



NDOT Research Report

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**Feasibility of Using Video Cameras for
Automated Enforcement on Red-Light
Running and Managed Lanes**



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**Nevada Department of Transportation
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Carson City, NV 89712**



Disclaimer

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**FEASIBILITY OF USING VIDEO CAMERAS FOR AUTOMATED
ENFORCEMENT ON RED-LIGHT RUNNING AND MANAGED LANES**

Final Report



Prepared for

NEVADA DEPARTMENT OF TRANSPORTATION

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PREFACE

Our transportation systems in the State of Nevada continue to face many challenges in dealing with traffic safety and traffic congestion. There are two areas that Nevada Department of Transportation (NDOT) has been focusing on: reducing traffic crashes at signalized intersections by installing red-light running cameras; and reducing freeway congestion by implementing managed lane strategies such as High-Occupancy Vehicle (HOV) lanes. While many studies have shown that red-light running cameras can significantly reduce traffic crashes at intersections, using red-light running cameras as an automated law enforcement alternative must be approved by the state's legislature. Similarly, using cameras for automated enforcement at managed lane sites can ensure effective use of the facility by minimizing violation rates. Therefore, several critical issues must be addressed before NDOT can make strategic decisions on possible application of video cameras for enforcement purposes. In particular, using cameras for red-light running and managed lanes must have wide public support before it can go to the legislature. Furthermore, there must be proven technologies in the video systems to ensure reliable results if citations will be issued based on the videos. This research was initiated to specifically address the above issues and needs.

ABSTRACT

The overall objective of this study is to evaluate the feasibility, effectiveness, legality, and public acceptance aspects of automated enforcement on red light running and HOV occupancy requirement using video cameras in Nevada. This objective was accomplished by conducting a literature review of previous studies and lessons learned in other states, conducting public opinion polls and agency survey, assessing the violation rate in HOV lanes, analyzing accident data related to red light running in Nevada's urban areas, and reviewing legal and public acceptance issues in other states. Since automated red-light running enforcement has proven to be reliable and supportive by most Nevada's public surveyed, pilot installation and test of red-light running camera systems are recommended at selected intersections where high-violation and high-crash rates exist. Considering the inherent difficulty of photo-HOV occupancy enforcement technology and the relatively low support of 43% from Nevada's residents, video camera systems are recommended as supplemental countermeasures for reducing HOV occupancy violations. The results of the study could be used as the basis for pursuing legislative changes to allow the automated red-light running enforcement and photo-HOV occupancy enforcement in Nevada.

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1.**EXE****CUTIVE SUMMARY****1.1 Introduction**

Red-light running is one of the major causes of traffic crashes and fatalities at signalized intersections. Many studies have confirmed the effectiveness of red-light running cameras in reducing crashes. There are currently 21 states which have either passed legislation or are considering legislation to use red-light running cameras for law enforcement purposes, while the State of Nevada has not yet passed authorizing use of red-light running cameras.

With the future potential installation of managed lanes such as HOV lanes in Nevada, vehicle occupancy enforcement is thus becoming critical for ensuring best use of these facilities. However, Nevada Revised Statutes do not allow the use of electronic devices for monitoring vehicle occupancy and issuing citations for violations in HOV lanes.

The overall objective of this study is to evaluate the feasibility, effectiveness, legality, and public acceptance for using of cameras to issue citations for red light running and HOV occupancy violations. The results of the study could be used as the basis for pursuing legislative changes to allow the video-photo based red-light running and photo-HOV occupancy enforcement in Nevada. The use of cameras and/or other electronic devices to issue citations is characterized as automated enforcement in this report.

1.2 Research Approach

This study included a literature review of previous studies and lessons learned in other states, exploring applicable technologies for automated enforcement in other countries and states, conducting public opinion polls and agency survey by on-site and on-line surveys, assessing the violation rate in HOV lanes, analyzing accident data related to red-right running in Nevada's urban area, and reviewing legal and public acceptance issues in other states.

The technical feasibility mainly focused on extracting and summarizing the technological experiences and lessons learned by operating automated enforcement systems in other states and jurisdictions. The public polls obtained from on-site interviews and on-line surveys indicated

public opinions about automated red-light running enforcement and photo-HOV occupancy enforcement in Nevada. Agency survey by on-line surveys gained experience and acquired lessons learned using automated enforcement systems. HOV violation rate survey provided a general indication of the degree of public understanding and support for the facility. Crash analysis revealed the seriousness and severity of traffic crashes related to red light running in Nevada's urban area. The review of legal and public acceptance issues in other states involved basic constitutional issues, evidentiary requirements, and the need to revise state and/or local laws before implementing automated enforcement programs.

1.3 Findings

Literature Review

With regard to the effects of red-light camera enforcement, numerous publications have been produced across the world. However, the methods and results of these studies vary considerably. The findings are summarized as follows.

1. The literature showed that a preponderance of evidence confirms that the use of camera-enforcement is highly effective in reducing red-light violations and right-angle injury crashes related to red-light running. However, the results are not conclusive partially because of the methodological flaws, such as seasonality bias, historical bias, regression-to-the-mean and halo effects.
2. Some evaluations pointed out that to a certain extent red-light camera enforcement might result in an increase of rear-end crashes, but the increase could be more than offset by the decrease of right-angle injury crashes.
3. Statistics on the frequency and characteristics of red-light crashes should be regarded as estimates since red-light crashes are difficult to recognize accurately from the existing crash databases.
4. Camera enforcement is just one possible countermeasure for red-light crashes. An appropriate countermeasure should be selected from comprehensive guidelines such as: *The Red-light Running Handbook: an Engineer's Guide to Reducing Red-Light-Related Crashes*, *Guidance for Using Red-Light Cameras*, and *Red-light Camera Systems Operational Guidelines*.

Several research studies have proven that video cameras are effective for enforcing compliance with vehicle occupancy requirements in HOV and high occupancy toll (HOT) lanes. The findings are summarized as follows.

- a. The video occupant detection system has been mainly used along the roadside which requires the detection of the number of vehicle occupants. The system still needs to resolve technique difficulties involved with effectiveness and reliability before actual implementation.
- b. Nearly all roadside video detection systems require a vantage point with sufficient illumination for optimizing the view into the vehicle cabin.
- c. Although additional cameras will enhance video systems, the cameras only detect unobstructed occupants. Consequently, there is difficulty detecting rear-facing infant seats, smaller rear seat occupants, occupants “curled up” sleeping in the back seat and people in vehicles with tinted windows.
- d. With respect to detection technologies, the main challenges can be categorized as follows:
 - Cabin penetration, such as seeing through tinted vehicle windows
 - Environmental conditions, such as operating in all weather conditions and at night
 - Good image resolution, such as resolving heads and limbs
 - Fast image acquisition, such as operating at high speeds
 - Observational restrictions

Technical Feasibility

There are three types of cameras available for use in automated enforcement of red light violations — film or digital still photography, digital video, or a combination of still photography and digital video. The unit can be placed atop a pole or on a cantilever arm. Camera and equipment positioning will vary depending on whether owner liability or driver liability is used to prosecute violations. A single rear camera is normally used for owner liability; however, front and rear cameras are used for driver liability. The pros and cons of three types of camera systems are summarized in Table S1.

Table S1 Comparison of Automated Red-Light Running Enforcement Technologies

Camera Unit Type	Pros	Cons
35mm Wet Film	<ul style="list-style-type: none"> • Relatively inexpensive installation • Higher pixel count (usually 18-20 million) • Less chance for manipulation 	<ul style="list-style-type: none"> • Labor intensive for collection • Storage
Digital Still Pictures	<ul style="list-style-type: none"> • Collection can be immediate • Digital format • Storage 	<ul style="list-style-type: none"> • Lower pixel count (usually 2 million) • Needs communication link (telephone wires, etc) • Impression of surveillance
Digital Video	<ul style="list-style-type: none"> • Collection can be immediate • Captures entire sequence • Storage 	<ul style="list-style-type: none"> • Needs communication link (telephone wires, etc) • Impression of surveillance

Automated enforcement techniques by video camera systems have existed for monitoring compliance with vehicle occupancy requirements by observing the appropriate number of occupants on HOV lanes. A typical strategy for video enforcement includes installing three or more cameras with artificial lighting sources to capture the front windshield image, the side window image, and the rear license plate image. The semiautomatic review process is activated when a violation has occurred and electronically saves the images of the vehicle's interior along with the license plate information for later use in violation processing. A number of automated systems have been explored and developed for utilizing such roadside photography from outside the vehicle to detect the number of vehicle occupants. The findings are summarized as follows:

- Automated HOV occupancy monitoring and enforcement would be beneficial if a reliable and accurate method of detecting vehicle occupants can be developed.
- While automated enforcement from outside the vehicle (including infrared, near-infrared, video and digital photography) has showed to have some potential benefits, there is some need for further improvement. The roadside technology for HOV occupancy enforcement has inherent difficulties for real-time enforcement for all relevant vehicle types, during daylight and weather conditions, and on both freeways and arterials.

Public Polls

The general findings from red-light running enforcement survey are summarized as follows:

- Most of 1,833 respondents (approximately 63%) indicated that they would support the automated enforcement cameras in Nevada, while a smaller percentage of the respondents (21%) would oppose it. A higher percentage of older citizens indicate support for automated enforcement, however, no significant difference was found among different income groups and among men and women.
- A majority (approximately 58%) of the respondents reported that they were in favor of the legislation to permit giving traffic tickets for drivers running red lights based on video evidence, while a quarter of the respondents (24%) would be against such legislation. Older Nevadans were more likely to express approval for such legislation. Additionally, support was nearly even among men and women and within income groups.
- Most respondents (approximately 82%) reported that red-light running is a serious and dangerous behavior in the community in which they live or work.
- Most respondents (approximately 60%) reported that they observe drivers running red lights on an average of one to five times per week.
- Nearly half (54%) of the respondents regarded “driving too fast to stop” as the main reason for drivers running red lights.
- Approximately half (50%) of the respondents were aware of automated enforcement programs in other communities before they took this survey.
- Sixty-seven percent of the respondents on average supported the opinion that the use of red-light cameras could provide a safer driving experience.
- Eight percent of the respondents on average reported that they have received tickets for red-light running during the past year, while 92% of the respondents reported that they had not received tickets for red-light running.

The general findings from the photo-HOV occupancy enforcement are summarized as follows:

- Forty-three percent of 1,163 respondents on average indicated that they would support the photo-HOV occupancy enforcement, while 28% of the respondents would oppose it. Support was higher among older Nevadans and among those who reported annual

individual incomes of below \$15,000 (47%) and at least \$50,000 (45%). Support was nearly even among women (37%) and men (40%).

- The number of respondents who would support or be against such legislation for HOV lane occupancy enforcement is almost even, with 40% support and 35% being against on average. Support was greater among older respondents and among those whose annual individual incomes are below \$15,000 (44%) and at least \$50,000 (46%). Support was almost equivalent among women (35%) and men (36%).
- Most respondents (approximately 58%) reported that vehicle occupancy violation is a serious problem in HOV lanes.
- Forty-three percent of the respondents reported that they observe on average one to five times per day vehicles violating occupancy requirements and 43% of the respondents reported that they never observed vehicles violating occupancy requirements.
- Two percent of the respondents on average indicated that they have received tickets for violating vehicle occupancy requirement in HOV lanes during the past year, while 98% of the respondents reported that they had not received tickets for violating vehicle occupancy requirements.

Accident Analyses

Three-year traffic accident data (between 2005 and 2008) acquired from NDOT at some high crash intersections revealed the level of possible red-light running related accidents in Nevada's major metropolitan areas. For the 52 high crash locations in Reno-Sparks, red-light running related accidents account for about 22%. For the 284 high crash intersections in Clark County, red-light running related accidents are about 26%.

Agency Survey

Preliminary results and findings from the agency survey are summarized as follows:

- Most respondents reported that the red-light running violation and traffic crashes could be reduced by red-light camera enforcement, while a quarter of respondents reported that rear-end crash might be increased.
- Most respondents (nearly 88% and 96%) indicated that digital still pictures and digital

video were two camera types used extensively for red-light running enforcement, while over 30% of respondents reported that both camera types have been used since 2008.

- Nearly all of respondents ranked all items to be at least average and most respondents ranked all items to be above average.
- Nearly 35% of respondents reported that the number of citations decreased by red-light camera enforcement, while most respondents (nearly 48%) reported that the number of citations increased. Nearly 17% of respondents answered “no change”.
- Most of respondents (nearly 82%) indicated that there was no public opinion polls conducted in their agencies, while nearly 18% of the respondents answered “yes”. The survey results provided by two respondents showed that nearly half of respondents would support red-light camera enforcement, while nearly a quarter of respondents would be against the enforcement.
- Educating the public is one of key steps in gaining success for red-light camera enforcement.
- A media campaign is encouraged to stress that photo enforcement is a traffic safety issue for the community rather than a revenue generator for the city.
- Local statistics for crashes caused by red-light running can be used as an important proof for supporting red-light camera enforcement.
- A comprehensive evaluation about accident history, the number of violations and constructability of the equipment, should be conducted in selecting intersections for red-light camera installation.
- A pre-determined designation for revenue sharing of the citations is necessary before implementing red-light camera enforcement.
- The selection of technologies and vendors is critical to ensure success in red-light camera enforcement.

HOV Violation Rate Survey

On average, the violation rates in the northbound HOV lane on I-95 in Las Vegas were 34 percent during the AM peak hours and 53 percent during the PM peak hours. The violation rates in the southbound HOV lane were 28 percent during the AM peak hours and 24 percent during the PM peak hours. The violation rates in both HOV lanes were much higher than the national

average (about 12 percent).

Legal and Public Acceptance Issues

Legal issues related to automated enforcement are myriad and complex. Basic constitutional issues, evidentiary requirements, and the need to revise state and/or local laws should be considered before implementing automated enforcement programs. The constitutional issues presented here deal primarily with the following:

- Right to privacy (First and Fourth Amendments),
- Due process and equal protection (Fifth and Fourteenth Amendments),
- Right to present a defense (Sixth Amendment),
- Admissibility of evidence, and
- Enabling legislation.

The use of automated enforcement in North America elicits differing responses from the public. Public opinion surveys have shown that most people have strong opinions about automated enforcement (some positive, some negative). Several public opinion surveys have shown approximately two-to-one or greater respondents in favor of using automated enforcement. Critics of automated enforcement programs for red-light violations often claim that the technology is unconstitutional.

1.4 Conclusions

Conclusions regarding the feasibility of automated red-light running enforcement in Nevada can be summarized below:

- The literature showed there is a preponderance of evidence indicating that red-light camera enforcement is highly effective in reducing red light violations and right-angle injury crashes associated with red-light running. However, the results are not conclusive due in part to the methodological weaknesses of the studies and the number of rear-end crashes could increase.
- Public polls of Nevada residents indicated that most of 1,833 respondents (approximately 63%) would support automated red-light running enforcement, while a smaller

percentage of the respondents (21%) would oppose it. A majority (58%) of the respondents reported that they would support legislation to permit giving traffic tickets for drivers running red lights based on video evidence, while a smaller percentage of the respondents (24%) would be against such legislation.

- The recent three-year traffic crash data between 2005 and 2008, in Nevada's urban areas indicated that red-light running related crashes account for a significant portion of the total crashes. At the 52 high crash intersections in the Reno-Sparks area, about 22% of the total crashes were related to red-light running. At the 284 high crash intersections in Southern Nevada, red-light running related crashes were about 26% of the total crashes.
- Most agencies indicated that key steps for gaining success in red-light camera enforcement include several issues, such as public education, media campaign, accident statistics, revenue sharing, selecting intersections, selecting technologies and vendors.

Conclusions regarding the feasibility of photo-HOV occupancy enforcement in Nevada can be summarized below:

- The results of relevant research indicated that video cameras have proven to be effective at determining compliance with vehicle occupancy requirements in HOV and HOT lanes, though the use of video cameras for actual enforcement would still require various enhancements.
- None of the research to date has identified a system that is effective and reliable enough to be implemented as a primary HOV occupancy enforcement strategy due to inherent difficulties.
- Public polls indicated that 43% of 1,163 respondents on average would support photo-HOV occupancy enforcement, while 28% of the respondents would oppose it. The number of respondents who would support or be against such legislation for HOV lane occupancy enforcement is almost even, with 40% support and 35% being against.
- On average, the violation rates in the northbound HOV lane were 34 percent during the AM peak hours and 53 percent during the PM peak hours. The violation rates in the southbound HOV lane were 28 percent during the AM peak hours and 24 percent during the PM peak hours. The violation rates in both HOV lanes were much higher than

national experience (about 12 percent).

1.5 Recommendations

Based on evidence from numerous automated enforcement studies in the United States, the following general recommendations are presented for evaluating the feasibility of automated red-light running enforcement and photo-HOV occupancy enforcement in Nevada.

- Pilot installations and tests of red-light running camera systems are recommended at selected intersections where high violations and high right-angle crashes exist. This is based on the overwhelming success of other states and good support from Nevada's residents.
- Considering inherent difficulty of photo-HOV occupancy enforcement technology, and the relatively low support from Nevada's residents, video camera systems are recommended as supplemental measures for reducing HOV occupancy violations if HOV lanes are used.
- Automated enforcement is recommended only if all other viable low-cost measures have been tried without success in eliminating red-light running and HOV occupancy violation problems. Such engineering measures may include traffic operational improvements, geometric improvements, signal control changes, and signal conspicuity.
- Only if traditional enforcement has proven to be ineffective or inefficient should automated enforcement technology be considered. Then it should be considered when video camera systems have proven reliable, properly installed and maintained technology, and processing of images and issuance of citations have proven to be accurate and efficient.
- Video cameras should only be considered at specific locations where an improvement in safety can be expected understanding that right-angle crashes will likely decline but rear-end crashes will likely increase.
- The State should enact provisions permitting the temporary use of red-light cameras at certain intersections so that the safety effects can be further studied. At the same time, the State should conduct a detailed, perpetual public information and educational effort regarding the automated enforcement.

- A pre-determined designation for revenue sharing of the citations is necessary before implementing red-light camera enforcement.
- The selections of technologies and vendors are critical to ensure success in red-light camera enforcement.

2. INTRODUCTION

2.1 Background

Red-light running is one of the major causes of traffic crashes and fatalities at signalized intersections. According to a study by the Federal Highway Administration (FHWA) in 2005 (1), red-light running resulted in more than 100,000 crashes and approximately 1,000 deaths per year in the United States. The number of crashes at signalized intersections has been increasing over the past several years, while traffic crashes related to red-light running are more likely to occur and lead to serious injuries and deaths than other types of crashes (2).

Over the past two decades, transportation agencies throughout the world have been seeking automated technologies to better enforce red-light running ordinances and improve safety. One of the major technologies is cameras installed at signalized intersection which has been used by more than 300 jurisdictions across the United States (3). There are currently 21 states which have either passed legislation or are considering legislation to use cameras to enforce red-light running laws. However, the State of Nevada has not yet passed authorizing use of cameras to enforce red-light running.

Many studies have confirmed the effectiveness of red-light running cameras in reducing crashes (1,4,5,6). The economic analyses of comprehensively considering rear-end and right-angle crash costs showed that the automated red-light running enforcement might save society \$39,000 to \$50,000 annually at each intersection. This should provide public support for using red-light running cameras for law enforcement purposes due to its proved success (7). However, there are also concerns, mainly related to privacy issues and the use of the cameras as primary revenue-generation sources. The Federal Highway Administration (FHWA) and National Highway Traffic Safety Administrations (NHTSA) have developed operational guidelines for implementation and operation of red-light running camera systems (8).

Managed lanes aim at employing various proactive management strategies to promote the effective and efficient use of freeways by improving traffic flow on freeway lanes. There are two types of enforcement methods usually adopted to maintain the integrity of managed lanes. Routine enforcement is to use freeway service patrols to monitor managed lanes. In contrast,

automated enforcement is to apply advanced Intelligent Transportation System (ITS) technologies such as Automated Vehicle Identification (AVI), License Plate Recognition (LPR), electronic toll collection, and image capturing technology to ensure motorists' compliance (9,10). Currently, HOV lanes along US 95 in Las Vegas have been implemented and operate during the peak periods. However, no automated enforcement devices are available for monitoring vehicle occupancy violations in HOV lanes.

In Nevada, Eyewitness News reported that North Las Vegas has installed sensors to track how many vehicles run red lights at two of the busiest intersections in the city: Martin Luther King Boulevard at Cheyenne Avenue, and Camino Al Norte at Craig Road. During a six-month period, about 70 northbound vehicles ran the red light each day at Martin Luther King at Cheyenne, and about 17 southbound vehicles ran the red light daily at Camino Al Norte at Craig. The city hoped data collected by the sensors would persuade state legislators to allow the use of traffic cameras at intersections to cite motorists who run red lights. North Las Vegas has unsuccessfully lobbied in the past two legislative sessions to allow the cameras. For the 2009 Legislature, the city hoped to make its case with actual data (11, 12).

The Center for Research Design and Analysis (CRDA) at the University of Nevada, Reno recently conducted a seatbelt related study for the Office of Traffic Safety at the Nevada Department of Public Safety. As part of the study, a state-wide telephone survey was conducted regarding public support of a photo enforcement law in Nevada (13). Of the 1,012 respondents who agreed to participate in the survey, 1,005 gave complete telephone interviews and 7 gave partial interviews. Respondents were asked to indicate the extent to which they favored or opposed a photo enforcement law aimed at drivers who run red lights. The vast majority of respondents (84.6%) reported that they were in favor of a photo enforcement law of this nature with more than half of the respondents (51.5%) reporting that they were strongly in favor of the law. A quarter of the respondents indicated that they opposed the law.

