Intersections

Intersection		Number of Accidents per Year															
		2 year before				1 year before				1 year after				2 year after			
		pdo	inj	fat	total	pdo	inj	fat	total	pdo	inj	fat	total	pdo	inj	fat	total
Camera	1*	5	0	0	5	4	1	0	5	2	5	0	7	2	3	0	5
	2	4	2	0	6	0	3	0	3	3	1	0	4	6	1	0	7
	3	9	3	0	12	10	10	0	20	3	7	0	10	5	1	0	6
	4	2	6	0	8	2	4	0	6	5	2	0	7	3	4	0	7
	5	10	4	0	14	7	5	0	12	7	7	0	14	5	6	0	11
	6	6	3	0	9	6	4	1	11	15	3	0	18	4	4	0	8
	7	5	1	0	6	1	5	0	6	4	1	0	5	3	2	0	5
	8	7	4	0	11	6	8	0	14	3	7	0	10	8	4	0	12
	9*	1	2	0	3	2	1	0	3	3	3	0	6	5	3	0	9
	10*	1	2	0	3	1	1	0	2	1	0	0	1	0	2	0	2
Total		**50**	**27**	**0**	**77**	**39**	**42**	**1**	**82**	**46**	**36**	**0**	**82**	**41**	**30**	**0**	**71**
Non-Camera	14*	5	3	0	8	8	9	0	17	14	4	0	18	5	5	0	10
	15*	0	4	0	4	6	2	0	8	2	3	0	5	5	7	0	12
Total		**5**	**7**	**0**	**12**	**14**	**11**	**0**	**25**	**16**	**7**	**0**	**23**	**10**	**12**	**0**	**22**
Control	16	13	5	0	18	6	9	0	15	9	5	0	14	15	3	0	19
	17	5	4	0	9	6	3	0	9	8	4	0	12	9	3	0	12
	18	5	2	0	7	6	6	0	12	5	2	0	7	2	2	0	4
	19	9	5	0	14	12	3	0	15	10	6	0	16	8	6	0	14
Total		**32**	**16**	**0**	**48**	**30**	**21**	**0**	**51**	**32**	**17**	**0**	**49**	**34**	**14**	**0**	**49**

Table A3 Accident Rate Data at Study Intersections

Intersection		Number of Accidents per 10,000 Vehicles															
		2 year before				1 year before				1 year after				2 year after			
		pdo	**inj**	**fat**	**total**	**pdo**	**inj**	**fat**	**total**	**pdo**	**inj**	**fat**	**total**	**pdo**	**inj**	**fat**	**total**
Camera	1*	0.0031	0.0000	0.0000	0.0031	0.0023	0.0006	0.0000	0.0029	0.0012	0.0031	0.0000	0.0044	0.0010	0.0015	0.0000	0.0025
	2	0.0015	0.0007	0.0000	0.0022	0.0000	0.0011	0.0000	0.0011	0.0011	0.0004	0.0000	0.0015	0.0022	0.0004	0.0000	0.0025
	3	0.0023	0.0008	0.0000	0.0030	0.0025	0.0025	0.0000	0.0051	0.0008	0.0018	0.0000	0.0025	0.0012	0.0002	0.0000	0.0015
	4	0.0010	0.0031	0.0000	0.0041	0.0010	0.0021	0.0000	0.0031	0.0027	0.0011	0.0000	0.0038	0.0011	0.0015	0.0000	0.0027
	5	0.0119	0.0048	0.0000	0.0167	0.0083	0.0060	0.0000	0.0143	0.0091	0.0091	0.0000	0.0183	0.0031	0.0037	0.0000	0.0068
	6	0.0028	0.0014	0.0000	0.0043	0.0028	0.0019	0.0005	0.0052	0.0071	0.0014	0.0000	0.0085	0.0020	0.0020	0.0000	0.0039
	7	0.0027	0.0005	0.0000	0.0032	0.0005	0.0027	0.0000	0.0032	0.0021	0.0005	0.0000	0.0027	0.0016	0.0011	0.0000	0.0026
	8	0.0041	0.0023	0.0000	0.0064	0.0036	0.0048	0.0000	0.0084	0.0016	0.0037	0.0000	0.0053	0.0035	0.0020	0.0000	0.0056
	9*	0.0004	0.0008	0.0000	0.0012	0.0008	0.0004	0.0000	0.0012	0.0014	0.0014	0.0000	0.0027	0.0027	0.0016	0.0000	0.0043
	10*	0.0004	0.0008	0.0000	0.0012	0.0004	0.0004	0.0000	0.0008	0.0005	0.0000	0.0000	0.0005	0.0000	0.0007	0.0000	0.0007
Total		0.0302	0.0153	0.0000	**0.046**	0.0225	0.0225	0.0005	**0.045**	0.028	0.023	0.000	**0.050**	0.018	0.015	0.000	**0.033**
Non-Camera	14*	0.0031	0.0016	0.0000	0.0047	0.0047	0.0052	0.0000	0.0099	0.0087	0.0025	0.0000	0.0112	0.0025	0.0025	0.0000	0.0051
	15*	0.0000	0.0023	0.0000	0.0023	0.0035	0.0012	0.0000	0.0047	0.0012	0.0019	0.0000	0.0031	0.0025	0.0036	0.0000	0.0061
Total		0.003	0.004	0.000	**0.007**	0.008	0.006	0.000	**0.015**	0.010	0.004	0.000	**0.014**	0.005	0.006	0.000	**0.011**
Control	16	0.0099	0.0038	0.0000	0.0137	0.0046	0.0068	0.0000	0.0114	0.0068	0.0038	0.0000	0.0107	0.0116	0.0025	0.0000	0.0141
	17	0.0043	0.0034	0.0000	0.0077	0.0051	0.0026	0.0000	0.0077	0.0061	0.0030	0.0000	0.0091	0.0065	0.0022	0.0000	0.0087
	18	0.0022	0.0009	0.0000	0.0030	0.0026	0.0026	0.0000	0.0052	0.0022	0.0009	0.0000	0.0030	0.0009	0.0009	0.0000	0.0017
	19	0.0047	0.0026	0.0000	0.0072	0.0062	0.0016	0.0000	0.0078	0.0051	0.0031	0.0000	0.0082	0.0041	0.0030	0.0000	0.0071
Total		0.021	0.011	0.000	**0.032**	0.019	0.014	0.000	**0.032**	0.020	0.011	0.000	**0.031**	0.0230	0.0086	0.0000	**0.032**

Table A4 Average Daily Traffic at Study Intersections

Intersection		Name	Average Daily Traffic (ADT) primary street (monitored)		
			2000	2001	2002
Camera	1	Leesburg Pike @ Towlston Rd. (EB)	47000	44000	54000
	2	Lee Jackson Memorial Highway @ Rugby Rd. (WB)	74000	74000	76000
	3	Lee Jackson Memorial Highway @ Fair Ridge Drive (WB)	108000	108000	110000
	4	Leesburg Pike @ Westpark Drive (WB)	53000	50000	72000
	5	Leesburg Pike @ Route 66 (WB)	23000	21000	44000
	6	Arlington Boulevard @ Jaguar Trail (WB)	58000	58000	56000
	7	Route28 @ Green Trail Boulevard (SB)	51000	51000	52000
	8	Leesburg Pike @ Dransville Rd (EB)	47000	44000	59000
	9	Fairfax County Parkway @ Popes Head Rd. (SB)	N/A	66000	55000
	10	Fairfax County Parkway @ Newington Rd. (NB)	N/A	66000	55000
	11	Route 236 @ Heritage Drive (EB)	51000	51000	52000
	12	Telegraph Rd. @ Huntington Avenue (NB)	N/A	30000	31000
	13	Route 7 @ Carlin Springs (WB)	41000	38000	46000
Non-Camera	14	Route 7 @ Lewinville Rd.	47000	44000	54000
	15	Route 7 @ Beulah Rd.	47000	44000	54000
Control	16	Route 644 @ Rolling Rd.	N/A	36,000	36000
	17	Richmond HY & Telegraph Rd.	32,000	32,000	38,000
	18	Braddock Rd. (620) & Rolling Rd. (638)	N/A	63,000	64000
	19	Rt 613 (S Van Dorn) @ Rt 644 (Franconia Rd.)	N/A	53,000	54,000

