NCHRP

SYNTHESIS 310

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Impact of Red Light Camera Enforcement on Crash Experience

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Impact of Red Light Camera Enforcement on Crash Experience

A Synthesis of Highway Practice

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SUBJECT AREAS
Highway Operations, Capacity, and Traffic Control, and Safety and Human Performance

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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FOREWORD

By Staff
Transportation Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

The synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This report of the Transportation Research Board will be of interest to local, regional, state, and federal officials, as well as to other transportation professionals and the public who work with them in the area of traffic engineering. This report examines what impact red light running camera enforcement has had on crashes and related crash severity at intersections. No new data collection or analysis was performed. The information base came from published literature, various websites, and from responses to a questionnaire distributed to those jurisdictions known or believed to have installed red light running camera systems.

Based on the information acquired and reviewed for this effort, it appears that red light running automated enforcement can be an effective safety countermeasure. However, there is currently insufficient empirical evidence based on statistically rigorous experimental design to state this conclusively.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write this report. Both the consultant and the members of the oversight panel are acknowledged on the title page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

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Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Thomas W. Brahms, Executive Director, Institute of Transportation Engineers; Lt. Glenn Hansen, Howard County Police Department; Patrick Hasson, Federal Highway Administration; Joseph E. Hummer, Associate Professor, Department of Civil Engineering, North Carolina State University; Frank R. McCullagh, Infrastructure Asset Manager, Transportation Planning Division, Arizona Department of Transportation; Hon. Patrick E. McGann, Supervising Judge, Chicago Traffic Center; Richard F. Pain, Senior Program Officer, Transportation Research Board; Richard A. Retting, Senior Transportation Engineer, Insurance Institute for Highway Safety; Samuel C. Tignor, Technical Director of Safety Research and Development, Federal Highway Administration; James David Valle-Schwenk, Assistant Transportation Engineer, City and County of San Francisco Department of Parking and Traffic; and Robert C. Weinholzer, State Programs Administrator, Minnesota Department of Transportation.

This study was managed by Donna Vlasak, Senior Program Officer, who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in project scope development was provided by Stephen F. Maher and Jon Williams, Managers, Synthesis Studies. Don Tippman was responsible for editing and production. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

IMPACT OF RED LIGHT CAMERA ENFORCEMENT ON CRASH EXPERIENCE

SUMMARY

The incidence of motorists entering a signalized intersection with the traffic signal showing red has become a national safety issue. When a motorist enters the intersection on red, commonly referred to as red light running, there is a chance that he or she will collide with a vehicle that has entered the intersection legally, either from the cross street or, in the case of a left-turning vehicle, from the opposite direction. Red light running is not only a traffic violation problem, but also a safety problem, for it can result in injuries and fatalities. Traditionally, the enforcement of this violation involves police observing the behavior and, after pulling the motorist to the side of the road, issuing a citation. However, this enforcement can now be automated through the use of red light camera systems that detect an offending motorist, capture an image of the license plate, and issue a citation by mail. Although these automated red light camera enforcement systems have been used in other countries for more than 20 years, it has been only in the last 10 years that they have been used in the United States.

For a variety of reasons the use of automated enforcement systems has not been widespread. One relates to the lack of convincing evidence that these systems improve safety, not only at the signalized intersections where they are used, but also throughout the jurisdiction that uses them. The literature shows that they reduce the frequency of violations, but questions remain about what impact they have on crash experience. The assumption or hypothesis of the safety effect of automated enforcement using cameras is that they reduce the incidence of red light running and thereby reduce the likelihood of related crashes. The most obvious crash type that would be reduced is the angle crash, involving a violating vehicle with an adjacent vehicle proceeding through the intersection legally on a green signal display. Another crash type likely to be reduced is a vehicle turning left colliding with a vehicle moving through the intersection from the opposite approach direction. For the latter scenario, the turning vehicle could be violating the red when the opposite direction has green, or vice-versa. On the other hand, there is a concern that rear-end collisions of vehicles approaching the intersection will increase with traffic enforcement. Knowing that there is a camera system, and on seeing the yellow display, a more cautious motorist may stop more abruptly, causing the following motorist, not anticipating the need to stop and likely to be following too closely, to hit the lead vehicle from behind. Assuming that these crash types produce equal crash severity, then a net benefit would accrue if the crash reductions of the angle type exceeded any crash increases of the rear-end type. In general, angle crashes are usually more severe and, therefore, even a zero change in total crashes may prove to be safer, if there is a smaller proportion of angle to rear-end crashes with the use of cameras.

This synthesis was undertaken to address the safety issue of red light running. The primary objective was to determine, from available information, what impact red light running camera enforcement has had on crashes and related severity. This impact was to be identified for intersections where a camera(s) had been installed and, if possible, areawide

within the jurisdiction or district. Furthermore, it was important to identify factors—geometry, operations, signage, public outreach, and others—that influence the observed changes. As part of this study, there was a supplementary objective of reporting how crash analyses were and are to be conducted and which findings could be used as guidance for other evaluations.

As with all synthesis documents, this report relied exclusively on available information; no new data collection or analysis was performed. The information came from published literature, various websites, and from a questionnaire sent to more than 50 jurisdictions, known or believed to have installed red light running camera systems.

The findings that can be drawn from the information accumulated are as follows. There is a preponderance of evidence, albeit not conclusive, indicating that red light running camera systems improve the overall safety of intersections where they are used. As expected, angle crashes are usually reduced and, in some situations, rear-end crashes increase, but to a lesser extent. There is also evidence, also not conclusive, that there is a "spillover" effect to other signalized intersections within a jurisdiction. To date, there have not been any research and effectiveness evaluations conducted to address or answer the question of what factors related to the intersection design or operations, the use of warning signs, the level of fines, or any public outreach, have on observed crash changes.

From the information that has been acquired and reviewed, it appears that automated enforcement of red light running can be an effective safety countermeasure. However, there is not enough empirical evidence based on a statistically rigorous experimental design to state that conclusively.

Nearly every study and crash analysis reviewed had some experimental design or analysis flaw. In many cases the flaw in the analysis was because of the lack of a proper control group, which would allow a valid comparison of the observed changes, increases or decreases, with changes in signalized intersections that did not have cameras. Cameras tend to be installed at problem locations; those with higher than average crash experience. Because of the manner in which crashes occur over time at a given location, these types of locations can experience reductions in subsequent years even without intervention. To account for this "regression-to-mean" phenomenon, control or reference sites are needed. In some cases, a reduction was observed, which when exposed to statistical testing proved to be statistically insignificant. This statistically insignificant finding is often attributed to small sample sizes pertaining to sites and the crash frequency at each site.

As the use of automated systems becomes more widespread and more mature, there will be better opportunities to conduct the research needed to reach a conclusive finding and to provide guidelines for where these systems may be appropriate. Those agencies that choose to use these systems will want to know which locations should be equipped, the expected safety benefit, and how many intersections need to be equipped to bring about an areawide benefit

CHAPTER ONE

INTRODUCTION

BACKGROUND

The incidence of motorists entering an intersection when the traffic signal has turned red has become a national safety issue. When a motorist enters the intersection on red, commonly referred to as red light running (RLR), there is a chance that he or she will collide with a vehicle that has entered the intersection legally, either from the cross street or, in the case of a left-turning vehicle, from the opposite direction. Hence, red light running is not only a traffic violation problem, but also a safety problem because it can result in injuries and fatalities. Some background statistics on the magnitude of this problem are provided in this chapter.

According to the Insurance Institute for Highway Safety (*1*), during the period from 1992 to 1998, almost 6,000 people (approximately 850 per year) died in RLR crashes in the Unites States, and another 1.4 million (approximately 200,000 per year) were injured in crashes that involved red light running. A study by Retting et al. (*2*) explored the frequency of RLR crashes. Using the 1996 General Estimates System—a crash database maintained by the National Highway Traffic Safety Administration that is based on a naturally representative probability sample of crashes with a varying degree of injury and property damage—it was estimated that approximately 260,000 RLR crashes occur annually in the United States.

Using 1997 data from the General Estimates System and a narrower definition of RLR crashes, Smith et al. (*3*) estimated that approximately 97,000 crashes, resulting in 961 fatalities, could be attributed to red light running in the United States. Table 1 shows the distribution of crashes by severity for all signalized intersections, those involving angle collisions, and those considered to be the result of red light running. As seen, slightly more than 44% of the fatalities at signalized intersections were attributed to red light running.

Traffic laws are generally enforced by police agencies. Traditionally, the enforcement for this type of violation involves police monitoring signalized intersections for violators, following the offending vehicle, pulling the offender off to the side of the street, and issuing the citation or warning. Such activity is costly and can be hazardous. Therefore, this type of manual enforcement is generally infrequent and usually does not have a positive lasting effect.

Using readily available vehicle detection and camera surveillance technology, it is now possible to automate this type of enforcement. RLR camera systems have been available for more than 30 years; however, it has only been since 1992, when two systems were installed in Jackson, Mississippi, that they have been used in the United States. Their use is slowly but steadily increasing across many states and local jurisdictions. Deployment of the systems has been limited because of the many concerns that affect public and lawmaker acceptance. One of these concerns is to what extent red light camera systems change crash experience at the signalized intersections where they are used and at other signalized intersections within the jurisdiction. Initial experience with red light cameras implies that their presence reduces the frequency of red light running; however, it is not clear whether a net safety gain is realized. As red light violations are reduced, angle crashes should also be reduced, but there is a concern that rear-end crashes will increase. A net safety gain is realized if the generally more severe angle crashes are reduced to a greater extent than is a potential increase in less severe rear-end crashes.

TABLE 1
CRASHES AT SIGNALIZED INTERSECTIONS, 1997

Crash Measure	Signalized Intersections	Angle Collisions at Signalized Intersections	Red Light Running
Fatal crashes	2,176	1,587	961
Injury crashes	318,000	261,000	51,000
PDO crashes	469,000	361,000	45,000
Total crashes	789,000	623,000	97,000
Fatalities	2,344	1,729	1,059
Injuries	543,000	464,000	91,000

Note: PDO = property damage only.

[*Source*: Smith et al. (*3*)].

OBJECTIVES

The primary objective of this synthesis was to determine, from available information, what impact RLR camera enforcement has had on crashes and their related severity. This impact was to be identified for intersections where a camera(s) had been installed and, if possible, areawide within the jurisdiction or district. Furthermore, it was important to identify factors—geometry, operations, signage, public outreach, and others—that influence the observed changes. As part of this crash analysis, there was a supplementary objective of reporting how crash analyses were and are to be conducted, and which findings could be used as guidance for other evaluations.

INFORMATION COLLECTION

This report relied exclusively on available information; no new data collection or analysis was performed. The information came from published literature, various websites, and from a questionnaire (Appendix A) distributed to more than 50 jurisdictions that were known or believed to have installed RLR camera systems.

REPORT CONTENT

The remainder of the report is organized as follows.

Chapter two presents the findings from the literature review, which focused on published reports of crash studies related to the use of RLR cameras. Unpublished information, which included material from relevant websites, is included as well.

Chapter three presents the findings from the questionnaire survey. The summary findings for each survey question asked is presented and discussed.

Chapter four discusses alternative crash analysis procedures that can be used for evaluating the safety impact of RLR camera deployments.

Chapter five summarizes the information from previous chapters and draws conclusions where possible.

CHAPTER TWO

RED LIGHT RUNNING AUTOMATED ENFORCEMENT SYSTEMS—FINDINGS FROM PRIOR STUDIES OF CRASH IMPACTS

This chapter presents the findings of the literature review on crash impacts of RLR camera systems. The primary focus of the literature review was to identify analysis and findings related to crash experience with using red light cameras. Each report was critically reviewed to determine the analysis methodology, database, and conclusions drawn from the analysis. Although the findings as reported by the authors of each study are provided, these findings were reviewed in context of the analysis employed. In many cases the information provided in the report was insufficient to make a complete assessment of the adequacy of the analysis.

Some introductory remarks are appropriate. First, it should be recognized that red light camera enforcement programs involve more than just implementing the camera systems and collecting fines. Such programs include, but are not limited to, education and publicity, level of fines, adjudication, the type of signage (at gateways to jurisdictions versus at equipped intersections), the number of intersections with cameras, and the baseline condition of the traffic signal operations, especially yellow-change intervals. These elements, which may influence any change in crash experience, are not consistent among the various jurisdictions and, therefore, some variation in automated enforcement effectiveness is to be expected.

Second, although the evaluation of safety effectiveness is discussed in chapter four, certain aspects of experimental design related to treatment evaluation should be understood at this point. Effective experimental design for treatment evaluation uses a before-and-after design with a randomized control group (*4*). For an ideal experimental design there would be a group of signalized intersections that are candidates for a treatment—in this case, RLR cameras. A portion would receive the treatment and the others would be considered control sites. The selection of both groups would be by a random procedure, with the intent that both groups would be equal on all factors except for the implementation of the treatment. In reality, cameras are installed at problem locations manifested by a high frequency of violations and/or crashes. An evaluator must then resort to selecting sites that are "comparative." From an experimental design point of view, this means that the untreated sites have the same level of factors that affect the intersection safety, such as geometry, volume, and traffic control. Therefore, in this study, reference will be made to treatment, control, and comparison sites. For the purposes of this report, the terms "control" and "comparison" will be used interchangeably as stated by the various authors. However, it can be stated here that there have been no studies that have employed the before-and-after design with randomized control site design.

Another factor influencing what constitutes a true comparison or control site is the so-called "halo" effect. In their review of literature on the effects of red light cameras on violations and crashes, Retting et al. (*1*) provide convincing data to show that automated enforcement programs are effective in reducing violations at both camera-equipped locations and nonequipped locations within the community. To the extent that reduced violations will yield a reduced number of crashes, selecting a nonequipped intersection as a comparison and control site for crash analysis within a community will affect the outcome.

Also related to safety evaluations using crash statistics is the issue of regression to mean. At a given location, there are fluctuations in the frequency of crashes per unit of time. A high crash frequency intersection during one year may not be so the next year, without any change in conditions. This variability in crash occurrence should be accounted for in before-and-after evaluations.

The findings of the literature review from the United States and other countries are presented here. Because automated enforcement for red light running started outside of the United States, the literature review starts with studies from foreign countries.

STUDIES FROM FOREIGN COUNTRIES

Australia

Maisey (*5*) performed the first study of RLR cameras in Australia in 1981. Although the report was not obtainable, it was reviewed by two other Australian researchers. The first was South et al. (*6*), who stated that the Maisey study involved only one camera installation at a single Perth intersection for 1 year, beginning in July 1979. Apparently, the reported data suggested that the camera brought about a reduction in right-angle crashes along with an increase in rear-end crashes. Maisey believed that this result was inconclusive because of the small sample number of crashes and the possibility that the chosen intersection was atypical. The second review was by Andreassen (*7*), who provided additional information on the Maisey study. He noted that one intersection with a RLR camera was compared with that of nine other intersections. Furthermore, he claims that Maisey reported that there were 50% fewer "right angle and indirect right angle" crashes in the first year of operation compared with the previous year, whereas the nine other sites combined increased by 12.5%. He also reported a nonsignificant increase of 71.1% for rear-end crashes at the RLR camera site. Andreassen was critical of Maisey's reporting, citing the following deficiencies:

- Maisey failed to report that a 2-year comparison showed that the crashes were similar before and after.
- Maisey's claim of significant difference between the before and after was incorrect because of a misinterpretation of the chi-square value.

The South et al. (*6*) study, performed in Melbourne, included 46 camera-equipped intersections (treatment sites) and 50 nonequipped signalized intersections as control sites. The treatment and control sites were selected to be as similar as possible with regard to geometrics and speed limits. The before period was from 1979 to 1984, and the after period from 1984 through 1986. To normalize the difference in time periods, a crash-per-year statistic was used. The analysis was based on a disaggregation of six crash types described as

1. Right angle—vehicles from adjacent approaches collide at right angles;
2. Right angle (turning)—vehicles from adjacent approaches with one or both vehicles turning (because motorists drive on the left side of the road in Australia, this would correspond to left-turning vehicles in the United States);
3. Right against—right-turning vehicle collides with oncoming vehicles (this would correspond to left-turning vehicles in the United States);
4. Rear end—vehicle collides with rear of another vehicle;
5. Rear end (turning)—rear-end collision in which the front vehicle was intending to turn at the intersection; and
6. Other.

The statistical analysis method used to compare the treatment and control sites was a 2 by 2 contingency table analysis using a chi-square test for independence. The overall results of the analysis are given in Table 2, which shows that there was a statistically significant reduction in right-angle crashes, with no statistically significant changes in all other categories. However, as pointed out by Andreassen (*7*), whose own study will be discussed later, the chi-square value for significance is 3.84 for the selected probability level and degrees of freedom. Therefore, South et al. (*6*) should have concluded that the observed right-angle crash reduction was not statistically significant as well.

TABLE 2
RESULTS OF RED LIGHT CAMERA USE

Accident Type	Change (%)	Statistical Significance
Right angle	–32	Yes
Right angle (turn)	–25	No
Left against through	+2	No
Rear end	–30.8	No
Rear end (turn)	+28.2	No
Other	–2.2	No
All crashes	–6.7	No
No. of casualties	–10.4	Not tested

[*Source*: South et al. (*6*)].

In 1987, an RLR camera program commenced in the Sydney metropolitan area. Camera housings and signs were installed at 20 locations from January 1988 to June 1989, and six cameras were circulated among the sites. A study of the crash effects was undertaken by Hillier et al. (*8*) of the New South Wales Roads and Traffic Authority. The study, published in 1993, included 16 intersections with cameras and another 16 intersections as control (the control sites were matched on the basis of crash history, traffic volume, and intersection configuration). The camera (treatment) and control sites were grouped as follows:

- Eight most-used camera sites,
- Eight least-used camera sites,
- Eight most-used control sites, and
- Eight least-used control sites.

The distinction between most used and least used is that at the least-used sites an active camera was not in place much of the time. The authors note that at the least-used camera sites, the camera was positioned for the approaches that did not have the highest incidence of red light running, and hence fewer violations were detected. It was also noted that the eight least-used control sites had other changes (e.g., left-turn lanes, S-lanes, and added signal phases) and therefore should be considered as a different group—an "other countermeasures" group.

A 2-year before (1986 and 1987) and 2-year after (1989 and 1990) analysis period was used. The report provides several before-and-after comparison tables, with percent changes reported. Also, a log-linear analysis was performed, although not much information is provided on the statistical methodology. The primary findings are summarized in Table 3, which shows the percent change from before to after for three crash statistics and the four camera and control groups. The researchers concluded that

- Red light cameras, in general, appeared to reduce right-angle and right- (left-) turn against crashes, and

TABLE 3
BEFORE-AND-AFTER CHANGES IN CRASHES, SYDNEY, AUSTRALIA

Intersection Group	Percent Change		
	Target Crashes	Rear-End Crashes	Overall Casualty Crashes
Most-used camera sites	–48	+62	–28
Least-used camera sites	–49	+27	–33
Most-used control sites	+2	–29	+17
Least-used control sites (other countermeasures)	–52	–18	–39

Notes: –, decrease; +, increase.

to increase (to a smaller extent) rear-end crashes. The overall crash severity was reduced.

- Red light camera hardware (signposting, signs, and housing for cameras) appeared to be effective at reducing right-angle and right- (left-) turn against crashes, even when seldom used as active sites.
- Other suitable countermeasures to the target crash types, such as turning lanes, S-lanes, and additional signal phases, also appear to be as effective as red light cameras.
- Because "most-used control sites" did not demonstrate any significant reduction suggested that there might not be any spillover (or halo) effect on RLR crashes at noncamera sites.

The analysis of the crash experience also led Hillier et al. (*8*) to conclude that red light cameras should be limited to locations with a clear history of RLR crashes.

With regard to the last bulleted conclusion, it should be noted that red light camera warning signs were posted at camera-equipped sites only. Although it is not proven, the spillover effect is believed to be influenced by the warning sign practice. It is thought that there would be a greater spillover effect if there were warning signs placed on streets shortly after a jurisdiction is entered, in addition to the signs placed at equipped intersections.

The RLR camera program in Adelaide, South Australia, began in July 1988. Five cameras were rotated among 15 sites, marked with signs, in the metropolitan area. Mann et al. (*9*), from the South Australian Department of Transport, evaluated the effectiveness of the program by comparing the crash change at 8 RLR camera sites with that of 14 similar noncamera sites for 5 years before vis-à-vis 5 years after installation. Also, there was a third set of five sites where, in addition to cameras, there were significant changes in signal phasing and/or road geometry. The researchers drew the following conclusions from their analysis:

- Although there were observed reductions in casualty-producing crashes, because of a lack of statistical significance, there was no evidence that the cameras were effective in preventing crashes.
- The sites with RLR cameras and the other modifications showed significantly greater crash reductions than did the control group, but the effects of RLR cameras could not be isolated.
- There was a strong improvement in crash rates at all sites, which was attributed to general improvements in road safety and the implementation of 4-s yellow phasing (increased from 3 s) that was introduced throughout the metropolitan area at the same time as the RLR camera program.

The researchers also noted two methodological issues inherent in the analyses that are prevalent in most of the studies discussed in this synthesis.

- The small number of intersections may have prevented a statistical detection of small effects.
- RLR cameras were installed at high-risk (crashes) intersections and therefore the control group is not strictly comparable with the treatment group. The regression-to-mean effect could have influenced the results.

In 1995, Andreassen (*7*) reported on his study of the long-term effect on crash types of red light cameras at 41 signalized intersections in Melbourne, from 1979 to 1989. His analysis was addressed in several ways.