The Las Vegas metropolitan area population and employment is expected to continue growing in the coming years with a consequential increase in traffic on the area's roadways. In each direction along the US-95 corridor, the section between Rainbow Boulevard and Martin Luther King Boulevard has HOV lanes marked with diamond signs. The Cheyenne Avenue and Lake Mead Boulevard entrance ramps also include High Occupancy Vehicle (HOV) or carpool bypass

lanes. The purpose of this special lane is to provide faster access for vehicles with two or more persons. This encourages ridesharing by providing a special benefit for those who carpool, vanpool, or ride the bus. More people carpooling means fewer cars on the road and less congestion. Hybrid vehicles only qualify if they have two or more passengers, including the driver. HOV lanes are restricted to high-occupancy travel Monday through Friday from 6 a.m. to 10 a.m., and during the afternoon from 2 p.m. to 7 p.m. HOV lanes are accessible throughout their entire distance. Drivers can enter and exit an HOV lane at any point along the solid white line. In addition, the Regional Transportation Commission of Southern Nevada (RTC) has developed a 2030 Regional Transportation Plan that identifies freeways and other highways where HOV facilities might be implemented (14,15,16). Appendix 1 shows the implementation of HOV freeway facilities for the near and long term in Nevada (16).

With the potentially high number of HOV facilities in the near future in Nevada, vehicle occupancy enforcement is thus becoming critical for ensuring best use of the facilities. Automated enforcement by video cameras can be a viable alternative. The Nevada Department of Transportation (NDOT) has designated the HOV/Managed Lane Design Manual developed in 2005 as the standard for HOV lanes (16).

2.2 Study Objective

The overall objective of this study was to evaluate the feasibility, effectiveness, legality, and public acceptance of automated enforcement for running red lights and HOV occupancy violations by using video cameras in Nevada. The results of the study might be used as the basis for pursuing legislative changes to allow the automated red-light running enforcement and photo-HOV occupancy enforcement in Nevada. This objective was accomplished by conducting a literature review of previous studies and lessons learned from other states, conducting public opinion polls and agency survey, assessing the violation rate in HOV lanes, and analyzing crash data related to red light running in Nevada's urban areas.

2.3 Definition of Automated Enforcement

Red-light running is defined as the act of a motorist entering an intersection after the traffic signal has turned red. According to the Uniform Vehicle Code (UVC) (17), a motorist "...facing a steady circular red signal shall stop at a clearly marked stop line, but if none, before entering

the crosswalk on the near side of the intersection, or if none, then before entering the intersection and shall remain standing until an indication to proceed is shown ...”. In general, a citation would not be issued if the motorist stops past the stop line or into the crosswalk, or even slightly into the physical intersection, only if the motorist who has passed through the intersection would be cited for running a red light (18).

According to the final report of Southern Nevada HOV Plan (16), dedicated freeway lanes, including HOV lanes, are collectively referred to as “managed lanes” by transportation professionals and local, state, and federal agencies. The definition of managed lanes varies from agency to agency. The Federal Highway Administration (FHWA) defines managed lanes as highway facilities or designated lanes in which operational strategies are implemented and managed (in real time) in response to changing conditions. Managed lanes include High Occupancy Vehicle (HOV) lanes, High Occupancy Toll (HOT) lanes, value-priced lanes, express lanes, separated or bypass lanes, truck or commercial vehicle lanes, dual facilities, and lane restrictions (15). A managed lane facility requires effective enforcement policies and programs to operate successfully.

In general, automated enforcement is defined as the use of electronic enforcement technology, including photo monitoring, photo detection, video traffic surveillance, and violation detection systems, and so on to monitor and enforce traffic control laws, regulations, or restrictions (19).

Automated red-light running enforcement is a technique in which a camera photographs a vehicle that enters an intersection after the traffic light has turned red; a human reviewer validates the potential violation; and if appropriate, the reviewer sends a civil citation for red light running to the vehicle’s registered owner (20).

An Automated Vehicle Occupancy Verification (AVOV) system generally operates in a three step process (21): in step 1, data are gathered from one or more sensors; the purpose of step 2 is to “clean up” the sensor data and render it into a form that can be optimally processed in the subsequent classification step; once the key features have been identified and extracted from the sensor data, the last step is to use them in the classification step to choose the appropriate decision alternative, e.g., whether or not an occupant is present in the vehicle.

3. LITERATURE REVIEW

As with many safety problems, red-light running may be solved by comprehensively considering several countermeasures of the three “E’s” — education, enforcement and engineering (19). Two principal countermeasures of the red-light running problems involve engineering and enforcement (22,23). The specified guidelines of many engineering countermeasures are available in the Manual on Uniform Traffic Control Devices (MUTCD) or the Institute of Transportation Engineers (ITE) Handbook. The following references included the detailed explanations for each engineering countermeasure: “*Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red Light Running*” (18), “*Engineering Countermeasures to Reduce Red-Light Running*” (23), “*Guidance for Using Red-Light Cameras*” (24), and “*Red-Light Camera Systems Operational Guidelines*” (8).

Currently, there is an abundant amount of literature on the effects of red-light cameras, evaluations of performing camera enforcement, and automated enforcement technology. The scope of this review will cover two main components of automated enforcement by video cameras, including automated red-light running enforcement and photo-HOV occupancy enforcement.

This section reports on information gathered from newspapers, academic and professional journals, magazines, product distributors, city governments, research records, and various other sources. Past research that has focused on automated red-light running enforcement and photo-HOV occupancy enforcement is also summarized.

3.1 Automated Red-Light Running Enforcement

3.1.1 Red-Light Running Statistics

Safety is the biggest concern associated with the red-light running and is usually measured by the number and severity of crashes. Numerous statistics have been published quantifying the magnitude of the problem in specific cities and states across the country.

Red-light running is one of the major contributing factors that cause crashes and injuries at signalized intersections. According to the statistics of the Highway Safety Information System (HSIS) (a multi-state crash database maintained by the FHWA), traffic crashes related to red-light running etc are 16 to 20% of the total crashes at urban signalized intersections (19,25). Overall, 56% of Americans admit to running red lights and 96% of drivers fear being hit by a red-light runner at signalized intersections (19,26). One in three Americans know someone who has been injured or killed because of a red-light runner (19).

The Federal Highway Administration (FHWA) reported that approximately 22% of some 1.8 million urban intersections had traffic crashes related to red-light running in the United States during 1997 (19,27). In 2001, the preliminary estimates from the FHWA indicated that nearly 218,000 crashes were attributed to red-light running at intersections, while these crashes resulted in as many as 181,000 injuries and 880 fatalities, and an economic loss was estimated at \$14 billion per year (19).

Crash data from the National Highway Traffic Safety Administration (NHTSA) indicated that red-light running resulted in 921 fatalities and 178,000 injuries from 207,000 crashes in 2002 (28). The NHTSA reported that there were 89,000 crashes, 80,000 injuries, and nearly 10,000 deaths per year in the United States attributed to motorists running red lights (4). From 1992 to 1998 in the United States, red-light running resulted in 6,000 deaths and 1.4 million injuries, while more than half of the deaths in these crashes were pedestrians who were hit by the red-light runners (1).

At least 736 fatalities and more than 165,000 injuries were caused by red-light running in the United States in 2005 (29). Across the United States each year, more than 800 people were killed and 200,000 were injured in red-light running crashes (27). In addition, the study of Greene found that 15% to 21% of the crashes were involved with red-light running at signalized intersections in the Australian states of Victoria, Western Australian, and Queensland (29).

Surveys conducted by the U.S. Department of Transportation and the American Trauma Society have reported that 63% of Americans witness someone running a red light more than once a week (30).

In December 2000, the Center for Transportation Research and Education (CTRE) at the Iowa State University studied the violation rates by videotaping the intersections and indicated that the

violation rate for the various intersections covers a wide range of values ranging from 0.45 violations per 1,000 entering vehicles to 6.08 (19).

The number of violations can reflect the seriousness of the red-light running problem. Thirty-six tickets were issued by traditional enforcement during two hours at a high-volume intersection in Raleigh, NC, which is a rate of one violation about every 3.5 minutes (19,31). A survey conducted over several months at a busy intersection in Arlington, VA, indicated violation rates of one red-light runner every 12 minutes, and during the morning peak hour, a higher rate of one violation every five minutes. A lower volume intersection, also in Arlington, had an average of 1.3 violations per hour and 3.4 in the evening peak hour (2,19).

3.1.2 Evolution of Red-Light Cameras

The automated enforcement technology by red-light cameras has existed for nearly 40 years. There are currently more than 45 countries throughout the world that have installed red-light camera systems (32). For example, red-light cameras were adopted for traffic enforcement in Israel as early as 1969, in Europe in the early 1970s, and in Australia on a wide scale in the 1980s. There are at least 19 red-light camera programs in Canada, including in the cities of Toronto, Edmonton, Regina, Saskatoon and Winnipeg (29).

The first red-light camera program in the United States appeared in New York City in 1993. When the National Campaign to Stop Red Light Running report, "Stop on Red = Safe on Green: A Guide to Red-light Camera Programs," (32) was published in 2002, red-light camera programs were operating in about 70 U.S. communities. As of summer in 2007, red-light camera programs had expanded to operate in more than 200 U.S. communities, including nine of the 10 largest cities (29). As one of the largest red-light camera programs, the New York City Department of Transportation adopted the doubled red-light cameras to rotate around 150 locations in September of 2006 (29).

As of October 2006, 21 states and the District of Columbia have passed legislation to allow the operation of automated enforcement cameras for detecting red-light running violations and permit enforcement agencies to cite the registered vehicle owners by mail (21).

Inductive loops, as a traffic detection technology adopted throughout the United States, have proven to be reliable and effective despite the fact that there may be minor problems, such as susceptibility to be damage during road construction (20).

There are primarily three types of camera systems used in the United States: 35 mm wet film, digital still pictures, and digital video. The most common type is 35 mm wet film, such as employed in Alexandria, Arlington, Fairfax City and Fairfax County in Virginia. With the development of innovative technologies, digital still cameras and digital videos are becoming more popular in jurisdictions, such as installed in the Virginia cities of Falls Church, Virginia Beach and Vienna. Other innovations include the ability for immediate download of digital media through phone lines or additional modes of communication (e.g., broadband). The modes of detection have also progressed from inductive loops to video modes of detection, though inductive loops still remain a widely used technology. The placement of cameras has changed as well, including curb-based standard placement and overhead placement for digital videos (20).

3.1.3 Effects of Red-Light Cameras on Violations

The deterrent effects of red-light cameras generally are defined as a “halo” effect of community wide reductions in signal violations generated by installing red-light cameras at a few intersections. In general, many communities post warning signs to enhance the deterrent effect of camera enforcement in areas without cameras (27).

Several studies are dedicated to explore such effects by comparing the changes of red-light violations at signalized intersections with and without camera enforcement. Retting et al. (33) reported that overall reductions of red-light running violations at non-camera sites were larger than at camera sites, and violation rates at the camera and non-camera sites did not show a statistically significant difference. Chin (34) also found a large spillover effect by analyzing the deterrent effects of red-light cameras at different locations of the same community without camera enforcement. After investigating the deterrent effects of red-light cameras in two cities with red-light camera enforcement, Chen et al. (35,36) revealed that red-light violation rates at non-camera intersections were reduced by 69% after introduction of cameras, and 38% after 6 months. Overall, the published literature indicated that, to some extent, red-light cameras

reduced red-light running violations at non-camera intersections around the communities and demonstrated a strong halo effect.

3.1.4 Effects of Red-Light Cameras on Crashes (International Literature)

The angle-crash and rear-end crash are the two most remarkable crash types related to red-light running. The angle-crash is generally defined as the offending motorist hitting or being hit by a vehicle from the adjacent approach at the intersection. The rear-end crash is defined as “rear end” by the crash type and occurring on any approach within 45.72 m (150 ft) of the intersection (17).

Red-light camera enforcement has existed for many years before it was first introduced into the United States. Retting (33) pointed out that red-light camera enforcement can produce a strong deterrent effect and residents in urban communities generally support photographic enforcement as a supplement to police efforts to enforce traffic signal laws. A review of international practice revealed that photographic enforcement generally can reduce red-light violations by an estimated 40-50%, and it can significantly reduce injury crashes at signalized intersections, in particular right-angle injury crashes (31,33). Overall, injury crashes, including rear-end collisions, were reduced by 25-30% as a result of photographic enforcement (31). A summary of many noteworthy studies across the world could shed light on what has been found in similar studies.

Australia

South et al. (37,38,39) reported that traffic accidents were decreased by 32% for right-angle crashes, 25% for right-angle (turning) collisions, 31% for rear-end collisions, 7% for total crashes, and increased by 2% for left-turn opposing direction collisions and 28% for rear-end (turning) crashes at 46 camera sites compared to 50 control sites on the basis of evaluating before-after camera enforcement from 1979 to 1986 in Melbourne. In Adelaide, Mann, et al (39,40) revealed that crashes tend to decrease by 8% for total crashes, 23% for injury crashes, 38% for total right-angle crashes, and 54% for crashes involving injuries at eight camera sites compared to 14 non-camera sites for five years before vis-à-vis five years after installation. In Sydney, a study of the crash effects by Hillier, et al. (41) indicated that crashes were reduced by 8% for total crashes and 26% for total injury crashes despite a 108% increase in rear-end crashes and a 29% increase in right-angle crashes at sixteen camera sites and sixteen control sites for a

two years before and two years after the analysis period. After observing three intersections, Kent, et al. (42) indicated that there were no differences between the red-light violation rates of camera and non-camera approaches and differences in red-light running behavior. The before and after evaluation of red-light camera installations at fifty-eight Perth metropolitan intersections by Radalj T. (43), revealed that crashes were reduced by 21% for right turns against 30% for right angles, 18% for other types, while rear-end crashes increased by 17% during the period between 1980 and 1999.

Great Britain

In Glasgow, Scotland, based on a three year before-after study of automated enforcement at eight camera sites and three pelican crossings, Fox (1,39,44) noted that traffic crashes were reduced by 44% for pedestrians crossing carelessly, 29% for unsafe right turns, 29% for others, 32% for overall crashes per month, and increased by 8% for failure to keep safe headways. A before-after comparison of red-light camera installations by Hooke, et al. (1,45) indicated that overall accidents fell by 18% at seventy-eight camera sites in England and Wales. A comparative analysis of a thirty-six month before-after camera enforcement evaluation by the London Accident Analysis Unit (46), reported that crashes were decreased by 16% for disobeying traffic signals at twelve camera sites.

Canada

In the City of Edmonton, Mullen (20,47) indicated that the frequency of average red-light violations was reduced by 6.5 violations per day after camera enforcement with six cameras operating at twelve locations.

Singapore

In 1997, a nine year before-after comparative study by Ng et al. (48) indicated that crashes were reduced by 10% for angle collisions and 9% for overall accidents, while rear-end collisions increased by 6% at forty-two camera sites and similar non-camera sites. In 2002, based on the study of red-light camera installation on driver behavior, Lum et al. (49) indicated that the revealed stopping/crossing decisions of non-platoon vehicle drivers were modeled as they responded to the onset of the yellow signal with a number of traffic and behavioral variables. In 2003, his another paper (50) about the impact of red-light camera on violation characteristics

indicated that red-light violations were reduced by more than 40% at camera approaches and 7% across all approaches.

3.1.5 Effects of Red-Light Cameras on Crashes (Domestic Literature)

The use of red-light running cameras has risen dramatically for the purpose of reducing red-light violations in the United States in recent years. The document *Safety Evaluation of Red Light cameras (1)* disseminated by the U.S. Department of Transportation evaluated the effectiveness of red-light running cameras in reducing crashes based on the comparative analysis of 132 treatment sites. The result showed that red-light running cameras reduced right-angle crashes, but could increase rear-end crashes. Moreover, the relative evaluations conducted in number of U.S. cities indicated that red-light running cameras should be reliable and effective in deterring red-light violations.

As a useful statistical methodology, the meta-analysis was used to evaluate the effectiveness of camera enforcement in Howard County, Maryland, and Charlotte, North Carolina (22). Meta-analysis techniques refer to a set of statistical techniques that involve several statistical and graphical methods of analysis to provide the means for synthesizing the results of a set of evaluation studies (22,51). The result of meta-analysis revealed that camera enforcement reduced target crashes by about 26% (22). However, it should be noted that the regression-to-the-mean and spillover effects could not be differentiated from the result of meta-analysis. A review on the evaluations of camera enforcement was updated by Persaud et al. (52) and the details are shown in Appendix 2. The review reported that camera enforcement has decreased right-angle crashes and increased rear-end crashes, even though many evaluations could not remove the regression-to-the-mean or spillover effects.

The evaluative results of camera enforcement in some states and cities are summarized according to the related reports as follows.

California

In 1996, California enacted *California Vehicle Code Section 21455.5*, which authorized government entities to use camera enforcement systems at intersections (53). Currently, more than 30 jurisdictions in California are using red-light cameras. In 1998, San Diego began its Red Light Photo Safety (RLPS) program and red-light cameras were installed at 19 sites throughout

the City of San Diego. The review of a six year before-after comparison study revealed that red-light violations decreased by 20 to 24%, and rear-end collisions increased 37% after camera installations (20,36). However, San Diego suspended its red-light camera program in June 2001 after a court ruling identified a lack of program oversight on the part of the city. Over the next four months, red-light accidents increased by 14% citywide and 30% for intersections where red-light cameras had been operating. The red-light camera program was restarted in July of 2002 (29,54).

In Sacramento, the evaluation of a one year before-after comparison study showed that crashes were reduced by 10% for all crashes, 27% for injury crashes, 26% for angle crashes, 12% for rear-end crashes, and 39% for red-light crashes (20,54). In Los Angeles County, accident rates decreased at three out of five camera sites (20,54). In Garden Grove, the one year before and after comparison study of camera enforcement indicated that right-of-way violation accidents decreased by 56.2%, and rear-end accidents increased by 1.2% at camera sites relative to five control sites (20,54). In San Francisco, Fleck and Smith (4) pointed out that injury collisions were decreased by 9% after six months of camera enforcement at six intersections. Based on a 29 month before-after study at 11 camera sites in Oxnard, compared with three control cities, Retting and Kyrychenko (4,55) stated that crashes were decreased by 7% for total crashes, 29% for injury crashes, 32% for right-angle crashes, 68% for right-angle injury crashes, and increased by 3% for rear-end crashes.

New York City

In New York City, camera enforcement has dramatically reduced red-light violations (40-60%) at camera sites. There has been a 24% reduction in all injuries at camera sites since 44 cameras were installed after January 1, 2001. From the beginning, the city's Department of Transportation has spent roughly \$85 million on the red-light camera enforcement and collected \$130 million from violations (4,29).

Maryland

In Howard County, a before-after comparison study with varying time periods showed that crashes were decreased by 31% for total collisions, 42% for angle collisions, and 30% for rear-end collisions at 25 camera sites (4). In Laurel, the evaluation showed that the number of accidents was decreased at all intersections. In Baltimore County, McGee and Eccles (4) reported

that, over a two year period with 17 cameras, crashes were reduced by 53% for total collisions, 57% for intersection related collisions, 21% for red light related collisions, 49% for personal injury crashes, and 58% for Property Damage Only (PDO) crashes. In Montgomery County, a two year before-after comparison study revealed that the overall crashes decreased slightly (20).

Pennsylvania

In Howard County, based on the 18-month before-after comparison study at two camera sites and non-camera sites, Butler, et al. (52) found that there were not statistically significant effects on the crashes at camera sites at the 95% confidence level after camera installations. There were no statistically significant differences between the changes at camera sites and non-camera sites.

Colorado

In Boulder, a 32-month before-after evaluation indicated that red-light crashes were reduced by 57%. In Ft. Collins, the evaluation of camera enforcement showed that there was no significant change in accident or injury frequency (39).

Ohio

In Columbus, crashes and violations have been dramatically decreased since cameras were installed in 2006. During the first six months, red-light violations reduced by 71% without a single rear-end crash (29).

Texas

In Garland, a 2006 study of camera enforcement found that red-light crashes were decreased by 56% at camera sites and 38% at non-camera sites. In addition, injuries at camera sites were decreased by 27% (29).

Arizona

In Phoenix, a five year before-after evaluation of camera enforcement indicated that angle-crash was reduced by 14% on all approaches and rear-end crashes were increased by 20%. In Scottsdale, a 14-year before-after comparison of camera enforcement showed that accidents were decreased by 20% for angle-crash, 45% for left-turn crashes, 11% for total crashes, and increased by 41% for rear-end crashes. In Paradise Valley, the evaluation of camera enforcement showed that the number of collisions was the same, but the severity of crashes was reduced. In Tempe,

the accident rate at two camera sites showed increases and decreases since camera enforcement. In Mesa, accident rates (per population) have declined each of five years since camera installations (39).

North Carolina

An investigation conducted by Burkey and Obeng (56) in Greensboro, claimed that camera enforcement did not reduce crashes or severity, while crash rates increased by 40%. Based on the comparison group study, Christopher et al. (4,26) reported that accidents were reduced by 17% for total crashes, 22% for red-light crashes, 42% for angle-crash, and 25% for rear-end crashes at camera sites. In Charlotte, a three year before-after comparison study at 17 sites indicated that accidents decreased by 37% for overall angle-crash at camera sites, 60% at camera approaches, 19% for all crash types, 16% for crash severity, and increased by 4% for rear-end crashes at camera approaches (39).