Table A5 Violation Rate Data at RLC intersections in Washington DC

Intersection (date in operation)	Average monthly violation per month						ADT	Average monthly violations/10,000 vehicle					
	initial	12 mon after	18 mon after	24 mon after	30 mon after	36 mon after		initial	12 mon after	18 mon after	24 mon after	30 mon after	36 mon after
Benning @ Minnesota (12/22/99)	120.6	175.1	161.8	149.6	134.7	128.1	22900	5.26	7.65	7.07	6.53	5.88	5.59
Bladensburg @ NY NB (10/08/99)	332.9	98.1	77.4	67.2	59.1	52.6	13400	24.84	7.32	5.78	5.01	4.41	3.92
Connecticut @ Military (02/14/00)	145.0	123.1	125.2	116.7	114.2	115.5	20500	7.07	6.00	6.11	5.69	5.57	5.63
Connecticut @ Nebraska (02/16/00)	93.7	82.7	66.1	55.6	56.0	54.4	37200	2.52	2.22	1.78	1.50	1.51	1.46
Constitution @ 15th (01/05/00)	70.3	231.9	207.5	184.1	174.8	161.9	32900	2.14	7.05	6.31	5.60	5.31	4.92
E. Capital @ Texas (09/13/99)	289.4	96.2	77.8	72.9	68.9	69.3	28400	10.19	3.39	2.74	2.57	2.43	2.44
E. Capital @ Benning (09/10/99)	844.5	253.5	204.1	196.6	183.5	173.4	28400	29.74	8.93	7.19	6.92	6.46	6.10
E. Capital @ Southern (12/21/99)	303.8	244.5	213.8	208.5	193.7	186.3	35100	8.66	6.97	6.09	5.94	5.52	5.31
Georgia @ Missouri (12/10/99)	575.7	114.9	104.9	83.1	68.4	61.2	36400	15.82	3.16	2.88	2.28	1.88	1.68
Independence @ Washington (01/01/00)	160.0	150.5	133.7	118.3	110.3	106.0	28400	5.63	5.30	4.71	4.17	3.88	3.73
Independence @ 3rd (12/24/99)	44.3	42.8	31.4	27.4	24.0	21.2	23400	1.89	1.83	1.34	1.17	1.03	0.91
K St @ 27 (02/14/00)	21.3	45.5	39.1	34.6	38.5	41.9	21800	0.98	2.09	1.79	1.59	1.77	1.92
K St @ 25 (11/04/99)	993.5	481.1	384.3	359.9	327.5	323.7	5200	191.05	92.52	73.91	69.20	62.98	62.25
Mt Olivet @ West Virginia (11/11/99)	167.4	83.5	67.8	58.3	58.5	59.9	12600	13.28	6.63	5.38	4.63	4.64	4.75
N. Capital @ Riggs (11/18/99)	470.0	313.4	287.1	287.7	275.9	267.2	33400	14.07	9.38	8.60	8.61	8.26	8.00
New York Ave @ New Jersey (02/14/00)	261.0	400.2	349.3	292.9	261.3	239.2	44200	5.90	9.05	7.90	6.63	5.91	5.41
New York Ave @ Florida (03/30/00)	930.0	220.1	188.8	182.4	173.2	163.4	49000	18.98	4.49	3.85	3.72	3.53	3.33
North Capital @ Harewood (10/26/99)	1258.6	549.7	596.6	413.8	372.1	351.2	27900	45.11	19.70	21.38	14.83	13.34	12.59
N. Capital @ Gallatin (10/27/99)	674.3	188.7	135.9	-	-	-	33000	20.43	5.72	4.12	-	-	-
New York @ Bladensburg EB (10/01/99)	660.0	246.2	238.9	220.3	209.6	205.9	35600	18.54	6.91	6.71	6.19	5.89	5.78
New York @ Bladensburg WB (10/01/99)	729.0	293.8	267.8	233.8	224.9	229.2	35200	20.71	8.35	7.61	6.64	6.39	6.51
New York @ 4th (08/01/99)	3733.0	1478.9	1306.3	1190.0	1069.2	997.7	27700	134.77	53.39	47.16	42.96	38.60	36.02
Penn @ Southern (09/01/00)	276.0	211.8	186.6	182.3	-	-	19000	14.53	11.15	9.82	9.59	-	-
Rhode Island @ Reed (01/12/00)	668.9	383.0	339.6	318.9	300.8	280.6	29200	22.91	13.12	11.63	10.92	10.30	9.61
Rhode Island @ 1st (02/07/00)	129.2	42.7	31.1	28.2	-	-	27700	4.66	1.54	1.12	1.02	-	-

Table A5 (cont') Violation Rate Data at RLC intersections in Washington DC

Intersection (date in operation)	Average monthly violation per month						ADT	Average monthly violations/10,000 vehicle					
	initial	12 mon after	18 mon after	24 mon after	30 mon after	36 mon after		initial	12 mon after	18 mon after	24 mon after	30 mon after	36 mon after
S Capital @ I (12/01/99)	1815.0	1421.0	1299.8	1238.4	1155.2	1093.3	73700	24.63	19.28	17.64	16.80	15.67	14.83
S Dakota @ Bladensburg (11/03/99)	460.0	148.7	124.9	111.0	104.0	109.5	36000	12.78	4.13	3.47	3.08	2.89	3.04
Suitland @ Firth Sterling (12/01/99)	573.0	337.0	310.1	285.7	272.8	254.6	44600	12.85	7.56	6.95	6.41	6.12	5.71
Suitland @ Stanton (12/10/99)	1062.9	398.7	367.2	362.4	372.1	348.8	34400	30.90	11.59	10.68	10.53	10.82	10.14
12th @ Constitution (12/21/99)	93.0	117.8	114.8	89.2	71.0	66.1	39000	2.38	3.02	2.94	2.29	1.82	1.70
14th @ C St (09/01/00)	415.0	404.1	339.3	283.8	-	-	43900	9.45	9.20	7.73	6.47	-	-
14th @ U St (08/01/99)	31.0	61.5	-	-	-	-	19900	1.56	3.09	-	-	-	-
16th @ Oak (12/01/99)	585.0	213.7	164.4	146.4	133.8	111.2	36600	15.98	5.84	4.49	4.00	3.65	3.04
16th @ Colorado (12/01/99)	119.0	38.6	-	-	-	-	30700	3.88	1.26	-	-	-	-
16th @ Irving (12/01/99)	87.0	52.2	-	-	-	-	22800	3.82	2.29	-	-	-	-
Totals	**19193.2**	**9745.2**	**8543.5**	**7600.0**	**6608.1**	**6273.4**		**757.91**	**371.11**	**316.87**	**283.50**	**246.46**	**236.35**

Table A6 Percent Change in Violations Rates at RLC intersections in Washington DC

Intersection (date in operation)	% change in violation per month				
	12 mon after	18 mon after	24 mon after	30 mon after	36 mon after
1.Benning @ Minnesota (12/22/99)	45.23	34.24	24.08	11.71	6.27
2.Bladensburg @ NY NB (10/08/99)	-70.54	-76.74	-79.82	-82.24	-84.21
3.Connecticut @ Military (02/14/00)	-15.11	-13.68	-19.51	-21.24	-20.37
4.Connecticut @ Nebraska (02/16/00)	-11.77	-29.50	-40.63	-40.23	-41.96
5.Constitution @ 15th (01/05/00)	229.68	194.97	161.68	148.53	130.09
6.E. Capital @ Texas (09/13/99)	-66.77	-73.13	-74.81	-76.18	-76.07
7.E. Capital @ Benning (09/10/99)	-69.98	-75.84	-76.72	-78.28	-79.47
8.E. Capital @ Southern (12/21/99)	-19.52	-29.61	-31.38	-36.23	-38.67
9.Georgia @ Missouri (12/10/99)	-80.04	-81.78	-85.56	-88.11	-89.37
10.Independence @ Washington (01/01/00)	-5.94	-16.46	-26.07	-31.04	-33.75
11.Independence @ 3rd (12/24/99)	-3.47	-29.07	-38.24	-45.81	-52.16
12.K St @ 27 (02/14/00)	114.16	83.75	62.81	81.03	97.14
13.K St @ 25 (11/04/99)	-51.57	-61.31	-63.78	-67.04	-67.42
14.Mt Olivet @ West Virginia (11/11/99)	-50.08	-59.49	-65.15	-65.07	-64.21
15.N. Capital @ Riggs (11/18/99)	-33.32	-38.91	-38.79	-41.29	-43.14
16.New York Ave @ New Jersey (02/14/00)	53.32	33.84	12.23	0.11	-8.34
17.New York Ave @ Florida (03/30/00)	-76.34	-79.70	-80.39	-81.38	-82.43
18.North Capital @ Harewood (10/26/99)	-56.33	-52.60	-67.12	-70.44	-72.09
19.N. Capital @ Gallatin (10/27/99)	-72.02	-79.84	-	-	-
20.New York @ Bladensburg EB (10/01/99)	-62.70	-63.80	-66.62	-68.24	-68.80
21.New York @ Bladensburg WB (10/01/99)	-59.71	-63.27	-67.94	-69.15	-68.56
22.New York @ 4th (08/01/99)	-60.38	-65.01	-68.12	-71.36	-73.27
23.Penn @ Southern (09/01/00)	-23.25	-32.39	-33.95	-	-
24.Rhode Island @ Reed (01/12/00)	-42.75	-49.23	-52.33	-55.03	-58.05
25.Rhode Island @ 1st (02/07/00)	-66.95	-75.90	-78.18	-	-
26.S Capital @ I (12/01/99)	-21.71	-28.38	-31.77	-36.35	-39.76
27.S Dakota @ Bladensburg (11/03/99)	-67.67	-72.85	-75.88	-77.38	-76.19
28.Suitland @ Firth Sterling (12/01/99)	-41.19	-45.88	-50.14	-52.40	-55.56
29.Suitland @ Stanton (12/10/99)	-62.49	-65.45	-65.90	-64.99	-67.18
30.12th @ Constitution (12/21/99)	26.67	23.45	-4.06	-23.62	-28.91
31.14th @ C St (09/01/00)	-2.63	-18.23	-31.61	-	-
32.14th @ U St (08/01/99)	98.39	-	-	-	-
33.16th @ Oak (12/01/99)	-63.47	-71.90	-74.98	-77.13	-80.99
34.16th @ Colorado (12/01/99)	-67.53	-	-	-	-
35.16th @ Irving (12/01/99)	-39.97	-	-	-	-
Totals	**-51.03**	**-54.27**	**-57.77**	**-59.35**	**-61.02**