- A grouped analysis taking the predominant accident types for all the RLR camera sites together and comparing the changes over time with the changes in the same crash types for the areas of metropolitan Melbourne and the rest of the state, as well as traffic signals in the metropolitan Melbourne area;
- A separate analysis of each crash type for the 41 sites;
- A classification of crashes at the individual RLR camera sites according to whether they involved the approach on which the camera was installed;
- An analysis of the frequency of each crash type before RLR camera installation and stratification of frequencies to ascertain if there was any difference in effect by initial frequency;
- Consideration of both direction and frequency; and
- Comparison of changes at the RLR camera sites with changes in crashes at traffic signals.

Of these various analyses, the most significant finding is shown in Table 4. The overall conclusion made by

TABLE 4
CHANGE IN CRASH TYPES AT RED LIGHT CAMERA SITES IN MELBOURNE, AUSTRALIA

Crash Type	Changes in Crashes with Red Light Cameras
Hit pedestrian	No significant change over time
Angle (adjacent approaches)	Sites with >2 crashes per year decreased for the first 4 years, but then no change Sites with ≤2 crashes per year had increase of 2.5 times
Left turn through	Sites with >3 crashes per year had no change Sites with ≤3 crashes per year showed general increase over time of 1.8 times
Rear end	Significant (nearly 2 times) increase

[*Source*: Andreassen (*7*)].

Andreassen was that the installation of RLR cameras at the 41 sites did not provide any reduction in crashes. Rather, there were increases in rear-end and adjacent approaches (right-angle) crashes on a before-and-after basis and also by comparison with changes in crashes at signalized intersections. However, these conclusions have to be tempered with some inherent analysis deficiencies; namely, not properly accounting for regression to mean and not considering the possible spillover effect—a general deterrence effect of RLR cameras at all signalized intersections within a jurisdiction. Comparison data included crashes at all signalized intersections in metropolitan Melbourne, including data for camera-equipped sites. Data cover 11 years, during which there were many changes in the composition of both camera and comparison sites, as indicated by the author, as well as the introduction of an extensive areawide speed camera enforcement program in Melbourne. Andreassen states that "trends in accidents at the camera sites cannot be compared reliably with those produced by the Vic Roads database"—which is what he did.

Great Britain

A 1997 study (*10*) examined the combined effects of 21 speed cameras and 12 red light cameras at selected trunk road locations in West London and looked at the overall effects in the area. This was a simple before-and-after comparison using 36 months for each period and a comparison group consisting of nontrunk "A" class roads external to the trunk road study area. For the camera portion of the evaluation, a 16% decrease in "disobeyed traffic signal" crashes was observed, but it was deemed to be statistically insignificant. Had there been a conclusion that RLR cameras reduced crashes significantly, then there would be a concern that the speed cameras would have influenced this result. It is likely that some RLR crashes are prevented by the speed cameras, because slower approach speeds will likely result in fewer red light runners.

In 1991, in Glasgow, Scotland, RLR cameras were installed at six signal-controlled intersections. While the cameras were operational, only warnings were issued until 1993, at which time fines were levied. Winn (*11*), a consultant to the Scottish Office, was commissioned to examine how the cameras affected violations and crash experience. A preliminary analysis revealed that for injury crashes in Glasgow for 1992, red light running was deemed to be the primary cause of 17% of the crashes at signal controlled intersections and a possible contributing factor in a further 8% of the crashes. For the violation study, his findings were as follows:

- A 69% reduction in the total number of red light violations,
- A violation rate (violations as percentage of number of opportunities for violation) that fell from 6.1% to 2.2%, and
- A significant reduction in the number of violations that occurred a longer period into the red-signal phase.

In the document reviewed (*11*) only summary information was reported for the crash analysis, which consisted of a 3-year before-and-after analysis of the six sites. It was found that there was a 62% reduction (70 crashes to 27 crashes) in the number of injury crashes. Although reference is made to six noncamera control sites, at least for the violation analysis, there is no indication that the crash reduction was compared with the control site crash experience. Thus, although a large reduction was observed for this type of crash, the study is neither complete nor conclusive with regard to the total safety benefit.

In 1996, a subsequent and more comprehensive analysis was conducted by Fox (*12*). This study had the following objectives:

- To determine the characteristics and frequency of crashes at signalized intersections and near pelican crossings (pedestrian crossings) for periods before and after the introduction of cameras;
- To assess the impact of the cameras on the number and type of crashes at all signalized intersections and pelican crossings within the Glasgow District; and
- To examine the results in light of national and regional trends in crashes, and of changes in traffic flows in the Glasgow District, to determine whether broader trends may be responsible for the observed changes.

The analysis was divided into three time periods: (1) before—January 1989 to June 1991; (2) interim—July 1991 to March 1993, when the cameras were used but only warnings were issued; and (3) after—April 1993 to November 1995, during which time fines were levied. With

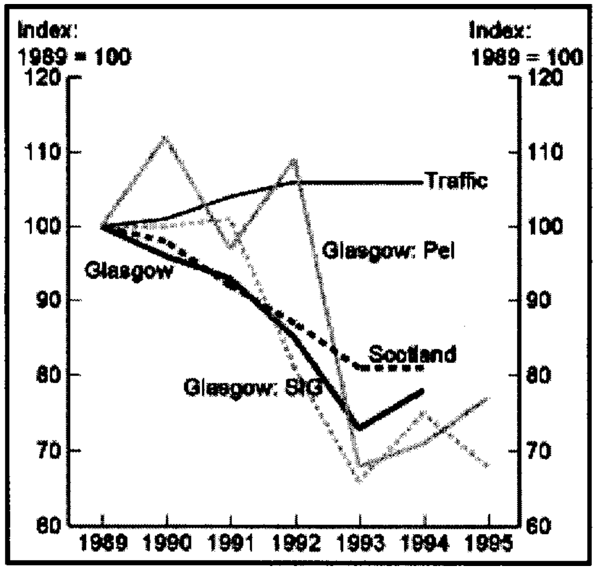

FIGURE 1 Personal injury accidents and traffic 1989–1995 [*Source*: Fox (*12*)].

TABLE 5
ACCIDENT SEVERITY AT SIGNALIZED JUNCTIONS BY TIME PERIOD (rate per month)

Accident Severity	Time Period			After–Before Change	
	Before	Interim	After	Difference	%
Fatal per month	0.8	0.5	0.3	–0.5	–67
Serious per month	12.9	8.6	7.8	–5.2	–40
Slight per month	46.3	38.5	33.2	–13.1	–28
Noninjury per month	127.2	109.2	98.8	–28.4	–22
Grand total per month	187.1	156.9	139.9	–47.2	–25

[*Source*: Fox (*12*)].

regard to the trend analysis, Figure 1 shows personal injury crashes and traffic volumes for the study period. Fox (*12*) noted that the overall decline of 25% of this crash type for signalized intersections in Glasgow is similar to Scotland's national decline of 20%. Furthermore, he noted that there was a "substantial drop in crashes in 1993, which was not matched at the national level and coincides with the introduction into full operation of the red light cameras." However, not mentioned is the upturn in 1994 for both signalized intersections and pelican crossings in Glasgow. That 1994 increase was then reversed for the signalized intersections in 1995.

Table 5 shows crashes per month by severity for the three time periods and the change in the before-and-after period. Substantial reductions are noted, especially for the more severe crashes.

With regard to the influence of traffic volume, although specific data were not provided in the report, Fox (*12*) claimed that the traffic volume near the camera sites increased "overall" with some local decreases. He noted that the crash reductions were achieved in the light of increasing traffic volume.

Fox examined the spillover effect by comparing the before to after change in personal injury accidents (PIAs) in four "camera present" areas of Glasgow as follows:

1. All 1-km squares that contain one or more of the six camera sites installed in 1990,
2. The 1-km squares containing one of two camera sites installed in early 1994,
3. The 1-km squares that are adjacent to areas 1 and 2, and
4. The rest of the Glasgow District.

Table 6 shows the results of the analysis. Fox (*12*) noted that the large reduction (32.7%) in RLR-related injury crashes was in the area most remote from the camera locations. He states that this "demonstrates that other factors such as junction improvements, local traffic management and increased pedestrian and driver vigilance may have been important in reducing RLR crashes across the whole area." This finding raises more issues and questions. Were these other improvements made in the other three areas? If not, are these improvements just as effective or more so than the cameras? If so, were the reductions attributed to the cameras or a combination of the camera and the other improvements?

TABLE 6
CHANGES IN THE NUMBER OF PERSONAL INJURY ACCIDENTS (per month) AT SIGNALIZED JUNCTIONS BY AREA OF INCIDENCE, PRIMARY CAUSATION, AND TIME PERIOD

	All PIAs			RLR PIAs			No. of
Area	Before	After	% Difference	Before	After	% Difference	Junctions
1	10.9	7.9	–27.6	3.2	2.4	–25.4	53
2	0.8	0.4	–51.8	0.3	0.9	–38.9	3
3	28.4	19.8	–30.2	3.9	3.1	–21.1	169
4	20.0	16.1	–19.5	3.1	2.1	–32.7	143

[*Source*: Fox (*12*)].

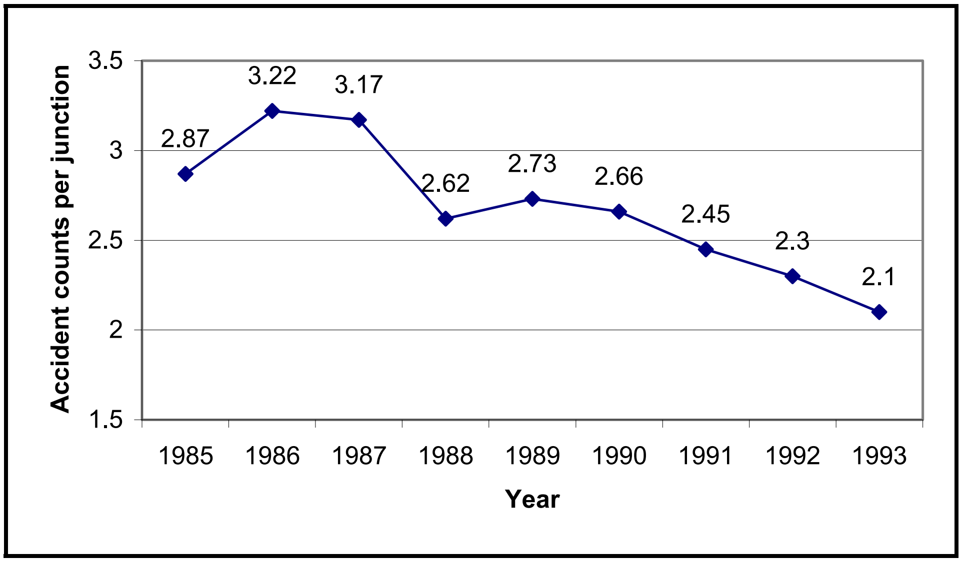

FIGURE 2 Average annual accident counts at camera junctions [*Source*: Ng et al. (*13*)].

Another interesting finding of Fox's analysis was that a reduction in RLR-related crashes involving buses and taxis was the only category subject to significant change. Fox conjectures that the level of awareness of the use of the cameras would be greater among professional drivers.

Singapore

The safety impact of RLR camera systems installed at a large number of signalized intersections in Singapore, during a 5-year program that started in August 1986, was reported by Ng et al. (*13*) in 1997. At the time of the report, the authors reported that about one in five signalized intersections was covered by one to three camera systems. (This would make Singapore the highest number and density location for RLR camera systems.) The researchers undertook different crash analyses. One was designed to review the trend of crashes at 125 camera locations over several years. Figure 2 shows that there has been a nearly steady decline in average annual crashes at camera locations since 1986, when the first stage of cameras was installed. The researchers noted that this decline occurred despite a 22% growth in vehicle population and a general flat crash trend among the population of signalized intersections. Another analysis examined the before-and-after change in crash types at the camera locations. Table 7 shows the results of that analysis. Although as recognized by the authors the reductions are impressive, there is no certainty that they are due solely to the cameras.

TABLE 7
CRASH RATE CHANGES FOR RED LIGHT RUNNING CAMERAS IN SINGAPORE

Type of Crash	Before	After	Change (%)
Angle	1.73	1.43	–17.3
Rear end	0.40	0.40	0.00
Head on/sideswipe	0.37	0.27	–27.0
Others	0.47	0.40	–14.9
All crashes	2.97	2.50	–15.8

[*Source*: Ng et al. (*13*)].

To better isolate the treatment effect, they compared the crash counts at 42 treatment locations to equivalent comparison locations that had an average "similarly high accident counts." The analysis period was a 3-year before and 3-year after, with the exclusion of the first phase of implementation to account for any novelty or familiarization

TABLE 8
CRASHES BEFORE AND AFTER ENFORCEMENT

City	Type of Intersection	Total Crashes			Injury Crashes		
		Before	After	Percent Change	Before	After	Percent Change
Bakersfield	Nonsignalized	760	753	–0.9	245	241	–1.6
	Signalized	771	739	–4.2	243	233	–4.1
San Bernardino	Nonsignalized	1,220	1,283	5.2	204	225	10.3
	Signalized	1,324	1,400	5.7	239	246	2.9
Santa Barbara	Nonsignalized	712	622	–12.6	113	115	1.8
	Signalized	488	438	–10.2	89	84	–5.6
Oxnard	Nonsignalized	994	1,011	1.7	173	194	12.1
	Signalized	1,322	1,250	–5.4	299	239	–20.1

[*Source*: Retting and Kyrychenko (*14*)].

effects. The treatment group had 26%, 22%, and 26% reductions in right-angle, rear-end, and all collisions, respectively, compared with 18%, 27%, and 19% reductions for the comparison group. Thus, the net effect on right-angle and total collisions was concluded to be 8% and 7%, respectively, with a slight increase of 5% in rear-end collisions. None of the changes, however, were found to be statistically significant based on a chi-square test.

Although using a comparison group strengthened the analysis and resulting conclusion, it did not fully account for possible regression to mean. It would have been better to select the comparison group based on equivalent volumes. Also, the comparison group came from a group of sites distributed geographically similar to that of the treatment group. There could have been a spillover effect wherein the behavior at the RLR cameras locations was carried over to other noncamera locations. If so, then the safety effects at the treatment sites and overall sites could be considerably underestimated.

STUDIES FROM THE UNITED STATES

Oxnard, California

One of the most widely publicized evaluations of red light cameras was that done for Oxnard by Retting and Kyrychenko (*14*) of the Insurance Institute of Highway Safety. Oxnard was one of the first jurisdictions in the United States to employ cameras. The authors compared the change in crashes for signalized and nonsignalized intersections in four similar (with respect to size and crash frequency) California cities—Oxnard, Bakersfield, San Bernardino, and Santa Barbara. In Oxnard, RLR cameras were installed for one approach at 11 of their approximately 125 signalized intersections; enforcement began in July 1997. The other three cities, which did not have RLR cameras, were used as control sites to establish that any observed change in crashes found in Oxnard was due to the camera program and not to potentially confounding external factors.

The evaluation consisted of comparing the before-and-after crash data for both signalized and nonsignalized intersections in Oxnard and the three control and comparable cities. The evaluation period was 29 months for both the before-and-after camera installation. The crash data for the 11 camera-equipped intersections in Oxnard were not isolated in the analysis. It was assumed that whatever effect cameras had on crash occurrence at the camera-equipped intersections would spill over to other signalized intersections within Oxnard. The findings from previous research related to before-and-after changes in violations were cited as support for this assumption. One study had been performed in Oxnard (*15*) and the other in Fairfax, Virginia (*16*). The assumption about effect may be reasonable if there is a direct correlation between violation rates and RLR crashes; however, this has not been established to date.

Changes in crash occurrences after RLR enforcement were compared for Oxnard and the three control cities, and for signalized as well as nonsignalized intersections. The data and comparison results for total crashes and injury crashes are displayed in Table 8.

A generalized linear regression model was developed to evaluate changes in crash and injury experience and an analysis of variance was used to test statistical significance. From these analyses, it was concluded that red light camera enforcement reduced the number of crashes at signalized intersections in Oxnard by 7% (with 95% confidence limits of 1.3 and 12.5) and the number of injury crashes by 29% (with 95% confidence limits of 16.6 and 39.1). The researchers also analyzed both right-angle and rear-end crashes separately and found that signalized intersections in Oxnard experienced a statistically significant 32% reduction in right-angle crashes and a significant 68% reduction in right-angle injury crashes. For rear-end crashes, there was a statistically insignificant 3% increase; no finding was offered for injury changes for this type of crash.

Based on the cited findings, Retting and Kyrychenko concluded that the study "provides evidence that red light cameras in the United States can reduce the risk of motor

TABLE 9
POLK COUNTY AND STATEWIDE FLORIDA CRASH DATA

Time of Year	1994 Crash Data Pre-RLR Campaign	1995 Crash Data Pre-RLR Campaign	1996 Crash Data Post-RLR Campaign
Polk County, Florida, Crash Data Pre- and Post-RLR Campaign			
January to June	113	133	122
July to December	114	127	119
Totals	227	260	241
Florida Statewide Crash Data			
January to June	5,294	5,310	5,412
July to December	4,945	4,835	5,230
Totals	10,239	10,145	10,642

[*Sources*: Smith et al. (*3*) and McFadden and McGee (*17*)].

vehicle crashes, in particular injury crashes, at intersections with traffic signals." However, to accept this conclusion, one must accept the assumption that the use of cameras at only 11 of 115 signalized intersections affects all intersections in the same way. A separate analysis of the 11 intersections leading to the same finding would have bolstered this conclusion.

Polk County, Florida

Polk County began using RLR automated enforcement technology in September 1994 as part of an FHWA demonstration project (*3, 17*). In 1994, an RLR camera system was placed at one intersection in four different areas within the county. As part of the demonstration project, the county implemented several public information and education strategies in 1996. The evaluation of the crash changes is shown in Table 9. These data were used to infer positive results (i.e., safety improvement), citing the reduction in crashes 1 year after installation (241 crashes) compared with those the year before (260 crashes). This 8% decrease was experienced in comparison with a 5% increase in Florida statewide crashes.

Conclusions should not be drawn from this simple comparison study for several reasons. That there were fewer crashes in 1994 gives evidence of the regression-to-mean phenomenon and downplays the reduction found in the 1995 to 1996 comparison period. Also, using a statewide trend for a base comparison is tenuous, given the many factors that are involved in the annual change in crashes at a state level. Finally, there is some question as to whether or not there was any actual enforcement connected with the camera use.

Mesa, Arizona

Mesa has a program of using both photo radar speed (PRS) and red light cameras. There are 18 intersections with RLR cameras and 5 mobile/speed stations. It is not known how many signalized intersections there are in Mesa.

Vinzant and Tatro (*18*) conducted a study to evaluate the effect of these technologies on the crash rate. This was a 2-year (1995–1996) before study versus a 2-year (1997–1998) after comparison. Twenty-four signalized intersections with the highest average crash rates were identified and divided equally into four quadrants of the city. Each of the those quadrants was then assigned as an experimental (i.e., treatment) or control area as follows:

- Quadrant One—No intervention (control).
- Quadrant Two—RLR camera and PRS.
- Quadrant Three—PRS.
- Quadrant Four—RLR camera.

For the analysis, crash rates were determined for each year by dividing the total crashes by the total approach volumes. Table 10 shows the average change in crash rates for the six intersections in each of the four quadrants. As shown, there was a decrease in all four quadrants, with the highest decrease found in Quadrant Two; however, the second highest was in Quadrant One, which was a control quadrant without either RLR cameras or PRS. When examining the data for the individual intersections, it is noted that there is a wide variation in the changes in rates. For example, in Quadrant Four, three of the intersections experienced an increase in the rate, albeit low, ranging from 1.1% to 3.5%, whereas three intersections experienced significantly higher reductions, ranging from –16.7% to –28.0%.

TABLE 10
MOTOR VEHICLE CRASH RATE BY QUADRANT

Quadrant	Average Crash Rate (1995–96)	Average Crash Rate (1997–98)	Change (%)
1: Control	3.23	2.90	–10.7
2: RLR camera and PRS	3.52	2.96	–15.9
3: PRS	3.2	2.96	–7.5
4: RLR camera	2.98	2.69	–9.7

Notes: RLR = red light running; PRS = photo radar speed.
[*Source*: Vinzant and Tatro (*18*)].

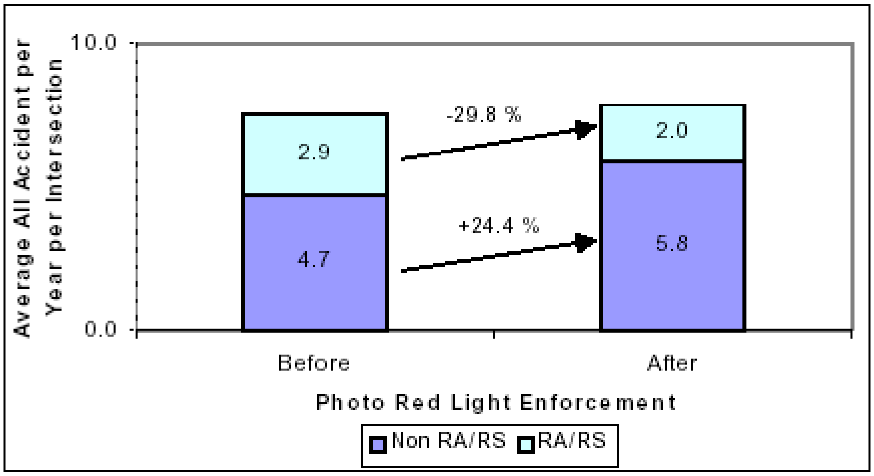

FIGURE 3 Change in accident rates before and after photo enforcement by type of accident. RA = right angle; RS = ran signal. [*Source*: PB Farradyne, Inc. (*19*).]

There was no disaggregation of the crash data to examine how crash types changed. However, crash injuries and fatalities were evaluated. Slight reductions (–4.1 to –4.9%) in the combined injury and fatality crash rates were observed for Quadrants 1, 2, and 4, but these were not statistically significant.