Virginia

In Virginia, seven jurisdictions conducted red-light camera enforcement since 1997: the cities of Alexandria, Fairfax, Falls Church, and Virginia Beach; the counties of Arlington and Fairfax; and the town of Vienna. An evaluation report of camera enforcement revealed that the number of citations at camera sites decreased by 46% in Alexandria, 12% in Arlington, 23% in Fairfax County, and increased by 6% in Vienna (20). Another evaluation (57) based on seven years of crash data, stated that rear-end crashes increased by 27% or 42% and red-light crashes decreased by 8% or 42% depending on different statistical methods. At five camera sites in Fairfax, the before-after comparisons of camera enforcement by Retting, et al. (58) indicated that overall red-light violations decreased by 7% after three months and 44% after one year. Overall reductions at two non-camera sites were 14% after three months and 34% after one year. Public support for camera use increased from 75% before enforcement to 84% one year after enforcement. In Fairfax County, an assessment by Daniel, et al. (20) also reported that accident rates decreased by 40% and violation rates reduced by 36% after three months and 69% for violation rates after six months of camera installations.

In Virginia Beach, the cancelation of red-light camera enforcement resulted in a dramatic increase of red-light violations from 488 in June to 1,056 in November of 2005 at four intersections (29). Another study of the Virginia Beach program by the Old Dominion University

indicated that camera enforcement decreased red-light violations by 69%, while drivers tended to revert to their previous behaviors of running red lights when red-light cameras were discontinued (29).

3.1.6 Statistical Methodological Flaws

As mentioned in the above reports and studies, most of the evaluations on the effects of camera enforcement were based on the comparative study of before-after crash data. Generally, this method is referred to as a trend analysis. The basic principle of the trend analysis is to predict what would have happened after a certain time period on the basis of a measure of the crash data before the time period at the treated sites. Then, the predicted results could be compared to what actually took place after the time period. There are the most inherent flaws in the trend analysis in spite of its extensive use (4).

As pointed out by Retting et al. (29), most of the evaluations and comparisons had several methodological flaws. The evaluations of camera enforcement by comparing camera sites with non-camera sites in the same jurisdiction could underestimate the effects of cameras on collisions due to the spillover effects of camera enforcement on non-camera sites. Regression-to-the-mean, as the second most common methodological flaw, has been verified by statisticians and researchers in many fields for years. In the evaluation analysis, intersections with high accident rates are usually selected as camera sites and control sites, which could cause certain bias. Campbell, et al. claimed that the distribution of extreme values will tend to move toward the group average in the following time period, even if no countermeasures are put into effect. Therefore, it is possible that sites with high crash rates would see a reduction toward its mean value in the following years simply due to random nature of crashes. The control group and comparison group are usually adopted to solve this problem. This regression-to-the-mean phenomenon could result in an overestimation of the positive effects of camera enforcement on crashes. Statistical techniques have been developed for estimating and adjusting the regression-to-the-mean effect at each site (19,59).

In addition, seasonality and historical effects are two important factors. The explanation of both factors is introduced by Cunningham et al. (4) as follows.

Seasonality bias occurs when the time of year is not accounted for. This is a common problem in many naïve before-after studies with limited data in the after period. If data in the after period were collected from November to April of the following year, it is very likely that collisions were higher during these months because weather such as snow and ice would cause traffic problems. Historical bias occurs when changes on the sites occur sometime during the study period. This is also a common problem with naïve before-after studies. For example, a certain type of arterials in the city may change speed limits from 55 to 45 mph for safety reasons. This could have an effect on collisions after this policy change. Therefore, not accounting for it could bias the study.

Based on published literature, various websites, and a survey, McGee, et al. (51) claimed that red-light camera enforcement could be an effective safety countermeasure. However, there is not currently enough empirical evidence to verify this finding due to the lack of statistically rigorous experimental design.

3.1.7 Guidance Related to Red-Light Camera Enforcement

The National Highway Traffic Safety Administration (NHTSA) and the Federal Highway Administration (FHWA) have published guidance for implementation and operation of red-light camera systems. The report (23) proposes a systematic approach to recognize intersections with a red-light running problem and improve them by the feasible countermeasures.

A report issued by the Institute of Transportation Engineers (ITE) provides various countermeasures to identify and deal with the red-light running problems at intersections (18). According to the report, “it provides a background on the characteristics of the problem; identifies how various engineering measures can be implemented to address it; suggests a procedure for selecting the appropriate engineering measures; and provides guidance on when enforcement measures, including red-light cameras, may be appropriate”.

In order to assess the accuracy of various cameras, a committee created by the International Association of Chiefs of Police (IACP) has been commissioned to investigate the photo-monitoring systems, even though no equipment standards are available across the industry (20).

Based on a study funded by the Federal Highway Administration’s (FHWA) Intelligent Transportation System Joint Program Office and the Office of Safety Research and Development, Forrest Council, et al. (60) proposed a modified methodology for estimating the

crash cost by crash geometry in light of an evaluation of camera enforcement in seven jurisdictions.

In general, there are two ways to treat red-light violations by camera enforcement in the twelve states: as a moving traffic violation or as a violation equal to that of a parking ticket. In New York, the vehicle's owner would be fined for a red-light violation the same as a parking violation, no matter who was driving the vehicle during a red-light violation (31). In Virginia, a red-light violation is also treated as a parking-type violation, but the vehicle's owner may file an affidavit swearing that he/she was not driving the vehicle at the time of the red-light violation, in order to avoid being fined (31).

3.1.8 Public Views on Red-Light Camera Enforcement

As indicated by the increase of camera enforcement programs, red-light camera enforcement has been extensively accepted and supported by public (4).

- In 1995, a survey by the Insurance Institute for Highway Safety showed that 66% of the polled people would support the use of red-light cameras. In 1996, another survey by the Insurance Research Council found that 83% would be in favor of the camera enforcement.
- In 2002, a driver survey by NHTSA indicated that a majority of respondents (75%) would support red-light camera enforcement (4,61).
- In August 2002, a Harris poll by the National Campaign to Stop Red Light Running found that 83% of respondents would be in favor of red-light camera enforcement in cities with red-light running problem (4,62).
- In 2004, a driver survey in Scottsdale, Arizona, reported that 75% of respondents would support red-light camera enforcement (4,63).
- In Mesa, Arizona, more than 85% of respondents would be in favor of red-light camera enforcement and nearly 80% would support to expand the camera enforcement program (4).
- In 2006, a poll of Arizona voters by the Arizona State University's Walter Cronkite School of Journalism and Mass Communication and KAET-TV reported that 64% of voters would support the camera enforcement on state highways (4).

- In the United Kingdom, an evaluation of the 3-year camera enforcement indicated that 79% of respondents would support the red-light camera enforcement and 68% agreed that camera enforcement could save lives (4,64).
- In 2003, a survey showed that 78% of Canadians would support the red-light camera enforcement (65).
- In 2008, a telephone survey by the Center for Research Design and Analysis (CRDA) in Nevada, of the 1,012 respondents, the vast majority of registered voters (84.6%) reported that they were in favor of a photo enforcement law aimed at drivers who run red lights with more than half of the respondents (51.5%) reporting that they were strongly in favor of the law. A quarter of the respondents indicated that they opposed the law.

3.1.9 Findings in the Literature

With regard to the effects of red-light camera enforcement, numerous evaluations and reports have been issued across the world. However, the methods and results of these studies vary considerably.

1. The reviewed literature shows that a preponderance of evidence verify considerable effectiveness of red-light camera enforcement in reducing red-light violations and right-angle injury crashes related to red-light running, even though the results still are not conclusive partially because of the methodological flaws discussed above.
2. Some evaluations pointed out that to a certain extent red-light camera enforcement might result in an increase of rear-end crashes, but the increase could be more than offset by the decrease of right-angle injury crashes.
3. Statistics on the frequency and characteristics of red-light crashes should be regarded as estimates since red-light crashes are difficult to accurately extract from the existing crash databases.
4. Camera enforcement is just one possible countermeasure for reducing red-light crashes. An appropriate countermeasure should be selected by consulting comprehensive publications, such as: *The Red-Light Running Handbook: an Engineer's Guide to Reducing Red-Light-Related Crashes* (66), *Guidance for Using Red-Light Cameras* (24), and *Red-Light Camera Systems Operational Guidelines* (8).

3.2 Automated Photo-HOV Occupancy Enforcement

3.2.1 The Evolution of HOV Lanes

The development and operation of High Occupancy Vehicle (HOV) facilities have evolved throughout North America and overseas since the late 1960s (21). In the United States, the inception of HOV application was traced back to the opening of the bus-only lane on the Shirley Highway (I-395) in northern Virginia/Washington, D.C. in 1969, and the contra-flow bus lane on the approach to the New York-New Jersey Lincoln Tunnel in 1970 (67). Various federal codes, guidelines, and legislation currently authorize the creation and operation of HOV facilities. The Federal Highway Administration (FHWA) has periodically issued guidance on HOV facilities. The latest version was issued on March 28, 2001 (68). In general, HOV facilities should be operated in congested corridors, especially when the expansion of roadways is limited. Currently, more than 130 freeway HOV facilities are operating in metropolitan areas in the U.S. (69,70). A NCHRP report provides guidance to states regarding the Federal-Aid Highway Program as it pertains to HOV lanes (71). The operation of HOV lanes has proven to be successful in realizing the primary purpose of HOV facilities which is to move more people rather than more vehicles. This is because HOV lanes carry vehicles with more occupants. HOV facilities save travel time and improve travel time reliability, especially in metropolitan areas where heavy roadway congestion occurs.

HOV lanes are dedicated to accommodate high occupancy vehicles, such as cars with multiple riders, vans, and buses (70). Because of this HOV lanes accommodate more movement of people and therefore, have proven to be a flexible and cost-effective strategy for congested metropolitan transportation systems. The concept emphasizes person movement rather than vehicle movement. Generally, the number of persons carried in a HOV lane is equivalent to that in two to five conventional lanes with a higher level of service. If an HOV lane becomes congested, the occupancy requirement can be increased to accommodate more people. Therefore, HOV facilities are a viable means to reduce congestion on freeway systems (21,72).

Many of the initial HOV lanes were bus-only applications or allowed only buses and vanpools. In order to maximize the efficiency of HOV facilities, the FHWA adopted a 3+ strategy for carpools on HOV projects funded through federal programs during the late 1970s and early

1980s. From then on, HOV projects dropped the threshold of vehicles using HOV lanes, including the Shirley Highway HOV lanes in northern Virginia and the El Monte Busway on the San Bernardino Freeway in Los Angeles. The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) defines a 2+ occupancy requirement for carpools using HOV lanes, with exceptions for specific exempted vehicles (21,69). The vehicle-occupancy requirements for carpools have also evolved over time. In the early and mid-1980s, a lot of projects began operating with a 2+ occupancy requirement. In 1987, federal legislation allowed local agencies to adjust the occupancy requirements in light of actual situations (73). Presently, most of the freeway HOV lanes use a 2+ occupancy requirement for carpools with some requiring a 3+ occupancy during the peak periods (74).

HOV lanes can be implemented on either arterials or freeways. HOV facilities on freeways or in separate right-of-way are typically classified into four categories as follows (21,70):

- Busway or exclusive HOV facility with separate right-of-way adopted in Pittsburgh, Miami, Minneapolis/St. Paul, and Ottawa, Canada.
- Exclusive HOV facility with freeway right-of-way adopted in Houston, Northern Virginia, Minneapolis, San Diego, and Los Angeles.
- Concurrent flow HOV lane adopted in Seattle, the San Francisco Bay Area, Los Angeles and Orange County, Denver, Salt Lake City, Phoenix, Dallas, Houston, Minneapolis, Atlanta, Miami and Ft. Lauderdale, Orlando, Northern Virginia, Maryland, New York/New Jersey, and other areas.
- Contraflow HOV lane adopted in the approach to the Lincoln Tunnel on Route 495, the Long Island Expressway, and the Gowanus Expressway; all of these are located in the New York/New Jersey area.

The NCHRP HOV Systems Manual #414 provides more information on the relative differences, advantages, and disadvantages with each of these types of treatment (70). Currently, four operating scenarios are typically used with HOV facilities; these are: 24/7, extended hours, peak-period only, and special events.

3.2.2 Vehicle Eligibility and Occupancy Requirement

Vehicle occupancy requirement enforcement has been a challenging issue with HOV facilities.

The enforcement has a significant influence on the operational effectiveness and efficiency of HOV facilities and also affects the public perception and acceptance to HOV application. This involves a close cooperation and coordination between the many interest groups, including managing, enforcing, and providing information to the public (72).

One merit of HOV facilities is the ability to match traffic demand through adjusting the vehicle occupancy requirements. When carpools are allowed to use HOV facilities, the vehicle occupancy requirement needs to be defined. Minimum occupancy requirements should maintain a balance between encouraging use of the facilities and avoiding both underutilization and overcrowding of HOV lanes (70).

Vehicle eligibility requirements identify the types of vehicles allowed to use HOV lanes. The determination of vehicle eligibility to a certain extent affects other decisions of operating HOV facilities. Generally, potential vehicles may be classified into three categories: vehicles meeting occupancy requirements, vehicles exempt from occupancy requirements, and vehicles not usually allowed regardless of occupancy levels (21). In order to take full advantage of HOV facilities, the restriction of vehicle eligibility requirements have allowed admitting specific vehicles, including tolled vehicles, low-emission and energy-efficient vehicles, and other exempt vehicles not meeting occupancy requirements. Commercial vehicles, especially semi-trucks, are not allowed to use any HOV facilities in the United States, regardless of occupancy levels (21).

Due to the innovation and evolution of HOV facilities, the use of HOV lanes has expanded to include various occupancy levels (e.g. HOV with a minimum of 2, 3, or 4 occupants) and types of occupancy-exempt vehicles (e.g. motorcycles, inherently low emission vehicles, emergency vehicles, deadheading buses, deadheading paratransit vehicles etc.). Restrictions can be in effect 24 hours varying by time of day or day of the week (53).

3.2.3 Enforcement of Vehicle Occupancy Requirements

A key to successfully operating HOV lanes is the effective enforcement of vehicle occupancy requirements for ensuring a minimum number of occupants in each vehicle. The role of HOV occupancy requirement enforcement is to protect eligible vehicles' travel time savings, discourage unauthorized vehicles, promote fairness and help gain acceptance among users and non-users (75). The effects of the vehicle occupancy enforcement in HOV lanes mainly involve

three items (21,69): 1) operating costs for enforcement; 2) violation rates for the HOV facilities; and 3) revenue resulting from the enforcement. The *HOV Performance Monitoring, Evaluation, and Reporting Handbook* provides a detailed guideline for developing and conducting HOV performance monitoring programs (21,69).

A variety of technologies have been explored in recent decades to improve the effectiveness and feasibility of vehicle occupancy verification. The effective enforcement of managed lanes requires appropriate application of available techniques. The various enforcement practices reveal that there are various enforcement techniques developed for managed lanes with varying levels of effectiveness and reliability. These techniques focus on providing surveillance of the lanes, detecting and apprehending violators, issuing citations and warnings to violators (76). The following enforcement techniques are summarized in this section. Most agencies use a combination of enforcement techniques (21).

- Manual enforcement (stationary patrols, roving patrols, team patrols, and multipurpose patrols)
- Roadside technologies (sensing technologies, video systems, passive microwave systems, ultra wideband radar systems, and infrared systems)
- In-vehicle technologies

Manual Enforcement

Currently, vehicle occupancy verification in HOV lanes mainly depends on manual methods. Visual observation by highway patrol officers is still a primary method to verify the vehicle occupancy level. Manual verification techniques for enforcing vehicle occupancy requirements on HOV facilities include routine enforcement, special enforcement, selective enforcement, and self-enforcement. The specific techniques used with each of these approaches might vary slightly. All of these strategies can be appropriate for comprehensively enforcing violations with the various types of HOV projects. However, several shortcomings of traditional enforcement have been revealed as follows (21):

- *Reliability: Current practices in occupancy verification and enforcement suffer from substantial problems. It is essentially impossible to verify the correct number of*

occupants in vehicles with very high accuracy using visual inspection. Many factors such as high speeds, window tint, and poor lighting conditions caused by bad weather or dawn/dusk conditions significantly impair an officer's ability to "eyeball" vehicle occupants. Rear-occupant detection is especially problematic—the few reports on accuracy of rear-occupant counts indicate that half the time, the officer fails to see rear occupants, especially when they are children.

- *Safety: The need for officers to position themselves at the roadside next to moving traffic creates a potentially dangerous enforcement environment. In order to reduce the exposure of officers to injury, expensive barriers must be built to protect officers while observing and apprehending violators.*
- *Cost: The high cost of visual occupancy verification manifests itself in two ways: infrastructure and operations. On the infrastructure side, visual enforcement requires enough space for an officer to stand and observe the interior of the vehicle cabin and sufficient room to apprehend a violator. Providing that space within the right-of-way can be expensive, particularly in retrofit situations. Physically separating HOVs from toll-paying vehicles has proven to be advantageous from an operations perspective, but it requires a separate lane where HOVs can self-declare their eligibility for a free or discounted toll. The additional lane for HOVs also requires space for the observer to verify vehicle passengers.*

Roadside Technologies

The enforcement technology of managed lanes is continually evolving with the development of Intelligent Transportation System (ITS). Over the years, as part of Transportation Demand Management (TDM) programs, ITS technologies have been extensively used for monitoring roadway systems. Automated enforcement of managed lanes can use some of the ITS technologies, including speed sensors, road-imbedded vehicle detectors, surveillance cameras, and centralized traffic management centers. Successful enforcement of managed lanes depends on the ability to isolate specific vehicles and determine the number of occupants. This has proven feasible with ITS technologies, such as license plate recognition and video-imaging technologies (10).

Currently, a number of advanced technologies have been utilized to help monitor HOV facilities

and identify potential violators. These technologies include: Closed Circuit Television Cameras (CCTV), infrared cameras, photographs of vehicles, license plates, etc. Current technologies employed for detecting vehicle occupancy have yet to overcome inherent difficulties. Therefore, vehicle occupancy verification cannot be readily resolved with current automated technologies (75).

In-vehicle Technologies

(Material in *italics* is drawn verbatim from the Reference 21.)

In-vehicle systems seek to leverage the capabilities of next-generation adaptive airbag systems for the purpose of occupant counting. These advanced airbag systems will have the ability to distinguish between an empty seat in a vehicle and one occupied by various sized adults, infants, and children. This information could then be used by a piggyback system or application to verify the number of vehicle occupants.

A study managed by the Ministry of Transportation of Ontario and funded by ENTERPRESE was undertaken in 2004 by McCormick Rankin (77). As outlined in the report, some key principles related to in-vehicle systems are stated as follows (77):

The main impetus for in-vehicle occupancy recognition systems appears to be air bag safety. The U.S. Federal Motor Vehicle Safety Occupant Crash Protection Standard (FMVSS 208) requires the use of “smart” air bags in the front seats of new vehicles sold in the U.S. Such systems are mandatory in 100% of new vehicles sold in the U.S. from the 2006 model year onwards. “Smart” air bags rely on sensors to cancel deployment when the occupant is in a potentially dangerous position. FMVSS 208 does not apply to rear seats. Some auto manufacturers are also using side curtain air bags, which are even more sensitive to out-of-position passengers than the frontal air bags due to the much shorter distance between the side of the vehicle and the passenger. Occupancy detection systems are consequently a critical part of some side air bag systems. To comply with FMVSS 208, the technology used to detect vehicle occupants is not specified, as long as it meets criteria in terms of reliability, cost-effectiveness, size / weight, etc.

There are two key obstacles that impact the development of occupancy verification techniques based on in-vehicle systems. (Material in *italics* is drawn verbatim from the Reference 21.)

In-vehicle systems are predicated on the assumption that occupancy information can be easily

retrieved from the advanced airbag systems and subsequently transmitted to roadside communications devices. This assumption may ultimately prove to be invalid if privacy objections or the reluctance of automotive manufacturers to accommodate occupancy verification technologies proves to be insurmountable. The second obstacle facing in-vehicle systems relates to their timetable for deployment. Advanced airbag systems are not expected to become a nearly universal presence in North American vehicle fleets for at least 10 to 15 years or even longer, and it is doubtful that occupancy verification technologies could be easily retrofitted to non-factory-equipped vehicles.

3.2.4 Video Enforcement System

As a controversial issue in the United States, automated enforcement techniques are more extensively used at signalized intersections than in managed lanes. Video enforcement technique has existed for monitoring compliance with vehicle occupancy requirements by observing the appropriate number of occupants in HOV lanes. A typical strategy of video enforcement includes installing three or more cameras with artificial lighting sources to capture the front windshield image, the side window image, and the rear license plate image. The semiautomatic review process is activated when a violation has occurred and electronically saves the images of the vehicle's interior along with the license plate information for later use in violation processing (10). Although video plays an important role in HOV facility monitoring, it still has some problems with verification adequate reliability and accuracy. The collective experience from several studies of implemented projects has reviewed the effectiveness and efficiency of video enforcement compared with live visual inspection. Further details of these projects are provided below (21,78).