Table A7 Accident Rate Data at RLC intersections in Washington DC

District of Columbia Red Light Camera Locations	Number of Accidents								ADT	Number of Accidents per 10,000 vehicles							
	2 Years Before		**1 Year Before**		**1 Year After**		**2 Years After**			**2 Years Before**		**1 Year Before**		**1 Year After**		**2 Years After**	
Red Light Cam. Location	Total	inj	Total	inj	Total	inj	Total	inj		Total	inj	Total	inj	Total	inj	Total	inj
1. 12th St. & Constitution Ave., NW	14	12	12	3	19	11	21	17	39000	3.59	3.08	3.08	0.77	4.87	2.82	5.38	4.36
2. 14th St. & C St., SW	0	0	0	0	0	0	8	10	43900	0.00	0.00	0.00	0.00	0.00	0.00	1.82	2.28
3. 14th St. & U St., NW	27	8	20	5	33	14	40	9	19900	13.57	4.02	10.05	2.51	16.58	7.04	20.10	4.52
4. 16th St. & Colorado Ave., NW	3	1	6	3	9	4	8	9	30700	0.98	0.33	1.95	0.98	2.93	1.30	2.61	2.93
5. 16th St. & Irving St., NW	17	11	11	3	16	20	21	10	22800	7.46	4.82	4.82	1.32	7.02	8.77	9.21	4.39
6. 16th St. & Oak St., NW	3	1	12	5	7	5	9	5	36600	0.82	0.27	3.28	1.37	1.91	1.37	2.46	1.37
7. Alabama Ave. & Branch Ave., SE	10	8	18	16	21	22	14	13	18200	5.49	4.40	9.89	8.79	11.54	12.09	7.69	7.14
8. Benning Rd. & Minnesota Ave., NE	18	12	26	13	33	28	53	36	22900	7.86	5.24	11.35	5.68	14.41	12.23	23.14	15.72
9. Connecticut Ave. & Military Rd., NW	4	4	10	12	8	8	20	12	20500	1.95	1.95	4.88	5.85	3.90	3.90	9.76	5.85
10. Connecticut Ave. & Nebraska Ave. NW	6	3	18	13	20	12	32	15	37200	1.61	0.81	4.84	3.49	5.38	3.23	8.60	4.03
11. Constitution Ave. & 15th St., NW	15	12	6	2	25	15	18	11	32900	4.56	3.65	1.82	0.61	7.60	4.56	5.47	3.34
12. East Capitol St. & Benning Rd., SE	23	17	15	4	36	10	22	12	28400	8.10	5.99	5.28	1.41	12.68	3.52	7.75	4.23
13. East Capitol St. & Southern Ave., NE	18	15	5	1	13	16	9	4	35100	5.13	4.27	1.42	0.28	3.70	4.56	2.56	1.14
14. East Capitol St. & Texas Ave., SE	2	0	3	0	10	17	5	2	28400	0.70	0.00	1.06	0.00	3.52	5.99	1.76	0.70
15. Georgia Ave. & Missouri Ave., NW	18	10	7	7	15	4	23	10	36400	4.95	2.75	1.92	1.92	4.12	1.10	6.32	2.75
16. Independence Ave. & Washington Ave., SW	1	0	5	3	5	5	5	0	28400	0.35	0.00	1.76	1.06	1.76	1.76	1.76	0.00
17. Independence Ave. & 3rd St., SW	0	0	0	0	1	0	1	0	33100	0.00	0.00	0.00	0.00	0.30	0.00	0.30	0.00
18. K St. & 25th St., NW	1	0	2	1	10	10	3	1	21800	0.46	0.00	0.92	0.46	4.59	4.59	1.38	0.46
19. K St. & 27th St., NW	2	0	2	1	4	1	3	0	5200	3.85	0.00	3.85	1.92	7.69	1.92	5.77	0.00
20. Mt. Olivet Rd. & West Virginia Ave., NE	17	9	10	10	17	15	25	14	12600	13.49	7.14	7.94	7.94	13.49	11.90	19.84	11.11
21. New York Ave. & 4th St., NW	13	5	8	3	15	8	26	20	27700	4.69	1.81	2.89	1.08	5.42	2.89	9.39	7.22

Table A7 (cont') Accident Rate Data at RLC intersections in Washington DC

District of Columbia Red Light Camera Locations	Number of Accidents								ADT	Number of Accidents per 10,000 vehicles							
	2 Years Before		1 Year Before		1 Year After		2 Years After			2 Years Before		1 Year Before		1 Year After		2 Years After	
Red Light Cam. Location	Total	inj	Total	inj	Total	inj	Total	inj		Total	inj	Total	inj	Total	inj	Total	inj
22. New York Ave. & Bladensburg Rd., NE (3 cameras)	42	29	52	34	85	77	90	79	35500	11.83	8.17	14.65	9.58	23.94	21.69	25.35	22.25
23. New York Ave. & Florida Ave., NE	22	18	35	27	42	20	49	32	49000	4.49	3.67	7.14	5.51	8.57	4.08	10.00	6.53
24. New York Ave & New Jersey Ave., NW	32	26	46	38	49	56	54	54	44200	7.24	5.88	10.41	8.60	11.09	12.67	12.22	12.22
25. North Capitol St. & Gallatin St., NW	4	2	3	4	1	4	4	2	33000	1.21	0.61	0.91	1.21	0.30	1.21	1.21	0.61
26. North Capitol St. & Harewood Rd., NW	12	5	14	16	9	6	13	1	27900	4.30	1.79	5.02	5.73	3.23	2.15	4.66	0.36
29. Pennsylvania Ave. & Southern Ave., SE	11	14	12	14	17	16	13	6	19000	5.79	7.37	6.32	7.37	8.95	8.42	6.84	3.16
30. Rhode Island Ave. & 1st St., NW	7	12	10	5	13	9	12	11	27700	2.53	4.33	3.61	1.81	4.69	3.25	4.33	3.97
31. Rhode Island Ave. & Reed, NE	2	0	4	3	8	8	4	4	29200	0.68	0.00	1.37	1.03	2.74	2.74	1.37	1.37
32. South Capitol & Eye ("I") St., SW	22	21	37	28	58	56	45	21	73700	2.99	2.85	5.02	3.80	7.87	7.60	6.11	2.85
33. South Dakota & Bladensburg Rd., NE	7	6	15	13	14	12	27	16	36000	1.94	1.67	4.17	3.61	3.89	3.33	7.50	4.44
34. Suitland Parkway & Firth Sterling Ave., SE	13	16	19	12	37	33	49	36	44600	2.91	3.59	4.26	2.69	8.30	7.40	10.99	8.07
35. Suitland Parkway & Stanton Rd., SE	14	15	23	19	32	52	58	60	34400	4.07	4.36	6.69	5.52	9.30	15.12	16.86	17.44
Totals	**400**	**292**	**466**	**318**	**682**	**574**	**784**	**532**		**139.6**	**94.80**	**152.6**	**103.90**	**226.28**	**185.19**	**260.51**	**166.81**