In summary, although the authors concluded that RLR cameras and photo-radar enforcement reduced the number of crashes, it should be noted that the control quadrant, which had neither cameras nor photo radar, experienced the second highest decrease. This could be attributed to the spillover effect of one or both of the enforcement systems.

San Diego, California

A recent evaluation of photo enforcement systems was conducted for San Diego by PB Farradyne, Inc. (*19*). San Diego deployed its first red light photo enforcement camera in July 1998 and had 19 installations by February 2000. Using crash data from April 1995 through October 2001 provided by the city, PB Farradyne, conducted several types of before-and-after analyses.

First, the researchers examined how two accident types, right angle (RA) and ran signal (RS), changed compared with all other crashes at the 19 locations. The statistic used was the average crash rate per year for all locations for each type, before and after camera installation. Figure 3 shows the results, which indicate that RA and RS crashes were reduced by 29.8%, whereas all other crashes increased by 24.4%

Subsequent examination of the non-RA/RS crashes revealed that the increase was attributed to rear-end crashes, which increased from an average of 3.3 to 4.5 (37%) per year per intersection. In another analysis of rear-end crashes, they were divided into two groups, those for approaches with camera enforcement and those without. It was observed that both groups increased, but the increase was higher for the approaches with camera enforcement (45% versus 31%). When the analysts looked at just the through movement (THM) enforcement—as opposed to the left-turn movement enforcement—they observed that there was a higher increase in rear-end crashes for the THM. The final analysis of rear-end crashes was designed to examine if the observed increase was consistent over the 4 “after” years. As shown in Figure 4, by the fourth year, the rate of rear-end crashes equaled that of the before period. The analysts note that a longer time is needed to determine if this trend will continue. Also, it should be noted that the report does not indicate if the 3.3 “before” rate is for the year just preceding the implementation or an average for the before years.

The RA and RS crash changes were also examined in more detail, with the following finding:

- Decreases in RA and RS crash rates were greater for the enforced movements (46%) than for the nonenforced movements (25%).
- Combined RA and RS crash rate reduction was greater for intersections where the THM is enforced (44%) than for those intersections where the left-turn movement is enforced (20%).

The crash analysis performed for San Diego was fairly comprehensive, but the findings must be tempered by the following observations:

- There were no control or comparison sites (although the nonenforced approaches could arguably be considered for comparison),

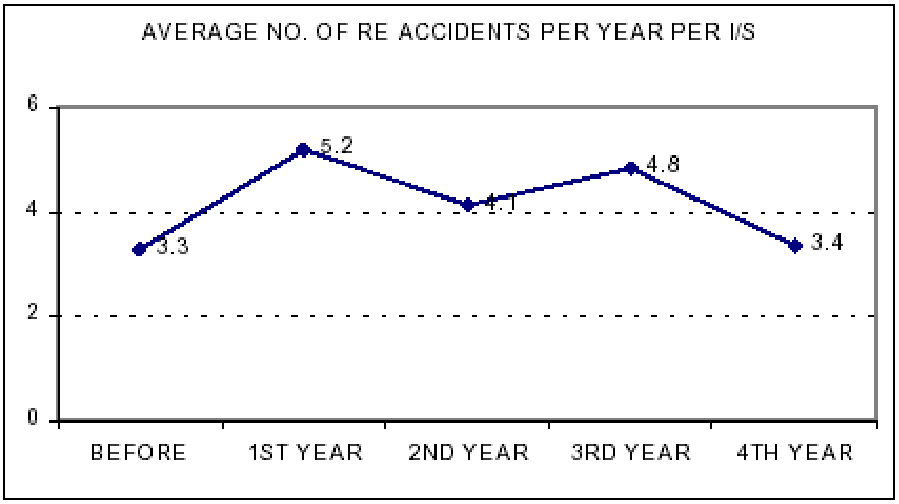

FIGURE 4 Longer-run, rear-end accident rates changes. RE = rear end; I/S = intersection. [*Source*: PB Farradyne, Inc. (*19*).]

TABLE 11
COLLISIONS CAUSED BY RED-LIGHT VIOLATORS IN SAN FRANCISCO, 1992–2001

Year	Injury Collisions	Fatalities	Total Injured
Before			
1992	780	3	1,367
1993	779	5	1,320
1994	781	4	1,293
1995	809	4	1,343
1996	780	5	1,297
After			
1997	726	1	1,202
1998	770	3	1,316
1999	727	3	1,221
2000	686	1	1,058
2001	672	1	1,047
5-yr average: 1992–1996	786	4	1,324
5-yr average: 1997–2001	716	2	1,169
Reduction	8.9%	50%	10.5%

Notes: Department of California Highway Patrol, Statewide Integrated Traffic Records System.
[*Sources*: Fleck and Smith (*20*) and the city of San Francisco.]

- There was no comparative analysis of citywide trends or changes,
- Traffic volume changes were not considered, and
- There was no statistical significance testing of the observed changes.

San Francisco, California

In 1998, Fleck and Smith (*20*) reported on the results to date of San Francisco's pilot red light camera enforcement program. Although the report does not specify, there were at least four and as many as six intersections in the pilot program.

The report provided a table that showed the injury collisions, fatalities, and total injuries for 1992 through 1997. San Francisco began issuing photo-enforcement citations in October 1996. Because one of the Topic Panel members for this synthesis was from San Francisco, the data reported by Fleck and Smith (*20*) were updated to 2001 and are given shown in Table 11. As shown in the table, there has been a nearly 9% reduction in injury collisions, a 10.5% reduction in injuries, and a 50% reduction in fatalities in the 5 years after use of the cameras compared with the 5 years before their use. In reviewing the data, it is observed that the count for injury collisions for any of the "after" years is lower than the lowest year for the "before" period. However, whether or not these reductions are statistically significant or can be attributed solely to the red light camera enforcement program cannot be determined. More information on crash impacts for San Francisco is found in chapter three.

TABLE 12
CRASH FREQUENCY DATA INCLUDED IN META-ANALYSIS

Location	Crashes Before*	Crashes After*	Change (%)	Observation Period
Howard County, Maryland				
Little Patuxent Parkway at Columbia Rd.	45	30	–33	2 yr 10 mo B/A
NB Broken Land Parkway at Stevens Forest Rd.	60	43	–28	2 yr 10 mo B/A
NB Broken Land Parkway at Snowden River Pkwy.	50	38	–24	2 yr 9 mo B/A
SB Broken Land Parkway at Snowden River Pkwy.	41	27	–34	2 yr 9 mo B/A
SB Broken Land Parkway at Cradlerock North	34	23	–32	2 yr 9 mo B/A
SB Broken Land Parkway at Stevens Forest Rd.	36	20	–44	2 yr 9 mo B/A
NB Cedar Lane at Hickory Ridge Rd.	22	12	–36	2 yr 8 mo B/A
EB Governor Warfield at Little Patuxent Pkwy.	39	30	–23	2 yr 8 mo B/A
NB Little Patuxent Pkwy. at Governor Warfield	33	26	–21	2 yr 7 mo B/A
SB Little Patuxent Pkwy. at Governor Warfield	31	22	–29	2 yr 5 mo B/A
SB Route 1 at Guilford Rd.	37	33	–40	2 yr 5 mo B/A
NB Route 1 at Guilford Rd.	31	23	–26	2 yr 5 mo B/A
SB Route 29 at Rivers Edge	25	18	–28	2 yr 5 mo B/A
Cedar Lane at Freetown Rd.	20	14	–30	2 yr 5 mo B/A
Route 32 at Route 144	26	16	–38	2 yr B/A
WB Route 40 at Chatham Rd.	23	15	–35	2 yr B/A
WB Route 40 at Rogers Ave.	43	32	–26	2 yr B/A
SB Route 29 at Route 216	26	19	–27	2 yr B/A
SB Broken Land Pkwy. at Hickory Ridge	29	21	–28	2 yr B/A
EB Snowden River at Oakland Mills	36	23	–36	1 yr 11 mo B/A
WB Snowden River Pkwy. at Broken Land Pkwy.	32	21	–34	1 yr 10 mo B/A
EB Route 40 at Rogers Ave.	30	20	–33	1 yr 8 mo B/A
WB Snowden River Pkwy. at Oakland Mills Rd.	19	14	–26	1 yr 6 mo B/A
WB Little Patuxent Pkwy. at Columbia Rd.	14	9	–36	1 yr 6 mo B/A
EB Route 40 at Marriottsville Rd.	14	10	–28	1 yr 4 mo B/A
Charlotte, North Carolina				
Beatties Ford Rd./Hoskins Rd.	4	2	–50.00	3 years B/A
Morehead St./College St.	29	10	–65.52	3 years B/A
Tyvola Rd./Wedgewood Dr.	27	12	–55.56	3 years B/A
Morehead St./McDowell St.	18	10	–44.44	3 years B/A
Brookshire Freeway/Hovis Rd.	44	28	–36.36	3 years B/A
11th St./Brevard St.	26	16	–38.46	3 years B/A
Arrowood Rd./Nations Ford Rd.	9	14	55.56	3 years B/A
N. Tryon St./Harris Blvd.	43	46	6.98	3 years B/A
South Blvd./Archdale Dr.	25	29	16.00	3 years B/A
Westinghouse Blvd./S. Tryon	23	11	–52.17	3 years B/A
Poplar St./4th St.	24	20	–16.67	3 years B/A
Albemarle Rd. at Harris Blvd.	61	34	–44.26	3 years B/A
Sharon Amity Rd. at Central Ave.	32	43	34.38	3 years B/A
Eastway Dr. at Kilborne Dr.	25	27	8.00	3 years B/A
Fairview Rd. at Sharon Rd.	27	28	3.70	3 years B/A
Idlewild Rd. at Independence Blvd.	33	25	–24.24	3 years B/A
Randolph Rd. at Sharon Amity Rd.	18	12	–33.33	3 years B/A

*Crash frequencies are total of rear-end and angle accidents on camera approaches.
Notes: B/A = before and after.
[*Source*: Flannery and Maccubbin (*21*).]

Meta-Analysis of Other Studies

Meta-analysis is a statistical technique that involves several statistical and graphical methods of analysis to quantitatively summarize the results of several studies and provide an estimate of the average effect of a measure. Such an analysis was performed by Flannery and Maccubbin (*21*) to establish the effect of automated red light enforcement systems on safety. After evaluating several reports and databases provided by a few jurisdictions, as discussed in chapter two or chapter three, the researchers were able to use the data only from Howard County, Maryland, and Charlotte, North Carolina. The crash data are shown in Table 12. Due to the limitation of the data set (i.e., only 42 observations from two studies) only three of six possible analyses were performed. The results are provided here.

- Skewness test—As explained by the researchers, if the data are not skewed, meaning a large number of points lying to the right or left of the mean value (in this case the change in crashes), then the mean result has more consequence and provides a better sense of the overall mean effect of the treatment. The funnel graph (Figure 5) was prepared to make this test. The

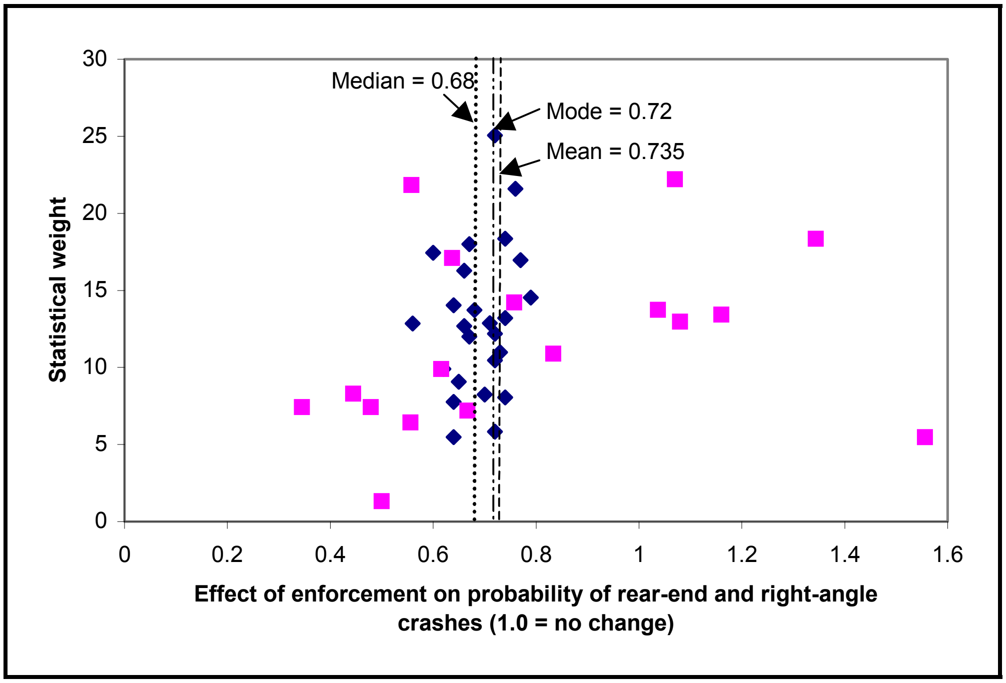

FIGURE 5 Funnel graph of crash data at intersections with camera enforcement [*Source*: Flannery and Maccubbin (*21*)].

horizontal axis represents the effect of automated enforcement programs on the probability of a rear-end or right-angle crash occurring. If no change occurred between the before-and-after periods, the effect would be equal to 1.00. As shown in the figure, the mean, mode, and median are 0.735, 0.72, and 0.68, respectively, leading the researchers to conclude that for the data set available, the probability of a right-angle or rear-end crash occurring at the study intersections was decreased by approximately 26%. Also, the researchers note that the small variation between the three measures gives additional confidence in the data by demonstrating only a small skew of the data.

- Modality test—Modality means the number of peaks in the data when plotted. If the data, when plotted, reveal more than one peak, then it can be argued that one or more studies differed significantly from the remaining data sets and the data should not be grouped together to determine a mean safety effect. For the funnel shape in Figure 5, the researchers concluded that the two data sets could be combined to provide a meaningful estimate of the effectiveness of enforcement cameras.
- Outlier test—This test seeks to identify any bias that has been introduced in the estimate of the mean effect by the presence of a single data point that is significantly affecting the mean. This test involves removing the outliers one at a time and recalculating the mean. If the mean is significantly changed, then the point can be identified as an outlier. Analysis revealed that the mean was hardly affected by the removal of any of the individual data points.

Although the results of this analysis seem to confirm positive benefits from the use of automated systems—a reduction of approximately 26% in both rear-end and right-angle crashes—the researchers are quick to state that because of the limited data "the results should not be emphasized and caution should be exercised when reviewing this study and applying the results" (*21*). Furthermore, they acknowledge the possibility that regression to mean and spillover effect could not be accounted for in the study, owing to limited available data.

CHAPTER THREE

RESULTS OF QUESTIONNAIRE SURVEY

QUESTIONNAIRE

Before now there was no inventory of jurisdictions with red light cameras in the United States. There were articles and news items in print and on the Internet that contained listing of jurisdictions, but no single agency or person had an up-to-date inventory. It was believed that the vendors who provide the camera systems would have the best information on this subject; therefore, each of the vendors was identified and asked to provide a list of customers; that is, jurisdictions. Responses were received from several vendors and from the information they provided, coupled with information from the literature and various websites, a listing of jurisdictions was compiled. The survey was then sent by NCHRP by e-mail to more than 50 jurisdictions, with responses received from 37 respondents from 36 jurisdictions.

The questionnaire with accompanying transmittal letter is provided in Appendix A. The following questions were posed:

- How many intersections are currently equipped with RLR camera systems?
- When was the first RLR system installed? When was the last RLR system installed?
- Before deploying RLR cameras at an intersection, does your agency typically try other engineering, education, or enforcement measures to reduce red light running?
- Has your agency conducted an evaluation of your RLR camera system with regard to
  - Crashes at RLR camera locations,
  - Crashes at non-RLR locations,
  - Violation rates,
  - Public opinion,
  - Driver behavior, or
  - Any other measure?
- If an evaluation of crashes at camera locations was conducted, describe the scope of the evaluation.
- Provide the results of the evaluation.
- Provide a copy of the data or report if available.
- What characteristics of the RLR camera enforcement program affected the outcome of the evaluation?
- Other comments.

The questionnaire was intentionally kept short to increase the likelihood of receiving a response. Also, because the focus of this synthesis was on the crash evaluation, questions were limited, relying on agencies to provide data where appropriate.

RESPONSE RESULTS

Appendix B is a series of tables that detail the responses for each survey respondent for each question. A summary of the responses for each question is provided here. For some questions the information from the surveys has been supplemented by additional information from other sources; where this has happened, it is so noted.

Jurisdictions with Cameras

Table 13 is a listing of jurisdictions (city and county) grouped by state, that are using RLR cameras. The list is compiled from the survey responses coupled with information gathered from recent literature and websites. For those jurisdictions that responded to the survey, the table includes the number of intersections equipped with one or more cameras, as well as the date of the first and latest installation (Question 2 of the survey).

It is not known how many signalized intersections there are in each jurisdiction—information that in hindsight would be useful. One of the issues to be resolved is what effect RLR cameras have on all signalized intersections, not just those equipped, and how many or what percentage of total signalized intersections within a jurisdiction are needed to bring about a jurisdiction-wide change in driver behavior and crashes.

Additional information on locations with RLR cameras was obtained from the literature, from data provided by the FHWA from an independent survey, and from Maryland, one of the states actively using such systems. When these data are combined with survey results, a more complete inventory of camera installations can be assembled (Table 13). From the information provided in Table 13, several observations can be made:

- There are only 14 states plus the District of Columbia with RLR camera locations. California (16) and Maryland (15) have the most jurisdictions using cameras. According to Maccubbin et al. (*22*), in addition to the states listed in the table, Delaware, Georgia, Illinois, and Washington have enabling legislation to allow cameras.
- New York City (60) has the greatest number of intersections with at least one camera. Other jurisdictions with a relatively large number include Howard County, Maryland, with 35; the city of Baltimore,

TABLE 13
JURISDICTIONS KNOWN TO HAVE RED LIGHT RUNNING CAMERA INSTALLATIONS

No.	City/County	State	No. Intersections with Camera(s)	First Installed	Last Installed	Source
1	Chandler	AZ	8	9/00	1/01	Survey
2	Mesa	AZ	17	1/97	1/00	Survey
3	Paradise Valley	AZ	2	9/96	3/01	Survey
4	Phoenix	AZ	Unknown	Unknown	Unknown	Ref. 4
5	Scottsdale	AZ	9	2/97	?/99	Survey
6	Tempe	AZ	2	4/97	4/97	Survey
7	Beverly Hills	CA	6	Unknown	Unknown	Ref. 1
8	Culver City	CA	2	Unknown	Unknown	Ref. 1
9	Cupertino	CA	Unknown	Unknown	Unknown	Ref. 4
10	El Cajon	CA	5	Unknown	Unknown	Ref. 1
11	Fremont City	CA	8	Unknown	Unknown	Ref. 2
12	Fresno	CA	Unknown	Unknown	Unknown	Ref. 4
13	Garden Grove	CA	1	7/00	7/00	Survey
14	Indian Wells	CA	Unknown	Unknown	Unknown	Ref. 4
15	Irvine	CA	2	8/00	4/01	Survey
16	Long Beach	CA	Unknown	Unknown	Unknown	Ref. 4
17	Los Angeles City	CA	8	12/00	6/01	Survey
18	Los Angeles County	CA	5	7/99	7/00	Survey
19	Oxnard	CA	15	Unknown	Unknown	Ref. 1
20	Poway	CA	8	Unknown	Unknown	Ref. 1
21	Redwood City	CA	Unknown	Unknown	Unknown	Ref. 4
22	Sacramento City	CA	10	5/99	7/00	Survey
23	Sacramento County	CA	5	3/01	10/01	Survey
24	San Buena Ventura	CA	Unknown	Unknown	Unknown	Ref. 4
25	San Diego	CA	20	9/98	5/00	Survey
26	San Francisco	CA	17	10/96	3/01	Survey
27	San Juan Capistrano	CA	Unknown	Unknown	Unknown	Ref. 4
28	West Hollywood	CA	16	Unknown	Unknown	Ref. 1
29	Boulder	CO	3	10/98	10/01	Survey
30	Denver	CO	Unknown	Unknown	Unknown	Ref. 4
31	Ft. Collins	CO	1	8/95	8/95	Survey
32	Washington	DC	10	Unknown	Unknown	Ref. 1
33	Wilmington	DE	Unknown	Unknown	Unknown	Ref. 4
34	Polk County	FL	4	Unknown	Unknown	Ref. 1
35	Honolulu City/County	HI	25	Unknown	Unknown	Ref. 2
36	Overland Park	KS	2	8/01	12/01	Survey
37	Annapolis	MD	0	Unknown	Unknown	Survey
38	Anne Arundel County	MD	5	Unknown	Unknown	Ref. 3
39	Baltimore City	MD	34	Unknown	Unknown	Ref. 3
40	Baltimore County	MD	20	12/99	6/01	Survey
41	Bel Air	MD	Unknown	Unknown	Unknown	Ref. 4
42	Bladensburg	MD	Unknown	Unknown	Unknown	Ref. 4
43	Charles County	MD	4	Unknown	Unknown	Ref. 3
44	Cheverly	MD	4	6/00	6/00	Survey
45	College Park	MD	Unknown	Unknown	Unknown	Ref. 4
46	Cottage City	MD	Unknown	Unknown	Unknown	Ref. 4
47	Forest Heights	MD	Unknown	Unknown	Unknown	Ref. 4
48	Greenbelt	MD	8	5/01	8/01	Survey
49	Hartford County	MD	3	Unknown	Unknown	Ref. 3
50	Howard County	MD	35	2/98	6/01	Survey
51	Hyattsville	MD	Unknown	Unknown	Unknown	Ref. 4
52	Landover Hills	MD	2	2/01	2/01	Survey
53	Laurel	MD	5	9/97	9/99	Survey
54	Montgomery County	MD	15	10/99	4/00	Survey
55	Morningside	MD	3	8/99	8/99	Survey
56	Prince Georges County	MD	26	Unknown	Unknown	Ref. 3
57	Riverdale Park	MD	4	6/99	6/00	Survey
58	Charlotte	NC	20	8/98	Unknown	Survey
59	Greensboro	NC	20	Unknown	Unknown	Ref. 2
60	Fayetteville	NC	Unknown	Unknown	Unknown	Ref. 4
61	High Point	NC	10	2/01	8/01	Survey
62	Wilmington	NC	Unknown	Unknown	Unknown	Ref. 4
63	New York City	NY	60	12/93	1/02	Survey
64	Toledo	OH	10	1/01	11/01	Survey
65	Beaverton	OR	5	1/01	4/01	Survey

TABLE 13 (*Continued*)

No.	City/County	State	No. Intersections with Camera(s)	First Installed	Last Installed	Source
66	Portland	OR	1	9/01	9/01	Survey
67	Chattanooga	TN	3	Unknown	Unknown	Ref. 1
68	Garland	TX	5	8/01	8/01	Survey
69	Alexandria	VA	3	11/97	11/97	Survey
70	Arlington	VA	5	Unknown	Unknown	Ref. 1
71	Fairfax City	VA	8	7/97	3/98	Survey
72	Fairfax County	VA	10	Unknown	Unknown	Survey
73	Falls Church	VA	Unknown	Unknown	Unknown	Ref. 4
74	Vienna	VA	3	Unknown	Unknown	Ref. 1
75	Lakewood	WA	Unknown	Unknown	Unknown	Ref. 4

Notes: Ref. 1—Literature; Ref. 2—FHWA; Ref. 3—Maryland State Highway Administration; Ref. 4—Insurance Institute for Highway Safety website: www.hwysafety.org/safety_facts/rlc_cities.htm.