Video systems used for enforcing vehicle occupancy requirements were tested in Los Angeles and Orange counties, California, in 1990 (78). The study shed light on the effectiveness and reliability of video equipment in determining the vehicle occupancy, documenting violator identity, and assisting the enforcement of HOV lanes (77). Several cameras were employed to take pictures inside vehicle cabins from different views and they were displayed on split-screen monitors. The results indicated that video enforcement is generally limited to those locations lacking enforcement officers, and video enforcement cannot be used alone since the number of vehicle occupants cannot be identified with enough certainty. The false alarm rate of video

enforcement was over one-fifth of overall identified violators, primarily due to the inability of the cameras to capture small children or sleeping adults in the rear seat of vehicles, and to resolve the negative influence of poor light conditions, glare, and tinted windows (74,77,78,79).

In 1995, the Dallas Area Rapid Transit (DART) and the Texas Department of Transportation (TxDOT) tested the use of real-time video and license plate reading for HOV lane enforcement on the I-30 HOV lanes in Dallas, Texas (77,80). The Texas Transportation Institute (TTI) project team worked with Transformation Systems (Transfo) and Computer Recognition Systems (CRS) to design and install the High-Occupancy Video-based Enforcement and Review (HOVER) system on the I-30 HOV lane. The HOVER system employed three-way views of vehicle cabins to observe vehicle occupancy. The License Plate Recognition (LPR) was used to identify the suspected vehicles. Enforcement agents reviewed the archived images to identify HOV violators. Testing of the enforcement system began in November 1997, and concluded in April 1998. The test results showed that the HOVER system could be effective to assist enforcement personnel in enforcing HOV occupancy requirement violations. In addition, high-quality video combined with automatic license plate readers have proven to be useful in improving the HOV enforcement process. However, an effectiveness study of the HOVER system revealed that the video and the License Plate Recognition (LPR) could not achieve images with enough certainty for effective enforcement screening. Use of the system for actual enforcement screening required various enhancements such as better quality video cameras, reduced video signal transmission loss, additional camera views, and better license plate recognition for vehicle identification (10,77,80, 81). There would still be some difficulties for video cameras capturing images of small passengers or children in car seats and “seeing through” tinted windows of vehicles (10,74,82).

A prototype vehicle occupancy system developed by the Georgia Technology Research Institute was used to detect vehicle occupancy for monitoring HOV lanes. The prototype system uses digital infrared cameras and infrared strobe lighting to capture views of vehicle interiors. A non-intrusive vehicle detection unit is used to trigger vehicle image capture, as well as collect vehicle volume and classification data (77).

In 1998, a study by the Minnesota Department of Transportation (MnDoT) and the University of Minnesota employed mid-infrared and near-infrared cameras to detect vehicle occupancy. The results showed that the mid-infrared setup could not achieve clear images at highway speeds and

the near-infrared scheme worked much better. However, the accuracy and reliability of the system still could not meet the requirements of actual occupancy detection. The study concluded that near-infrared bandwidth had a potential to be effective enough for enforcement. Moreover, it should be noted that near-infrared cameras used for vehicle occupancy detection still exist with some difficulties, such as looking through glass with metal or heavy clothes, identifying children in car seats or persons who are lying down in a car (77).

The I-15 Congestion Pricing Project in San Diego, California, used gantry-mounted video cameras to monitor violators in the HOV lanes. Operators were employed to review the videotape and record a count of HOV occupancy violators. However, the program was suspended in 1998 due to the inability of the operators to reliably distinguish violators on the videotapes and to discern the number of vehicle occupants, especially those in back seats (74).

In Leeds, U.K., a three-year research project developed an automated occupancy camera detection system for enforcing HOV occupancy violations in 2003. Infrared cameras and state-of-the-art high-speed image processing methods were adopted to identify the number of vehicle occupants. A comprehensive image of the visual and infrared systems yielded an image of a face as a “darker blob” which contrasts with its surroundings and can be recognized immediately by the specially-developed processing software. A working prototype of the system was demonstrated on a HOV lane in Leeds in September 2004 (77).

3.2.5 Findings in the Literature

In the United States, the successful operation of many HOV facilities with low violation rates mainly depends on an effective combination of law enforcement resources, physical enforcement areas on the facility, supporting violation fine structure and adjudication authorization (21). Many research studies have indicated that video cameras have been effective in helping to determine compliance with vehicle occupancy requirements in HOV and HOT lanes; however, video camera technology needs improvement for actual enforcement. The findings are summarized as follows (21,78):

1. The video occupant detection system has been used mainly as a roadside system which requires remote methods to detect vehicle occupants. The system had technological difficulties involved with effectiveness and reliability that still need to be resolved before applying to

enforcement.

2. Nearly all video roadside detectors must choose the vantage point for illumination to optimize the view into the vehicle cabin.

3. Although additional cameras enhanced video systems, the video systems can only detect unobstructed occupants and there would still be some difficulties detecting rear-facing infant seats, smaller rear seat occupants, occupants “curled up” sleeping in the back seat and people in vehicles with tinted windows.

4. With respect to sensing technologies, the main challenges can be categorized as follows:

- Cabin penetration, such as seeing through tinted vehicle windows
- Environmental conditions, such as operating in all weather conditions and during night-time
- Good image resolution, such as differentiating heads and limbs
- Fast image acquisition, such as operating at high speeds
- Observational restrictions.

4. TECHNICAL FEASIBILITY

4.1 Automated Red-Light Running Enforcement Technology

The red-light camera technology has evolved since the 1960s (29). Since then, various red-light camera systems have been utilized in many countries in the world. The main purpose of technical feasibility study is to extract and summarize the technological experiences for successfully operating red-light camera system in other jurisdictions. Technical feasibility focuses on whether red-light camera systems perform with sufficient accuracy and reliability to be acceptable by the public.

4.1.1 Requirements for Automated Enforcement Technology

Red-light camera system has been successfully employed by numerous communities to curb the red-light running violations at signalized intersections. The system should have ability to accurately detect and record violations and to achieve clear images under various field conditions. In general, an automated enforcement technology is proposed to meet the minimal requirements quoted as follows (83):

- *The ability to capture, transmit, process, store and recover captured images so that data may be managed in an efficient manner.*
- *Sufficient resolution to satisfy court standards for the image-reading of vehicle license plates, clear detail of the vehicle, and identification of the vehicle operator (if necessary).*
- *The capability to prevent the spreading of overexposed portions of an image (anti-blooming) that may result from vehicle headlights or sunlight from highly reflective surfaces.*
- *Adequate differentiation of light to dark areas within an image to provide necessary details (also referred to as contrast latitude).*
- *The ability to provide blur-free images of moving vehicles.*
- *The ability to detect at varying levels of light.*
- *Image enhancement circuitry to eliminate major sensor defects such as bright or dark columns, which detract from the visible presentation of an image.*

- *Continuous read-out of images to support monitoring along with single frame capture capability for recognizing several successive vehicles committing a violation.*
- *The ability to be moved to different locations or to be mounted into a permanent position. Components are environmentally friendly.*

4.1.2 Components of a Red-Light Running Camera System

A red-light running camera system is composed of many components involving the connection of traffic signal system and the identification of red-light running violation. The camera system usually contains two components, one fixed and the other portable. The fixed component generally consists of detection and triggering mechanisms, a roadside computer, and camera housings (84). The FHWA identified six components as common to red-light camera systems (23): camera, intersection lighting, camera housing and supporting structure, vehicle detection, communication device and warning signs.

The detection is usually composed of electromagnetic loops buried in the pavement, a terminal block that houses a microprocessor, and a camera atop a 15 +/- foot pole (85). Electromagnetic loops deployed near the intersection entry point detect vehicle presence. Cameras housed in a durable cabinet generally can be placed at the top a pole located at the curb or on a cantilever mast arm. The camera is usually connected to the traffic signal system to monitor the status of the traffic signal. The deployment of cameras mainly depends on whose liability is used to prosecute violations. The rear camera is normally used for owner liability and front and rear cameras are used for driver liability (29). Normally, the camera records the date, time of day, time elapsed since beginning of red signal and the speed of the vehicle (86). By placing camera housings at multiple intersections without cameras actually being installed, each camera influence more intersections because of driver deterrence (29).

As shown in an intersection schematic diagram in Figure 4.1 (84), one camera is usually mounted on a street light pole mast arm for recording signal status of an intersection approach, while the other was attached to a traffic signal mast arm for recording vehicles approaching the intersection's stop bar.

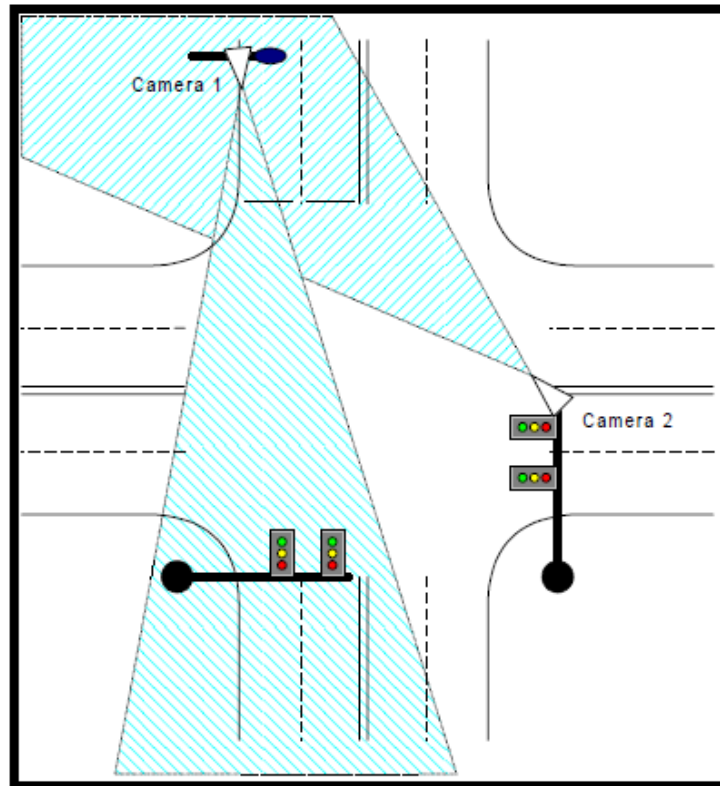


Figure 4.1 Typical Positions of Cameras (84)

4.1.3 Red-Light Camera Technology

There are three types of cameras available for use with automated enforcement of red light violations, namely, — film or digital still photography, digital video, or a combination of still photography and digital video (83). The 35 mm film-based cameras have been the most common cameras used for automated enforcement, but digital technology is becoming more popular in numerous jurisdictions. When picking out a camera system, consideration should be focused on cost (including equipment, installation, operation and maintenance), feasibility of installation at certain sites, reliability, evidentiary credibility, and the clarity of images produced by the system (29).

The following sections provide a general description of the three types of red-light camera systems based on the related reports.

Vehicle detection

In most red-light camera systems, the camera is connected to the traffic signal system—to obtain a reading of when the signal changes from green to amber to red — and to sensing devices near the crosswalk or the point of violation. These sensors, commonly inductive loops placed in the pavement, continuously monitor the flow and speed of traffic and serve as the triggering mechanism for the red-light camera. During the green phase of the traffic signal cycle, the camera system is deactivated and photographs cannot be taken. During the amber phase, the unit is automatically switched to standby. With the red phase, the camera is activated but only takes a photo when a violation is detected by a vehicle passing over the sensors and entering the intersection against the red. The placement of the detection sensors will often determine how many pictures will be taken by the system and to differentiate between vehicles accelerating to run the traffic signal and vehicles attempting to stop or turn right. To activate the camera, a vehicle must approach and then enter the intersection after the light has changed from yellow to red. Vehicles do not trigger the camera if they enter the intersection prior to the light turning red but are trapped in the intersection when the light changes. In owner liability jurisdictions, when the system is activated by a vehicle running a red light, normally two pictures are taken with a rear camera only. The first picture will show the offending vehicle approaching the intersection against the red traffic signal but before the vehicle crosses the intersections demarcation point (limit line, crosswalk or other designator). The second picture will show the vehicle continuing through the intersection a short time later (0.5 to 1.0 seconds), against the red traffic signal. The red traffic signal should be clearly depicted in both pictures. The camera should also record the date and time, amber signal time, time elapsed since the beginning of the red signal in both pictures, the speed of the vehicle, and a location designator. If driver identification is necessary, a third picture to capture an image of the driver will be taken with a frontal camera, which can also be used to record the front plate of the vehicle if necessary (29).

Inductive in-ground loops have been in use the longest and remain the most accurate method of vehicle detection. Some photo enforcement systems may offer above-ground radar, laser or video sensors to detect violators. These systems can eliminate the need to cut into the roadway for loop placement and the associated traffic congestion that can result, the trade-off being that above-ground detection systems have not been proven to be as accurate in registering speed as in-ground inductive loops (29).

Wet film/35-mm Cameras

The 35 mm camera is relatively well known and understood; therefore, legislators are more comfortable with the capabilities. Each photograph produced by the 35 mm camera is an actual snapshot of what occurred. Therefore, photographs are not subject to possible alterations as could occur with digital images or videotapes (84).

Film for wet film cameras comes in expensive, bulk rolls containing 800 or more exposures (16). Pictures can be taken in black and white or in color. Film must be manually collected, processed, and analyzed. Personnel must make frequent trips to camera sites to change film. The extra-large film rolls must be sent to a special processor for developing. After processing, film is sent to enforcement agencies for ticket distribution (84).

The camera system is typically connected to both the traffic signal system controller and to loops or sensors. The loops or sensors are placed in the pavement to detect on-coming vehicles and determine vehicle speeds. Cameras are located in a special unit to protect them from weather or vandalism and placed atop poles or existing signal mast arms. Poles may be either hinged or contain specially designed "elevator" systems to allow access to the cameras (83).

When the traffic signal switches to the red phase, the camera used by the automated enforcement system becomes active. Vehicles traveling over the detectors while the camera is active are to be photographed. A "grace" period of about 0.3 to 0.5 seconds after the signal turns red is common in these systems. A minimum speed of 15 to 20 miles per hour is needed to activate the system. The minimum speed threshold is used to differentiate between vehicles attempting to stop or turn right on red and vehicles that are clearly running the red light (19).

Upon activation of the system, at least two pictures are taken by the camera. The first picture shows the vehicle as it approaches the intersection during the red phase, the pavement marking defining the intersection, and the traffic signal showing the red phase. In some systems the first picture shows the front of the vehicle, while for others it shows the rear of the vehicle. The second picture then shows the vehicle in the intersection a short time later (about 0.5 to 1.5 second). Systems are available to show the second photograph at a preset distance from the first photograph. If driver identification is necessary, a third picture of the driver may be taken. From the pictures taken, the license plate will be magnified to allow for identification (19).

The use of 35-mm camera units has the advantage of being portable. Although each intersection has to be equipped with the necessary sensors and connections to the traffic signal field box, several housing units for the camera can be placed at intersections without a camera actually being in the unit, a so called "false installation." By having many housing units at different intersections, more areas per camera can be covered and drivers do not know which unit has a camera and which does not (19).

The 35 mm cameras are also subject to costly malfunctions. With 800 exposures on each roll of film, one mistake may lead to expensive loss of evidence. If a problem occurs with the camera's triggering function, for example, the full roll of film may be used within a couple of hours. If this happens, violations will not be recorded and an entire roll of film may be wasted. Human errors during collection or processing may also cause the film to be ruined and evidence lost (84).

Several vendors offer 35 mm cameras for red light running enforcement. These companies include Lockheed Martin, Aviar, Inc., American Traffic Systems (ATS; now TransCore), and Electronic Data Systems (EDS). Wet film technology programs in the United States have primarily been furnished by Lockheed Martin (previously U.S. Public Technologies) (84).

Digital Cameras

The digital image camera offers a newer automated enforcement system that has begun to replace traditional 35 mm cameras. Digital cameras have the capability to produce higher resolution; more sharply detailed images of vehicles, and are equipped to prevent reflections or headlights from smearing the image. Photographs produced by digital cameras may be in color or black and white. The configuration of digital camera applications is very similar to the one described for applications using 35-mm cameras. As with 35-mm cameras, digital cameras are placed in protective housings atop poles. Sensors are placed in the pavement in the same manner as for 35-mm applications, with two sets of sensors per lane to detect vehicle presence and speeds. The cameras are wired to the signal controller and the loop sensors so when the signal turns red, the system becomes active (85).

A major benefit of digital cameras is in improving the photo collection and accelerating the processing and distribution of notices of violation (tickets). Digital cameras have the capability to be linked using dedicated lines or existing phone lines to a computer located in a central facility. Once the images have been transferred from the digital cameras to the central facility,

pattern and optical character algorithms can be used to determine the owner of the vehicle by cross referencing the license number with records of vehicle registration databases. After license plate numbers are successfully matched with registered vehicle owners, citations can be automatically processed and mailed to violators. In addition, digital cameras eliminate film cost, processing development time and cost, and the field personnel required for daily film handling. Depending on the digital system being used, digital images can be remotely accessed at a processing center and all violation data and images downloaded either via wired telecommunication lines or wirelessly (85).

Hansen introduced a variety of issues associated with digital cameras. Very importantly, he questioned how the courts would view digital violation images. Specifically, he pointed out the ease with which digital images can be tampered. In comparison with a wet film system, an original 35-mm slide and photo can be produced in court to support the veracity of the evidence. This back-up plan does not exist with digital images. The following suggestions are offered (85):

- When a digital image is transferred to a review facility, store a duplicate image at the camera site using a "tamper proof" data storage device.*
- The storage media should, when full, be handled as evidence and viewed only in instances when the original is questioned.*
- Maintain a documented chain of custody so that the court can be shown an image that has not been viewed by human eyes.*

Other issues with digital cameras include the large file sizes for high-resolution photos. This in turn brings about slower and more costly file transfers. This could be especially cumbersome with multi-camera systems. Another issue is that some digital cameras are out of service while capturing an image. This could result in an inability to capture multiple violators i.e. the second or third violators going through the red signal (85).

Several vendors offer digital image cameras for the red-light running enforcement. These companies include RedFlex, Driver Safety Systems Ltd., Tecnicon International, Inc., American Traffic Systems (now TransCore), Peek Traffic, and Roper Scientific, MASD (Kodak) (84).

Video Cameras

The use of digital video cameras and video processing technologies is a recent development for red light enforcement activities and is growing in popularity. However, initial and operating costs are comparatively high. Video systems provide more images than the other two camera types, which generally only provide two still images. With a video camera system, the entire violation sequence is filmed; hence, there are more opportunities to identify a vehicle's license plate or driver. The video system can use an electronic detection system to identify approaching vehicles. Computer software establishes a bar electronically on the video view screen that identifies vehicles passing over that point. This software can then record pertinent enforcement data such as speed, volume, and other desired data. With this system, sensors on or under the pavement are not needed, thus requiring less installation time and disturbance (84).

Video cameras can be used to determine a vehicle's speed as it approaches the intersection, predict whether or not the vehicle will stop for the red light and then track the vehicle through the intersection and record a brief video sequence of the violation. Video images allow close-ups of both the front and rear license plates. Newer video cameras are digital, which allows real-time transmission of images and, like digital still cameras, reduced transport, handling and reproduction costs. Full video sequences can increase the number of detected violations for subsequent ticketing (85).

An advantage of a video system may be its ability to detect vehicle speed and predict whether or not a red-light running violation will take place. With this prediction, it is possible to preempt the normal signal changes to create an all-red signal to prevent crossing traffic from entering the intersection when a collision is possible. Though this does not prevent the violation, it can help to mitigate the potential consequences of the violation. Additionally, video cameras can be used for non-enforcement activities such as traffic monitoring and surveillance, incident response, and crash reconstruction. If digital video cameras are used, the same concerns, i.e., lack of negatives and other non-tamperproof forms of evidence, etc. apply as for the digital still cameras (85).

In recent years, digital video technology has made significant advances in red-light running applications. Digital video technology offers the opportunity to place red-light running

violations “in context,” by making it possible to view the entire intersection. Some systems have the capability to “hold” cross street traffic when a red-light running violator is detected (19).

The relatively inexpensive cost of video traffic monitoring systems and the ability to move cameras to different locations with little cost give jurisdictions with a limited budget a means to begin a red-light running enforcement program that can be expanded to include automated enforcement using other types of cameras in the future (19).

However, video systems can require extensive lighting to capture the license plate and/or driver at night and in poor weather conditions. This lighting has been questioned in the courts as a distraction to drivers. Also, claims of Big Brother are more common with video since the video clips of violators can show more than just the traffic violator (29).

Many cities are also supplementing their existing wet-film and digital still photography systems with digital video cameras. The cameras are added to the existing camera system so they can capture video clips (usually six seconds prior to the violation and six seconds after) in order to reveal the full violation in progress. In most cases, when violators receive their citations in the mail, there will be an included internet web link. Violators can access the link and watch the full video clip of the violation. In the cities where this option has been provided, it has dramatically reduced the number of citations that are challenged in court. It also allows violators to view the evidence of their violation without having to travel to a police station or court hearing (29).

Vendors that provide video cameras for red light running enforcement include Nestor Inc., Monitron Inc., ATD Northwest, and Iteris (formerly Odetics ITS) (84).

Comparisons

Pros and cons of three types of camera systems generally used for automated red-light running enforcement are summarized in Table 4.1 (20).