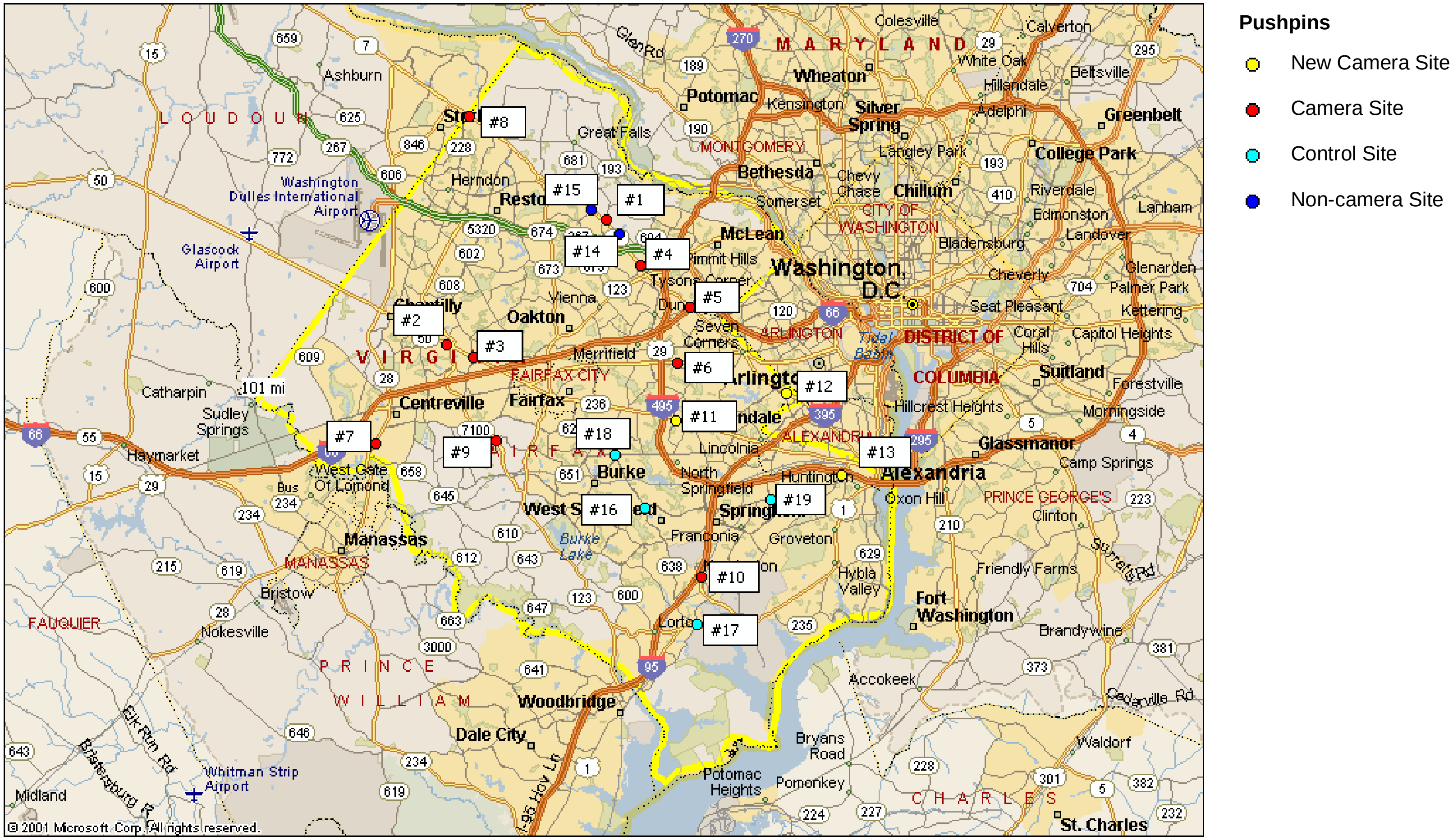
Table A8 Percent Change in Accidents Data
at RLC intersections in Washington DC

District of Columbia Red Light Camera Locations	% change in accidents per 10,000 vehicles							
	1 year aft vs 2 Year bef		1 Year aft vs 1 Year bef		2 year aft vs 2 Year bef		2 Year aft vs 1 Year bef	
Red Light Cam. Location	Total	inj	Total	inj	Total	inj	Total	inj
1. 12th St. & Constitution Ave., NW	35.7	-8.33	58.3	267	50	41.67	75	467
2. 14th St. & C St., SW	0	0	0	0	+	+	+	+
3. 14th St. & U St., NW	22.2	75	65	180	48.15	12.5	100	80
4. 16th St. & Colorado Ave., NW	200	300	50	33.3	166.7	800	33.3	200
5. 16th St. & Irving St., NW	-5.88	81.82	45.5	567	23.53	-9.09	90.9	233
6. 16th St. & Oak St., NW	133	400	-41.7	0	200	400	-25	0
7. Alabama Ave. & Branch Ave., SE	110	175	16.7	37.5	40	62.5	-22.2	-18.8
8. Benning Rd. & Minnesota Ave., NE	83.3	133.3	26.9	115	194.4	200	104	177
9. Connecticut Ave. & Military Rd., NW	100	100	-20	-33.3	400	200	100	0
10. Connecticut Ave. & Nebraska Ave. NW	233	300	11.1	-7.69	433.3	400	77.8	15.4
11. Constitution Ave. & 15th St., NW	66.7	25	317	650	20	-8.33	200	450
12. East Capitol St. & Benning Rd., SE	56.5	-41.2	140	150	-4.35	-29.4	46.7	200
13. East Capitol St. & Southern Ave., NE	-27.8	6.667	160	1500	-50	-73.3	80	300
14. East Capitol St. & Texas Ave., SE	400	+	233	+	150	+	66.7	+
15. Georgia Ave. & Missouri Ave., NW	-16.7	-60	114	-42.9	27.78	0	229	42.9
16. Independence Ave. & Washington Ave., SW	400	+	0	66.7	400	0	0	-100
17. Independence Ave. & 3rd St., SW	+	0	+	0	+	0	+	0
18. K St. & 25th St., NW	900	+	400	900	200	+	50	0
19. K St. & 27th St., NW	100	+	100	0	50	0	50	-100
20. Mt. Olivet Rd. & West Virginia Ave., NE	0	66.67	70	50	47.06	55.56	150	40
21. New York Ave. & 4th St., NW	15.4	60	87.5	167	100	300	225	567
22. New York Ave. & Bladensburg Rd., NE (3 cameras)	102	165.5	63.5	126	114.3	172.4	73.1	132
23. New York Ave. & Florida Ave., NE	90.9	11.11	20	-25.9	122.7	77.78	40	18.5
24. New York Ave & New Jersey Ave., NW	53.1	115.4	6.52	47.4	68.75	107.7	17.4	42.1
25. North Capitol St. & Gallatin St., NW	-75	100	-66.7	0	0	0	33.3	-50
26. North Capitol St. & Harewood Rd., NW	-25	20	-35.7	-62.5	8.333	-80	-7.14	-93.8
27. Pennsylvania Ave. & Southern Ave., SE	54.5	14.29	41.7	14.3	18.18	-57.1	8.33	-57.1
28. Rhode Island Ave. & 1st St., NW	85.7	-25	30	80	71.43	-8.33	20	120
29. Rhode Island Ave. & Reed, NE	300	+	100	167	100	+	0	33.3
30. South Capitol & Eye (“I”) St., SW	164	166.7	56.8	100	104.5	0	21.6	-25
31. South Dakota & Bladensburg Rd., NE	100	100	-6.67	-7.69	285.7	166.7	80	23.1
32. Suitland Parkway & Firth Sterling Ave., SE	185	106.3	94.7	175	276.9	125	158	200
33. Suitland Parkway & Stanton Rd., SE	129	246.7	39.1	174	314.3	300	152	216
Totals	**62.1**	**95.34**	**48.3**	**78.2**	**86.62**	**75.96**	**70.8**	**60.6**

APPENDIX B

Map and Legislations

Figure B1 Locations of The Study Intersections



Summarization

of

Automated Photo Enforcement Legislation in 10 Studied States

Arizona

The State of Arizona has considered the law regarding the photo enforcement since 1997. In Arizona it is not allowed to have the system implemented if it is not approved by a majority of the qualified voters within the jurisdiction. As of 2003, there are 7 cities that are operating the photo enforcement system; Paradise of Valley, Peoria, Scottsdale, Mesa, Tempe, Chandler and Phoenix. A jurisdiction is allowed to have a contract to provide fee based on each violation with a private vendor. The state requires a photograph of a vehicle and a vehicle's driver with a record of speed at the time of violation therefore the front and rear photographs are required. The House Bill 2277 specifies the civil penalty of at least $250 per person for a red light violation. In the same time, a person violating red light stop signal also required to attend Traffic Survival School (TSS). A citation is mailed out regardless of whether a vehicle committing the violation is from Arizona County or other states.

California

In California, the automated enforcement system was begun with the enforcement at rail crossing. Since 1995, the legislation has been extended to other intersections with traffic control signal. The automated enforcement system operated in California is required that prior to issuing citations the program that issues only warning notices shall be implemented for 30 days. In the same time, the local jurisdiction must make the public announcement about the use of the automated traffic enforcement system for at lease 30 days before the program begins. As in Virginia and Oregon, a sign indicating the system's presence is required. It should be made visible to traffic approaching from all directions or at all major entrances to the city. The evidences needed for the automated enforcement in California are different from other states. The driver identification is required therefore the frontal photo of a driver together with a photo of a vehicle's license plate must be provided. In 2003, the State of California has passed the bill 1022 that the minimum yellow time interval of the traffic signal of the camera intersection must be established in accordance with the Traffic Manual of the California Department of Transportation. . Another change of the law made in 2003 is that the governmental agency is not allowed to have a contract with a manufacturer or supplier of automated enforcement equipment including a provision for the payment or compensation to the private agency based on the number of citations generated or as a percentage of the revenue generated.