Maryland, with 34; and Prince Georges County, Maryland, with 26. Although it is not known how many signalized intersections there are in each of the jurisdictions, the percentage of intersections with at least one camera is most likely higher for the Maryland jurisdictions than for New York City. Also, some of the jurisdictions listed in Table 13 may have a higher percentage of intersections equipped with a camera.

For those agencies responding, New York City records the first installation, dating back to December 1993. [However, according to an Institute of Transportation Engineers publication, *Automated Enforcement in Transportation* (*23*), Jackson, Mississippi, had two intersections equipped with cameras in 1992. New York City had the first automated red light enforcement program in the United States to issue citations by mail.]

Measures Taken Before Installing Red Light Running Cameras

For this synthesis effort it was important to determine what other measures, related to engineering, education, or standard enforcement, were tried before installing the cameras. Most of the respondents indicated that measures related to at least one of these three areas were undertaken to some degree.

Appendix B provides the responses to this question for each of the jurisdictions. In an attempt to tabulate the responses, Table 14 provides a listing of seven measures mentioned by at least one respondent, with the number of jurisdictions responding to that particular measure. The first five are engineering measures, the sixth is enhanced police enforcement, and the seventh is education and media.

Twenty jurisdictions indicated that increased police enforcement was tried before cameras were installed and 10 jurisdictions claimed that they tried an assortment of education measures including public service announcements (PSAs), print articles, and educational programs targeted to high schools. The most frequent engineering measure cited was revising the signal phasing and/or timing. This measure could include reviewing the yellow-change interval, but seven respondents cited that separately. Increasing signal visibility was the second most frequently mentioned engineering measure. Two jurisdictions responded that they conducted engineering studies without noting what engineering measures were used.

TABLE 14
MEASURES TAKEN BEFORE INSTALLING CAMERAS

Measures Taken	No. Responding
Improve signal head visibility	8
Review yellow-change interval	7
Review intersection geometric design	7
Revise signal phasing and/or timing	11
Warning signs (e.g., signal ahead)	1
Increased police enforcement	20
Education/media (e.g., PSAs, high school, newspaper	11

Notes: PSAs = public service announcements.

Provided here are excerpts from a few respondents indicating what type of measures were taken.

- Officers on routine patrol monitor all intersections in the city. If a particular intersection is identified as having a problem or a high accident rate, then selective enforcement is tried. Most of the selective enforcement is done with overtime because of the commitment needed to concentrate on this effort. A significant effort was made in the year before red light cameras were first installed.
- Measures are taken with respect to engineering, education, and enforcement as follows:
  - Engineering—Review geometrics, traffic flow patterns, signal phasing/timing, collision data, and classification studies. Further, establish that traffic signal is in full *Manual on Uniform Traffic Control Devices* (MUTCD) (*24*) compliance.

- Education—Involvement in Traffic Safety Week promotion, PSAs on both cable television and local television stations, and local high school programs.
- Enforcement—Selective enforcement programs developed in collaboration with Police Department Traffic Safety Enforcement Unit.

- For all signalized intersections that experience a high concentration of accidents, the signal timing is reviewed and modified accordingly. Provisions such as left-turn phasing or all-red phasing are examined. The design/configuration of the intersections are examined to determine if improvements are needed (such as sight distance). Existing traffic control devices (signs) are reviewed at which time additional controls are examined such as the provision of "Signal Ahead" warning signs. For all traffic issues our department is in close contact with law enforcement agencies (i.e., California Highway Patrol, sheriffs).
- Prior to the start of our program (and throughout its life) we have been engaged in a Capital Development Program to expend sales tax dollars on signal visibility upgrades and hardware replacement. In some cases, we install cameras where upgrades are planned (in the long term) as mitigation. In some cases, because we try to disperse the cameras citywide, we install them in lieu of other improvements.
- Local media coverage as to problem intersections; enforcement task forces targeting red light runners shown in both print media as well as local news media. Local access cable television with the information as shown above.
- We evaluated intersections under consideration for red light cameras to look for engineering solutions to the problem. We found several instances where issues were addressed instead of using photo enforcement. These issues included poor visibility of signal heads, inadequate clearance times, and stop lines that were deteriorated. Intersections where engineering improvements were made were re-evaluated later to determine if the changes had improved the situation.
- Measures are taken with respect to engineering, education, and enforcement as follows:
  - Enforcement—We dispatched uniform officers in marked patrol cars and motorcycle officers to those areas heavily violated by red light runners. The officers would issue warnings verbally and written, and in some cases would issue citations.
  - Education—We utilized television and radio to warn the public when the cameras would be activated.
  - Engineering—We checked with traffic engineering to verify if certain intersections were suitable for photo enforcement. We also acted on citizen complaints of red light running and officer observations.

Evaluation of Red Light Running Cameras

Questions 4 through 8 dealt with the agency's evaluation of the RLR cameras, especially regarding crash effects.

TABLE 15
JURISDICTIONS REPORTING EVALUATIONS BY VARIOUS MEASURES

Jurisdiction	Accident at RLR Intersection	Accident at non-RLR Intersecton	Violation	Public Opinion	Driver Behavior
Alexandria, VA			X		
Baltimore County, MD	X	X	X	X	X
Beaverton, OR	X	X	X	X	
Boulder, CO	X		X	X	
Charlotte, NC	X	X	X	X	
Fairfax City, VA	X	X	X	X	X
Fairfax County, VA				X	
Ft. Collins, CO	X	X	X	X	
Garden Grove, CA	X	X	X	X	X
High Point, NC	X	X	X	X	
Howard County, MD	X	X	X	X	
Irvine, CA	X	X	X		
Laurel, MD	X		X		
Los Angeles County, CA	X				
Mesa, AZ	X	X	X	X	
Montgomery County, MD	X	X	X		
Morningside, MD			X	X	X
New York City, NY			X		
Paradise Valley, AZ	X		X	X	X
Riverdale Park, MD	X	X	X	X	
Sacramento County, CA	X	X	X		
Sacramento, CA	X		X		X
San Diego, CA	X	X	X	X	
San Francisco, CA	X		X	X	
Scottsdale, AZ	X	X	X	X	X
Tempe, AZ	X	X	X	X	X

This series of questions started by asking if evaluations were conducted with regard to crashes, violations, public opinion, driver behavior, or any other measure. Appendix B provides the responses and comments. In summary, Table 15 shows the number of locations that reported conducting an evaluation for each of the measures. Most jurisdictions responded that they have conducted evaluations, but the scope of evaluations varied among the respondents.

The primary focus of this synthesis effort was to ascertain how effective RLR camera systems are in reducing crashes and crash severity at those intersections where they are installed and at other signalized intersections within the jurisdiction. Therefore, the remaining discussions will deal with evaluations based on crashes.

Table 16 provides a summary of the evaluations for the 18 jurisdictions that claimed to have conducted crash evaluations. The table concisely states the type of evaluation and the findings, and indicates if supporting data were provided.

There were a variety of evaluation types that can be classified as follows:

- Monitoring high crash locations to see if camera sites are high on the list,
- Annual crash statistics for all intersections,
- Before-and-after comparisons of crashes for intersections with cameras,
- Before-and-after comparisons of crashes for approaches with cameras,
- Before-and-after comparisons of crashes for intersections with cameras compared with all intersections.

For many locations, supporting data were not provided to substantiate their claims of effectiveness.

Owing to the lack of supporting data in many cases and the less than rigorous evaluation procedure, an overall conclusion cannot be made from the data presented in the table. However, it is noteworthy that, in general, nearly all jurisdictions reported favorable results with respect to crash changes. The exceptions to this positive finding were as follows:

- Tempe, Arizona—Collision rates for both intersections have shown increases and decreases.
- Riverdale Park, Maryland—Accident data remained consistent.
- San Diego, California—Injury accidents remained the same.
- Ft. Collins, Colorado—No significant change was found at one intersection.

Summarized here are the results of evaluations by those jurisdictions that provided supporting data.

Baltimore County, Maryland

Baltimore County installed cameras at 20 intersections between December 1999 and June 2001. A comparison of the number of crashes and severity was conducted for 1 year before and after installation of the cameras for 17 intersections. Table 17 shows the results. It lists the before-and-after frequencies for each intersection and a total for all intersections' changes and percent changes for (1) all crashes coded to the intersection, (2) intersection-related crashes, (3) red light-related crashes, (4) personal injury crashes, and (5) property damage crashes. From this table the following results emerge:

- Total crashes and intersection-related crashes were reduced at 14 of the 17 intersections, with an overall average reduction of 53% and 57% for total crashes and intersection-related crashes, respectively.
- The number of red light-related crashes was reduced at 6 of the 17 intersections, increased at 4 intersections, and did not change at the remaining 7 intersections.
- Crashes involving personal injury decreased by 49% for all intersections, with 10 intersections experienceing decreases, 4 experiencing increases, and 3 with no change.
- Property damage crashes decreased at 14 of the 17 intersections, and none experienced an increase.

Data were not available regarding rear-end crashes or any other type of crash. However, the reduction in red light-related crashes was much less than for all crashes or just intersection-related crashes. One might expect that the reductions would be more dramatic for the red light-related crashes. However, there were relatively few in the before period (19 of 174 total crashes), which might indicate that it may not be easy to identify this type of crash from the database.

Because there was no statistical analysis performed and the evaluation did not consider comparison sites for control and traffic volumes, it is not possible to draw a definitive conclusion. Nonetheless, that a vast majority of intersections experienced a reduction in intersection-related crashes would indicate that there is a net safety benefit attributed to the cameras.

Charlotte, North Carolina

Charlotte began its RLR camera program, Safelight, in August 1998. Based on information provided from its website (www.ci.charlotte.nc.us/citransportation/programs/safelight.htm) there are 27 intersections equipped with cameras. Their first examination of the crash changes after installation occurred in 2001, when there were 3 complete years of data for 17 of the original 20 locations. Tables 18 and 19

TABLE 16
FINDINGS OF CRASH EVALUATIONS AS REPORTED BY RESPONDING JURISDICTIONS

Location	No. of Intersections	Type of Evaluation	Finding	Comments
Garden Grove, CA	1	1-yr B/A compared to 5 other high violation locations	56.2% reduction in right-of-way violation accidents; 1.2% increase in rear-end accidents	Supporting data not provided
Irvine, CA	2	Annual monitoring	The two locations are not listed in high accident locations	Supporting data not provided
Howard County, MD (two separate evaluations)	35	1-yr B/A for 24 intersections	Rear-end collisions increased by 6%; angle collisions decreased by 47%; other collisions decreased by 11%	Supporting data not provided
		Total intersections	Reductions in total collisions from 1998 to 2000	
	29	1+-yr B/A for 25 intersections	For all RLR intersections: 30% decrease for rear end; 42% decrease for angle; 21% decrease for other; 31% decrease total	Summary data for each intersection provided
Laurel, MD	5	3-yr before compared with ?-yr after	Reduction in number of accidents at all locations	Supporting data not provided
Boulder, CO	3	32-month after evaluation	57% reduction in red light-related accidents	Supporting data not provided
Los Angeles County, CA	5	Not explained	Accident rates for 3 of 5 locations reduced, 4th remained relatively the same, and 5th did not improve	Supporting data not provided
San Francisco City, CA	17	5-yr B/A for 1st camera in '96	RLR collisions declined	Supporting data not provided
Tempe, AZ	2	4-yr B/A	Collision rate for both intersections has shown increases and decreases since inception	Supporting data not provided
Mesa, AZ	17	Yearly collision rates	Intersection-related accident rates (per population) have decreased each of 5 years since installation	Can't compare rates of RLR intersections with non-RLR intersections
Baltimore County, MD	20	1-yr B/A	Total crashes decreased 51%; intersection-related decreased 55%; RLR crashes decreased 30%; injury crashes decreased 51%; PDO crashes decreased 51%	Summary data for each intersection provided
Riverdale Park, MD	4	1-yr B/A for all intersections	Accident data remained consistent	Supporting data not provided
Paradise Valley, AZ	2	B/A; time frame unknown	Same number of collisions, but reduced severity	Supporting data not provided
Scottsdale, AZ	9	Comparison of RLR accidents city-wide B/A	RLR accidents dropped first year after cameras but have crept up but not to the level before installation. RLR accidents at camera locations are too low to make a conclusion. Difficult to isolate RLR camera effect.	
Sacramento, CA	10	Comparison of crashes 1 yr B/A	Reductions: 10% for all crashes; 27% for injury crashes; 26% for angle crashes; 12% for rear-end crashes; 39% for red light crashes	Summary data provided
Montgomery County, MD	15	B/A for 2 yr	Overall number of crashes went down slightly, but probably not significant	Supporting data not provided
San Diego, CA	20	B/A for 2 yr at 16 intersections	Injury accidents remained the same at most locations; but incidents of RLR decreased dramatically	Supporting data not provided
Charlotte, NC	20	B/A for 3 yr for 17 intersections	Overall angle crashes reduced by 37% at intersections with cameras and 60% for approaches with cameras; all crash types reduced by 19%; crash severity reduced by 16%; rear-end crashes increased by 4% on camera approaches	Supporting data provided
Ft. Collins, CO	1	Before for 2.5 yr and after for 5.5 yr	No significant change in accident or injury frequency	Supporting data provided

Notes: B/A = before and after; RLR = red light running; PDO = property damage only.

TABLE 17
BALTIMORE COUNTY CRASH ANALYSIS

	Total Crashes			Intersection Related			Red Light Related			Personal Injury			Property Damage		
Location	Before	After	Change (%)	Before	After	Change (%)	Before	After	Change (%)	Before	After	Change (%)	Before	After	Change (%)
1	9	5	4 (44)	6	4	2 (33)	1	1	0 (0)	2	3	–1 (–50)	7	2	5 (71)
2	5	3	2 (40)	3	0	3 (100)	0	0	0 (0)	2	1	1 (50)	3	2	1 (33)
3	21	9	12 (57)	17	6	11 (65)	3	1	2 (67)	10	4	6 (60)	11	5	6 (55)
4	20	10	10 (50)	12	6	6 (50)	4	2	2 (50)	12	6	6 (50)	8	4	4 (50)
5	14	9	5 (36)	10	6	4 (40)	2	3	–1 (–50)	6	5	1 (17)	8	4	4 (50)
6	11	1	10 (91)	10	1	9 (90)	2	1	1 (50)	6	1	5 (83)	5	0	5 (100)
7	8	1	7 (88)	3	1	2 (67)	1	0	1 (100)	3	0	3 (100)	5	1	4 (80)
8	11	6	5 (45)	10	5	5 (50)	3	1	2 (67)	6	2	4 (67)	5	4	1 (20)
9	4	2	2 (50)	1	1	0 (0)	0	0	0 (0)	2	0	2 (100)	2	2	0 (0)
10	2	2	0 (0)	2	2	0 (0)	1	1	0 (0)	1	2	–1 (–100)	1	0	1 (100)
11	24	6	18 (75)	14	1	13 (93)	0	0	0 (0)	8	1	7 (88)	16	5	11 (69)
12	19	9	10 (53)	14	8	6 (43)	0	2	–2 (>–100)	6	3	3 (50)	13	6	7 (54)
13	2	0	2 (100)	1	0	1 (100)	0	0	0 (>–100)	0	0	0 (0)	2	0	2 (100)
14	4	5	–1 (–25)	3	3	0 (0)	0	1	–1 (>–100)	0	1	–1 (>–100)	4	4	0 (0)
15	4	2	2 (50)	3	2	1 (33)	0	1	–1 (>–100)	1	1	0 (0)	3	1	2 (67)
16	11	6	5 (45)	8	2	6 (75)	1	0	1 (100)	2	2	0 (0)	9	4	5 (56)
17	5	6	–1 (–20)	5	4	1 (20)	1	1	0 (0)	2	3	–1 (–50)	3	3	0 (0)
Total	174	82	92 (53)	122	52	70 (57)	19	15	4 (21)	69	35	34 (49)	105	47	58 (55)

(*Source*: Baltimore County, Maryland.)

TABLE 18
CHARLOTTE THREE-YEAR ANALYSIS OF ALL APPROACHES AT EACH OF THE 17 ORIGINAL SAFELIGHT INTERSECTIONS

	Accident Totals			Angle Accidents[a]			Rear–End Accidents			EPDO Rate[b]		
Inter-section	3 Years Before	3 Years After	Change (%)	3 Years Before	3 Years After	Change (%)	3 Years Before	3 Years After	Change (%)	3 Years Before	3 Years After	Change (%)
1	60	30	–50.00	21	6	–71.43	12	14	16.67	23.40	10.47	–55.27
2	32	29	–9.38	27	19	–29.63	2	16	700.00	22.91	30.16	31.62
3	216	226	4.63	19	17	–10.53	148	146	–1.35	16.30	13.09	–19.66
4	105	131	24.76	28	22	–21.43	52	74	42.31	12.71	14.25	12.13
5	71	78	9.86	24	19	–20.83	20	26	30.00	16.71	15.52	–7.15
6	14	13	–7.14	1	1	0.00	6	6	0.00	4.06	3.32	–18.10
7	63	55	–12.70	34	15	–55.88	24	30	25.00	12.97	12.60	–2.92
8	205	242	18.05	28	18	–35.71	114	166	45.61	20.88	20.17	–3.39
9	52	21	–59.62	34	2	–94.12	14	12	–14.29	20.06	6.33	–68.48
10	75	80	6.67	10	14	40.00	46	48	4.35	12.70	12.43	–2.19
11	170	171	0.59	12	17	41.67	114	118	3.51	11.75	9.31	–20.73
12	155	152	–1.94	18	11	–38.89	104	100	–3.85	12.94	7.44	–42.50
13	212	266	25.47	35	30	–14.29	132	192	45.45	14.88	12.70	–14.62
14	64	39	–39.06	10	8	–20.00	26	14	–46.15	9.93	7.86	–20.86
15	84	77	–8.33	17	22	29.41	38	30	–21.05	5.50	8.32	51.07
16	115	79	–31.30	31	9	–70.97	50	48	–4.00	19.41	12.00	–38.20
17	34	25	–26.47	20	1	–95.00	10	16	60.00	11.03	5.35	–51.53
Totals	1,727	1,714	–0.75	369	231	–37.40	912	1,056	15.79	248.14	201.32	–15.93

[a]Angle accidents were estimates based on accident types 24, 26, and 30, all being the result of red light running.
[b]EPDO (equivalent property damage only) rates were calculated based on the same factors used in generating the annual high accident locations.

show the before-and-after crash data for these 17 intersections. The analysis examined total crashes, angle crashes, rear-end crashes, and equivalent property damage only (EPDO) rate for all approaches and then the first three crash types for just the approaches with the camera. The tables reveal the following findings as provide by Charlotte:

- Angle crashes decreased by 37% at camera-equipped intersections.
- Angle crashes decreased by 60% on the approaches with a camera.
- Crashes of all types decreased by 19% on the approaches with a camera.

TABLE 19
CHARLOTTE THREE-YEAR ANALYSIS OF CAMERA APPROACHES ONLY AT EACH OF THE 17 ORIGINAL SAFELIGHT INTERSECTIONS

Intersection	Accidents on Camera Approach			Angle Accidents[a] on Camera Approach			Rear-End Accidents on Camera Approach		
	3 Years Before	3 Years After	Change (%)	3 Years Before	3 Years After	Change (%)	3 Years Before	3 Years After	Change (%)
1	46	21	–54.35	14	4	–71.43	12	12	0.00
2	25	20	–20.00	22	18	–18.18	2	2	0.00
3	79	52	–34.18	11	4	–63.64	50	30	–40.00
4	33	43	30.30	7	5	–28.57	18	24	33.33
5	17	23	35.29	7	2	–71.43	2	12	500.00
6	5	2	–60.00	0	0	0.00	4	2	–50.00
7	45	33	–26.67	30	10	–66.67	14	18	28.57
8	47	56	19.15	10	5	–50.00	22	38	72.73
9	27	10	–62.95	23	0	–100.00	6	10	66.67
10	30	28	–6.67	7	5	–28.57	18	22	22.22
11	39	40	2.56	5	4	–20.00	22	24	9.09
12	50	55	10.00	3	4	33.33	40	42	5.00
13	45	34	–24.44	7	3	–57.14	25	22	–15.38
14	28	17	–39.29	2	0	–100.00	16	10	–37.50
15	21	18	–14.29	4	6	50.00	14	6	–57.14
16	28	12	–57.14	19	5	–73.68	4	6	50.00
17	24	13	–45.63	17	0	–100.00	10	12	20.00
Totals	589	477	–19.02	188	75	–60.11	280	292	4.29

[a]Angle accidents were estimates based on accident types 24, 26, and 30, all being the result of red light running.