Table 4.1 Comparison of Automated Red-Light Running Enforcement Technologies (20)

Camera Unit Type	Pros	Cons
35mm Wet Film	<ul style="list-style-type: none"> • Relatively inexpensive installation • Higher pixel count (usually 18-20 million) • Less chance for manipulation 	<ul style="list-style-type: none"> • Labor intensive for collection • Storage
Digital Still Pictures	<ul style="list-style-type: none"> • Collection can be immediate • Digital format • Storage 	<ul style="list-style-type: none"> • Lower pixel count (usually 2 million) • Needs communication link (telephone wires, etc) • Impression of surveillance
Digital Video	<ul style="list-style-type: none"> • Collection can be immediate • Captures entire sequence • Storage 	<ul style="list-style-type: none"> • Needs communication link (telephone wires, etc) • Impression of surveillance

4.2 Automated HOV Occupancy Detection Technology

4.2.1 Automated Vehicle Occupancy Detection System

Automated HOV occupancy enforcement may promote the safe and efficient use of the HOV lanes by deterring possible violators. The functionality of an HOV lane relies on exclusive use by the designed type / class of vehicles. The misuse of ineligible vehicles would result in suffering the performance of HOV lanes and the public support. Research to date has focused on using video-camera systems to record vehicle occupancy from outside the moving vehicles.

Sensor Technologies

Roadside detectors are restricted by the type of sensing technology they can employ. Radar systems are not appropriate, as a vehicle's metal chassis creates too much interference to effectively image anything inside the vehicle. Visible light systems cannot be used at night, since any supplemental illumination would pose a hazard to drivers (21,87).

Infrared sensors, especially those sensitive to near infrared wavelengths, have near ideal properties for seeing into vehicle interiors. Near infrared sensing is not affected by weather conditions such as rain, fog, or haze. Near infrared system can employ supplementary infrared illumination which is invisible to drivers in darkness. Most notably, the reflection characteristics

of human skin change significantly in the near-infrared region, being highly reflective at shorter wavelengths and almost completely absorbent at longer wavelengths (21,87).

Infrared sensors have until recently been prohibitively expensive, requiring integrated mechanical systems for cooling and image scanning. Advances in semiconductor manufacturing are now yielding faster and cheaper sensor arrays which either require no cooling or can be cooled by solid state methods (thermoelectric). Such sensors offer great promise in terms of their speed and mechanical reliability (21,87).

Image Processing

The principal image processing problem in roadside occupancy detection has traditionally been reliable segmentation of occupants from other objects in the vehicle cabin. Near infrared fusion techniques have been demonstrated to isolate the “signature” of human skin, making this an ideal method for detecting the faces of vehicle occupants. This method combines short- and long-wavelength infrared images to create a composite image. The pronounced difference in skin reflectance between the two infrared bands results in a unique feature that is readily distinguished from the rest of the vehicle cabin (87).

Figure 4.2 shows a schematic diagram of an occupancy sensor coupled with a vehicle identification sensor (88). This could correspond to a system mounted on an overhead gantry system shown in Figure 4.3 (88). The figure illustrates the controller connecting to its management station via a wireless radio link (88).

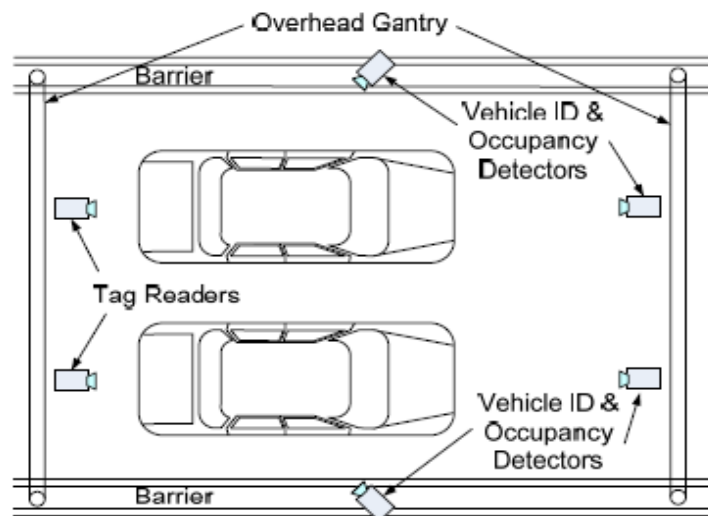


Figure 4.2 Fully Automated Vehicle Occupancy Detection System (88)

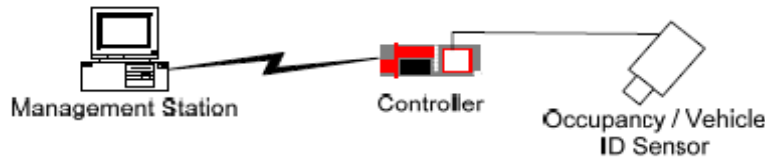


Figure 4.3 Remote Vehicle Occupancy Monitoring Station (88)

While the potential for roadside occupancy detection systems has never been greater, no system has yet entered commercial production. Currently, the only system in development is the Cyclops system from Vehicle Occupancy Limited. Results from field trials of this system indicate that additional improvements are needed before the system can be considered sufficiently accurate and reliable. These systems have shown some promise, but suffer from inherent flaws in dealing with tinted windows, different vehicle types and passenger seating arrangements, varying weather and light conditions, and high-volume high-speed operation, and as a consequence appear unlikely to be able to be relied upon as a fully automated HOV monitoring system (87).

4.2.2 Research Lessons on Automated HOV Occupancy Detection

Over the years, the technology of automated HOV occupancy enforcement by detecting occupants from outside the vehicle has evolved and renovated. Numerous jurisdictions have developed and tested multiple methods for monitoring and enforcing HOV occupancy violations. The following section provides a brief description of video and other photographic technology tested by many jurisdictions for HOV occupancy enforcement (77).

- Caltrans (1990): Video
- TxDot/ DART (1995-1999): Video
- Georgia DoT (1997): Digital Infrared
- MnDoT (1998): Infrared/Video
- Leeds, UK (2002): Video

Brief descriptions of the tests and their results follow.

California Department of Transportation (Caltrans)

The use of video in HOV lane surveillance and enforcement was tested by Caltrans in 1990. The study was conducted to test and demonstrate the use of video equipment in determining the vehicle occupancy, documenting violator identity, and assisting in the enforcement of HOV lanes.

The study reached the following conclusions regarding the use of video cameras in HOV lane enforcement (77):

- Video cameras operating alone cannot identify the number of vehicle occupants with enough certainty to support citations for HOV lane restrictions. The video tests had a false alarm rate of 21 percent (21 percent of vehicles identified by video tape reviewers as violators actually had the required number of occupants). Small children or sleeping adults in the rear seat were not captured by the video camera; poor light conditions, glare, and tinted windows compounded the problem of viewing passengers in the interior of the vehicle.
- The use of video as a real-time enforcement aid appears to be limited to those locations lacking enforcement areas for officer observation. At these locations, a video camera could be safely positioned to assist a downstream officer in determination of vehicle occupancy. The study noted, however, that an officer stationed beside an HOV lane in an enforcement area was in a much better position to observe violations than an officer at a remote video monitor.
- Videotape provides a freeway and HOV lane monitoring tool that is potentially more consistent and accurate than existing techniques for documenting vehicle occupancy.

There does not appear to have any further work on this or related projects in California since the above referenced study. Conventional on-road enforcement efforts, combined with good design and strong utilization, have maintained HOV lane violation rates well within acceptable levels on most facilities (77).

Dallas, Texas

The Dallas Area Rapid Transit (DART) and the TxDOT tested the use of real-time video and license plate reading for HOV lane enforcement on the I-30 HOV lane in Dallas, Texas (77).

A one-day demonstration test and subsequent video analyses in 1995 determined that current pattern recognition algorithms would not be sufficient to automatically determine vehicle occupancy. Results of the demonstration test did reveal that high-quality video combined with automatic license plate readers could be useful in improving the HOV enforcement process.

The Texas Transportation Institute (TTI) project team worked with Transformation Systems

(Transfo) and Computer Recognition Systems (CRS) to design and install High-Occupancy Video-based Enforcement and Review (HOVER) system on the I-30 HOV lane. The system could ultimately be used to assist DART enforcement personnel in determining compliance with vehicle occupancy restrictions. The enforcement system performs the following basic functions (77):

- *Collect and transmit video images of vehicle license plates and vehicle compartments for all HOV lane users to a remote computer workstation.*
- *Perform automatic license plate character recognition on the license plate video image.*
- *Synchronize the captured video images of vehicle occupants with license plate numbers. Search a license plate database containing vehicles that have been observed with two or more occupants (“whitelist”) and display the vehicle license plate number and vehicle compartment images of potential violators on an enforcement workstation.*

Transfo and CRS installed and integrated an HOV lane enforcement and review system on the HOV lane in Dallas. Testing of the enforcement system began in November 1997 and concluded in April 1998. The results of the operational test indicated that the HOVER system, in its current state, could support a program that mails HOV information to suspected violators (77).

The study’s limited budget prevented several enhancements that could improve the capabilities of the HOVER system. With several enhancements to the system (e.g., improved license plate recognition and “whitelist” license plate database), the HOVER system could be used to perform enforcement screening (77).

Significant enhancements to the system (e.g., high-quality video cameras, additional camera views, improved video signal transmission, improved license plate capture and recognition) could enable its use for HOV mailed citation programs, although enabling legislation does not currently exist in Texas. The research team recommended implementation of these enhancements and further testing (77).

The existing HOVER system met the original performance specifications in terms of its features and functions. Several changes and/or enhancements to the system could significantly improve its usability and its potential for use in HOV lane enforcement (77).

The performance of the system in darkness remains unclear. It is noted that while the system is reported to have the potential to be used for automatic enforcement, there are many

enhancements that were noted as being necessary to enable this potential to be further evaluated. No further testing has been undertaken since the 1997-98 tests (77).

Atlanta, Georgia

The Georgia Tech Research Institute has developed a prototype vehicle occupancy system that may help Georgia DOT to determine the number of persons in a moving vehicle. Although the prototype system was developed for freeway and HOV lane monitoring purposes, the accurate detection of vehicle occupancy is a key component of automated HOV enforcement systems. The prototype system uses digital infrared cameras and infrared strobe lighting to capture views of vehicle interiors, and it is capable of collecting vehicle images at the rate of two per second. A non-intrusive vehicle detection unit is used to trigger vehicle image capture, as well as collect vehicle volume and classification data (77).

Georgia Tech researchers have advised that no further work has been undertaken on this project since the proof of concept prototype was developed (77).

Minneapolis, Minnesota

In 1998, the Minnesota Department of Transportation carried out a study with the Department of Computer Science from the University of Minnesota to examine the prospect of using mid-infrared and near-infrared cameras to determine vehicle occupancy. The mid-infrared setup could not produce clear images at highway speeds. The near-infrared scheme worked much better, but the team could not develop the system to the level of accuracy and reliability needed for real-world automated occupancy detection. It was noted that side images were clearer than images taken through the front windshield, due to the different spectral composition of the two types of glass (77).

Ultimately, the study concluded that, “there is potential for developing an automatic vehicle occupant counting system using the near-infrared bandwidth. However, near-infrared cameras can only produce images when looking through glass not metal or heavy clothes.” It notes that “there may be a limit to the level of accuracy that can be obtained with this technology if an automatic vehicle occupant counting system would be required to count children in car seats or persons who are lying down in an automobile” (77).

Clearly, there would also be issues with this technology accurately counting passengers in panel

vans and similar types of vehicles (77).

Discussions with Mr. Kevin Schwartz of Minnesota Department of Transportation indicated that the Department has not undertaken further work on the project since the report above was published. The findings suggest that the technology may be useful for HOV monitoring for data collection purposes; however, it would probably not be suitable for automated enforcement (77).

Leeds, UK

A three year research project to develop an automated occupancy camera detection system for use in the enforcement of HOV lanes began in Leeds, U.K. in 2003. Funded by the U.K. Department of the Environment, Transport and the Regions, the project research partners are (77):

- *Photonics Consultancy (lead partner);*
- *University of Sussex;*
- *Laser Optical Engineering Limited;*
- *Golden River Traffic Limited; and*
- *Leeds City Council.*

The system was proposed to use infrared cameras and state-of-the-art high-speed image processing methods to count and recognize occupants inside moving vehicles from the roadside. Initial testing showed that the near-infrared part of the spectrum was not suited to the task, due to the absorptive qualities of most car windows at those wavelengths. Subsequent study focused on automating the task of searching for faces in pictures taken of front or side windows of a moving car. Some success was noted in that area of work. Meanwhile, infrared cameras were also tested, despite their very high cost. A 1.5 micron gap in the absorption of the heat-resistant layers on car windows was found, through which infrared cameras could “see”. Under bright sunlight the infrared approach could yield images in which human skin could readily be distinguished, but practical obstacles remain in creating an infrared system that would work under cloudy or dusk lighting conditions. Laser diodes would provide the infrared response but would add substantially to the cost (77).

Field testing brought the visual and infrared systems together; a combination of the two images yields an image of a face as a “darker blob” which contrasts with its surroundings and can be

recognized immediately by the specially-developed processing software. A working prototype of the system was intended to be demonstrated on the A647 HOV lane in Leeds in September 2004 (77).

4.2.3 Comments of Photo-HOV Occupancy Enforcement Technology

Over the years, a number of automated systems have been explored and improved for detecting vehicle occupancy. A primary focus of the research has been on systems that utilize roadside photography from outside the vehicle to detect the number of vehicle occupants. Despite numerous research efforts and pilot projects, none of the research to date has identified a system that is effective and reliable enough to be implemented as a primary HOV occupancy enforcement strategy due to the inherent difficulties.

It is concluded from a review of the material outlined above that (21,77):

- Automated HOV occupancy monitoring and enforcement would be beneficial, but a more reliable and accurate method is needed.
- While automated HOV enforcement from outside the vehicle (including infrared, near-infrared, video and digital photography) has potential, the roadside technology for HOV occupancy enforcement as to resolve inherent difficulties for real-time enforcement for all vehicle types, in all lighting and weather conditions, and for both freeway and arterial applications.

5. AUTOMATED ENFORCEMENT SURVEYS AND ANALYSES

5.1 Purpose and Overview

The primary objective of public polls is to assess the level of public support on using automated enforcement camera for red-light running and managed-lane violations in Nevada. Accident analyses are to reveal the seriousness and severity of traffic crashes related to red light running in Nevada. Agency survey is intended to gain experience and acquire lessons learned using automated enforcement systems. HOV violation rate survey is to provide a general indication of the degree of public understanding and support for the facility.

Public opinions on automated red-light running enforcement and photo-HOV occupancy enforcement were collected and analyzed by both on-site and on-line surveys of adult Nevada residents. Traffic crashes related to red-light running were extracted and explored from the traffic accident data provided by the Nevada Department of Transportation (NDOT). Agency survey was conducted by on-line survey of agencies throughout the country. HOV violation rate was surveyed by stationing personnel to obtain violation counts and by reviewing videotapes to observe the total traffic volumes.

The survey results provided important information regarding public support for enabling legislation to allow automated enforcement in Nevada. The surveys sought to gain an understanding of public support for automated enforcement legislation and use of such equipment at specific intersections and in HOV lanes.

5.2 Public Opinions about Automated Enforcement

5.2.1 Public Polls

On-site and on-line surveys for collecting public opinions were conducted in Reno, Sparks, Carson City, Las Vegas, North Las Vegas, and Henderson. Before conducting the on-site and on-line surveys, the research team developed a list of questions that should be critical for reflecting public attitudes toward using automated enforcement in Nevada's major metropolitan areas. An important component of the survey questionnaire is the reliance on respondent-friendly wording of questions to ensure that technical terms can be clearly conveyed to the general public. Two

separate survey forms were developed for the Reno-Sparks area and the Las Vegas area. The questionnaire for the Reno-Sparks area only includes questions related to red-light running, while the questionnaire for the Las Vegas area includes questions related to both red-light running enforcement and photo-HOV occupancy enforcement. Survey questionnaires were approved by the research panel before formally conducting the surveys. The survey forms are included in Appendix 3.

The on-site and on-line surveys were conducted between December 2008 and January 2009. The on-site survey locations included some densely populated public areas, such as shopping malls, supermarkets, Department of Motor Vehicles (DMV) offices, and public libraries. An on-line survey site was created with the same questionnaire posted. Agencies with major employment were contacted to inform the availability of the on-line survey. These agencies include DMVs, Police Departments, NDOT, many corporations, and faculty and students at UNR. The collected surveys were coded into a database for analyses. Each survey questionnaire was carefully examined for its validity before entering the database.

The required sample size was based on population distribution and experiences of similar studies conducted in other states. A total of 1,833 valid survey forms were collected, among which 1,780 were obtained through the on-site interviews and 53 were from on-line submissions. The sampling rate is about 0.12% of the local population distribution. This rate is significantly higher than similar surveys conducted before in other states. For example, a red-light-running camera survey conducted in Iowa had a sampling rate of 0.05%, and a similar survey conducted in Virginia had a sampling rate of 0.07%. The margin of error of this public opinion survey is about 2.3% based on a 95-percent confidence level (89,90), i.e., if similar surveys were conducted 100 times, 95% of the survey results would be the same as this survey plus and minus the margin of error of 2.3%. Therefore, the number of samples received in this survey is sufficient to adequately reflect the opinions of the general public in the aforementioned metropolitan areas. Table 5.1 shows the sample rate of public surveys in Nevada compared with those done in Iowa and Virginia. Table 5.2 reflects the sample distribution and sample rate in the surveyed major cities in Nevada.

Table 5.1 Sample Rate Comparison of Public Polls

Survey	Iowa	Virginia	Nevada
Population	2,926,324	7,567,500	1,473,600
Valid returns (two methods)	503+1,008=1,511	44+565=609	53+1,780=1,833
Sample rate	0.05 %	0.07 %	0.12 %

Note. 1. The population in Nevada only includes the surveyed cities, and it was based on the 2007 census data; 2. Sample rate refers to the ratio between the population and the number of valid returns; 3. There are two methods adopted for public polls, such as mail survey and telephone interview in Iowa, Email and on-site surveys in Virginia, and on-line and on-site surveys in Nevada.

Table 5.2 Survey Distribution and Sample Rate

City	Reno	Sparks	Carson City	Las Vegas	North Las Vegas	Henderson	Total
Population	211,700	90,000	56,000	603,100	243,000	269,800	1,473,600
Valid returns	369	153	55	347	682	174	1,780
Sample rate	0.17 %	0.17 %	0.10 %	0.06 %	0.28 %	0.06 %	0.12 %

5.2.2 Respondents Demographics

On-site survey

Surveys obtained from the on-site interviews account for 97% of the total surveys. Figures 5.1 through 5.4 show the various demographic characteristics from the on-site survey. Figure 5.1 shows, of the 1,780 completed respondents, 49% on average were male and 51% were female, a near even split. Figure 5.2 shows, of the 1,780 residents surveyed, 85% on average reported that they possessed valid Nevada driver's licenses and only 15% respondents reported that they did not currently have driver's licenses. Figure 5.3 indicates that the respondents consisted of a wide range of age groups. The majority of the respondents were between 20 and 39 (approximately 46%). Figure 5.4 shows that 55% of the respondents on average reported annual incomes of at least \$25,000.

Note: In this section, the average value in the tables and figures refers to as the weighted average related to the sample rates in surveyed cities, which shows an overall statistic at the state level.