Colorado

The House Bill 1364 that allows the use of automated vehicle identification systems in Colorado was passed in 1999. The regulation of Colorado states the same as California and Texas's regulation that no portion of any fine collected through the use of such system may be paid to the manufacturer or vendor of the automated vehicle identification system equipment. As in many states, appropriate signs informing about the system must be provided in a noticeable place. The maximum penalty is, the same as Texas, $75. However, if the violation occurred in the school zone, the maximum penalty can be double. The Colorado's Bill is different from other state's law that for the first time of violation, the driver may not impose any penalty or surcharge. In case that a registered owner was not operating the vehicle at the time of violation, he or she has an alternative of submitting an evidence to avoid the penalty.

Hawaii

In 2003, the State of Hawaii has passed the House Bill 57 that allows the establishment of a 3-year automated red light enforcement pilot project in the city and county of Honolulu at five intersections. The project has followed the red light violation enforcement program in Howard County, Maryland. The required evidences which are almost the same as in Maryland include two or more photographs, microphotographs, electronic images, videotape, or any other medium showing the rear of a vehicle and the plate number. The difference is that a photograph showing a driver's face is also required. Signs indicating the photo monitoring system are optional. A warning notice program and public awareness program shall be conducted along the first year of the pilot project. The maximum civil penalty is also the same as in Maryland, $100. A registered owner of a vehicle may defend himself or herself if the vehicle was stolen or was not operated by the owner at the time of violation. The project evaluation must be submitted at the end of the project. In addition, the law includes the prohibition of the use of number plate cover that distorts a recorded image of a vehicle's number plate.

Illinois

The State of Illinois passed the Senate Bill 2159 in April, 2002 that allows municipalities and counties in Illinois to install automated red light enforcement system. The bill states only that clear photographs of vehicle and vehicle's license plate must be obtained from the red light camera while the vehicle violated the traffic signal.

Maryland

Since 1997, Maryland has had the vehicle law that permits the use of traffic control signal monitoring system. The required recorded images are two or more photographs, microphotographs, electronic images, videotape, or any other medium that shows the rear of a motor vehicle and, on at least one image or portion of tape, clearly identifying the registration plate number of the vehicle. The maximum fine is as high as $100. The owner of the vehicle has an option to stand in a court if he or she did not operate the vehicle at the time of violation.

New York

The red light camera legislation has been proposed and adopted in New York since 1993. In March 2003, the State of New York passed the bill A0565 that makes the demonstration program of traffic- control signal photo monitoring system operated in any municipality permanent. The required evidences of the violation, as well as in Virginia, are two or more photographs, microphotographs, videotape, or other recorded images produced by a monitoring system that show the violation. However, the number of photos is not specified in the legislature. It depends on the law of each municipality. The maximum fine is $50. The photo monitoring system is also required at the highway-railroad crossing in any municipality having the system operated.

Oregon

The state of Oregon has passed the House Bill 2085 in December 2001. It allows the operation of camera designed to photograph drivers who failed to obey a traffic control device in 6 cities; Beaverton, Bend, Medford, Newberg, Portland, and Tigard.

The public information campaign about the use of camera must be provided before citations are issued. Signs indicating that a camera may be in operation shall be posted at the camera intersection in a practical distance. The mail of citation together with a notice of innocent are sent to the registered owner of the vehicle that performed the violation. If the owner was not driving at the time of the alleged violation, he or she can return a signed "certificate of innocence" along with a photocopied drivers license and the citation will be dismissed. In the same way, if the vehicle was belong to a business or public agency, the owner may send a certificate of nonliability stating that the vehicle was in custody of employee, renter or lessee in that time of violation. The penalty for the violation initiated by a camera is the same as for the violation initiated by other means.

Texas

The House Committee on Transportation of the State of Texas passed house bill 901 in March 2003 that allows the implementation of photographic traffic signal enforcement system in Texas. As in California, the municipality that operates a photo enforcement system is not allowed to compensate the contractor as a specified percentage of, or dollar amount from, each civil penalty collected. However, the monthly fee or other type of payment are permitted. The requirement that distinguishes Texas's regulation from other state is that before the implementation of the photographic traffic signal enforcement system, the municipality shall conduct a traffic engineering study of the approach to determine whether a design change to the approach or a change in the signalization of the intersection is likely to reduce the number of red light violations at the intersection. Other alternatives must also be considered in addition to the photographic enforcement system. Signs indicating the use of the photographic enforcement system, same requirement as in California, must be erected to inform motorists entering the municipality. The public awareness and education program of the system shall be launched along the first year that the system is used. At least 2 photos of the rear license plate of a vehicle violating the traffic control signal are required to prove the violation. The civil penalty may not exceed $75.

In addition, if a vehicle is being rented or leased at the time of violation, the owner may be except from the penalty. However, in other cases, similar to a parking ticket, an owner is subjected to the penalty regardless of if he or she was operating the vehicle at the time of violation.

Virginia

The latest enacted House Bill 1696 that is related to the photo-monitoring systems to enforce traffic light signals was prefiled in January 2003. The public awareness program must be conducted before the implementation of the system. The required proofs of the violation are two or more photographs, microphotographs, videotape, or other recorded images produced by a traffic light signal violation monitoring system. One of the images must show a vehicle illegally entered the intersection and at least one other image shall show the same vehicle after it has illegally entered that intersection. Conspicuous warning signs are required at the intersection approach at which a photo-monitoring system is used. The penalty may not exceed $50. The signal timing and other location-specific safety features are needed to be considered before the camera implementation. The length of yellow time must be established based on the recommended methodology of the Institute of Transportation Engineers (ITE). In addition, the red light camera program established in Virginia is now required to have at least annually evaluation. The subject matter that is different from the legislation of other states is that each locality may install or operate the red light camera at no more than 25 intersections within each locality at any one time.

APPENDIX C

Statistical Test

1. F-Test

The F-test applied in this study is the variance ratio test. The objective of this test is to investigate the significance of the difference between two population variances. The limitation of this test is that two populations should both follow normal distribution. However, it is not necessary that they should have the same means.

Method

Given samples of size n_1 with value x_1, x_2, …., x_{n1} and size n_2 with values y_1, y_2, …, y_{n2} from the two populations, the value of

$$\bar{x} = \frac{\sum x_i}{n_1} \quad \text{and} \quad \bar{y} = \frac{\sum y_i}{n_2} \quad \text{……..(1)}$$

and

$$S_1^2 = \frac{\sum (x_i - \bar{x})^2}{n_1 - 1} \quad \text{and} \quad S_2^2 = \frac{\sum (y_i - \bar{y})^2}{n_2 - 1} \text{………} \quad (2)$$

$$F = \frac{S_1^2}{S_2^2} \text{………(3)} \quad \text{where } S_1^2 > S_2^2$$

Compare the observed F value with the critical F value from table C8 at degree of freedom = (n_1-1, n_2-1).

If the observed F value is less than the critical F value from the table, the two population variances are not significantly different from each other.

If the observed F value is equal or greater than critical F value from the table, the two population variances are significantly different from each other.

Example

This example illustrates how to test the difference of variances between 2 data categories:

- The number of violations per 10,000 vehicles at 13 camera intersections in the initial period of the camera installation. The initial period is the first 3 months of camera operation.
- The number of violations per 10,000 vehicles at 11 camera intersections in the 10th-15th month of the camera operation.

Step 1: Average violation rate to present the violations rate at the initial period and the 10^{th}-15^{th} month of the camera operation.

For example: find the average violation rate at initial period and 10^{th}-15^{th} month of the camera operation at intersection 1.

Table C1 Number of Violations per Month at Intersection 1.

Intersection 1			
Year	Month	Number of Violations	
2000	Oct (first operation month)	2.79	
	Nov	2.48	Initial period (first 3 month)
	Dec	3.31	
2001	Jan	2.82	
	Feb	2.24	
	Mar	2.90	
	Apr	1.72	
	May	3.82	
	Jun	2.71	
	Jul	1.05	
	Aug	0.77	
	Sep	0.70	10^{th} – 15^{th} month period
	Oct	1.08	
	Nov	0.89	
	Dec	0.77	
2002	Jan	0.85	
	:	:	
	:	:	

The average number of violations per month of the initial period
= (2.48+3.31+2.82)/3 = **2.86**

The average number of violations per month of the 12-month after period

= (1.05+0.77+0.70+1.08+0.89+0.77)/12 = **0.88**

The same method is applied for every intersection. The results are shown in table C2

Table C2 Average Number of Violations per Months at initial period and 10-15 month after period.

Intersection	Number of Violations per Month	
	Initial period (3 months after camera installation)	**12 months after camera installation**
	(x)	**(y)**
1	**2.86**	**0.88**
2	1.59	0.26
3	0.64	0.04
4	2.33	0.88
5	8.68	2.67
6	2.13	2.56
7	3.45	1.38
8	2.15	2.29
9	2.44	2.78
10	2.21	1.83
11	0.99	1.06
12	2.08	-
13	1.24	-
Total	32.8	16.6

Step 2: Calculate the variance (S^2) of 'x' and 'y' using formular (1), (2) and (3).

	S^2	n	df = n-1
Initial Period (x)	3.99	13	12
10-15 months after (y)	0.95	11	10

$F_{12,10} = S^2_x/S^2_y = 3.99/0.95 = 4.20$

Step 3: Find the Critical $F_{12,10}$ at 0.05 significant level from table C6.