- Crash severity, as expressed by EPDO, decreased by 16%.
- Rear-end crashes increased by 4% on the approaches with a camera. (It is also observed that rear-end crashes increased by nearly 16% for all approaches.)

Charlotte analysts also note that overall all crashes decreased by less than 1% and only 12 of the 17 locations experienced an overall crash reduction on the camera approaches.

This type of analysis is similar to that conducted in Baltimore County, discussed previously, and in Howard County, which is discussed next. Although there appears to be some positive benefits, without the use of control sites, consideration of traffic volume changes, and statistical significance testing, it is difficult to draw conclusions.

Howard County, Maryland

Howard County has one of the highest numbers of intersections equipped with red light cameras—35. Tabular data were provided by Howard County for a before-and-after crash analysis of most of its locations (Table 20). The table shows the frequency of rear-end, angle, other, and total crashes before and after installation of the cameras and the percent of change for 25 intersections. Because cameras were installed at different times, there are varying before-and-after evaluation periods.

The observed crash changes are summarized here.

- Collectively, there was a reduction of 31% in all crashes before (796) to all crashes after camera installation (552). Reductions were observed at all sites.
- Angle crashes decreased by 42%—from 195 before to 113 after, and all but two sites experienced a reduction.
- Rear-end crashes decreased by 30%—from 413 before to 291 after, and all but one site experienced a reduction.

These reductions in crashes are impressive, but it must be considered that comparison sites were not investigated and no provision was made for possible changes in traffic volumes.

Howard County continues to monitor its camera-equipped intersections and periodically adds to the crash database for evaluation. Following the questionnaire response, a more recent before-and-after crash evaluation was provided (Table 21). In Tables 20 and 21, the site numbers represent the same locations.

Similar to the previous before-and-after evaluation, there are observed crash reductions in all crash-type categories. However, when the reductions shown by the two tables are compared, the percent reductions are consistently lower for the longer evaluation period (Table 21). These findings may indicate that there is a diminishing crash benefit as the systems age, but that this cannot be proven simply from these data. Nonetheless, it does indicate that the selection of the evaluation periods can affect the evaluation finding. Using long before-and-after periods

TABLE 20
BEFORE VERSUS AFTER CRASH DATA FOR HOWARD COUNTY, MARYLAND, 16- TO 33-MONTH PERIODS

Int. No.	Evaluation Period (months)	Before				After				Percent Change			
		Rear End	Angle	Other	Total	Rear End	Angle	Other	Total	Rear End	Angle	Other	Total
1	33	27	9	9	45	19	4	7	30	–30	–56	–22	–33
2	33	40	14	6	60	28	6	9	43	–30	–57	50	–28
3	32	28	10	12	50	21	4	13	38	–25	–60	8	–24
4	32	21	8	12	41	11	3	13	27	–48	–63	8	–34
5	31	19	8	7	34	16	3	4	23	–16	–63	–43	–32
6	31	21	9	6	36	12	3	5	20	–43	–67	–17	–44
7	30	7	10	5	22	8	3	3	14	14	–70	–40	–36
8	27	21	7	11	39	19	3	8	30	–10	–57	–27	–23
9	25	18	6	9	33	14	3	9	26	–22	–50	0	–21
10	25	16	8	7	31	13	2	9	24	–19	–75	29	–23
11	27	17	11	9	37	6	10	6	22	–65	–9	–33	–41
12	27	11	9	11	31	10	7	6	23	–9	–22	–45	–26
13	27	14	4	7	25	8	7	3	18	–43	75	–57	–28
14	27	6	10	4	20	2	8	4	14	–67	–20	0	–30
15	23	9	10	7	26	5	7	4	16	–44	–30	–43	–38
16	24	12	5	6	23	9	3	3	15	–25	–40	–50	–35
17	24	21	13	9	43	17	9	6	32	–19	–31	–33	–26
18	24	21	3	2	26	9	7	3	19	–57	133	50	–27
19	24	17	5	7	29	11	4	6	21	–35	–20	–14	–28
20	23	19	7	10	36	18	2	3	23	–5	–71	–70	–36
21	22	15	5	12	32	13	1	7	21	–13	–80	–42	–34
22	20	14	9	7	30	9	5	6	20	–36	–44	–14	–33
23	18	9	5	5	19	6	3	5	14	–33	–40	0	–26
24	18	6	4	4	14	4	2	3	9	–33	–50	–25	–36
25	16	4	6	4	14	3	4	3	10	–25	–33	–25	–29
Totals		413	195	188	796	291	113	148	552	–30	–42	–21	–31

Notes: Int. = intersection.
(*Source*: Howard County, Maryland.)

is desirable, as long as other possible changes during those periods are accounted for. One likely change is traffic volume, and therefore this type of analysis would be improved if crash rates were used.

Mesa, Arizona

Mesa has 17 intersections equipped with at least one red light camera. These cameras were installed from January 1997 to December 2000. Evaluation of the effectiveness of the cameras was limited to comparing the trend of one statistic—intersection-related crashes per 10,000 population for all intersections. For each of the 5 years since the deployment of the cameras, this statistic has decreased, as shown in Table 22.

These data alone do not permit a conclusion regarding the influence of red light cameras in obtaining a consistent reduction in the performance measure. At a minimum, this statistic should be compared to the yearly trend for all crashes, for crashes at all signalized intersections, and for crashes just at the camera-equipped intersections. Also, the number of intersections (or signalized intersections) per year should have been factored into the analysis.

Sacramento, California

The city of Sacramento provided summary data of a 1-year before-and-after comparison of crashes for 10 intersections equipped with cameras (Table 23). A favorable result is shown by the reductions in crashes; however, this cannot be considered conclusive because there was no consideration for traffic volume changes nor a comparison with a set of control sites.

Ft. Collins, Colorado

Ft. Collins provided the crash data found in Table 24 for one intersection where a camera was installed in August 1995. A review of the data shows no significant change in crashes after the camera was installed. However, it would be difficult to draw any conclusions about this one intersection without more information, such as crash types, volumes, etc. Also, there is no information on how crash data may have changed at other, similar intersections.

Characteristics of the Red Light Running Camera Enforcement Program Affecting Evaluation Outcome

The intent of this question was to elicit the jurisdictions' opinion as to what characteristics or features of their

TABLE 21
BEFORE VERSUS AFTER CRASH DATA FOR HOWARD COUNTY, MARYLAND, 14-TO 46-MONTH PERIODS

	Evaluation	Before				After				Percent Change			
Int. No.	Period (months)	Rear End	Angle	Other	Total	Rear End	Angle	Other	Total	Rear End	Angle	Other	Total
1	46	31	10	11	52	29	6	11	46	–6.5	–40.0	0.0	–11.5
2	46	42	16	9	67	36	10	12	58	–14.3	–37.5	33.3	–13.4
3	45	31	9	15	55	26	6	16	48	–16.1	–33.3	6.7	–12.7
4	45	22	9	14	45	15	3	15	33	–31.8	–66.7	7.1	–26.7
5	45	23	10	8	41	23	5	9	37	0.0	–50.0	12.5	–9.8
6	45	24	11	7	42	16	5	6	27	–33.3	–54.5	–14.3	–35.7
7	44	9	12	7	28	10	7	8	25	11.1	–41.7	14.3	–10.7
8	44	23	10	12	45	22	4	12	38	–4.3	–60.0	0.0	–15.6
9	43	21	8	10	39	19	7	12	38	-9.5	–12.5	20.0	–2.6
10	43	18	10	9	37	20	4	11	35	11.1	–60.0	22.2	–5.4
11						Removed from service							
12	41	13	13	14	40	12	10	8	30	–7.7	–23.1	–42.9	–25.0
13	40	16	6	10	32	17	7	8	32	6.3	16.7	–20.0	0.0
14	40	7	13	5	25	3	11	5	19	– 57.1	–15.4	0.0	–24.0
15	38	10	14	7	31	7	8	5	20	–30.0	–42.9	–28.6	–35.5
16	36	15	9	8	32	15	5	4	24	0.0	–44.4	–50.0	–25.0
17	36	30	17	12	59	27	11	7	45	–10.0	–35.3	–41.7	–23.7
18						Removed from service							
19	36	19	5	7	31	16	4	6	26	–15.8	–20.0	–14.3	–16.1
20	35	21	8	11	40	28	4	8	40	33.3	–50.0	–27.3	0.0
21	34	19	6	13	38	18	3	12	33	–5.3	–50.0	–7.7	–13.2
22	32	19	10	9	38	15	7	8	30	–21.1	–30.0	–11.1	–21.1
23	30	10	7	8	25	10	4	7	21	0.0	–42.9	–12.5	–16.0
24	30	9	7	8	24	9	2	4	15	0.0	–71.4	–50.0	–37.5
25						Removed from service							
26	14	5	2	3	10	2	1	1	4	–60.0	–50.0	–66.7	–60.0
27						Removed from service							
28	4	1	2	1	4	1	1	1	3	0.0	–50.0	0.0	–25.0
29	14	3	3	2	8	2	4	1	7	–33.3	33.3	–50.0	–12.5
	Totals	441	227	220	888	398	139	197	734	–9.8	–38.8	–10.5	–17.3

Notes: Int. = intersection.
(*Source*: Howard County, Maryland.)

TABLE 22
YEARLY INTERSECTION-RELATED CRASHES PER 10,000 POPULATION IN MESA, ARIZONA

Year	Intersection-Related Crashes per 10,000 Population
1997	130.9
1998	127.5
1999	120.8
2000	119.1
2001	117.9

automated enforcement program affected the outcome of any evaluation done. It should be recognized that the comments are the opinions of the respondents and not necessarily based on a detailed evaluation that would have isolated one or more features. None of the jurisdictions contacted had an evaluation procedure that would have permitted such an analysis.

Again, all the responses to this question can be found in Appendix A. Following are some informative survey comments:

- Perceived fairness of RLR program.
  - Civil violation in Maryland: no points, no insurance company notification, $75 fine.
  - County selects sites for monitoring. County decides if citation is issued. No vendor access to signal controller.
  - Vendor provides camera systems/maintenance and “back room services” with payment based on a monthly fee.
  - Penalty for not paying fine is prevention of tag renewal.
- In my view, public education (and resultant driver behavioral modification) more than any other factors has resulted in the safety benefits we have seen.
- We have not identified any single factor that was more important than the others.
- The RLR campaign enforcement program has been incredibly successful. Ninety-nine percent of Beaverton residents are aware of the campaign and 77% support red light photo enforcement. Public acceptance is an integral part of our program.
- Two items:
  - Change of yellow phase of signal on left turns from 3.00 to 4.00 s.
  - Education of public awareness, PSA messages, and speaking at various neighborhood group watches.
- Public awareness; education regarding red light cameras and safe driving.

TABLE 23
RESULTS OF ONE-YEAR BEFORE-AND-AFTER STUDY IN SACRAMENTO, CALIFORNIA

Crashes	No. of Crashes 12 Months Before Installation	No. of Crashes 12 Months After Installation	Change (%)
Total number of crashes	81	73	–10
Injury crashes	60	44	–27
Right-angle crashes	42	31	–26
Rear-end crashes	32	28	–12
Red light crashes	28	17	–39

TABLE 24
CRASH DATA FOR FT. COLLINS, COLORADO, FOR ONE INTERSECTION WITH RED LIGHT RUNNING CAMERA

Year	Crashes on Approach to Intersection	Crashes in Intersection	Total no. Injuries	Injuries in Intersection
1993	15	11	5	2
1994	21	9	6	3
1995	23	14	12	4
1996	23	11	10	3
1997	28	3	2	1
1998	25	9	3	2
1999	27	4	7	1
2000	24	10	9	2

Notes: Camera installed in August 1995.

- We believe consistent enforcement and public outreach affected the outcome the most.
- Public outreach, media coverage, grace periods, website (especially useful for media), police scrutiny of the tickets, sending out information about Safelight program through the mail with the tickets.
- Public outreach and signing.
- We have put up signs at most of the roadway entrances into Montgomery County as well as on some major arterial highways after Interstate exit ramps.
- Prior to installation—public demonstration and input newspaper, television advertisement, education. Periodic newspaper inquiries. Grace period (30 day) prior to "live" activation.

Other Comments

The final part of the questionnaire provided space for other comments. Some respondents used this area to expand on a previous question, whereas others used it to provide supplemental information, some of which was germane to the issues related to this synthesis. All the comments can be seen in Appendix B. Those comments that provide some additional insights are excerpted and listed here.

- We looked at accident statistics at our intersections, but could not draw any meaningful conclusions. There seem to be many factors about crashes that affect the analysis. Even if we go back to the original accident reports, it may be difficult to determine whether or not red light running was the cause of an accident. Many times one of the drivers is charged with failure to obey a traffic signal, but just as often one is charged with failure to pay full-time attention or some other violation. Since the officer is not usually there to view the accident, some judgment must be used as to what actually happened. The drivers are interviewed and if the stories conflict, the officer must decide who is more credible, or maybe it is decided to not issue a citation. There will always be some question about the analysis if the data are not accurate.
- In looking at accidents over any period of time, factors such as traffic volume, weather conditions, ambient light conditions, traffic signal operations, enforcement and safety programs, and vehicle equipment will also vary. In a study of a small sample, like accidents at a handful of intersections in the city, these factors could change enough to skew the results. In order to minimize these effects, larger samples of intersections should be examined including intersections with cameras, intersections without cameras, and intersections in communities far away from where cameras are located.
- The number of citations that are being issued on our two RLR camera sites has decreased significantly. This shows the cameras are working.
- High Point officers scrutinize every ticket before it is mailed. This has helped a great deal to boost the integrity of the program. Someone dedicated to the program completely from the time of choosing the

contractor, selecting the sites, talking to the media, and analyzing the intersections has been very useful.

- Scottsdale implemented eight RLR cameras in 1997. We are currently looking to expand our RLR camera program and all intersections are being evaluated as possible candidates. We are ranking intersections based on the number of accidents, the number of RLR accidents, the volume of traffic, and the number of serious injury accidents.
- While the RLR cameras do impact drivers at certain intersections, public awareness of the program and traffic safety has an impact throughout the city.
- We feel confident that RLR cameras will be an effective tool to help modify bad driver behavior in order to decrease the number of red light crashes, especially at intersections where traditional enforcement methods are not an option.
- Our program is doing exactly what we wanted—"making our streets safer by changing drivers behavior."
- Once a photo red light program is operational in a city, there is a lot of misinformation disseminated about the system being not reliable. Any city with a desire to install a photo enforcement system should heavily promote and explain the technology before activating the system. Discussions should be held in public forums by city and law enforcement officials to explain how the technology works. The judges, traffic engineering, and city attorney's office needs to be informed and involved.

CHAPTER FOUR

EVALUATION PROCEDURES

As seen from the literature review and the survey responses, there have been several methodologies followed to determine whether or not automated enforcement of red light running using cameras has made not only the intersections where they are used safer but other signalized intersections as well. However, many of the studies discussed did not adequately and defensibly identify the safety effect.

Conducting evaluations of countermeasures after their implementation is important to provide support for their use. This is especially important for RLR cameras, because their use has been controversial. Evaluating the cameras helps the implementing agency to determine if it is achieving the desired goal of reducing signal violations and ultimately improving safety. An effective evaluation of RLR cameras through an observational study of crashes employs a robust study design, uses many years of good quality crash and roadway data, accounts for other factors that may affect the crash experience, and employs a defensible statistical procedures in the analysis of results.

This chapter is not intended to be a detailed guide on how to evaluate automated enforcement programs, but it should provide enough guidance for those considering evaluations and a basic understanding of what would be entailed. Those desiring to have a better understanding of safety study procedures should review the following publications:

- *Observational Before–After Studies in Road Safety—Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety*, by Hauer (*25*);
- *NCHRP Synthesis 295: Statistical Methods in Highway Safety Analysis*, by Persaud (*26*); and
- *Accident Research Manual*, by Council et al. (*27*).

This chapter presents information on how an evaluation of RLR cameras could be conducted by an agency. It includes information on the elements of an evaluation, study designs, statistical analysis procedures, and other considerations in camera evaluations.

ELEMENTS OF EVALUATION

Numerous factors must be considered before beginning an evaluation of RLR cameras, including the scope of the study, the available data, and the study duration. Agencies should consider these items before selecting an evaluation methodology. Some of these considerations are described briefly here.

Scope of Study

Before conducting an evaluation of RLR cameras, the evaluating agency must define the scope of the study. For example, specific questions might include

- Does the installation of an RLR camera on only one approach to an intersection have an effect on the number of crashes involving at least one vehicle from that approach to the intersection?
- Does the installation of RLR cameras on all approaches to an intersection have an effect on the safety of the intersection where it was installed?
- Does the installation of RLR cameras at some signalized intersections have an effect on all signalized intersections in the jurisdiction?

The scope also identifies how many intersections will be used in the evaluation. For example, an agency may have installed cameras at more than 50 intersections, but it only has the resources to evaluate 10 of the intersections.

A distinction should be made between the two types of evaluations that are being conducted. The first type applies to a single agency that has installed one or more cameras and wants to know if crashes have changed solely because of the use of cameras and, if so, what is the direction and magnitude of that change. Presumably, the jurisdiction would like to know if the rate of crashes has changed at the locations where the cameras were installed and if there was any spillover effect to other signalized intersections.

The second type of evaluation also attempts to identify and define the effect on crashes at signalized intersections from the use of cameras. However, this type of evaluation attempts to identify an effect that is transferable to the installation of cameras at other intersections and in other jurisdictions. That is, this type of study determines the effect that can be expected if cameras are used in other jurisdictions. It may also attempt to identify what factors influence any observed effect. Although the answers to the same questions of concern to the single agency are included, this analysis would examine other potentially influencing factors, such as the level of fines, the presence or absence of warning signs, the percentage of signalized intersections with cameras, etc. Answers to the second type of analysis could lead to guidelines and recommendations for the installation of camera systems. This type of analysis has a much broader scope and requires data from multiple jurisdictions.

The second evaluation is necessarily more complex and requires a robust design. At this writing, there was an FHWA project that had the objective of developing a study design for such an analysis. Consequently, the second type of evaluation is not within the scope of this chapter. The focus of this chapter is on the first type of evaluation, providing information on conducting evaluations by a single agency that has installed one or more cameras.

Measures of Effectiveness

Three general measures could be used to quantify or measure the effect that RLR cameras have on safety: (1) red light violations, (2) traffic conflicts or near misses, and (3) crashes.

Although the relationship between red light violations and crashes at an intersection has not been quantified, it is logical to assume that intersection safety will have been improved if there is a reduction in red light violations. Numerous evaluations (*3, 16, 17*) have concluded that RLR cameras reduce signal violations at intersections. Therefore, this chapter will not provide information on evaluating the effect of RLR cameras on violations.

Similarly, traffic conflicts or near misses can be used to evaluate the effect of RLR cameras on safety. Traffic conflicts are generally defined as an event involving two or more road users (vehicles, pedestrians, or bicyclists) in which the action of one user causes the other user to make an evasive maneuver (e.g., braking or weaving) to avoid a collision (*28*). Conflicts commonly associated with RLR crashes include left-turn cross-traffic conflicts, through and cross-traffic conflicts, slow vehicle same-direction conflicts, and pedestrian conflicts.

The relationship between traffic conflicts and crashes at intersections has been identified (*29*); as conflicts decrease at intersections, safety is improved. Therefore, conflicts can be used to evaluate the effectiveness of RLR cameras on safety. Other references already provide information on using conflicts to evaluate the effectiveness of a countermeasure (*28, 30, 31*). The reader is directed to those sources for further information.

Crashes are the ultimate measure of the safety effect. The measure of effectiveness discussed in this chapter is the effect that RLR cameras have on crashes.

Data Availability and Quality

The agency evaluating camera use should consider the availability and quality of data that will be used in the evaluation. This includes both crash data and other supporting data, such as traffic volume. Potential problems in crash data have been extensively documented (*32*). The quality of crash data used will directly affect the quality of any findings of the evaluation. Understanding any problems or changes in the data or how they were collected can help an agency construct a study to accommodate those problems. For example, if the reporting threshold for PDO crashes changed during the period of the study, the evaluating agency may decide to use only injury and fatal crashes in the evaluation of the RLR cameras.

The agency should also consider the accuracy of the database. Some agencies will have access only to coded computer files and not the original source—the police report. Errors can occur in transferring the data from the police report into a computer database. For example, crashes can be linked to intersections when they are not intersection related, or accident types can be erroneous and misleading. Because in many cases the evaluation will be limited in the number of intersections, if possible it is preferable that the police reports be obtained and that a new database be created for the analysis.

Study Duration

Ideally, the agency should use as long a study period for both before and after the camera installation as the data and resources allow. In general, the longer the better, provided that there have been no significant changes, other than the camera installation, in conditions that would affect the occurrence of crashes at the intersection or in the area. Although it may be relatively easy to retrieve data from before the camera was installed, historical data on traffic volumes, signal timing parameters, and other features may not be readily available.

After a camera is installed, agencies may be eager to determine its effect on crashes. The analysis can begin at any time after implementation, recognizing that the level of confidence in observed changes would increase as the period after the camera installation lengthens.