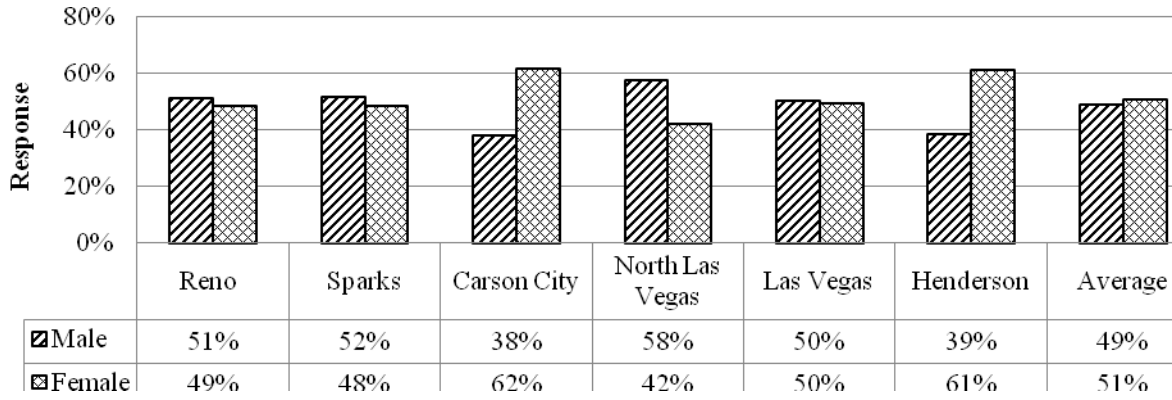


Figure 5.1 Distribution of Gender in the On-site Surveys

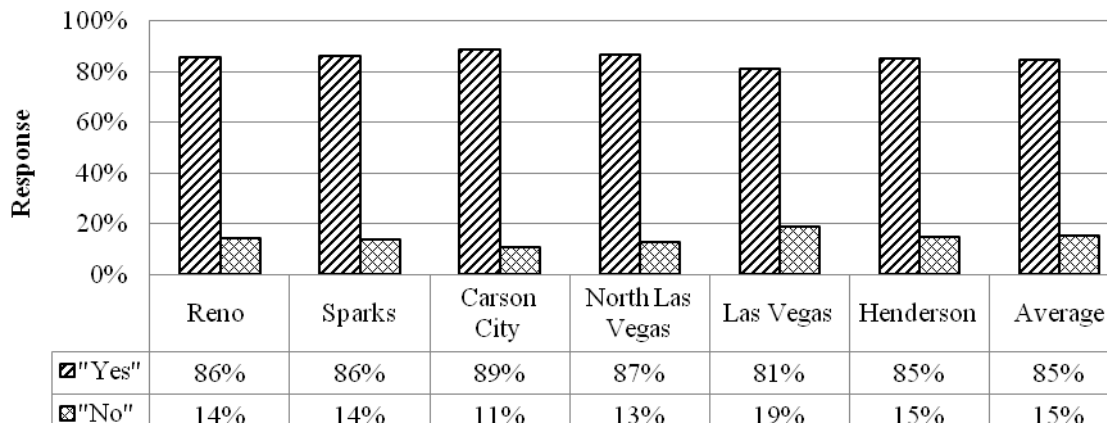


Figure 5.2 Distribution of Driver's License Holding in the On-site Surveys

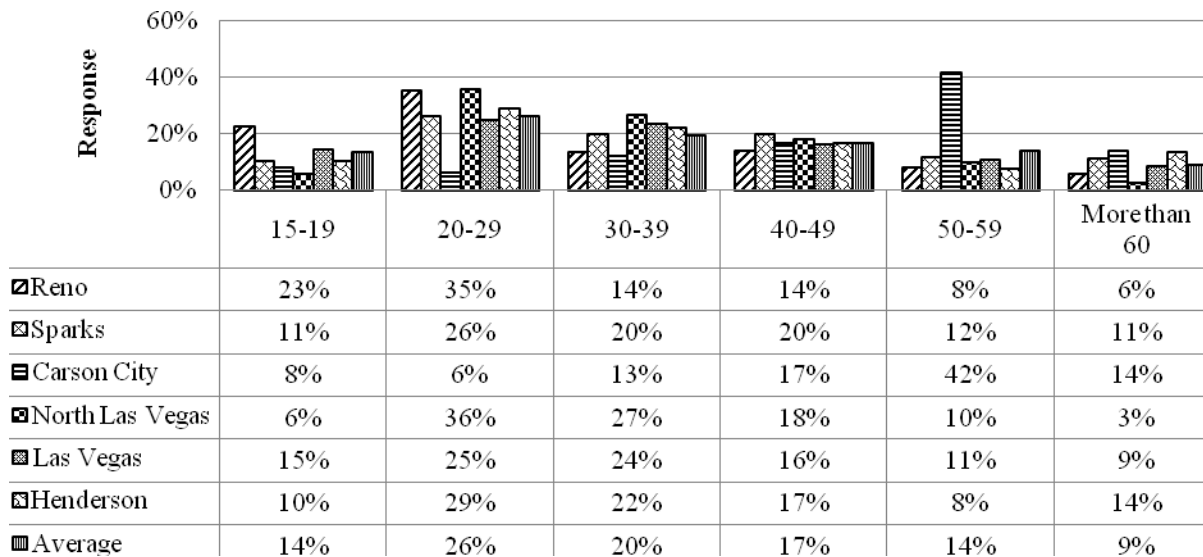


Figure 5.3 Distribution of Age in the On-site Surveys

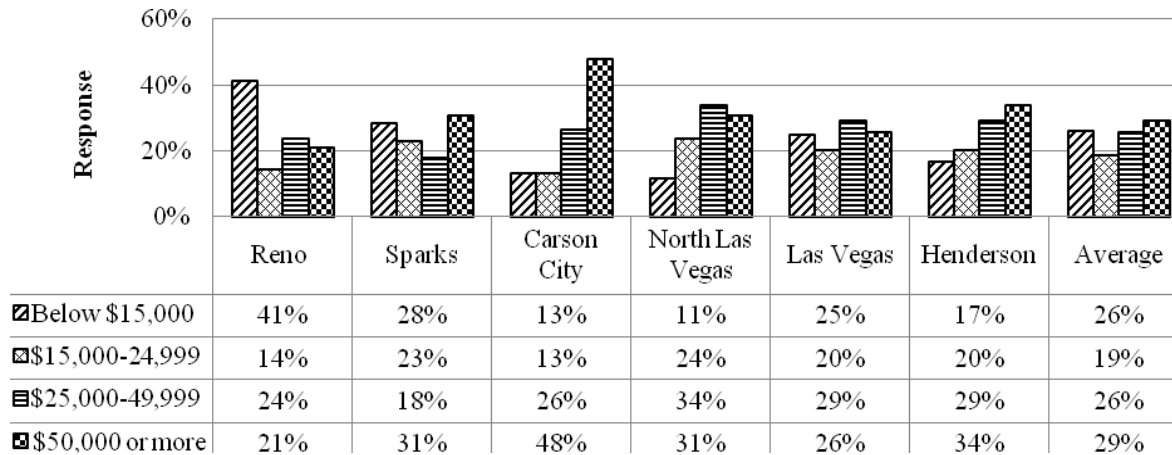


Figure 5.4 Distribution of Income in the On-site Surveys

On-line Survey

By the end of January, 2009, only a total of 53 responses were received, among which only four were from the Las Vegas area. The number of the on-line surveys related to photo-HOV occupancy enforcement was too small to be represented. The demographic characteristics of the on-line surveys are shown in Figures 5.5 through 5.8. Figure 5.5 shows, of the 53 completed respondents, more men (66%) than women (25%) were involved thus males were over-represented in the on-line surveys. Ninety-six percent of the respondents reported that they possessed valid Nevada driver’s licenses. More than half of the respondents were over 40 years old. Nearly 64% of respondents reported annual incomes of at least \$50,000.

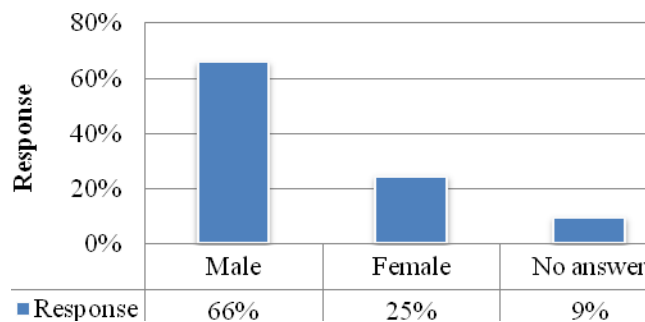


Figure 5.5 Distribution of Gender in the On-line Surveys

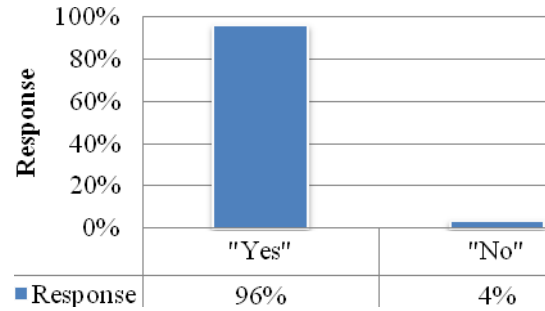


Figure 5.6 Distribution of Driver’s License in the On-line Surveys

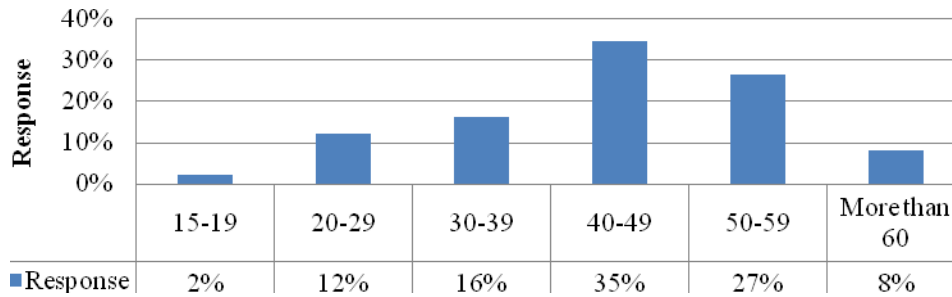


Figure 5.7 Distribution of Age in the On-line Surveys

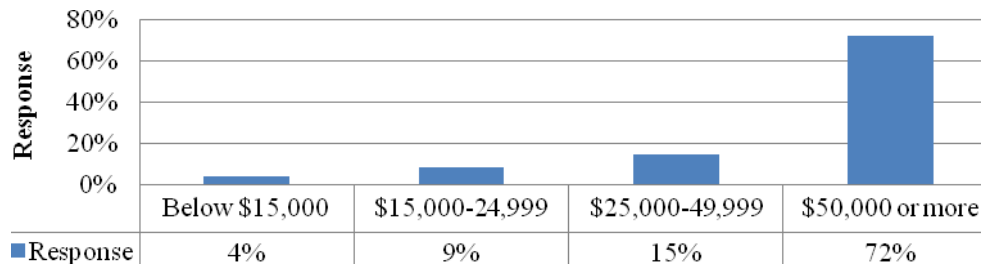


Figure 5.8 Distribution of Income in the On-line Surveys

5.2.3 Public Opinion Survey Results

Preliminary results and findings from the public opinion survey are provided next in two categories: red-light running and HOV occupancy enforcement. A brief summary of the general findings is given first followed by detailed analyses of each survey question and response.

Red-light running

The general findings from red-light running enforcement survey are summarized as follows:

- Most of 1,833 respondents (approximately 63%) indicated that they would support the

automated enforcement cameras in Nevada, while a smaller percentage of the respondents (21%) would oppose it. A higher percentage of older citizens indicate support for automated enforcement, however, no significant difference was found among different income groups and among men and women.

- A majority (approximately 58%) of the respondents reported that they were in favor of the legislation to permit giving traffic tickets for drivers running red lights based on video evidence, while a quarter of the respondents (24%) would be against such legislation. Older Nevadans were more likely to express approval for such legislation. Additionally, support was nearly even among men and women and within income groups.
- Most respondents (approximately 82%) reported that red-light running is a serious and dangerous behavior in the community in which they live or work.
- Most respondents (approximately 60%) reported that they observe on average 1-5 times per week for drivers running red lights.
- Nearly half (approximately 54%) of the respondents regarded “driving too fast to stop” as a main reason of drivers running red lights.
- Approximately half (approximately 50%) of the respondents were aware of automated enforcement programs in other communities before they took this survey.
- Sixty-seven percent of the respondents on average supported the opinion that the use of red-light cameras could provide a safer driving experience.
- Eight percent of the respondents on average reported that they have received tickets for red-light running during the past year, while 92% of the respondents responded “no”.

The detailed analysis of each question related to red-light running enforcement is presented next.

Q: How serious do you believe the problem of red-light running is in your community?

The survey results show that most respondents (approximately 82%) view red-light running as a serious safety problem in their communities (see Figures 5.9 and 5.10). The likelihood of reporting red-light running seriousness was the same for men and women and not associated with age and income groups.

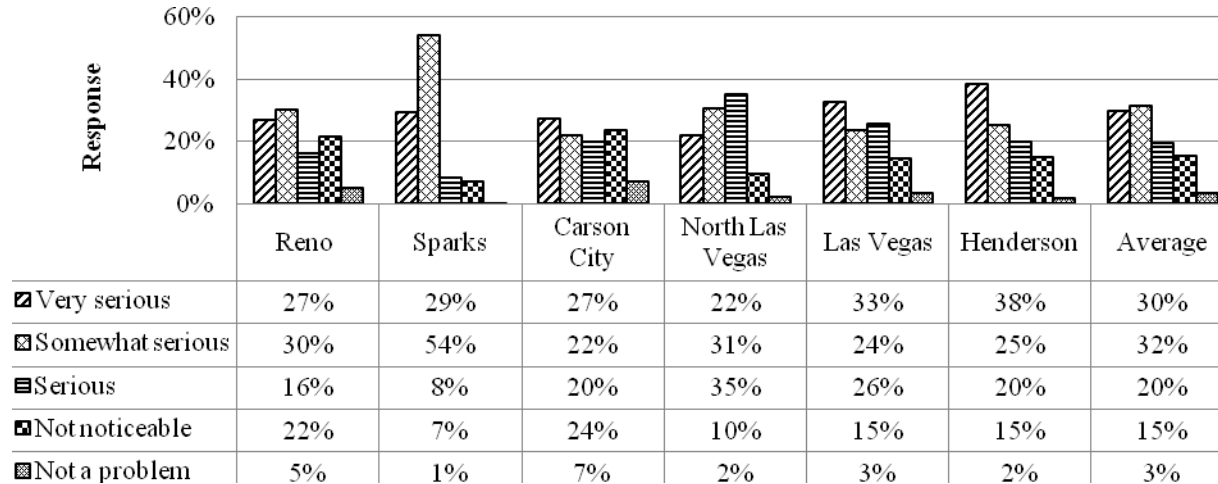


Figure 5.9 Seriousness of Red-Light Running by the On-site Survey

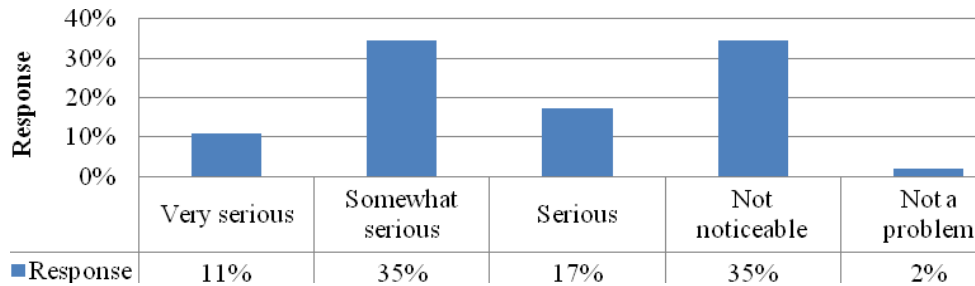


Figure 5.10 Seriousness of Red-Light Running by the On-line Survey

Q: (1) How many times (on average) per week do you observe drivers running red lights? (2) How many of these result in accidents?

Most respondents (approximately 60%) reported that they observe on average 1 to 5 times per week for drivers running red lights, as shown in Figures 5.11 and 5.12. Nearly 40% of all respondents reported that they have observed traffic accidents caused by drivers running red lights.

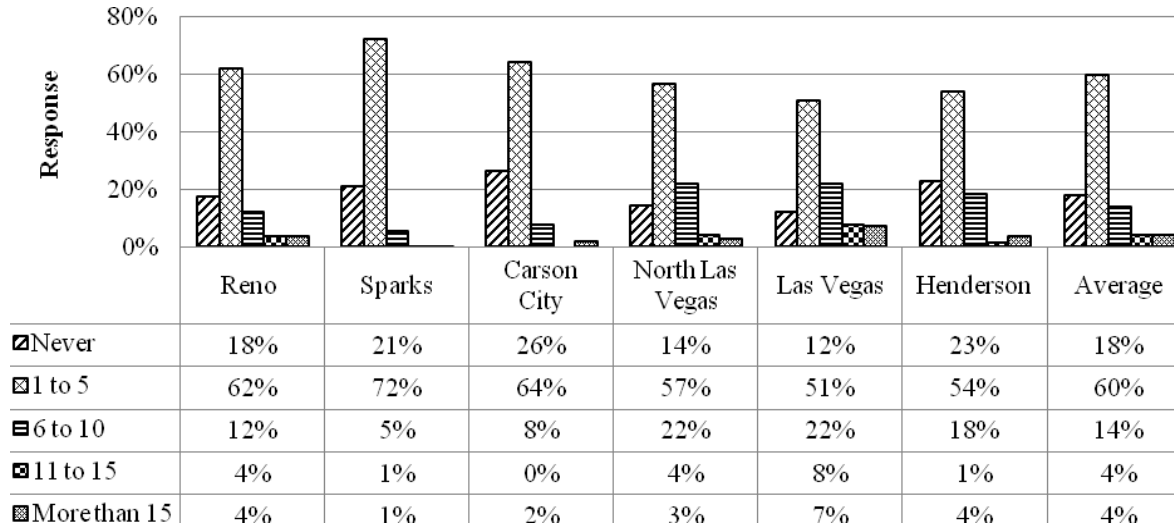


Figure 5.11 Times Observed for Drivers Running Red Lights by the On-site Survey

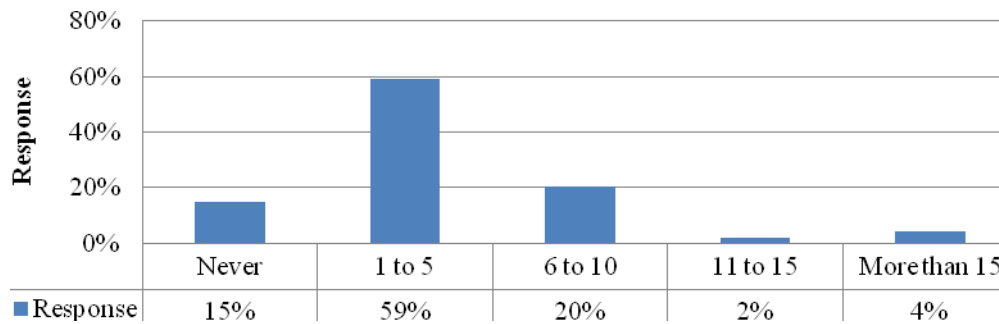


Figure 5.12 Times Observed for Drivers Running Red Lights by the On-line Survey

Q: In your opinion, why do drivers run red lights?

The survey results indicate that nearly half (approximately 54%) of the respondents regarded “driving too fast to stop” as a main reason for drivers running red lights and 39% of the respondents agreed “Conscious decision not to stop” as a main reason. About 31% of the respondents also considered “Yellow interval is too short” as a main reason, as shown in Figures 5.13 and 5.14.

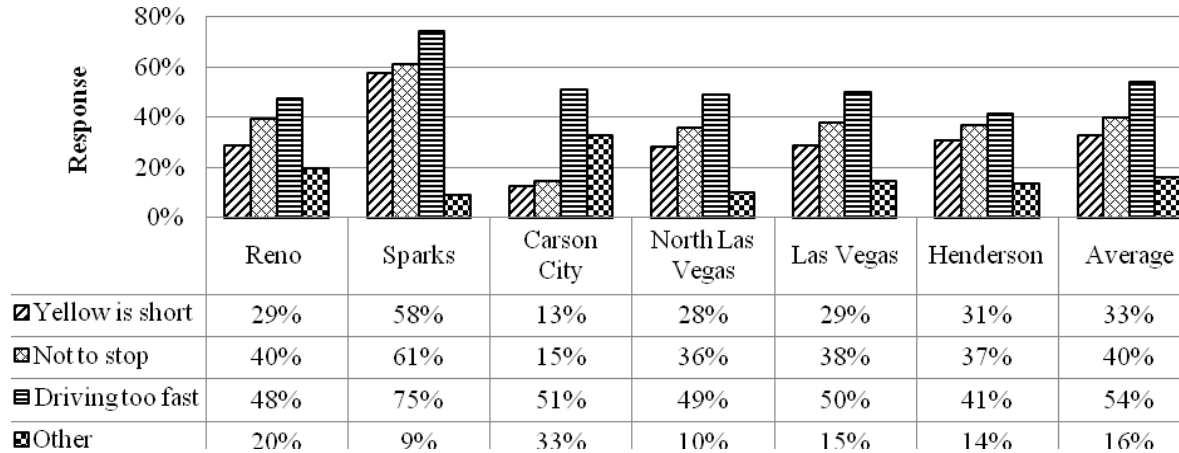


Figure 5.13 Reasons for Drivers Running Red Lights by the On-site Survey

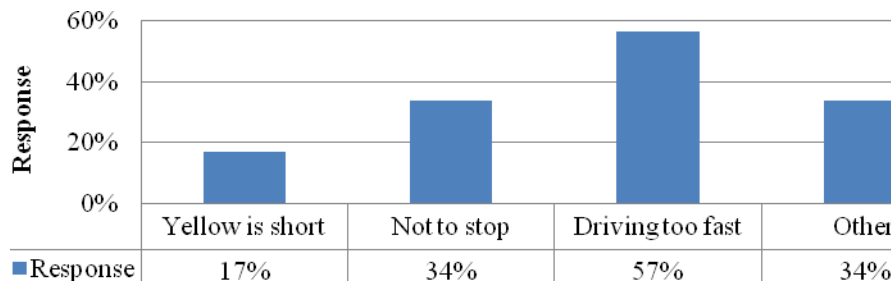


Figure 5.14 Reasons for Drivers Running Red Lights by the On-line Survey

Q: Were you aware of automated enforcement programs in other communities before you took this survey?

One half (approximately 50%) of the respondents indicated that they were aware of automated enforcement programs (see Figures 5.15 and 5.16).