$F_{12,10,\alpha=0.05} = 2.91$ (from table C6)

Compare the observed F value with the critical F value;

4.20 > 2.91 therefore, the two population variances are significantly different from each other. In other words, there is a significant difference in variance of the violation rate between at initial period and 10-15 months after camera operation period.

2. Chi-Square Test

The Chi-Square test is one of the most widely used nonparametric techniques. The nonparametric statistics are a group of techniques designed to analyze data that fail to meet the assumption for parametric techniques, i.e., distribution and variance assumptions. The nonparametric techniques do not make numerous or stringent assumptions about parameters. They result in conclusions, which require fewer qualifications than when using parametric technique.

The Chi-Square test can be of the goodness-of-fit type in that it may be used to test whether a significant difference exists between an 'observed' number of objects or responses falling in each category and an 'expected' number. It is also used to determine the significance of the differences between 2 independent groups or among K independent groups.

The Chi-Square test applied for this study is the latter case. It is applied to test for independence in a p x q table. The objective of applying the Chi-Square test is to investigate the difference in frequency when classified by one attribute after classification by a second attribute.

Method

The sample, of size N, can be classified into p classes by the first attribute and into q classes by the second. The frequencies of individuals in each classification can be shown symbolically by the table:

		First Attribute				
		1	2	………i………	p	Total
Second Attribute	1	f_{11}	f_{21}	…….f_{i1}……	f_{p1}	$f_{.1}$
	2	f_{12}	f_{22}	………f_{i2}……..	f_{p2}	$f_{.2}$
	:	:	:	:	:	:
	j	f_{1j}	f_{2j}	……….f_{ij}………	f_{pj}	$f_{.j}$
	:	:	:	:	:	:
	q	f_{1q}	f_{2q}	………f_{iq}……..	f_{pq}	$f_{.q}$
	Total	$f_{1.}$	$f_{2.}$	……… $f_{i.}$ ……	$f_{p.}$	N

The null hypothesis (H_0) is that the p samples of frequencies or proportions have come from the same population or from identical population. This hypothesis, that the p samples do not differ among themselves maybe tested by applying formula (3):

$$X^2 = \sum_{i=1}^{p} \sum_{j=1}^{q} \left\{ \frac{\left(f_{ij} - F_{ij}\right)^2}{F_{ij}} \right\} \quad (3)$$

$$\text{Where } F_{ij} = \frac{f_{.j} \times f_{i.}}{N} \quad (4)$$

Under H_0, the sampling distribution of X^2 as computed from formular (3) can be shown to be approximated by a chi-square distribution with degree of freedom = $(p-1)\times(q-1)$, where p= the number of columns and r = the number of rows. Thus, the probability associated with the occurrence of values as large as an observed X^2 is given in Table C9. If an observed value of X^2 is equal or greater that the critical X^2 value given in table C9 for a particular level of significance and for df=$(p-1)\times(q-1)$, the null hypothesis, H_0 is rejected.

Example

This example illustrates how to determine the significance of the differences among 3 groups of data:

The number of accidents per 100,000,000 vehicles at camera intersections.

The number of accidents per 100,000,000 vehicles at non-camera intersections.

The number of accidents per 100,000,000 vehicles at control intersections.

The null hypothesis is that the proportion of numbers of accidents per 100,000,000 vehicles for three types of intersections is the same between before and after period.

<u>Step 1:</u> Determine the average number of accidents per 100,000,000 vehicles per year for each type of intersection.

The accident data was at first in the form of the number of accidents per month at each intersection. The total number of accidents per year at each intersection is determined and categorized into 1-year and 2-year before and 1-year and 2-year after camera installation period. Then, the numbers of accidents per year are measured by per 100,000,000 vehicles to make the frequencies larger so that the inaccuracy due to the small frequencies is avoided. The numbers of accident per 100,000,000 vehicles in the before and after period at each intersection are shown in table C3. The average numbers of accidents per 100,000,000 vehicles of each type of intersection are also determined.

Table C3 Number of Accidents per 100,000,000 vehicles per year

Intersection		Number of accident per 100,000,000 vehicles per year			
		Before		After	
		2 years before	1 years before	1 years after	2 years after
Camera	1	31.1	29.1	43.6	25.4
	2	22.2	11.1	14.8	25.2
	3	30.4	50.7	25.4	14.9
	4	41.4	31.0	38.4	26.6
	5	166.8	142.9	182.6	68.5
	6	42.5	52.0	85.0	39.1
	7	32.2	32.2	26.6	26.3
	8	64.1	84.3	53.2	7.0
	9	12.5	12.5	27.4	43.5
	10	12.5	8.3	5.0	7.5
Total		455.6	454.2	502.0	284.1
Average		**45.6**	**45.4**	**50.2**	**28.4**
Average		**45.5**		**39.3**	
Non-Camera	14	46.6	99.1	112.1	50.7
	15	23.3	46.6	31.1	60.9
Total		70.0	145.7	143.2	111.6
Average		**35.0**	**72.9**	**71.6**	**55.8**
Average		**53.9**		**63.7**	
Control	16	137.0	114.2	106.5	141.1
	17	77.1	77.1	91.3	86.5
	18	30.4	52.2	30.2	17.1
	19	72.4	77.5	81.9	71.0
Total		316.9	320.9	310.0	315.8
Average		**79.2**	**80.2**	**77.5**	**79.0**
Average		**79.7**		**78.2**	

Step 2: Summarize the average number of accidents per 100,000,000 vehicles for each type of intersection.

The data is now prepared in the form that can be statistically test. The results are shown in table C4.

Table C4 Average Number of Accidents for Three types of Intersections

Intersection	Average Number of Accidents/100,000,000 vehicles per Year		
	Before	After	SUM
Camera	45.49(f_{11})	39.30(f_{21})	84.79($f_{.1}$)
Non-Camera	53.92(f_{12})	63.71(f_{22})	117.63($f_{.2}$)
Control	79.72(f_{13})	78.23(f_{23})	157.95($f_{.3}$)
SUM	179.14($f_{1.}$)	181.24($f_{2.}$)	360.37(N)

p = 2, q = 3, degree of freedom = (2-1)(3-1) = 2

Step 3: determine f_{ij}, F_{ij} and X^2 value

For example:

f_{11} = 45.49

Apply formular (4), F_{11}= ($f_{.1}$* $f_{1.}$)/N = (84.79*179.14)/360.37= 42.15

The same formular is applied for every f_{ij}. The results are summarized in table C5

Table C5 Example of f_{ij}, F_{ij}, and X^2 value.

fij	Fij	(fij-Fij)^2/Fij
45.49	42.15	0.26
39.30	42.64	0.26
53.92	58.47	0.35
63.71	59.16	0.35
79.72	78.51	0.02
78.23	79.44	0.02
SUM		**1.27**

From formular (3) the X^2 value is 1.27.

Step 4: Find the Critical X^2 value with degree of freedom equal to 2 at 0.05 significant level from table C.

$X^2_{2,\alpha = 0.05}$ = 5.99 (from table C)

Compare the observed X^2 value with the critical X^2 value;

1.27 < 5.99 therefore, the two attributes are independent of each other. The null hypothesis is accepted. In other words, the proportion of number of accidents per 100,000,000 vehicles at three types of intersection is the same betweeen before and after camera installation period.

3. T test

The t-test has a purpose to determine the significance of difference between two means. Several t techniques can be applied for different types of data. Before applying a t-test, a problem should be examined to find an appropriate technique. Three techniques are presented here for different problems as follows:

- The Pool Variance Technique
- The Separate Variance Technique
- Correlated Data Technique

<u>Method</u>

<u>The Pool Variance Technique</u>

This technique is applied to determine the significance of difference between two means of the data that has following nature:

1. Equal sample sizes between two data groups and no significant difference exists between the two sample variances; or
2. Unequal sample sizes between two data groups and no significant difference exists between the two sample variances; or
3. No correlation between 2 data groups

Formula

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\left(\frac{\sum x_1^2 + \sum x_2^2}{n_1 + n_2 - 2}\right)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

$\overline{X_1}$ = mean of the first sample

$\overline{X_2}$ = mean of the second sample

$\sum x_{1,2}^2 = \sum X^2 - \frac{(\sum X)^2}{N}$

$n_{1,2} =$ sample size

<u>The Separate Variance Technique</u>

This technique is applied to determine the significance of difference between two means of the data that has following nature:

1. Equal sample sizes between two data groups and a significant difference exists between the two sample variances; or
2. Unequal sample sizes between two data groups and a significant difference exists between the two sample variances; or

3. No correlation between 2 data groups

Formula

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

$\overline{X_1}$, $\overline{X_2}$ = mean of the each sample

$s_1^2, s_2^2 =$ variance of each group

$n_1, n_2 =$ sample size of each group

Correlated Data Technique

This technique is applied where two groups of data have been matched or taken from the same individuals. The data, then, is considered correlated. For example, the data is produced from pre- and post-testing on the same subjects. The degree of relationship of two groups is represented by coefficient Pearson r.