Continual Monitoring

Often when a treatment such as an RLR camera is applied to an intersection it is evaluated only for a defined period after the implementation. However, some of the effects on the safety of the intersection may change over time. Therefore, agencies should consider either evaluating the cameras again after they have been in operation longer or continually monitoring the effect of the cameras on a regular interval, such as every year.

Quantifying Crashes and Crash Types

To compare the effect of RLR cameras on the safety of intersections using crashes, the crashes must be quantified or expressed as units. The basic way to express crashes is simply by the frequency of crashes at the intersection. Crashes can also be expressed as proportions or rates, depending on the available information and the depth of the evaluation. Some basic considerations for using frequency, proportions, or rates to quantify crashes are discussed in this section.

Crash Frequency

Using crash frequency, or crash counts, is the most straightforward method of quantifying crashes at an intersection. The use of frequency could also be tailored based on the implementation of the cameras or targeted crash types as discussed in a subsequent section.

Proportions

A proportion quantifies the crashes of interest in relation to another value; for example, the number of crashes related to red light signal violations versus the total crashes at the intersection, the number of crashes at a signalized intersection versus the total crashes in the jurisdiction, or the number of angle crashes at an intersection versus the total crashes at the intersection.

Rate

A rate is a form of a proportion. Rates represent the frequency of crashes in the context of an exposure measure, typically volume. A common method for expressing the crash rate of an intersection is by the number of crashes per million vehicles entering the intersection. The resulting crash rates are frequently used to compare the relative safety of locations or the change in safety before and after the installation of the cameras. To use the crash rate to evaluate the effect of the cameras, it would be necessary to know the traffic volume entering the intersection before the installation of the cameras and after the installation of the cameras for most study designs. Expressing crashes as a rate assumes that the relationship between traffic volumes and crashes is linear. However, as will be discussed later, the relationship between crash frequency and traffic volume is not necessarily linear. Thus, using rates can inaccurately represent the effect of cameras on crash occurrence.

Expected Crash Frequency

As emphasized by Hauer (*25*), it is not simply the count of crashes for any given time period that determines the safety of an intersection, but the *expected* frequency during a specified period. The number of crashes that would be expected to occur in the years preceding the installation of cameras if the cameras had not been installed can be estimated using a method described by Hauer (*25*). This method accounts for other factors that could affect crash occurrence, such as changes in volume and regression-to-mean bias. As discussed later, this expected crash frequency is compared with the observed crash frequency to determine the effect of the camera systems.

Targeting Crash Types

A simple evaluation of RLR cameras would use all crashes occurring at the intersection or on the approach in the evaluation, regardless of how the crashes are quantified (e.g., frequency, expected frequency, proportion, or rate). However, these comparisons can be refined. Certain crash scenarios (types) or results (crash severity) can be analyzed separately to provide a more targeted evaluation.

Crash Type

The analysis could be targeted to include only the crash types of interest. It is generally accepted that RLR cameras have the potential to reduce angle crashes at signalized intersections and possibly increase rear-end crashes on the intersection approaches. Angle crashes and rear-end crashes could both be quantified at the intersection and used in separate evaluations.

Crash Severity

Crashes could be described by the severity of the crash. For instance, the crash quantity could be expressed as the frequency of EPDO crashes. Or, the agency could target the more severe crashes and use injury and fatal crashes instead of all crashes to quantify the crash experience at each intersection, either by frequency or rate. The proportion of severe crashes versus total crashes could also be quantified.

Violation Charged

Most agencies include information on any violations charged during a crash in the crash database. Crashes that involve traffic signal violations could be quantified for each intersection and expressed as the frequency of signal violation crashes, the rate of signal violation crashes, or the proportion of signal violation crashes to total crashes at the intersection. However, this quantifying could underestimate the number of crashes that involved a signal violation, because the reporting officer does not always issue a citation when a violation occurs in a crash.

Installation

The crashes could be quantified in the context of the installation. For example, if the RLR cameras were installed only on one approach, the crashes involving at least one vehicle from that approach could be quantified and then expressed as a frequency, a proportion to the total crashes at the intersection, or a rate based on the volume of that approach.

EVALUATION METHODOLOGY

One of the most important elements of an evaluation is the methodology that will be followed. It consists of the study design and the type of statistical analysis employed. The evaluation methodology must be selected in the context of how the intersections were selected for the installation of cameras, the available data, and the resources available to conduct the evaluation.

Study Design Alternatives

Although there are numerous study designs used in safety analysis of highway countermeasures (*26*), the following five methods that may be used by an agency to evaluate the safety effects of RLR cameras are described in this section: (1) before and after with control group, (2) before and after with comparison group, (3) simple before-and-after evaluation, (4) cross-sectional evaluation, and (5) trend analysis. The application, advantages, and potential problems of each study design are identified.

Before and After with Control Group

A before and after with control group methodology is a paired comparison of measurements taken twice at a treatment location—once before a change and once after a change. These measurements are also taken at a similar control location that did not receive the treatment. The measurements at the treatment locations are then compared with those of the control locations. The treatment and control locations should be very similar. They are both selected for consideration of receiving the treatment. The locations that receive the treatment and those that become control sites are randomly selected from the pool of potential candidates. For evaluations of RLR cameras, a group of intersections that are potential candidates for the cameras are selected. Randomly, one-half of those intersections are selected to have cameras installed. The other half of the group becomes the control group. The crash experience before the cameras were installed is compared with the crash experience after camera installation. This crash experience is compared with the same before-and-after periods in the control group.

Because of the randomized assignment of intersections that receive cameras and those that do not (i.e., the control group), this evaluation methodology is the most defensible. It overcomes many of the threats to validity of other study designs. However, this methodology is not realistic in practice. Treatments such as RLR cameras are not randomly assigned to intersections. Instead, the cameras are installed at the intersections most in need of the treatment, usually because of a demonstrated crash problem. To be considered a control group intersection, the intersection cannot receive treatment of any kind. This would introduce ethical considerations since the reason the intersection was selected for the evaluation was likely because of a demonstrated crash problem.

Before and After with Comparison Group

A variation on the before and after with control group methodology is the before and after with comparison group methodology. This methodology, similar to the former, compares the difference in crash experience at an intersection before and after the installation of RLR cameras. The crash experience is compared with measurements taken at similar intersections that do not have cameras. Referred to as comparison intersections, they are used to ensure that any observed change is not because of some factor that has affected intersection crashes areawide (e.g., an unusually harsh winter).

The comparison intersections are selected based on their similarity to the intersections with cameras. The intention is that, without the installation of the cameras, the two groups of intersections would be expected to have similar crash experiences in the after period. The strength of the study is directly proportional to how similar the intersections with cameras are to the comparison intersections (*33*). Aspects that likely affect the occurrence of RLR crashes, such as the yellow-interval length, the number of through lanes, the average daily traffic, and the approach speed, should be comparable between the two groups. If the group of intersections equipped with cameras is diverse in these aspects, then separate comparison groups would be specified for each intersection or subgroup of intersections. The comparison intersections also have to be free of any effects of the cameras applied at the treatment intersections.

For the more rigorous statistical analysis methods, the comparison intersections would be used to determine what the *expected* crash frequency would be at the treatment intersections had the cameras not been installed. The observed crash frequencies are then compared to these expected crash frequencies to determine the effect of the cameras.

Even though the comparison intersections are selected based on their similarity to the intersections with cameras, differences will exist. That is a substantial problem of this methodology. In most instances, it would stand to reason that because the comparison intersections were not selected for camera installation, they are not as "needy" as the intersections that were selected (*33*). However, the comparability of the treatment sites with the comparison sites can be tested as described by Hauer (*25*), by comparing the crash histories of both groups expressed as odds ratios.

Another potential problem with this methodology is regression-to-mean bias. Regression to mean refers to the tendency for a fluctuating characteristic of an entity to return to a typical value in the period after an extraordinary value has been observed (*34*). At intersections, this would be the tendency for an intersection with a particularly high crash frequency during a given period to return to a more typical value in the next time period. It would likely result in the overestimation of the safety effect of the cameras (*26*). Regression to mean is a particular problem for evaluations of RLR cameras where intersections are selected for the installation of a camera based on a high crash frequency. Where intersections are selected for camera installation based on something other than the crash frequency at the intersection (e.g., signal violation frequency), the bias of regression to mean is reduced, although it can still occur. Unless the agency can demonstrate that the before-period crash count is not unusually high or if the study period starts after the decision to use the camera has been made, the potential for regression-to-mean bias should be considered. As will be explained later, this bias can be overcome by employing a statistical analysis with a reference population.

Still another problem with this study methodology is the potential for a spillover effect of the cameras to the intersections without cameras (*15, 26*). This potential problem is discussed in more detail in a subsequent section.

Simple Before-and-After Evaluation

A simple before-and-after methodology is also a paired comparison of measurements taken at the same location twice—once before a change and once after a change. When used to evaluate the effect of RLR cameras on crashes at an intersection, the crash experience before a camera is installed would be compared with the crash experience after the camera is installed. The assumption in this study design is that the crash frequency in the after period would have been the same as the before period if the camera had not been installed. No comparison sites are used and, therefore, this study design requires less effort than the previous two study designs. However, this is a weak methodology and should be avoided if possible.

When the crashes are quantified for the before-and-after periods, the crashes in the two periods must be compared, and differences in the two quantities of crashes calculated. The difference between the two periods then has to be evaluated to determine if it represents an effect on the safety of the intersections caused by the installation of the RLR cameras.

The simple before-and-after methodology is attractive because it allows a comparison to be performed without having to consider variations between locations (*34*). It requires fewer intersections and less effort than the other before-and-after study designs. However, there are some well-documented potential drawbacks to using a simple before-and-after evaluation, which should be considered because they may affect the confidence of the findings of the evaluation. The following are the seven primary drawbacks to a simple before-and-after study design (*34*):

- The study may require a longer time between the decision to conduct a study and the achievement of a conclusion than other types of studies.
- It may be difficult to design while treatments are being implemented.
- Subjects may not react instantaneously to a treatment or may exhibit unusual behaviors that bias the study.
- Subjects may react in an unstable or random fashion.
- Factors other than the treatment (history) may cause the changes in the measure of effectiveness.
- The measure of effectiveness may mature or change over time (maturation).
- Regression to mean may occur.

Of particular concern to the evaluation of RLR cameras are history, maturation, and regression to mean. History and maturation are potential problems in simple before-and-after studies because there are other factors that affect the crash experience at an intersection. For example, improvements in braking systems and fluctuations in weather could affect the crash experience at an intersection between the before-and-after periods. Changes in the crash experience caused by such factors could be erroneously attributed to the use of cameras. Therefore, a simple before-and-after study should not be used to evaluate RLR cameras (*26*). If an agency does use a simple before-and-after study, they should be cognizant that regression to mean, history, and maturation will reduce the confidence of the findings of the study. The effect of the cameras on the safety of the intersection will likely be overestimated.

Cross-Sectional Evaluation

A cross-sectional evaluation could also be used to evaluate the effect of the RLR cameras on crashes, although this type of evaluation is not preferable. A cross-sectional evaluation compares the difference in crashes at an intersection or group of intersections with RLR cameras to a similar intersection or group of intersections without RLR cameras.

Similar comparisons can be made using a cross-sectional evaluation as are made in a before-and-after evaluation; for example, crashes can be quantified by frequency, proportion, or rate. A cross-sectional evaluation would be used if crash data before the cameras were installed are not available, are insufficient, or are problematic. Most intersections where RLR cameras are installed have a sufficient crash history that supported the decision to install the treatments. Cross-sectional evaluations are also useful when the intersection or intersections have changed significantly since the installation of RLR cameras. An agency may apply other treatments to an intersection in combination with the installation of RLR cameras. For example, the approaches may be repaved, the signal heads may be replaced with larger lenses, and the phase-change interval may be lengthened.

Cross-sectional evaluations usually involve complex modeling in which crashes are related to a variety of highway features in a regression equation. This complex modeling is outside the scope of this chapter, although there are many references that provide this information (*26*). Simple comparisons can also be made in a cross-sectional evaluation. For example, crash rates can be compared between intersections equipped with cameras and similar intersections not equipped with cameras. The appropriate statistical test for making these types of comparisons is the *t*-test, which is described in a subsequent section.

The greatest problem with cross-sectional evaluations is the difficulty in attributing differences in the crash experience of the two groups (i.e., intersections with cameras and intersections without cameras) to the cameras. There are many factors that affect the crash experience of an intersection. Even the most complex of models cannot control for all of the factors. The intersections must be similar in all elements that would affect crashes at the intersection (e.g., approach volumes, geometry, signal timing, and turning treatments), except for the presence of RLR cameras. The level of similarity between the two groups determines the confidence from which one can conclude that any differences in crashes between the two intersections or groups of intersections can be attributed to the cameras.

This type of evaluation is not preferable because of the difficulty in finding suitable comparison intersections. Additionally, the analysis required to account for differences in the comparison intersections is often too in depth for most agencies.

Trend Analysis

The effectiveness of RLR cameras can be evaluated informally using various types of trend analysis. Using trend analysis, an agency would monitor changes in crash statistics as a function of time and camera installations. Trend analysis is an informal before-and-after evaluation. Agencies would monitor changes in crash experience over a period of years in the context of RLR camera installations. This monitoring could be at the individual intersection level or at the area or jurisdiction level. Some examples of the type of crash statistics that would be monitored over a period of time include

- Proportion of crashes within the area or jurisdiction occurring at intersections,
- Rate of fatal and injury crashes within the area or jurisdiction occurring at intersections,
- Proportion of angle crashes within the area or jurisdiction, and
- Frequency of crashes that are reported as being caused by signal violations.

Each of these descriptive statistics would be monitored over a specific period of time; for example, 5 years using intervals of 1 month. Events such as the installation of RLR cameras could be noted on graphs that display the data so that the trends could be interpreted in the context of the camera installations.

This type evaluation would be useful for an agency that did not install all of the RLR cameras at the same time, but is installing them at intersections as needed. This type of evaluation could also be useful to monitor any degradation in the RLR cameras effect on crashes.

Trends analysis evaluations would have the same potential problems as before-and-after evaluations of RLR cameras. Mainly, without a comparison group, the agency could not conclude that changes in crash statistics can be attributed to the installation of the RLR cameras. Conclusions drawn from this type of evaluation are not as defensible as other methodologies, such as before and after with comparison group evaluations.

Statistical Analysis

After the study design is determined, the evaluating agency can choose to employ various statistical techniques to assess the effectiveness of the RLR cameras on safety. For most study designs, the techniques involve making comparisons, either between the before-and-after periods or between locations with cameras and those without (either control or comparison sites).

Statistical tests are employed to establish confidence in the magnitude of the difference observed. The type of statistical test performed depends on the units used to quantify the crashes, the sample size of the evaluation, the underlying distribution of the sample, and the confidence in the findings desired. The statistical analysis techniques can be grouped by those that are used to estimate what the expected crash frequency would be without the installation of the cameras, and those that do not. Those that estimate the expected crash frequency and compare the observed crash experience with the expected experience to determine the effect of the cameras are the more defensible statistical analysis techniques; however, they are also more computationally rigorous.

Empirical Bayes Method

The most defensible statistical method for evaluating RLR cameras in any of the before-and-after study designs is the use of Empirical Bayes (EB) statistics. The EB method uses a reference group to account for regression to mean. The reference group is the population of intersections with characteristics similar to the characteristics of the intersection with cameras. Because the intersections with cameras were likely chosen because of their crash experience, the crash frequency before the installation of the cameras is likely unusually high. The reference population is used to develop an estimate of the crash frequency before the cameras were installed, which in turn is used in the calculation of the expected crash frequency. Hauer (*25*) advocates the use of EB statistics in observational evaluations and identifies the following three advantages: (1) it helps to deal with regression-to-mean bias, (2) the estimates of the expected crash frequency are more precise than other methods, and (3) it allows for the estimation of the expected crash frequency for an entire time series.

The EB method estimates the expected crash frequency for the intersection or group of intersections had the cameras not been installed. This estimate is compared with the observed crash frequency. This statistical method is strongest when a comparison group is used. However, EB statistics can also be applied to a simple before-and-after study design. The primary disadvantage of this statistical technique is that it is relatively rigorous, requiring detailed inputs and potentially challenging calculations. Detailed information on applying this statistical methodology can be found in Hauer (*25*).

Chi-Squared Statistic

The chi-squared (χ^2) statistic is conducted on discrete crash frequencies (i.e., crash counts) at an intersection or group of intersections. The frequency of crashes is assumed to follow a Poisson distribution. It is used in before-and-after studies with control or comparison groups to determine if any changes in crash frequency between the before-and-after periods are equivalent for both the intersections with RLR cameras and the comparison or control intersections. Traffic volumes between the before-and-after periods should be equivalent. One of the benefits of a chi-squared test is that it can be used if the duration of the before period is not the same as the duration of the after period (*27*).

Poisson Probability

A basic Poisson probability distribution can be used to compare the two periods in a simple before-and-after study. If the crashes for the intersection or group of intersections are assumed to be Poisson distributed, the mean equals the variance. Accordingly, the percent reduction and the standard deviation of the reduction can be calculated between the before-and-after periods in a simple before-and-after study.

Paired t-*Test for Significance in Differences*

The paired *t*-test is used to determine whether differences in crashes between groups or periods are statistically significant or merely due to chance variations that result from sampling. The paired *t*-test can be used when crashes are quantified by either frequency or rate. When frequency is used, normality must be assumed to apply this test. Additionally, this test is applied to continuous data. It can be used to compare the mean crash frequency or rate for a group of intersections between the before-and-after periods.

z-*Test for Proportions*

The *z*-test is a comparison of proportions between two groups. It is a common statistical test employed in comparing two samples when the number of observations in each sample is above 30. The assumption in using this test is that the observations are independent.

For the simple before-and-after study design, the comparison is between the crash quantities between the before-and-after periods. The *z*-test is used in a before and after with comparison study similarly to how it is used in a simple before-and-after study. However, in the simple before-and-after study, the comparison was between the proportion in the before period to the proportion in the after period. For a before and after with comparison study, the difference between the crashes is calculated between the before-and-after periods for both the intersections with cameras and those intersections without cameras. The two differences (expressed as proportions) are then compared in the *z*-test. For a cross-sectional evaluation, the proportions are compared between those locations with cameras and those locations without.

Of all of the combinations of study designs and statistical methods, an evaluation methodology that employs a before and after with comparison group study design and EB statistics with a reference population will provide the best assessment of the safety effect of RLR cameras.

ADDITIONAL CONSIDERATIONS IN CAMERA EVALUATIONS

Other Countermeasures

When evaluating the effect of RLR cameras on the safety of an intersection or group of intersections, the findings of the evaluation are strengthened if the cameras were installed in isolation; that is, when the cameras were installed, were there any other changes made to the intersection? Or have there been any other changes made to the intersection in the study period? If so, these changes at the intersection could confound the effect on the safety of the intersection. The evaluating agency should not attribute any findings as solely the effect of the RLR cameras. Instead, the agency should report a combined effect. For example, if RLR cameras were installed and the yellow interval was changed, any changes in the crash experience should be attributed to a combined effect of the cameras and the change in interval, not just the cameras.

Traffic Volumes

As discussed previously, traffic volumes are typically used as the measure of exposure when rates are used to quantify crashes. However, traffic volumes can present some problems. First, traffic volumes by movement are not always readily available for intersections. If an agency anticipates before the installation of cameras that it will be evaluating the intersections using any form of a before-and-after study, the agency should conduct a turning movement count at the involved intersections. Another turning movement count would be conducted after the installation of the cameras.

The second problem with using traffic volumes is more complex. Rates are used to account for any difference in crash frequencies between before-and-after periods or between two groups that are caused by differences in traffic volumes. However, it should be recognized that *crashes are not necessarily linearly related to volume*. That is, as traffic volumes increase at an intersection, the crashes at the intersection do not necessarily increase proportionally (*25*). Therefore, the simplest evaluations of RLR cameras would have similar traffic volumes in both the before-and-after periods or in both the treatment and the comparison group. If the traffic volumes are not similar between the two periods, an adjustment can be made if the relationship between volume and traffic crashes is known. However, this may be a difficult correction for most agencies.

Spillover Effect

There is some evidence that RLR cameras will not only deter motorists from violating a signal at intersections equipped with cameras, but will also modify driver behavior at other intersections. If cameras do have an effect on driver behavior beyond those intersections where the cameras are used, then the other intersections in the area will likely also experience a decrease in angle crashes. This is a spillover effect or a halo effect.

A study of an RLR camera program in Oxnard, California, found a decrease in crashes at intersections with cameras and intersections without cameras. The study's authors attributed this reduction to spillover (*15*). An evaluation of cameras in Sydney, Australia, did not find a significant reduction in RLR-related crashes at intersections without cameras. The authors concluded that spillover did not occur at noncamera intersections used as control group intersections (*8*). (A national study involving multiple jurisdictions has yet to prove that this red light camera spillover effect does or does not occur.) Consequently, agencies should consider the possibility of this spillover in their evaluation of RLR cameras and modify their methodology or conclusions accordingly. Also, agencies may want to evaluate and quantify the spillover effect in addition to the effect at intersections equipped with cameras.

Avoiding Potential Bias from Spillover

If RLR cameras do have a spillover effect on intersections in the area not equipped with RLR cameras, agencies should consider the potential for this in their evaluation. The results would affect the selection of comparisons sites for before-and-after evaluations and cross-sectional evaluations. Instead of selecting comparison intersections within the vicinity of the intersections equipped with RLR cameras, the comparison intersections would be selected from a similar vicinity where RLR cameras are not used. For example, if an agency wants to evaluate the effect of RLR cameras on crashes at intersections in a county that uses the cameras, the comparison sites should be selected from another similar county that does not use cameras. The agency would want to ensure that the county from which the comparison intersections were selected is similar to the county with RLR cameras in aspects that would affect the crash experience (for example, demographics and terrain).