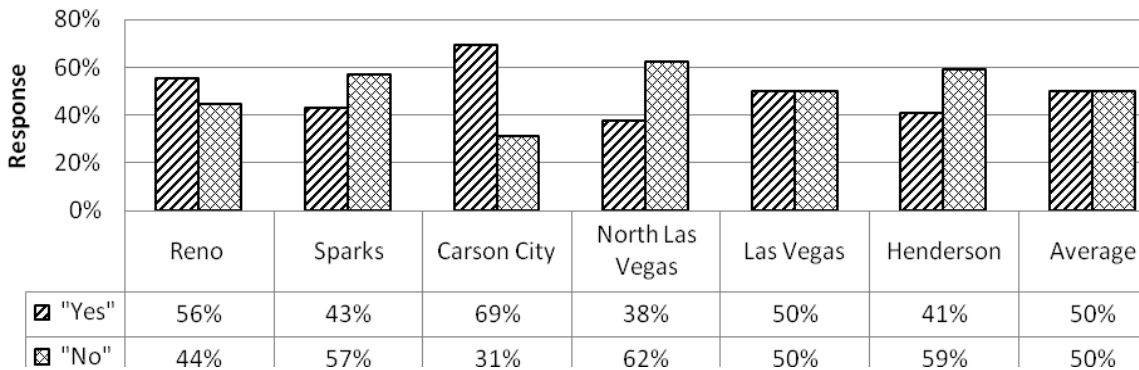


Figure 5.15 Awareness of Automated Enforcement Programs by the On-site Survey

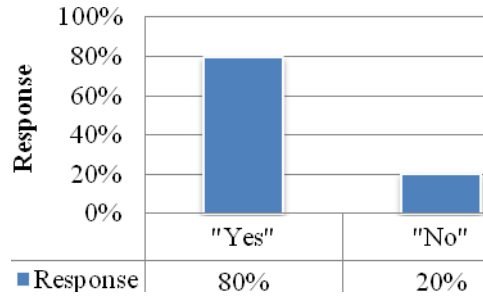


Figure 5.16 Awareness of Automated Enforcement Programs by the On-line Survey

Q: Do you support or oppose using red-light running cameras to improve traffic safety in your community? If you support, please indicate why you support the automated enforcement on red-light running. If you oppose, please indicate why you oppose the automated enforcement on red-light running.

Most respondents (approximately 63%) indicated that they would support the automated enforcement cameras, while a smaller percentage of the respondents (21%) would oppose it. Sixteen percent of the respondents reported that they were unsure whether they supported such use of video cameras, as shown in Figures 5.17 and 5.18.

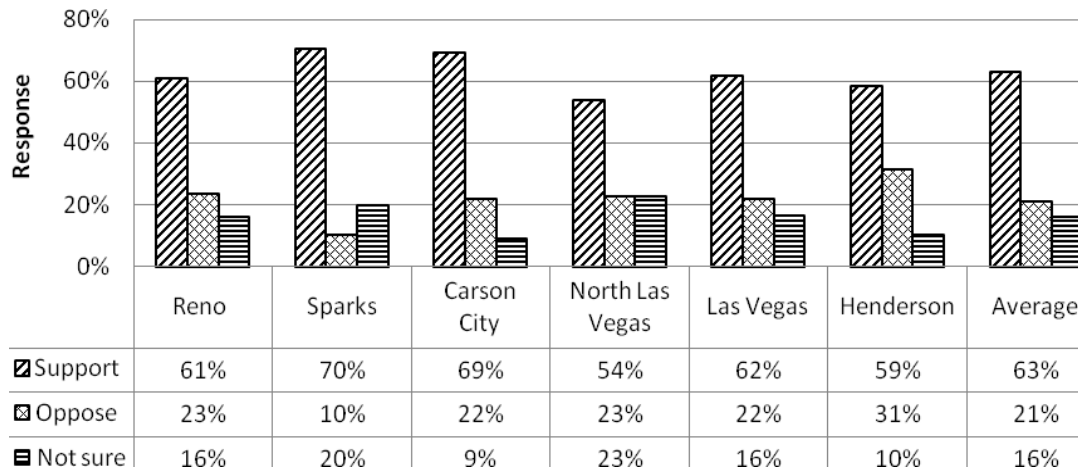


Figure 5.17 Opinions of Using Red-Light Running Cameras by the On-site Survey

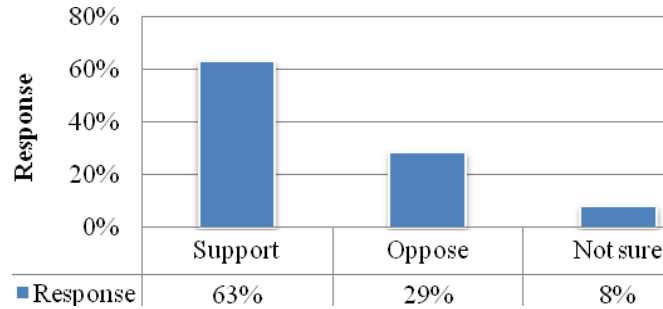


Figure 5.18 Opinions of Using Red-Light Running Cameras by the On-line Survey

As to the reasons of supporting red-light running cameras, an average of fifty-one percent of the respondents agreed that automated enforcement could reduce traffic crashes. Thirty-two percent of the respondents regarded “reduce violations” as a main reason while 31% of the respondents considered “reduce speeds” as a main reason, as indicated in Figures 5.19 and 5.20.

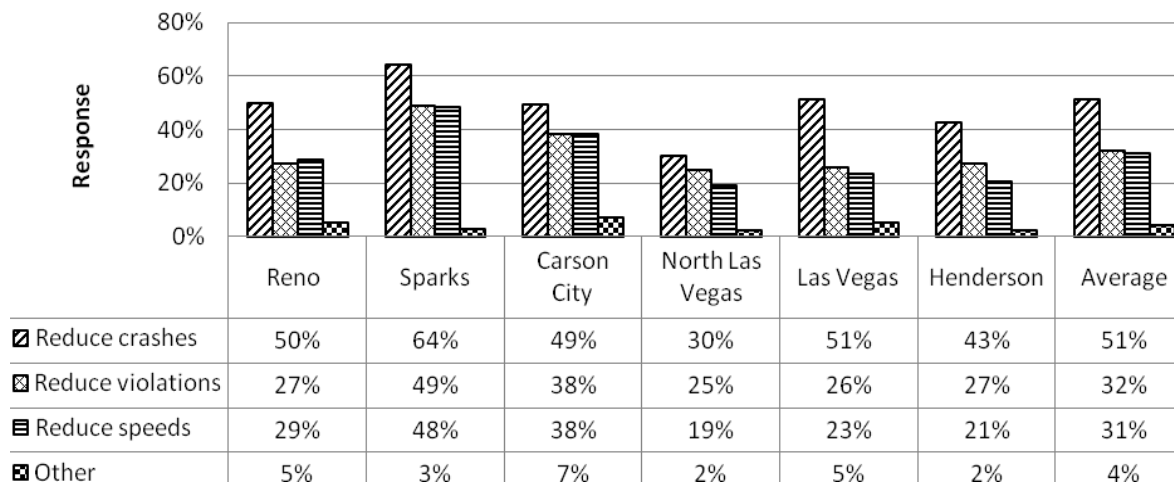


Figure 5.19 Reasons of Supporting Red-Light Running Cameras by the On-site Survey

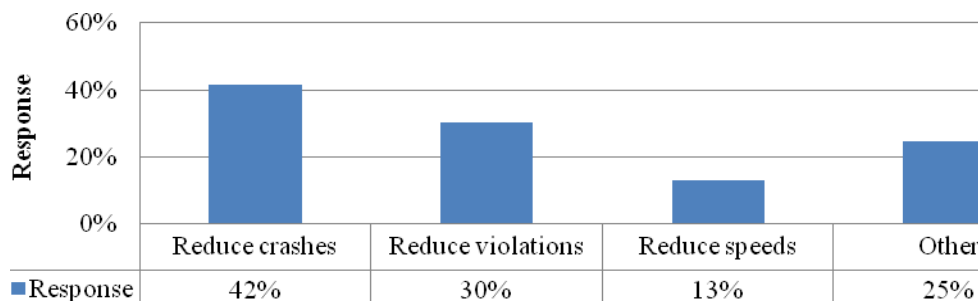


Figure 5.20 Reasons of Supporting Red-Light Running Cameras by the On-line Survey

With regard to the reasons of opposing red-light running cameras, twelve percent of the respondents on average regarded “privacy concerns” as a main reason. Eight percent of the respondents regarded “not reliable” as a main reason and 11% of the respondents considered “unfair practice” as a main reason, as indicated in Figures 5.21 and 5.22.

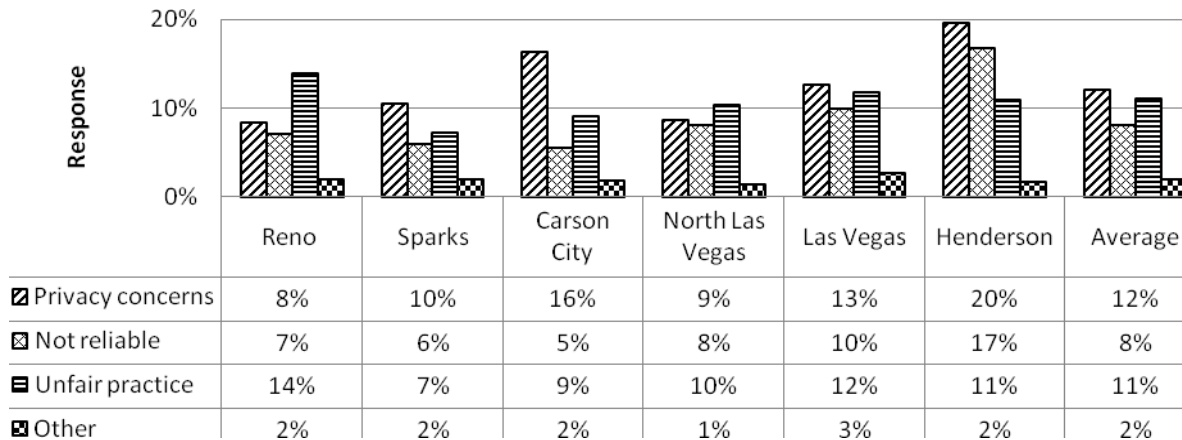


Figure 5.21 Reasons of Opposing Red-Light Running Cameras by the On-site Survey

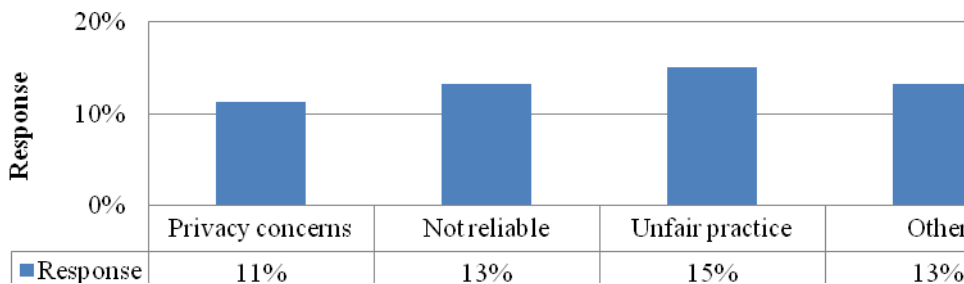


Figure 5.22 Reasons of Opposing Red-Light Running Cameras by the On-line Survey

Support of using red-light running cameras was greater among those who reported that running red light is a serious and dangerous behavior (approximately 90%) than among those who reported it is not a serious and dangerous behavior (10%) (see Figure 5.23). The support was generally higher among older Nevadans (see Figure 5.24). The support was nearly even within income groups (see Figure 5.25) and among men and women (see Figure 5.26).

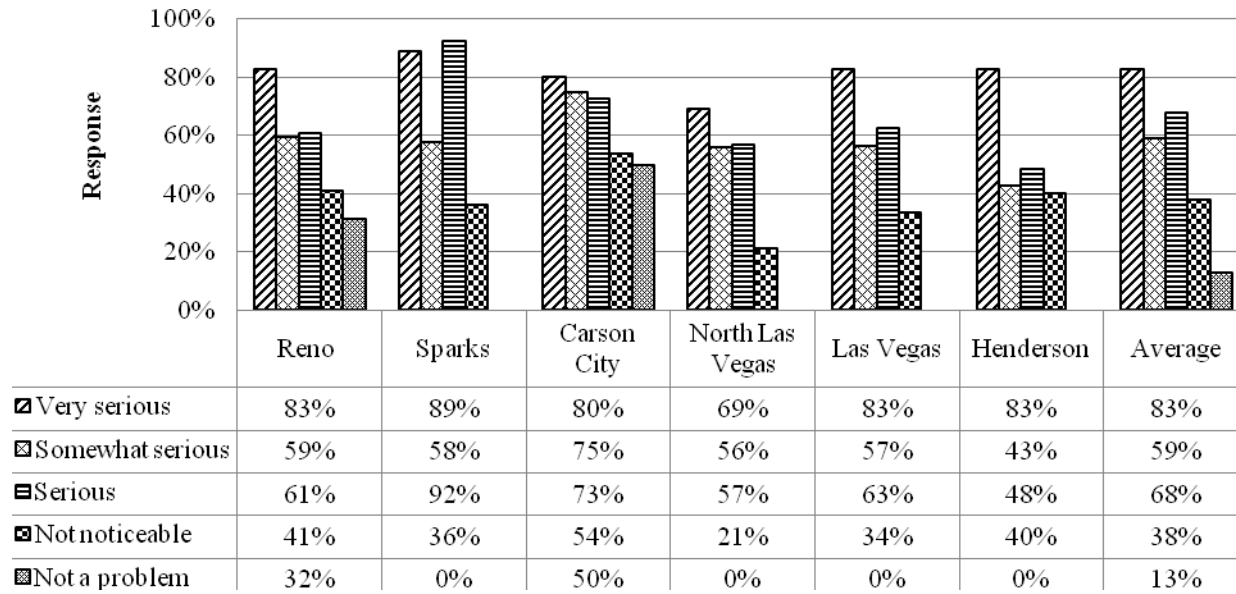


Figure 5.23 Support of Using Red-Light Running Cameras within Serious Groups

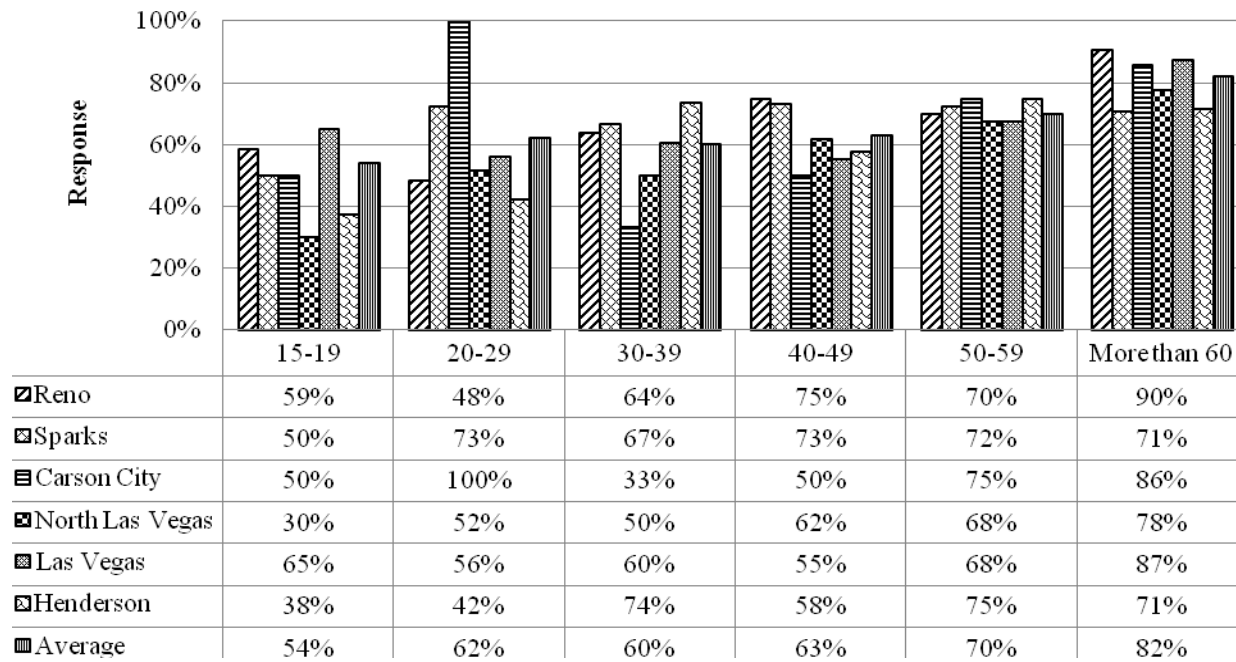


Figure 5.24 Support of Using Red-Light Running Cameras within Age Groups

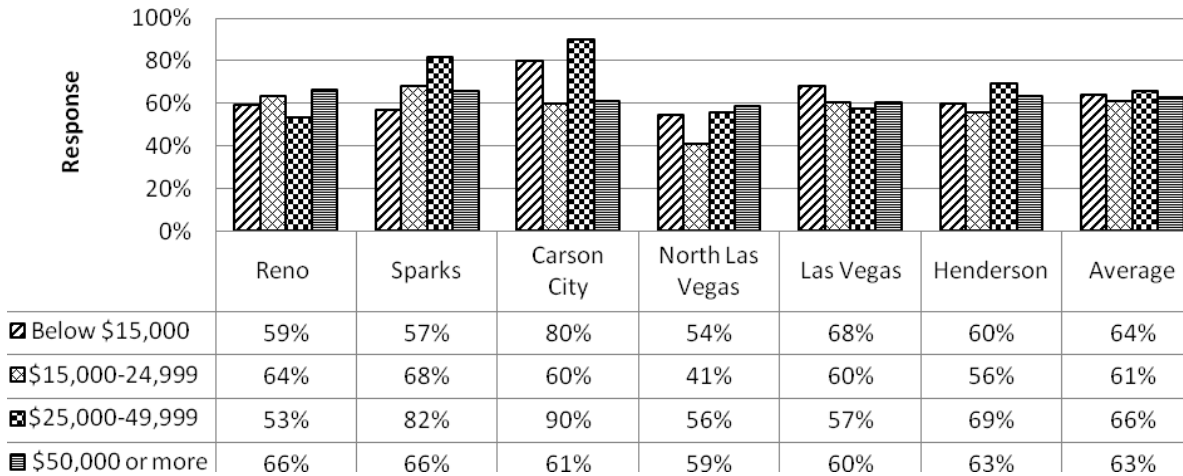


Figure 5.25 Support of Using Red-Light Running Cameras within Income Groups

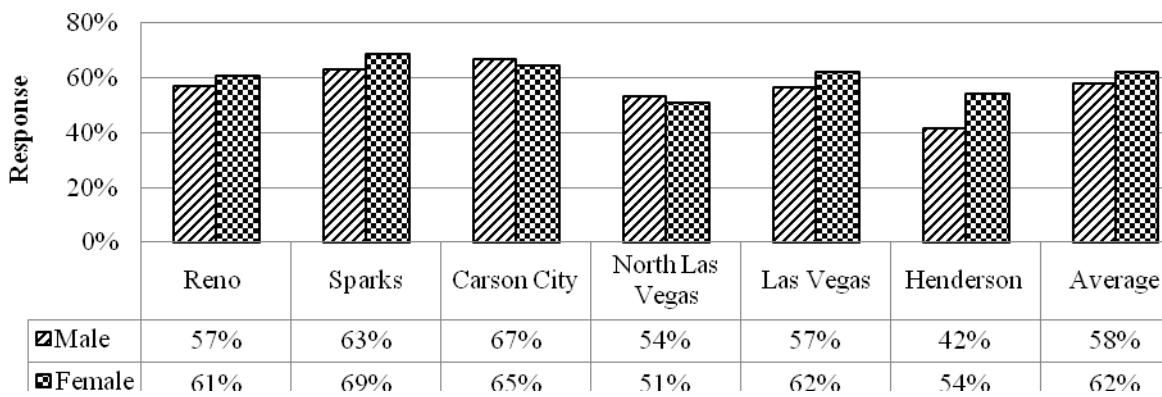


Figure 5.26 Support of Using Red-Light Running Cameras among Men and Women

Q: Do you support initiatives such as using red-light cameras to provide for a safer driving experience?

Nearly 67% of the respondents on average regarded that automated enforcement could help improve safety, while 18% of the respondents did not think so and 15% of the respondents were not sure, as indicated in Figures 5.27 and 5.28.

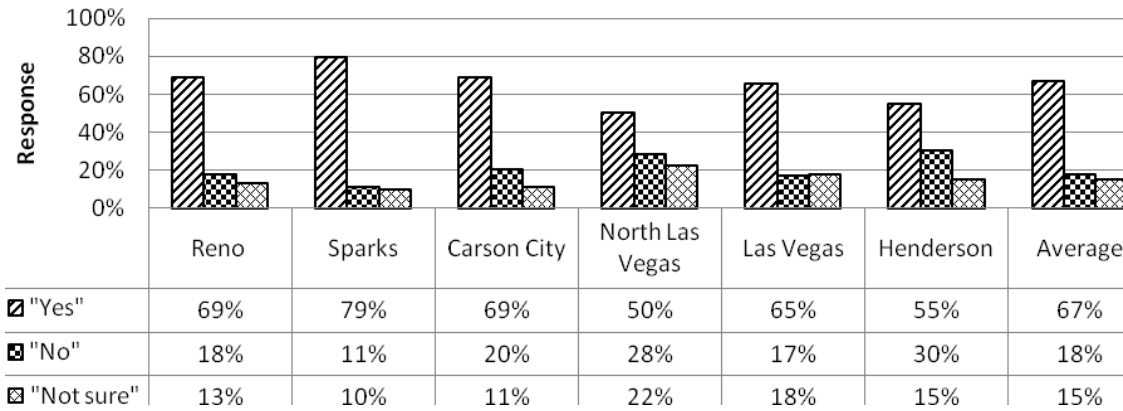


Figure 5.27 Support of Automated Enforcement Improving Safety by the On-site Survey

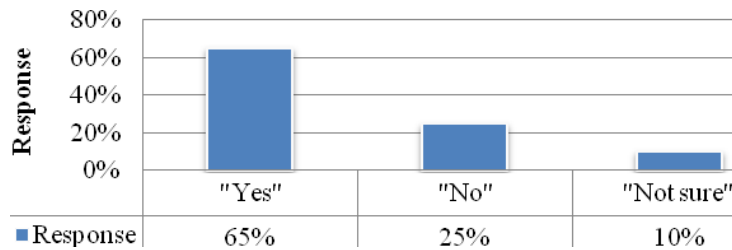


Figure 5.28 Support of Automated Enforcement Improving Safety by the On-line Survey

Q: Would you support legislation permitting the issuance of citations based on automated red-light running enforcement?