Formula

$$r = \frac{N\sum XY - \left[\left(\sum X\right)\left(\sum Y\right)\right]}{\sqrt{\left(N\sum X^2 - \left(\sum X\right)^2\right)\left(N\sum Y^2 - \left(\sum Y\right)^2\right)}}$$

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2} - 2r\left(\frac{s_1}{\sqrt{n_1}}\right)\left(\frac{s_2}{\sqrt{n_2}}\right)}}$$

After the data is examined and the appropriate method is selected, the t value is obtained from the formula. Compare the computed t value with t value from the table C10 at degree of freedom equal to $n_1 + n_2 - 2$.

If the computed t value is less than the t value from the table, the two population means are not significantly different from each other.

If the observed t value is greater than the t value from the table, the two population variances are significantly different from each other.

Example

This example illustrates how to test the difference of means between 2 data categories:

- The number of violations per 10,000 vehicles at 13 camera intersections in the initial period of the camera installation. The initial period is the first 3 months of camera operation.
- The number of violations per 10,000 vehicles at 13 camera intersections in the 4^{th} –9^{th} month of the camera operation.

Step 1: Average violation rates to present the violation rate at the initial period and the 4^{th} –9^{th} month of the camera operation.

For example: find the average number of violation rate at initial period and the 4^{th} -9^{th} month of the camera operation of intersection 1.

Intersection 1		
Year	Month	Number of Violations
2000	Oct (first operation month)	2.79
	Nov	2.48
	Dec	3.31
2001	Jan	2.82
	Feb	2.24
	Mar	2.90
	Apr	1.72
	May	3.82
	Jun	2.71
	Jul	1.05
	:	:
	:	:

Initial period (Oct–Dec); 4^{th} -9^{th} month (Jan–Jun)

Table C6 Number of Violations per 10,000 vehicles at Intersection 1

The average number of violations per month of the initial period

= (2.79+2.48+3.31)/3 = **2.86**

The average number of violations per month of the 12-month after period

= (2.82+2.24+2.90+1.72+3.82+2.71)/6 = **2.70**

The same method is applied for every intersection. The results are shown in table C7

Table C7 Average Number of Violations per 10,000 vehicles at initial period and 6-month after period.

Intersection	Number of Violations per Month	
	Initial period (3 months after camera installation)	6 months after camera installation
	(x)	(y)
1	**2.86**	**2.70**
2	1.59	0.59
3	0.64	0.05
4	2.33	1.19
5	8.68	6.73
6	2.13	2.34
7	3.45	1.67
8	2.15	2.21
9	2.44	2.26
10	2.21	2.15
11	0.99	0.98
12	2.08	1.74
13	1.24	1.34
Total	32.8	26.0

Step 2: Examine the data to find the appropriate t technique.

First of all, test the data by F test to determine if there is a significance of difference in variances between the 2 data groups. The detail of how to conduct the F test is previously provided.

After test this data by F test, the results show that there is no significance of difference in variances of violation rates between at initial period and the 4^{th} -9^{th} month period. Finally, it is found that these 2 groups of data have equal sample sizes and no significant difference in variances exists between them. Therefore, the pool variance technique is chosen.

Step 3: Find the t value using the following formula

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\left(\frac{\sum x_1^2 + \sum x_2^2}{n_1 + n_2 - 2}\right)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

$\overline{X_1}$ = mean of the first sample

$\overline{X_2}$ = mean of the second sample

$$\sum x_{1,2}^2 = \sum X^2 - \frac{(\sum X)^2}{N}$$

$n_{1,2} =$ sample size
$\overline{X}_1 = 2.52$ $\overline{X}_2 = 2.00$
$\sum x_1^2 = 41.9$ $\sum x_2^2 = 31.2$
$n_1 = 13$ $n_2 = 13$
t = 0.74

Step 3: Find the t value from table C10.
Degree of freedom = $n_1 + n_2 - 2$ = 13+13-2 = 24
Find the t_{22} at 0.05 significant level from table C10.

$t_{22,\ \alpha = 0.05} = 2.06$

Compare the computed t value with the t value from the table;

0.74 < 2.07 therefore, the two population means are not significantly different from each other. In other words, there is no significant difference in mean of the number of violations per 10,000 vehicles between at initial period and the 4th -9th months of the camera operation.

Table C8
The 5% (Roman Type) and 1% (Boldface Type) Points for the Distribution of F

Numerator df

Denominator df	1	2	3	4	5	6	7	8	9	10	11	12	14	16	20	24	30	40	50	75	100	200	500	∞
1	161 **4,052**	200 **4,999**	216 **5,403**	225 **5,625**	230 **5,764**	234 **5,859**	237 **5,928**	239 **5,981**	241 **6,022**	242 **6,056**	243 **6,082**	244 **6,106**	245 **6,142**	246 **6,169**	248 **6,208**	249 **6,234**	250 **6,258**	251 **6,286**	252 **6,302**	253 **6,323**	253 **6,334**	254 **6,352**	254 **6,361**	254 **6,366**
2	18.51 **98.49**	19.00 **99.00**	19.16 **99.17**	19.25 **99.25**	19.30 **99.30**	19.33 **99.33**	19.36 **99.34**	19.37 **99.36**	19.38 **99.38**	19.39 **99.40**	19.40 **99.41**	19.41 **99.42**	19.42 **99.43**	19.43 **99.44**	19.44 **99.45**	19.45 **99.46**	19.46 **99.47**	19.47 **99.48**	19.47 **99.48**	19.48 **99.49**	19.49 **99.49**	19.49 **99.49**	19.50 **99.50**	19.50 **99.50**
3	10.13 **34.12**	9.55 **30.82**	9.28 **29.46**	9.12 **28.71**	9.01 **28.24**	8.94 **27.91**	8.88 **27.67**	8.84 **27.49**	8.81 **27.34**	8.78 **27.23**	8.76 **27.13**	8.74 **27.05**	8.71 **26.92**	8.69 **26.83**	8.66 **26.69**	8.64 **26.60**	8.62 **26.50**	8.60 **26.41**	8.58 **26.35**	8.57 **26.27**	8.56 **26.23**	8.54 **26.18**	8.54 **26.14**	8.53 **26.12**
4	7.71 **21.20**	6.94 **18.00**	6.59 **16.69**	6.39 **15.98**	6.26 **15.52**	6.16 **15.21**	6.09 **14.98**	6.04 **14.80**	6.00 **14.66**	5.96 **14.54**	5.93 **14.45**	5.91 **14.37**	5.87 **14.24**	5.84 **14.15**	5.80 **14.02**	5.77 **13.93**	5.74 **13.83**	5.71 **13.74**	5.70 **13.69**	5.68 **13.61**	5.66 **13.57**	5.65 **13.52**	5.64 **13.48**	5.63 **13.46**
5	6.61 **16.26**	5.79 **13.27**	5.41 **12.06**	5.19 **11.39**	5.05 **10.97**	4.95 **10.67**	4.88 **10.45**	4.82 **10.27**	4.78 **10.15**	4.74 **10.05**	4.70 **9.96**	4.68 **9.89**	4.64 **9.77**	4.60 **9.68**	4.56 **9.55**	4.53 **9.47**	4.50 **9.38**	4.46 **9.29**	4.44 **9.24**	4.42 **9.17**	4.40 **9.13**	4.38 **9.07**	4.37 **9.04**	4.36 **9.02**
6	5.99 **13.74**	5.14 **10.92**	4.76 **9.78**	4.53 **9.15**	4.39 **8.75**	4.28 **8.47**	4.21 **8.26**	4.15 **8.10**	4.10 **7.98**	4.06 **7.87**	4.03 **7.79**	4.00 **7.72**	3.96 **7.60**	3.92 **7.52**	3.87 **7.39**	3.84 **7.31**	3.81 **7.23**	3.77 **7.14**	3.75 **7.09**	3.72 **7.02**	3.71 **6.99**	3.69 **6.94**	3.68 **6.90**	3.67 **6.88**
7	5.59 **12.25**	4.74 **9.55**	4.35 **8.45**	4.12 **7.85**	3.97 **7.46**	3.87 **7.19**	3.79 **7.00**	3.73 **6.84**	3.68 **6.71**	3.63 **6.62**	3.60 **6.54**	3.57 **6.47**	3.52 **6.35**	3.49 **6.27**	3.44 **6.15**	3.41 **6.07**	3.38 **5.98**	3.34 **5.90**	3.32 **5.85**	3.29 **5.78**	3.28 **5.75**	3.25 **5.70**	3.24 **5.67**	3.23 **5.65**
8	5.32 **11.26**	4.46 **8.65**	4.07 **7.59**	3.84 **7.01**	3.69 **6.63**	3.58 **6.37**	3.50 **6.19**	3.44 **6.03**	3.39 **5.91**	3.34 **5.82**	3.31 **5.74**	3.28 **5.67**	3.23 **5.56**	3.20 **5.48**	3.15 **5.36**	3.12 **5.28**	3.08 **5.20**	3.05 **5.11**	3.03 **5.06**	3.00 **5.00**	2.98 **4.96**	2.96 **4.91**	2.94 **4.88**	2.93 **4.86**
9	5.12 **10.56**	4.26 **8.02**	3.86 **6.99**	3.63 **6.42**	3.48 **6.06**	3.37 **5.80**	3.29 **5.62**	3.23 **5.47**	3.18 **5.35**	3.13 **5.26**	3.10 **5.18**	3.07 **5.11**	3.02 **5.00**	2.98 **4.92**	2.93 **4.80**	2.90 **4.73**	2.86 **4.64**	2.82 **4.56**	2.80 **4.51**	2.77 **4.45**	2.76 **4.41**	2.73 **4.36**	2.72 **4.33**	2.71 **4.31**
10	4.96 **10.04**	4.10 **7.56**	3.71 **6.55**	3.48 **5.99**	3.33 **5.64**	3.22 **5.39**	3.14 **5.21**	3.07 **5.06**	3.02 **4.95**	2.97 **4.85**	2.94 **4.78**	2.91 **4.71**	2.86 **4.60**	2.82 **4.52**	2.77 **4.41**	2.74 **4.33**	2.70 **4.25**	2.67 **4.17**	2.64 **4.12**	2.61 **4.05**	2.59 **4.01**	2.56 **3.96**	2.55 **3.93**	2.54 **3.91**
11	4.84 **9.65**	3.98 **7.20**	3.59 **6.22**	3.36 **5.67**	3.20 **5.32**	3.09 **5.07**	3.01 **4.88**	2.95 **4.74**	2.90 **4.63**	2.86 **4.54**	2.82 **4.46**	2.79 **4.40**	2.74 **4.29**	2.70 **4.21**	2.65 **4.10**	2.61 **4.02**	2.57 **3.94**	2.53 **3.86**	2.50 **3.80**	2.47 **3.74**	2.45 **3.70**	2.42 **3.66**	2.41 **3.62**	2.40 **3.60**
12	4.75 **9.33**	3.88 **6.93**	3.49 **5.95**	3.26 **5.41**	3.11 **5.06**	3.00 **4.82**	2.92 **4.65**	2.85 **4.50**	2.80 **4.39**	2.76 **4.30**	2.72 **4.22**	2.69 **4.16**	2.64 **4.05**	2.60 **3.98**	2.54 **3.86**	2.50 **3.78**	2.46 **3.70**	2.42 **3.61**	2.40 **3.56**	2.36 **3.49**	2.35 **3.46**	2.32 **3.41**	2.31 **3.38**	2.30 **3.36**
13	4.67 **9.07**	3.80 **6.70**	3.41 **5.74**	3.18 **5.20**	3.02 **4.86**	2.92 **4.62**	2.84 **4.44**	2.77 **4.30**	2.72 **4.19**	2.67 **4.10**	2.63 **4.02**	2.60 **3.96**	2.55 **3.85**	2.51 **3.78**	2.46 **3.67**	2.42 **3.59**	2.38 **3.51**	2.34 **3.42**	2.32 **3.37**	2.28 **3.30**	2.26 **3.27**	2.24 **3.21**	2.22 **3.18**	2.21 **3.16**