If another suitable jurisdiction or vicinity cannot be identified, then the agency should be aware that crash effects of RLR cameras that are identified in evaluations with comparison sites are potentially biased by spillover.

Evaluating Potential Spillover Effect

To evaluate the potential of a spillover effect from the RLR cameras in a before-and-after study, three groups of intersections are needed.

1. A group of intersections equipped with RLR cameras in the vicinity,
2. A group of similar intersections in the vicinity that are not equipped with RLR cameras, and
3. A group of similar intersections in a comparable but separate vicinity where cameras have not been installed.

The term “vicinity” is used here to describe the boundaries of the area where RLR cameras are used or could potentially be used. That is, if a city installs RLR cameras at some locations in the city and the application of the cameras is not confined to one neighborhood or part of the city, the city is considered the vicinity. In the case of a county that uses the cameras, the entire county would constitute the vicinity unless the application of the cameras has been limited to one municipality in the county. The determination of the boundary of the vicinity should also be made in the context of the public’s understanding of where the cameras are located or could be located.

The evaluation of a potential spillover effect is similar to the evaluation done in a before and after with comparison group study. However, now there are two experimental groups and one comparison group. The first group is the treatment group used to determine the effect of RLR cameras on intersections that are equipped with them. The second group is the experimental group used to determine the effect of RLR cameras at other noncamera intersections in the vicinity. The third group is the comparison group for both experimental groups. The difference in the crash experience between the before-and-after periods is measured for each group. Then the differences in the crash experience of the experimental groups are compared with the results of the comparison group as described previously.

SUMMARY

The following suggestions are offered to transportation agencies interested in evaluating RLR cameras in their jurisdictions:

- Collect and archive detailed traffic flow data.
- Collect detailed roadway inventory information and record when changes are programmed at the intersections.
- Collect and maintain good-quality crash data and save as many years of collision data as possible.
- Employ the most robust study design possible with the available resources, ideally a before and after with comparison group study.
- Consider not only the number of crashes that are occurring but also the type of crashes and the severity of the crashes.
- Carefully select comparison sites that are as similar as possible to the sites with cameras.
- Be aware of the potential for spillover.
- Use as many years of crash data as available in the evaluation.
- Use the most rigorous and defensible statistical methods available, ideally EB statistics with a reference population.

Transportation agencies have many options in how they conduct their evaluation of the effect of RLR cameras on crashes. Various statistical tests can be used to strengthen the confidence in their findings. If possible, a before and after with comparison group study should be designed and EB statistics should be used. If this is not possible, the agency should be aware of potential problems in attributing changes in the crash experience to the cameras.

CHAPTER FIVE

CONCLUSIONS

The primary objective of this synthesis was to determine what impact red light running (RLR) camera enforcement programs have had on crashes and related severity. Specifically, the questions that needed to be answered were

- What factors related to the intersection design or operations, the use of warning signs, the level of fines or any public outreach, etc., influence any observed changes in crashes?
- Do RLR cameras reduce or otherwise change crashes at intersections where they are deployed?
- Does whatever safety effect automated enforcement has at camera-equipped locations spill over to other signalized intersections?

Although there are other issues and questions to consider, these three points were determined to be the primary ones to address through the review of published literature and information provided from responses to a questionnaire.

• What Factors Influence Crash Changes?

There has not been any study that followed an experimental design that could have answered the several aspects of this question. In Glasgow, Scotland, there was a 2-year period during which the cameras were active, but only warnings were issued because of an error in the act that authorized camera use. The researcher, Fox, provided data for this interim period in addition to the official after period when levies were imposed. Table 5 in chapter two shows that crash reductions, if valid, were observed during the interim and even further reductions were observed during the after period. Setting aside the deficiencies of that crash analysis, it would appear that imposing fines presumably brings about better compliance and a greater decrease in crashes compared with just warnings. This conclusion is fairly academic, because every agency that uses automated enforcement is imposing fines for violations. What would be of interest is the influence of the level of fines. Presumably, as the fine increases, the level of noncompliance will decrease and, hypothetically, the crashes related to red light running further decrease. Testing the "elasticity" of fine levels with driver compliance and crash experience is not likely to be undertaken owing to political constraints; therefore, this one aspect of factors influence is not likely to be answered.

With regard to isolating the influence of other factors, this may prove to be difficult because of the experimental design requirements. For example, to isolate the influence of warning signs—whether or not using a sign that warns the motorist of the use of cameras is more effective than not using one—would require a larger sample of locations and the identification of control sites with and without cameras that are similar in all other influence variables. The effort might require using sites from various jurisdictions and, once that is done, then there is a possibility that still other factors may come into play. Notably, during the preparation of this synthesis, there was an ongoing effort sponsored by the FHWA Joint Programs Office to develop an experimental design that would address such issues.

• Are Crashes and Crash Severity Affected by RLR Cameras?

The assumption or hypothesis about the safety effect of automated enforcement of RLR violations using cameras is that they reduce the incidence of red light running and thereby reduce the likelihood of related crashes. The most obvious crash type that would be reduced is the angle crash, involving a violating vehicle with an adjacent vehicle proceeding through the intersection on a green-signal display. Another crash type likely to be reduced is a vehicle turning left colliding with a vehicle moving through the intersection from the opposite direction. For this latter scenario, the turning vehicle could be violating the red when the opposite direction has green, or vice versa. Conversely, there is a concern that rear-end collisions of vehicles approaching the intersection will increase. Upon seeing the yellow display, a more cautious motorist may stop more abruptly, causing the motorist immediately following, not anticipating the need to stop and likely following too closely, to hit the lead vehicle from behind. Assuming that these crash types produce equal crash severity (injury and fatality), then a net benefit would accrue if the crash reductions of the angle type exceeded any crash increases of the rear-end type. In general, angle crashes are usually more severe; therefore, even a zero change in total crashes may prove to be safer if there are a smaller proportion of angle to rear-end crashes with the use of cameras.

Although nearly every study and crash analysis performed, as discussed in chapters two and three, has had some experimental design or analysis flaw or deficiency, there is considerable "evidence" that RLR cameras do have an overall positive effect. Most of the various studies and analyses have shown "observed" reductions in angle crashes, with some showing smaller increases in rear-end crashes. In many cases, the flaw in the analysis was the lack of a proper control group, which would allow a valid comparison of the observed changes, increases or decreases, with changes in signalized intersections that did not have cameras. Cameras tend to be installed at problem locations, those manifested by higher than average crash experience. These types of locations can experience reductions in subsequent years even without intervention. To account for this regression-to-mean phenomenon, control sites are needed.

In some cases, a reduction was observed, which when exposed to statistical testing proved to be statistically insignificant. Often, this statistically insignificant finding is attributed to small sample sizes pertaining to the number of sites and crash frequency at each site. It should be noted that statistical significance is always coupled with a confidence or probability level. What may have been statistically insignificant at the 95% confidence level may have been significant at the 90% or a lower, but still relatively high, confidence level. This chosen significance level merely provides the level of confidence that the observed difference is due solely to the treatment and not some other situation or artifact.

- **Is There a Spillover Effect?**

Assuming that there is a net safety benefit to using cameras, an important question is whether or not there is a spillover or halo effect to signalized intersections that do not have cameras. The answer is important because it can be used to decide how many intersections that would be candidates for cameras need to be so equipped to bring about a change in driver behavior areawide.

The assumption that there can be a spillover effect was inherent in the finding of the Oxnard, California, study, where the researchers concluded that significant crash reductions at 125 signalized intersections was attributed to the use of RLR cameras at 11 of the intersections. They based that assumption on the findings of studies on before-and-after violation changes in Oxnard and in Fairfax, Virginia, where violation reductions were observed at both camera-equipped and nonequipped intersections and differences between camera and noncamera sites were not significant.

The Glasgow study examined this assumption. Fox found that there was a reduction in RLR-related crashes in a 1-km square area adjacent to the areas where there were cameras, but he also observed an even higher reduction at intersections in the area most remote to where the cameras were deployed. However, he attributed that reduction to other safety measures. Also, recall that Hillier et al. concluded that because the eight control sites did not demonstrate a significant reduction in RLR crashes, there was no spillover or halo effect.

Signage practices have a substantial impact on spillover effects. In the Oxnard and Fairfax studies warning signs were not posted at camera-equipped sites, but areawide warning signs were used. In Australian studies, warning signs were posted at camera-equipped sites, thus reducing possible spillover effects.

It is important that potential spillover effect be conclusively resolved, because it is a factor to be considered in any evaluation. If indeed there is a spillover effect—and it might be expected, especially if there is an aggressive public information campaign—then using nonequipped intersections as a control is problematic. At the very least, if nonequipped intersections are used as control or comparison, then the possibility of the change at the equipped intersections being greater or less than observed should be recognized. Using nonequipped intersections from another jurisdiction or area outside the influence of the RLR program is preferred for effectiveness evaluations.

- **Are the Safety Benefits Lasting?**

Of concern for any safety countermeasure is the long-term effectiveness. Are such measures effective for just a year or so, or will the benefits be accrued for many more years? With respect to automated enforcement of red light running, there is some preliminary indication that the safety benefits are reduced over time. The data provided by Howard County, Maryland, and presented in chapter three indicate that this may be the case. In general, the data showed that the average reductions in RLR-related crashes were less as the after period increased. However, this one analysis is not conclusive, and even if the safety benefits, when viewed over a period of several years, are less than in the initial experience, an overall safety benefit has been provided.

- **Evaluating the Effectiveness of RLR Camera Programs**

Agencies are encouraged to continually conduct evaluations of their RLR camera enforcement programs. The effect on RLR violations will become apparent with the change in citations and fines collected. Although not discussed in this synthesis, background literature and discussions with jurisdiction officials indicate that initially citations and fines are high, but then at many locations they decline over time, even to the extent that the cameras are removed.

Evaluation of the crash changes needs to be conducted with proper methodology to avoid making incorrect conclusions about observed changes, be they higher or lower. There are alternative methodologies of varying statistical rigor that provide corresponding variation in the level of confidence in the conclusions drawn. The most important point is for the evaluator to understand the implications of the chosen procedure.

- **Overall Conclusions**

Based on the information that has been acquired and reviewed, it appears that RLR automated enforcement can be an effective safety countermeasure. Although data on violation changes were not covered in this synthesis, there are many studies showing that violations are significantly reduced with the camera systems. This behavioral change should translate to a safety benefit in the form of reduced crashes and/or crash severity. Furthermore, it appears from the findings of several studies that, in general, RLR cameras can bring about a reduction in the more severe angle crashes with, at worst, a slight increase in less severe rear-end crashes. However, there is not enough empirical evidence based on proper experimental design procedures to state this conclusively.

As the use of automated systems becomes more widespread and more mature, there will be better opportunities to conduct the research needed to reach a conclusive finding and to provide guidelines for where those systems may be appropriate. Those who choose to use these systems will want to know what locations should be equipped, the expected safety benefit, and how many locations need to be equipped to bring about an areawide benefit.

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APPENDIX A

Questionnaire

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Project 20-5/Topic 32-03

IMPACT OF RED LIGHT CAMERA ENFORCEMENT ON CRASH EXPERIENCE

QUESTIONNAIRE

The NCHRP Synthesis Project, under the Transportation Research Board, was developed to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern. This project deals with the increasing usage of red light camera enforcement as a means to reduce running red light violations at traffic signals and presumably reduce associated crashes. Your agency has been identified as one that has implemented red light running (RLR) cameras and therefore, we seek your assistance by completing the attached questionnaire.

The main focus of the synthesis is to identify how crashes have been changed with the use of RLR camera enforcement programs. We wish to know this for intersections where the cameras are used as well as within the jurisdiction, if possible. We also wish to know how the crash evaluation was conducted, and if the data can be made available for subsequent analyses for the synthesis.

In addition, we are interested in knowing what other types of evaluations were conducted and what your agency has learned regarding any positive or negative impacts of the RLR program.

The few questions that are included are designed to elicit this information. Feel free to add any comments you may have related to this issue.

Thank you for your participation. You may return the questionnaire and supporting documentation to:

Hugh W. McGee
BMI
8330 Boone Boulevard, Suite 700
Vienna, VA 22182

The questionnaire can be faxed, if appropriate, to 703-847-0298. If you have any questions or comments, feel free to contact the above at 703-847-3071 or by e-mail at hmcgee@bmiengineers.com.

NCHRP SYNTHESIS TOPIC 32-03 QUESTIONNAIRE

IMPACT OF RED LIGHT CAMERA ENFORCEMENT ON CRASH EXPERIENCE

BACKGROUND INFORMATION

Agency/Organization Reporting :____

Name of Respondent :____

Title :____

Address :____

Phone # :____________________E-mail :____________________Fax # :________________

---

1. How many intersections are currently equipped with red light running (RLR) camera systems? (Include those intersections where the camera is installed for only a portion of the time.) ______

2. When was the first RLR system installed? (enter mo/yr _____) When was the latest system installed? ______

3. Before deploying RLR cameras at an intersection, does your agency typically try other engineering, education, or enforcement measures to reduce red light running?
   Yes_______No _______Please explain ____

4. Has your agency conducted an evaluation of your RLR camera system with regard to any of these measures?

	YES	NO
Accidents at RLR locations	________	________
Accidents at non-RLR locations	________	________
Violation rates at RLR locations	________	________
Public opinion	________	________
Driver behavior at RLR locations	________	________
Other: (specify)	________	________
____________________	________	________
____________________	________	________

5. If your agency conducted an evaluation of crashes at RLR camera locations, briefly describe the scope of that study (how many locations, before/after, time frame, analytical procedure, etc.).

6. In summary, what were the results of the evaluation described in Question 5?

7. Are the data and results described in Questions 5 and 6 available in a document? Yes___ No___. If yes, and if available, please return with questionnaire.

8. What characteristics of the RLR camera enforcement program affected the outcome of the evaluation (e.g., grace periods, signing, public outreach)?

9. Other comments:

Please return the completed questionnaire and supporting documents by August 20, 2001 to:

Hugh McGee
BMI
8330 Boone Boulevard, Suite 700
Vienna, Virginia 22182
Fax: 703-847-0298
Tel: 703-847-3071
E-mail: hmcgee@bmiengineers.com

APPENDIX B

Responses to Questionnaire

TABLE B1
RESPONSES TO QUESTIONS 1, 2, AND 3, BY AGENCY

No.	Responding Agency	State	No. of Intersections with RLR Cameras	Date First Installed	Date Last Installed	Measures Employed Before Installing Cameras
1	City of Los Angeles	CA	8	12/1/00	6/1/01	We ensure that signal heads are clearly visible and that there are no immediately adjacent signalized intersections. Also, yellow change interval times are reviewed.
2	City of Garden Grove	CA	1	7/1/00	7/1/00	Video camera with police traffic personnel. Selective enforcement.
3	City of Chandler	AZ	8	9/1/00	1/1/01	Police enforcement.
4	City of Fairfax	VA	8	7/1/97	3/1/98	All intersections in the city are monitored by officers on routine patrol. If a particular intersection is identified as having a problem or a high accident rate, then selective enforcement is tried. Most of the selective enforcement is done with overtime because of the commitment needed to concentrate on this effort. A significant effort was made in the year before red light cameras were first installed. Fairfax City police also participate in regional efforts such as "Smooth Operator" that target specific violations or behavior. A key difference between red light running and other types of violations is the inherent danger to the officer in pursuing a red light runner through a red light. The courts require that the officer testify that the signal was red, so the officer must be on the same side of the signal as the violator. The officer cannot radio ahead to another officer because this is usually impractical from a resource standpoint and the courts require that the officer issuing the citation also be the one that viewed the violation. At many locations there is nowhere for an officer to observe the intersection, be able to safely pull into traffic and not be seen by the motorists. An officer visible at the side of the road will deter most red light running but only while the officer is present. Thus, conventional enforcement can be largely ineffective and dangerous while yielding little positive benefit. In the year before the camera program was begun, the city police handed out about 3 times as many citations for red light running as in any prior year, at considerable expense—about $30,000 in overtime expenses for about 500 citations. In the first year of the camera program more than 11,000 citations were issued and the incidence of red light running at the monitored intersections dropped on average by 40%. At several of the high intersection locations the city has tried various signing and striping schemes to affect accident rates; however, these attempts at driver education were ineffective. Signal timing and phasing changes have been more effective, but usually at the expense of increased traffic congestion and delay.

TABLE B1 (*continued*)

No.	Responding Agency	State	No. of Intersections with RLR Cameras	Date First Installed	Date Last Installed	Measures Employed Before Installing Cameras
5	City of Irvine	CA	2	8/1/00	4/1/01	Increased enforcement.
6	Howard County	MD	35	2/1/98	6/1/01	Engineering: review geometrics, traffic flow patterns, signal phasing/timing, collision data, and classification studies. Further, establish that traffic signal is in full MUTCD compliance. Education: Involvement in Traffic Safety Week promotion, public service announcements on both Cable TV and local TV stations, and local high school programs. Enforcement: Selective enforcement programs developed in collaboration with Police Department Traffic Safety Enforcement Unit.
7	Laurel	MD	5	9/1/97	9/1/99	Stationary radar to reduce speeds. Stationary stop teams for red light violations.
8	City of Boulder	CO	3	10/1/98	10/1/01	The city of Boulder has a hazard elimination program, which annually reviews traffic accident records to identify high accident locations and appropriate mitigation strategies. Strategies have focused on signal timing and phasing and geometric improvements. Clearance intervals are based on the ITE proposed recommended practice. The city has not sponsored any red light safety public information efforts beyond those done in support of the red light cameras. Traditional officer based enforcement is extremely limited due to deployment constraints and safety concerns. The city has recently commissioned a new motorcycle based traffic unit, which has provided another viable red light enforcement tool.
9	Portland	OR	1	9/1/01	9/1/01	Review for the use of signs, changing signal timing, lanes, prohibiting or restricting turns, etc. Also review for enforcement methods.
10	Los Angeles County	CA	5	7/1/99	7/1/00	For all signalized intersections that experience a high concentration of accidents, the signal timing is reviewed and modified accordingly. Provisions such as left-turn phasing or all-red phasing are examined. The design/configuration of the intersections are examined to determine if improvements are needed (such as site distance). Existing traffic control devices (signs) are reviewed, at which time additional controls are examined such as the provision of "Signal Ahead" warning signs. For all traffic issues our department is in close contact with law enforcement agencies (i.e., CHP, sheriffs).
11	Greenbelt	MD	8	5/1/01	8/1/01	Public service announcements. Selective enforcement.
12	Landover Hills	MD	2	2/1/01	2/1/01	Officer enforcement, articles in town newsletter for public awareness.
13	Cheverly	MD	4	6/1/00	6/1/00	
14	San Francisco	CA	17	10/1/96	3/1/01	We have viewed the installation of camera systems as simply one tool in our efforts to minimize incidences of red light running. Throughout our automated enforcement program, we have been actively educating the public and encouraging police enforcement. Prior to the start of our program (and throughout its life) we have been engaged in a Capital Development Program to expand sales tax dollars on signal visibility upgrades and hardware replacement. In some cases, we install cameras where upgrades are planned (in the long term) as mitigation. In some cases, because we try to disperse the cameras citywide, we install them in lieu of other improvements.
15	Annapolis	MD	0			Education and enforcement.

TABLE B1 (*continued*)

No.	Responding Agency	State	No. of Intersections with RLR Cameras	Date First Installed	Date Last Installed	Measures Employed Before Installing Cameras
16	City of Alexandria	VA	3	11/1/97	11/1/97	None other than routine enforcement.
17	Tempe	AZ	2			Local media coverage as to problem intersections, enforcement task forces targeting red light runners shown in both print media as well as local news media. Local access cable television with the information as shown above.
18	City of Beaverton	OR	5	1/1/01	4/1/01	Conducted an extensive red light running campaign in 1998 and 1999. The campaign was awarded a grant from the Oregon DOT. The primary goal was to change driving behavior by increasing awareness and educating the public to the dangers of running red lights.
19	Mesa	AZ	17	1/1/97	1/1/00	Motor officers' selective enforcement. Speed trailers. Public service announcements.
20	Morningside	MD	3			High visibility patrol with marked police cruisers.
21	Howard County	MD	29	2/1/98	10/1/00	Public safety awareness, traditional enforcement, engineering issues resolved or changed.
22	Baltimore County	MD	20	12/1/99	6/1/01	In the past there had been design changes and selective enforcement used at problem locations.
23	Riverdale	MD	4	6/1/99	6/1/00	Interviews with TV news programs as well as articles in local newspapers six months prior to implementation of RLR camera program. Traffic calming construction has been taking place on the roadway where most cameras are located. All cameras are located on state roads.
24	City of High Point	NC	10	2/1/01	8/1/01	We have all-red interval as a deterrent/safeguard for people running red lights. We analyze intersections to study the pattern of accidents, changed the signal heads, added new signal heads, and increased the visibility of signal heads. Took Police Department's help to get good enforcement at intersections. Used a number of engineering measures to improve safety at the intersections.
25	Paradise Valley	AZ	2	9/1/96	3/1/01	Extensive publicity regarding implementation. Paradise Valley first in county to have photo enforcement in 1987. First in Arizona to have red light enforcement in 1996.
26	City of Scottsdale	AZ	9	2/1/97		
27	City of Garland	TX	5	8/1/01	8/1/01	The city has used and continues to employ public awareness campaigns, targeted enforcement at key intersections, and other traditional law enforcement and public education techniques and programs. Intersection engineering (including increasing amber light duration) is considered at intersections evidencing a need for adjustments. The city has installed indicator lights slaved to the red light so that officers watching for red light violators may stay downstream of traffic in order to increase officer and innocent driver safety. Nonetheless, there are intersections that are virtually unenforceable due to various factors including traffic volume.
28	City of Sacramento	CA	10	5/1/99	7/1/00	Signal timing, signal equipment/visibility, enforcement.
29	Montgomery County	MD	15	10/1/99	4/1/00	We evaluated intersections under consideration for red light cameras to look for engineering solutions to the problem. We found several instances where issues were addressed instead of using photo enforcement. These issues included poor visibility of signal heads, inadequate clearance times, stop lines that were deteriorated. Intersections where engineering improvements were made were reevaluated later to determine if the changes had improved the situation.

TABLE B1 (*continued*)

No.	Responding Agency	State	No. of Intersections with RLR Cameras	Date First Installed	Date Last Installed	Measures Employed Before Installing Cameras
30	Sacramento	CA	5	3/1/01	10/1/01	Prior to red light cameras, the only program that would fit into education about red light running would be POP program (problem-oriented policing). Red light running is only a small part of that program.
31	San Diego	CA	20	9/1/98	5/1/00	Enforcement: We dispatched uniform officers in marked patrol cars and motorcycle officers to those areas heavily violated by red light runners. The officers would issue warnings verbally and written, and in some cases would issue citations. Education: We utilized television and radio to warn the public when the cameras would be activated. Engineering: We checked with traffic engineering to verify if certain intersections were suitable for photo enforcement. We also acted on citizen complaints of red light running and officer observations.
32	City of Charlotte	NC	20	8/1/98		
33	City of Overland Park	KS	2	8/1/01	12/1/01	Our police department targets enforcement efforts at high accident locations and known red light running intersections. Also, in public works we evaluate crash data and look for potential improvements (i.e., better signal timings, coordination, geometric modifications, etc.). At this time we are just conducting a one-year pilot study of different red light running technologies for the Kansas DOT. We hope to use the results of this study to convince legislators to provide statewide enabling legislation. Kansas State University will be using our data to prepare a summary report.
34	Toledo	OH	10	1/1/01	11/1/01	Traditional enforcement and engineering studies.
35	Ft. Collins	CO	1	8/1/95	8/1/95	Intersection redesign, leading/lagging light control.
36	Fairfax County	VA	10			Police Department attempts to enforce red light laws. Prior to putting in cameras the Virginia DOT reviews locations and signal timings.
37	New York City	NY	60	12/1/93	1/2/02	Engineering: Checked signal timing and signal displays.

TABLE B2
RESPONSES TO QUESTION 4, BY AGENCY

No.	Responding Agency	Have Conducted Evaluation of RLR System with Regard to:						Comments
		Accidents at RLR Camera Locations	Accidents at non-RLR Camera Locations	Violation Rates	Public Opinion	Driver Behavior	Other	
1	City of Los Angeles	No	No	No	No	No	No	
2	City of Garden Grove	Yes	Yes	Yes	Yes	Yes	No	
3	City of Chandler	No	No	No	No	No	No	
4	City of Fairfax	Yes	Yes	Yes	Yes	No	Yes	Speed of violators, time after red for violators, repeat violators.
5	City of Irvine	Yes	Yes	Yes	No	No	No	
6	Howard County	Yes	Yes	Yes	Yes	No	No	
7	Laurel	Yes	No	Yes	No	No	No	
8	City of Boulder	Yes	No	Yes	Yes	No	No	
9	Portland	No	No	No	No	No	No	
10	Los Angeles County	Yes	No	No	No	No	No	
11	Greenbelt	No	No	No	No	No	No	
12	Landover Hills	No	No	No	No	No	No	
13	Cheverly	No	No	No	No	No	No	
14	San Francisco	Yes	No	Yes	Yes	No	Yes	Accidents citywide where RLR was deemed a contributing factor.
15	Annapolis	No	No	No	No	No	No	
16	City of Alexandria	No	No	Yes	No	No	No	

TABLE B2 (*continued*)

No.	Responding Agency	Have Conducted Evaluation of RLR System with Regard to: Accidents at RLR Camera Locations	Accidents at non-RLR Camera Locations	Violation Rates	Public Opinion	Driver Behavior	Other	Comments
17	Tempe	Yes	Yes	Yes	Yes	Yes	No	
18	City of Beaverton	Yes	Yes	Yes	Yes	No	No	The evaluations are not yet complete.
19	Mesa	Yes	Yes	Yes	Yes	No	No	
20	Morningside	No	No	Yes	Yes	Yes	No	
21	Howard County	Yes	Yes	Yes	Yes	Yes	No	
22	Baltimore County	Yes	Yes	Yes	Yes	Yes	No	
23	Riverdale	Yes	Yes	Yes	Yes	No	No	
24	City of High Point	Yes	Yes	Yes	No	No	Yes	Public opinion through newspapers and in other cities.
25	Paradise Valley	Yes	No	Yes	Yes	Yes	No	
26	City of Scottsdale	Yes	Yes	Yes	Yes	Yes	No	
27	City of Garland	No	No	No	No	No	No	
28	City of Sacramento	Yes	No	Yes	No	Yes	No	
29	Montgomery County	Yes	Yes	Yes	No	No	No	
30	Sacramento	No	No	Yes	No	No	No	
31	San Diego	Yes	Yes	Yes	Yes	No	Yes	
32	City of Charlotte	Yes	Yes	Yes	Yes	Yes	No	
33	City of Overland Park	Yes	Yes	Yes	No	Yes	No	
34	Toledo	No	No	No	No	No	No	
35	Ft. Collins	Yes	Yes	Yes	Yes	No	No	
36	Fairfax County	No	No	No	Yes	No	No	
37	New York City	No	No	Yes	No	No	No	

TABLE B3
RESPONSES TO QUESTIONS 5, 6, AND 7, BY AGENCY

No.	Responding Agency	Evaluation Scope	Evaluation Results Summary	Data Available?
1	City of Los Angeles			No
2	City of Garden Grove	A 1-year before-and-after accident analysis was conducted at the RLR intersection and five other high-violation intersections.	The intersection with RLR had a 56.2% reduction in right-of-way violation accidents and a 1.2% increase in rear-end-type accidents. A 10-year citywide accident history was developed to show that broadside accidents are more severe than rear-end-type accidents.	No
3	City of Chandler			No
4	City of Fairfax	Attempts were made to correlate before-and-after camera system accident data; however, the city changed systems around that time and the pre-1998 data are not easily accessible. No one in the police department today remembers how that system worked and how things were defined. What is needed is for someone to go back to each of the individual accident reports and determine which accidents involved red light running. To date no one has had the time to do that.	No conclusion could be reached because there was no certainty how the accident data prior to 1998 are defined.	No
5	City of Irvine	We do an annual analysis of accident history in the city. The two locations are not shown on this year's high collision intersections.	The two intersections were chosen for ease of installation rather than accident history, as this was a better program to evaluate two vendors. However, one of the intersections is no longer on the high collision intersection list.	No

TABLE B3 (*continued*)

No.	Responding Agency	Evaluation Scope	Evaluation Results Summary	Data Available?
6	Howard County	For all signalized intersections having had at least 1-year experience with red light running detection systems issuing citations, a total of 24 signalized intersections. Only the approaches being monitored by cameras were assessed. However, it was observed that collision totals for all approaches were influenced by presence of cameras, regardless of monitoring. Note: One of 24 cameras (U.S. Rte. 40 at Marriottsville Rd.) was removed after 14 months when violation rate declined to zero. Another camera site (U.S. Rte. 29 at MD Rte. 216) was eliminated by a grade separation project. Collision types analyzed were: rear end, angle, and other.	Rear-end collisions increased by 6%. Angle collisions decreased by 47%. Other collisions decreased by 11%. Approach speeds at sites monitored by cameras declined by 9%.	No
7	Laurel	All five locations had the number of accidents after red light cameras were installed compared to the number of accidents three years prior to installation.	Reduction in number of accidents at all locations.	No
8	City of Boulder		Red light violations have decreased by 36% and red light related traffic accidents by 57% on the approaches where the cameras were deployed.	No
9	Portland			No
10	Los Angeles County	Our RLR locations were mainly determined based on the number of accidents resulting from red light violations. One of the main intentions of our program is to reduce or eliminate accidents resulting from red light running. In evaluating our intersections for photo enforcement we determined the accident rate for each location. The components of the accident rate include: number of accidents, period, and number of vehicles. This rate is then compared to the county average for accidents expected at a signalized intersection.	Preliminary results regarding the effectiveness of the program shows that the accident rates for three of the five locations have improved, the fourth location has remained relatively the same, and the fifth location has not improved.	Yes
11	Greenbelt			No
12	Landover Hills			No
13	Cheverly			No
14	San Francisco	We looked at RLR injury collisions, fatal collisions, and number of RLR collisions 5 years prior to and 5 years after the implementation of our first camera in October 1996. This incorporated accident history from the "Statewide Integrated Traffic Records System" from over 1,000 traffic-signalized intersections in S.F. A brief statistical analysis was conducted.	With 90% confidence, RLR collisions have declined since the installation of cameras in San Francisco. We recognize the combination of engineering (including mast-arm installation, etc.), education, and enforcement (including automated enforcement) is the reason for the decline.	Yes
15	Annapolis			No
16	City of Alexandria		We have seen a reduction in violation rates at all three intersections; however, because other traffic management changes were made at two of the intersections after the camera was installed, we can only be certain of a reduction solely attributable to the Red Light Program at one of our intersections (Duke Street and Walker Street—graph of violations per pass). (Attached below.) (Not included here.)	Yes
17	Tempe	See the accompanying document. (Not included here.)	There has been a reduction in the number of collisions since the installation of the red light cameras in both the intersections.	Yes

TABLE B3 (*continued*)

No.	Responding Agency	Evaluation Scope	Evaluation Results Summary	Data Available?
18	City of Beaverton	The city established criteria for intersection selection based upon accident data, citation issuance, volume of traffic. The engineering department evaluated all 153 traffic signals and selected 5 for camera installation.	The program is still very new, so not much data have been analyzed yet. To date, Beaverton has had no accidents at photo-enforced intersections. Citation issuance has increased with the increased monitoring of the program.	Yes
19	Mesa	Intersection crashes per 10,000 population have decreased each year from 1997 as follows: 130.9 (1997); 127.5 (1998); 120.8 (1999); 119.1 (2000); 117.9 (2001).	Graph attached. (Not included here.)	Yes
20	Morningside	Analyzed data of citations issued prior to inception of RLR compared to after inception.	Fewer citations and violations; fewer motor vehicle accidents related to failing to obey signal.	No
21	Howard County	A study was conducted in the fall of 2000 by the Howard County Traffic Engineers. It was a study of all locations with relative before-and-after time frames. A more comprehensive evaluation is currently underway with more meaningful data.	Overall, there was a 43% reduction in red light running accidents. A report prepared by the Howard County DPW shows an overall 31% reduction.	Yes
22	Baltimore County	A comparison of the number of crashes and severity was conducted for the calendar year prior to use and the full calendar year after installation at the specific intersections.	Over 50% drop in total crashes and a proportional reduction in severity.	Yes
23	Riverdale	Accident data were evaluated one year prior to and one year after installation of camera systems. The data were compiled for all intersections and focused on comparison of personal injury and causes.	For the most part, accident data remained consistent between the two years. This is due mostly to accidents occurring at intersections not equipped with camera systems.	No
24	City of High Point	Before study was done to see the number and type of accidents, after study will be performed after one year of installation.		Yes
25	Paradise Valley	First system installed in 1996, second in 2001. Superficial review showed nearly the same number of collisions, but reduced severity. Initial increase in number of rear-end collisions.	Technology is very worthwhile portion of an overall traffic enforcement program.	No
26	City of Scottsdale	We have done a basic review of the accident history at RLR camera locations to get a before and after picture of RLR accidents. We reviewed a few years prior to the cameras being installed and every year since the cameras have been installed. We have accident information available. We have not compiled it into a report, but we can easily search for total accidents and RLR accidents for the city or for individual intersections.	Overall, RLR accidents in the city dropped the first year after the RLR cameras were installed. RLR accidents have slowly crept back up but are still below the figures for 1996, the last year before the cameras were installed. RLR accident numbers for individual intersections are low, so it is hard to make any profound conclusions about individual intersections. Also, in our city we have had some significant traffic pattern changes in the past few years due to a freeway being constructed in the city. It is difficult to isolate the effect of the RLR cameras from other circumstances in the city.	No
27	City of Garland	The city has just completed initial installation of RLR cameras and has yet to put them into operational status.		No
28	City of Sacramento	1 year prior, last 12 months.		Yes
29	Montgomery County	We looked at about 50 locations previously identified as having a higher number of red light running collisions. Accident data from 1997 through 2000 were compared to determine effectiveness.	We saw a slight decrease in accidents resulting from red light running; although the number of accidents at specific locations was low and probably not statistically significant, the overall number of accidents went down slightly in the two years after implementation.	No
30	Sacramento			No

TABLE B3 (*continued*)

No.	Responding Agency	Evaluation Scope	Evaluation Results Summary	Data Available?
31	San Diego	Pre-installation: Statistics were gathered to determine which intersections had the most red light violations. We also looked at intersection accidents in controlled intersections. After installation: A post-program analysis was conducted after a 2-year period at 16 intersections to determine the affect of enforcement.	Stats on intersection accidents were not conclusive, because non-injury accidents are not documented, nor are accident reports taken. The injury accidents remained the same in most locations, but the incidents of red light running decreased dramatically, which reduces the potential for intersection accidents, road rage, and road congestion.	No
32	City of Charlotte	See report.	See report.	Yes
33	City of Overland Park	We looked at all of our signals (220) and determined which had the highest number of red light running accidents. This was used to help police target their enforcement efforts and to determine where the best locations might be for placing cameras during our pilot program. We have data going back 3 to 4 years specific to the red light running problems in our city. We do not have cameras that are being used to send out citations or warnings, just for data collection purposes during the pilot program.	The only anecdotal story I can pass along is that we used to have about 12 accidents annually at our first installation...although we are not notifying red light runners directly, there has been much publicity about this location and accidents are down (only 3 RLR accidents last year.)	No
34	Toledo	An evaluation will be done after the system has been in operation for at least one year.		No
35	Ft. Collins	Data Analysis 95–99 for crashes and violations	Data showed NO significant impact in accident rates or injury rates.	Yes
36	Fairfax County	Only pre-implementation crash data were obtained.		No
37	New York City			No

TABLE B4
RESPONSES TO QUESTIONS 8 AND 9, BY AGENCY.

No.	Responding Agency	Features of RLR System Affecting Outcome	Other Comments
1	City of Los Angeles		
2	City of Garden Grove	Changes in driver behavior (i.e., many skid marks on new pavement indicating stopping because of presence of RLR).	A comparison of citations written by officers vs. the number of citations issued as a result of the RLR. Officer-written citations averaged 0.2 per day. The RLR number averaged 3 per day.
3	City of Chandler		
4	City of Fairfax		We looked at accident statistics at our intersections, but could not draw any meaningful conclusions. There seem to be many factors about crashes that affect the analysis. Even if we go back to the original accident reports, it may be difficult to determine whether or not red light running was the cause of an accident. Many times one of the drivers is charged with failure to obey a traffic signal, but just as often one is charged with failure to pay full-time attention or some other violation. Since the officer is not usually there to view the accident, some judgment must be used as to what actually happened. The drivers are interviewed and if the stories conflict, the officer must decide who is more credible, or maybe it is decided to not issue a citation. There will always be some question about the analysis if the data are not accurate. In looking at accidents over any period of time, factors such as traffic volume, weather conditions, ambient light conditions, traffic signal operations, enforcement and safety programs, and vehicle equipment will also vary. In a study of a small sample, like accidents at a handful of intersections in the city, these factors could change enough to skew the results. To minimize these effects, larger samples of intersections should be examined including intersections with cameras, intersections without cameras, and intersections in communities far away from where cameras are located.

TABLE B4 (*continued*)

No.	Responding Agency	Features of RLR System Affecting Outcome	Other Comments
5	City of Irvine	The systems were evaluated on ease of use, clarity of the photo, acceptance of the courts, DMV coordination, and, of course, reduction of RLR violations.	
6	Howard County	Perceived fairness of RLR Program: 1. Civil violation under Maryland. No points. No insurance company notification. $75 fine. 2. County selects sites for monitoring. County decides if citation is issued. No vendor access to signal controller. 3. Vendor provides camera systems/maintenance and "back room services" with payment based on a monthly fee. 4. Penalty for not paying fine is prevention of tag renewal.	Appeal rate to the courts ranges from 2–2-1/2%. Of those appealing 95% are found guilty. Decline in total collisions for county road system, 1998–2000, is due partly to traffic calming program and automated enforcement. However, red light running systems are, in reality, high tech forms of traffic calming.
7	Laurel	None.	Significant reduction in the number of violations since implementation of program. Praise by local officials for reduction of accidents.
8	City of Boulder	The city's program operates within the parameters of state enabling legislation. Legislative action on a state level has largely been hostile to use of photo enforcement techniques. Original state enabling legislation (House Bill No. 97-36) created a driver liability, no point, $40 maximum fine system. Service is required within 90 days or the violation is voided. Traditional law enforcement mechanisms such as Outstanding Judgment Warrants are excluded for photo enforcement detected violations. Subsequent legislation (House Bill No. 99-1364) allowed for a fine increase to a maximum of $75.	
9	Portland		
10	Los Angeles County	Grace periods, signing, and press releases were all provided prior to photo enforcement. As drivers become "more aware" of photo enforcement in their area, it will be the change in their driving behavior that will positively affect the outcome of the program.	
11	Greenbelt		Our program is too recent to have conducted evaluations.
12	Landover Hills		An evaluation of accidents will be conducted after the red light camera sites have been in use for 1 year. The number of citations that are being issued on our two RLC sites have decreased significantly. This shows the cameras are working.
13	Cheverly		
14	San Francisco	In my view, public education (and resultant driver behavioral modification) more than any other factors has resulted in the safety benefits we've seen.	We will soon evaluate RLR camera locations installed as part of our original pilot program in 1996 and plot the results of signal timing changes, camera installation, and visibility upgrades—all of which occurred at different points in time during the course of the past 5 years.
15	Annapolis		We have a contract with Lockheed Martin to install the cameras for over a year, but they have not installed them yet so no evaluation has been done.
16	City of Alexandria	We have not identified any single factor that was more important than the others.	Graph of our violations per pass experience at all three intersections is attached (not included here). Only Duke and Walker did not involve other post-implementation traffic engineering modifications.
17	Tempe		

TABLE B4 (*continued*)

No.	Responding Agency	Features of RLR System Affecting Outcome	Other Comments
18	City of Beaverton	The red light running campaign enforcement program has been incredibly successful. 99% of Beaverton residents are aware of the campaign and 77% support red light photo enforcement. Public acceptance is an integral part of our program.	
19	Mesa	1. Change of yellow phase of signal on left turns from 3.00 to 4.00 seconds. 2. Education of public awareness, PSA messages, training DDS trainers, speaking at various neighborhood group watches.	
20	Morningside	Public awareness; education regarding red light cameras and safe driving.	
21	Howard County	We believe consistent enforcement and public outreach affected the outcome the most.	
22	Baltimore County	None.	
23	Riverdale	The consistency of automated enforcement.	
24	City of High Point	Public outreach, media coverage, grace periods, website (especially useful for media), police scrutiny of tickets, sending out information about "safelight" program through the mail with tickets.	High Point officers scrutinize every ticket before it is mailed; this has helped a great deal to boost the integrity of the program. Using the digital cameras helping to "smooth" the program. Someone dedicated to the program completely from the time of choosing the contractor, selecting the sites, talking to the media, analyzing the intersections has been very useful.
25	Paradise Valley		
26	City of Scottsdale	Public outreach and signing.	Scottsdale implemented eight RLR cameras in 1997. We are currently looking to expand our RLR camera program and all intersections are being evaluated as possible candidates. We are ranking intersections based on the number of accidents, the number of RLR accidents, the volume of traffic, and the number of serious injury accidents. While the RLR cameras do impact drivers at certain intersections, public awareness of the program and traffic safety has an impact throughout the city.
27	City of Garland		We feel confident that RLR cameras will be an effective tool to help modify bad driver behavior in order to decrease the number of red light crashes, especially at intersections where traditional enforcement methods are not an option.
28	City of Sacramento	California is a "driver responsible" state vs. "owner," which makes a big difference.	Our program is doing exactly what we wanted—"making our streets safer by changing driver behavior."
29	Montgomery County	We have put up signs at most of the roadway entrances into Montgomery County as well as on some major arterial highways after interstate exit ramps.	
30	Sacramento		We have requested crash data at all intersections within the county of Sacramento in order to help in our selection of intersections to put red light cameras. We have chosen intersections based on a combination of high total crash, red light crash, and high violation intersections. Our program is somewhat unique based on the fact that it was started by the Sheriff Department, but they have contracted with the CHP to help run the program. Myself and one other CHP officer are dedicated full time to the program and our salaries are paid by the Sheriff Department. Statistics of how our program has affected accidents are not yet available because of how new our program is, but we will be compiling statistics in the future.

TABLE B4 (*continued*)

No.	Responding Agency	Features of RLR System Affecting Outcome	Other Comments
31	San Diego	This question is not clear.	Once a photo red light program is operational in a city, there is a lot of misinformation disseminated about the system being not reliable. Any city with a desire to install a photo enforcement system should heavily promote and explain the technology before activating the system. Discussions should be held in public forums by city and law enforcement officials to explain how the technology works. The judges, traffic engineering, and city attorney's office need to be informed and involved.
32	City of Charlotte		
33	City of Overland Park		
34	Toledo		
35	Ft. Collins	Prior to installation—public demonstration and input newspaper, television advertisement, education. Periodic newspaper inquiries. Grace period (30 day) prior to "live" activation.	ATS/Redflex system RLR supplier/contractor. Photo to summons ratio <50%.
36	Fairfax County		Item 4 evaluations of effectiveness are scheduled to be accomplished in Spring 2002.
37	New York City		

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