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Table C9
X^2 Values

PROBABILITY

df	.90	.80	.70	.50	.30	.20	.10	.05	.02	.01	.001
1	.016	.064	.15	.46	1.07	1.64	2.71	3.84	5.41	6.64	10.83
2	.21	.45	.71	1.39	2.41	3.22	4.60	5.99	7.82	9.21	13.82
3	.58	1.00	1.42	2.37	3.66	4.64	6.25	7.82	9.84	11.34	16.27
4	1.06	1.65	2.20	3.36	4.88	5.99	7.78	9.49	11.67	13.28	18.46
5	1.61	2.34	3.00	4.35	6.06	7.29	9.24	11.07	13.39	15.09	20.52
6	2.20	3.07	3.83	5.35	7.23	8.56	10.64	12.59	15.03	16.81	22.46
7	2.83	3.82	4.67	6.35	8.38	9.80	12.02	14.07	16.62	18.48	24.32
8	3.49	4.59	5.53	7.34	9.52	11.03	13.36	15.51	18.17	20.09	26.12
9	4.17	5.38	6.39	8.34	10.66	12.24	14.68	16.92	19.68	21.67	27.88
10	4.86	6.18	7.27	9.34	11.78	13.44	15.99	18.31	21.16	23.21	29.59
11	5.58	6.99	8.15	10.34	12.90	14.63	17.28	19.68	22.62	24.72	31.26
12	6.30	7.81	9.03	11.34	14.01	15.81	18.55	21.03	24.05	26.22	32.91
13	7.04	8.63	9.93	12.34	15.12	16.98	19.81	22.36	25.47	27.69	34.53
14	7.79	9.47	10.82	13.34	16.22	18.15	21.06	23.68	26.87	29.14	36.12
15	8.55	10.31	11.72	14.34	17.32	19.31	22.31	25.00	28.26	30.58	37.70
16	9.31	11.15	12.62	15.34	18.42	20.46	23.54	26.30	29.63	32.00	39.29
17	10.08	12.00	13.53	16.34	19.51	21.62	24.77	27.59	31.00	33.41	40.75
18	10.86	12.86	14.44	17.34	20.60	22.76	25.99	28.87	32.35	34.80	42.31
19	11.65	13.72	15.35	18.34	21.69	23.90	27.20	30.14	33.69	36.19	43.82
20	12.44	14.58	16.27	19.34	22.78	25.04	28.41	31.41	35.02	37.57	45.32
21	13.24	15.44	17.18	20.34	23.86	26.17	29.62	32.67	36.34	38.93	46.80
22	14.04	16.31	18.10	21.24	24.94	27.30	30.81	33.92	37.66	40.29	48.27
23	14.85	17.19	19.02	22.34	26.02	28.43	32.01	35.17	38.97	41.64	49.73
24	15.66	18.06	19.94	23.34	27.10	29.55	33.20	36.42	40.27	42.98	51.18
25	16.47	18.94	20.87	24.34	28.17	30.68	34.38	37.65	41.57	44.31	52.62
26	17.29	19.82	21.79	25.34	29.25	31.80	35.56	38.88	42.86	45.64	54.05
27	18.11	20.70	22.72	26.34	30.32	32.91	36.74	40.11	44.14	46.96	55.48
28	18.94	21.59	23.65	27.34	31.39	34.03	37.92	41.34	45.42	48.28	56.89
29	19.77	22.48	24.58	28.34	32.46	35.14	39.09	42.56	46.69	49.59	58.30
30	20.60	23.36	25.51	29.34	33.53	36.25	40.26	43.77	47.96	50.89	59.70

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Table C10
t Values

	Level of significance for one-tailed test					
	.10	.05	.025	.01	.005	.0005
	Level of significance for two-tailed test					
df	.20	.10	.05	.02	.01	.001
1	3.078	6.314	12.706	31.821	63.657	636.619
2	1.886	2.920	4.303	6.965	9.925	31.598
3	1.638	2.353	3.182	4.541	5.841	12.941
4	1.533	2.132	2.776	3.747	4.604	8.610
5	1.476	2.015	2.571	3.365	4.032	6.859
6	1.440	1.943	2.447	3.143	3.707	5.959
7	1.415	1.895	2.365	2.998	3.499	5.405
8	1.397	1.860	2.306	2.896	3.355	5.041
9	1.383	1.833	2.262	2.821	3.250	4.781
10	1.372	1.812	2.228	2.764	3.169	4.587
11	1.363	1.796	2.201	2.718	3.106	4.437
12	1.356	1.782	2.179	2.681	3.055	4.318
13	1.350	1.771	2.160	2.650	3.012	4.221
14	1.345	1.761	2.145	2.624	2.977	4.140
15	1.341	1.753	2.131	2.602	2.947	4.073
16	1.337	1.746	2.120	2.583	2.921	4.015
17	1.333	1.740	2.110	2.567	2.898	3.965
18	1.330	1.734	2.101	2.552	2.878	3.922
19	1.328	1.729	2.093	2.539	2.861	3.883
20	1.325	1.725	2.086	2.528	2.845	3.850
21	1.323	1.721	2.080	2.518	2.831	3.819
22	1.321	1.717	2.074	2.508	2.819	3.792
23	1.319	1.714	2.069	2.500	2.807	3.767
24	1.318	1.711	2.064	2.492	2.797	3.745
25	1.316	1.708	2.060	2.485	2.787	3.725
26	1.315	1.706	2.056	2.479	2.779	3.707
27	1.314	1.703	2.052	2.473	2.771	3.690
28	1.313	1.701	2.048	2.467	2.763	3.674
29	1.311	1.699	2.045	2.462	2.756	3.659
30	1.310	1.697	2.042	2.457	2.750	3.646
40	1.303	1.684	2.021	2.423	2.704	3.551
60	1.296	1.671	2.000	2.390	2.660	3.460
120	1.289	1.658	1.980	2.358	2.617	3.373
∞	1.282	1.645	1.960	2.326	2.576	3.291

VITA

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