Overall, a majority (approximately 58%) of the respondents reported that they would support legislation for drivers running red lights, while about one-quarter of the respondents (24%) would be against such legislation and 18% of the respondents were unsure for support such legislation (see Figures 5.29 and 5.30).

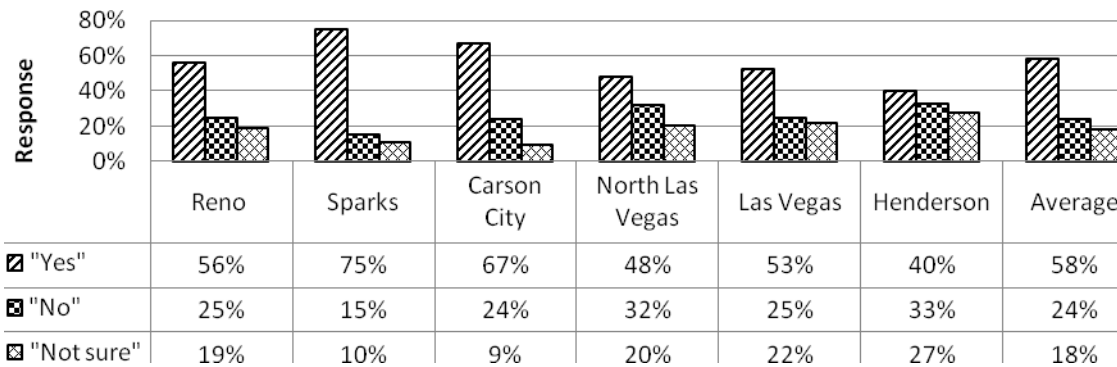


Figure 5.29 Opinions of Support Legislation by the On-site Survey

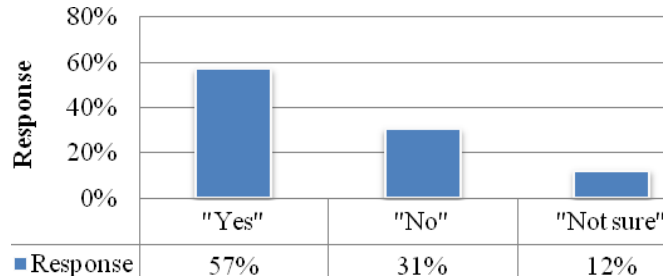


Figure 5.30 Opinions of Support Legislation by the On-line Survey

Based on the survey results, support was greater among older respondents (see Figure 5.31). Also, support was greater among those who reported that running red light is a serious and dangerous behavior (approximately 59%) than among those who reported it is not a serious and dangerous behavior (28%) (see Figure 5.32). Support was greater among those who did than those who did not support using red-light running cameras (see Figure 5.33). Support was nearly even among men and women (see Figure 5.34) and within income groups (see Figure 5.35).

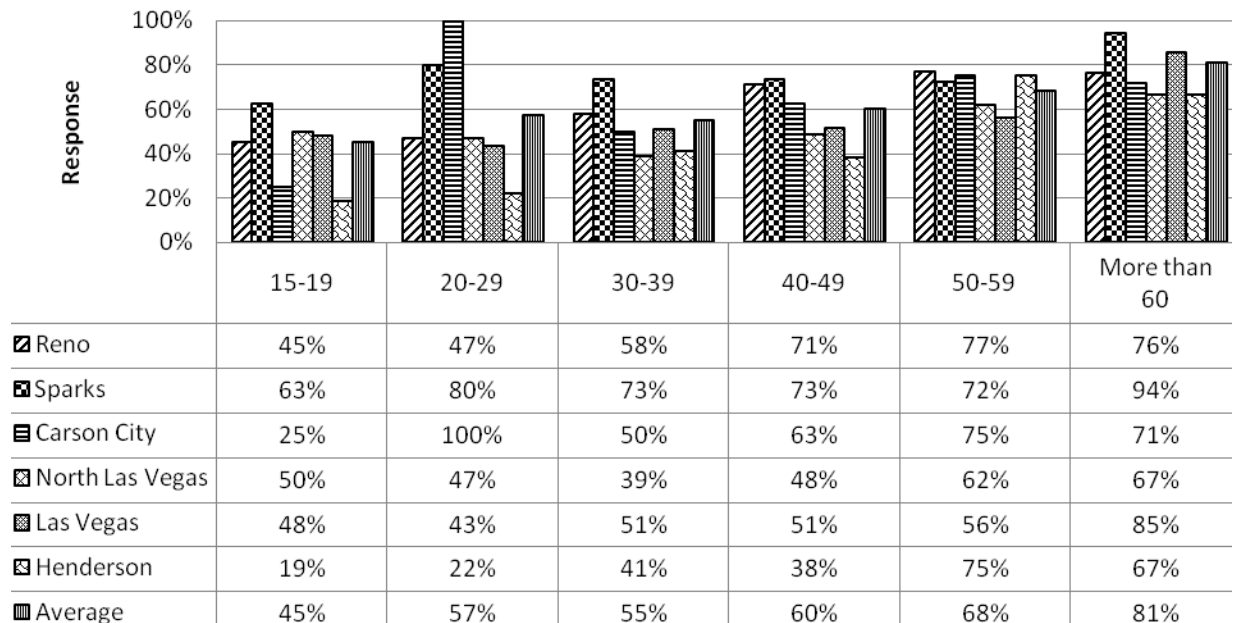


Figure 5.31 Support Legislation within Age Groups

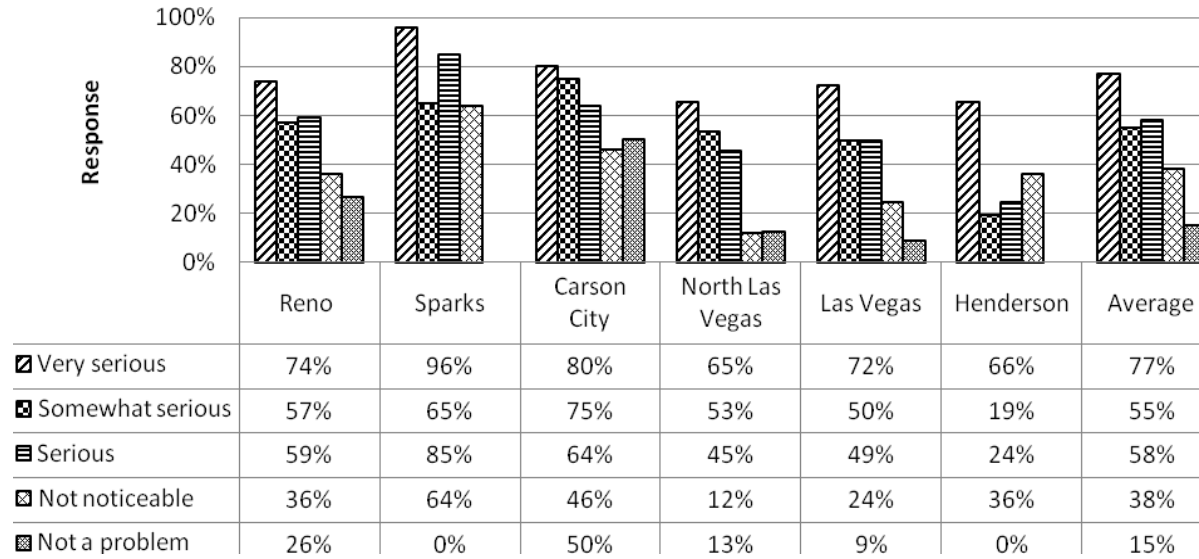


Figure 5.32 Support Legislation within Serious Groups

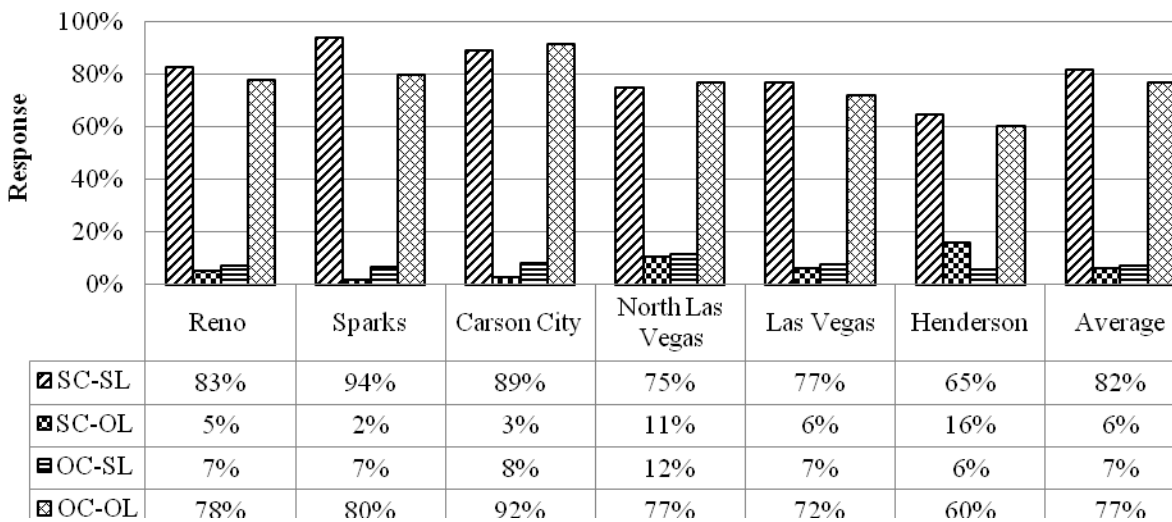


Figure 5.33 Support Legislation within Support Red-Light Running Cameras

- Note: 1. SC denotes "support camera";
 2. SL denotes "support legislation";
 3. OC denotes "oppose camera";
 4. OL denotes "oppose legislation".

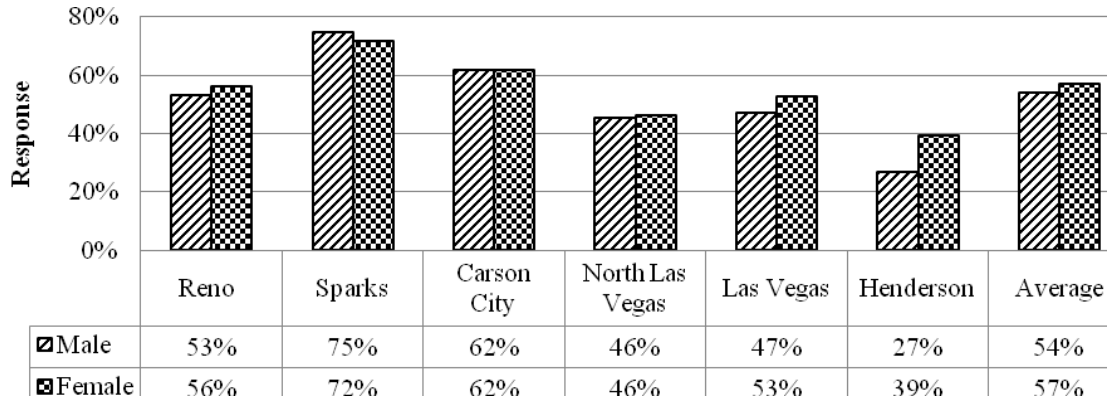


Figure 5.34 Support Legislation among Men and Women

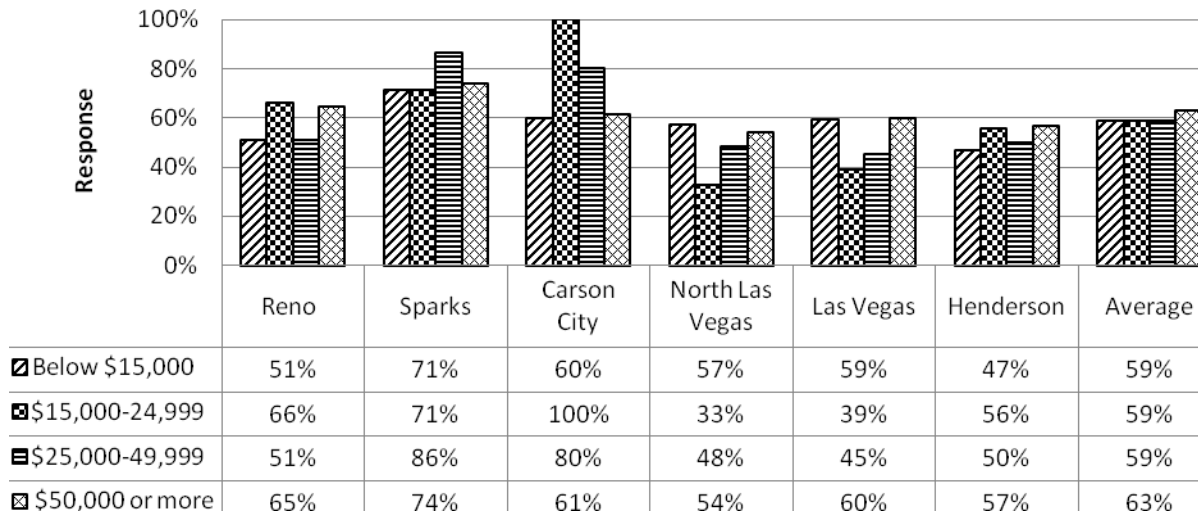


Figure 5.35 Support Legislation within Income Groups

Q: Have you received a ticket for running a red light during the past year?

Nearly 8% of the respondents on average reported that they had received tickets for running red lights, while 92% of the respondents responded “no” (see Figure 5.36). In addition, the on-line survey showed that no respondents had received tickets for running red lights.

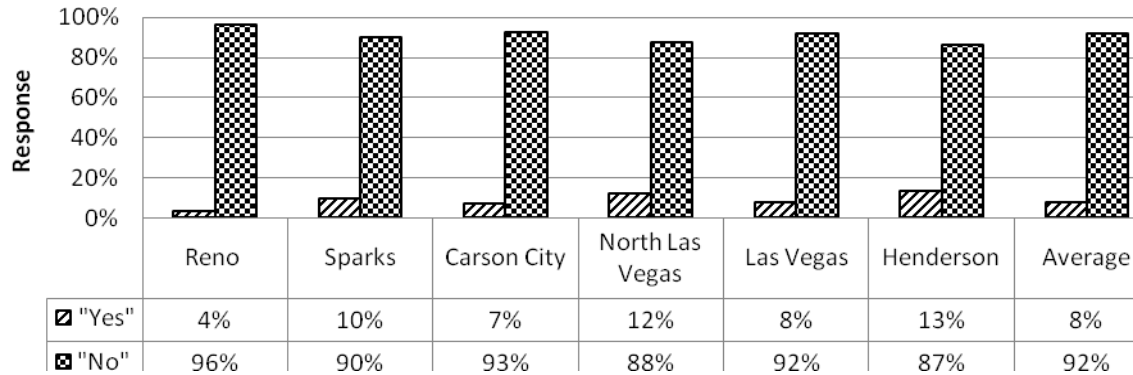


Figure 5.36 Experience of Receiving Tickets by the On-site Survey

Photo-HOV occupancy enforcement

The general findings from the photo-HOV occupancy enforcement are summarized as follows:

- Forty-three percent of 1,163 respondents on average indicated that they would support the photo-HOV occupancy enforcement, while 28% of the respondents would oppose it. Support was higher among older Nevadans and among those who reported annual incomes of below \$15,000 (47%) and at least \$50,000 (45%). Support was nearly even among women (37%) and men (40%).
- The number of respondents who would support or be against such legislation for HOV lane occupancy enforcement is almost even, with 40% support and 35% being against on average. Support was greater among older respondents and among those who reported annual incomes of below \$15,000 (44%) and at least \$50,000 (46%). Support was almost equivalent among women (35%) and men (36%).
- Most respondents (approximately 58%) reported that vehicle occupancy violation is a serious problem in HOV lanes.
- Forty-three percent of the respondents reported that they observe on average 1 to 5 times per day for vehicles violating occupancy requirement and 43% of the respondents responded “never”.
- Two percent of the respondents on average indicated that they have received tickets for violating vehicle occupancy requirement in HOV lanes during the past year, while 98% of the respondents responded “no”.

The detailed analysis of each question related to photo-HOV occupancy enforcement is presented next.

Q: How serious do you believe the problem of violating vehicle occupancy requirements is in HOV lanes?

Most respondents (approximately 58%) reported that vehicle occupancy requirement violation is a serious problem in HOV lanes, while 34% of the respondents responded “not noticeable” and 8% of the respondents responded “not a problem” (see Figure 5.37). The likelihood of reporting vehicle occupancy requirement violation seriousness was the same for men and women and not associated with age and income groups.

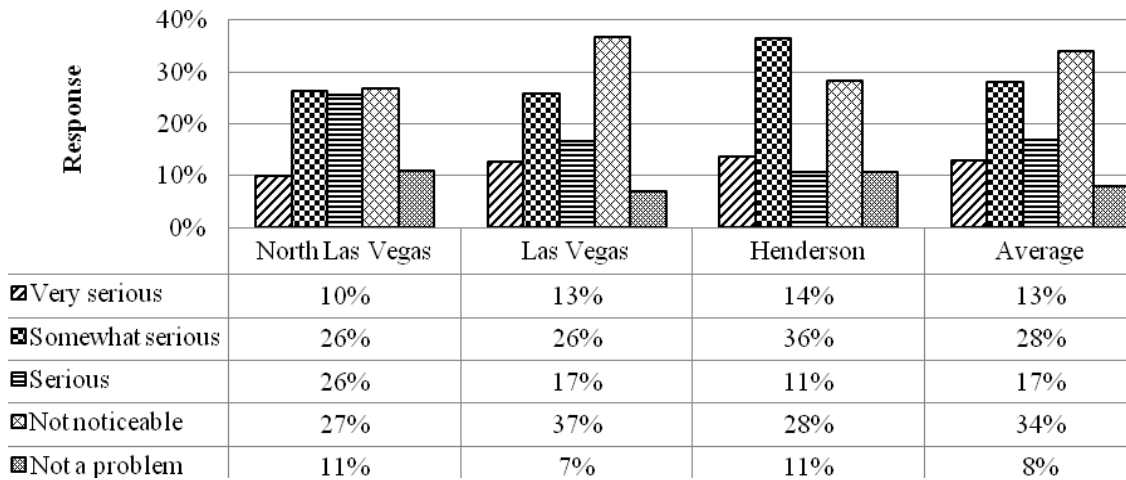


Figure 5.37 Seriousness of Violating Vehicle Occupancy Requirements

Q: How many times (on average) per day do you observe vehicles violating occupancy requirements in HOV lanes?

Most respondents (approximately 43%) reported that they observe on average 1 to 5 times per day for vehicles violating occupancy requirement, while 43% of the respondents responded “never” (see Figure 5.38).

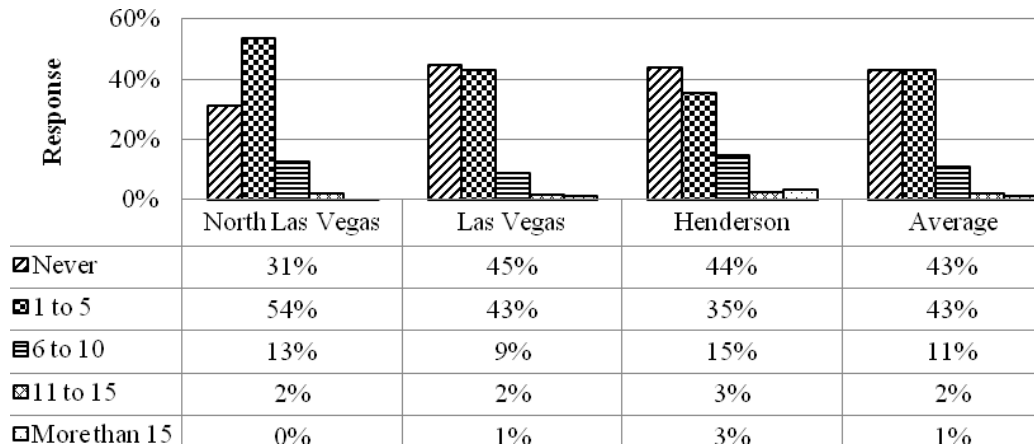


Figure 5.38 Times Observed for Vehicles Violating Occupancy Requirements

Q: Do you support or oppose using video cameras to reduce vehicle occupancy requirement violations in HOV lanes? If you support, please indicate why you support the automated enforcement on violating vehicle occupancy requirements. If you oppose, please indicate why you oppose the automated enforcement on violating vehicle occupancy requirements.

Overall, most respondents (approximately 43%) indicated that they would support the photo-HOV occupancy enforcement, while 28% of the respondents would oppose it and 29% of the respondents were unsure about supporting video cameras (see Figure 5.39).

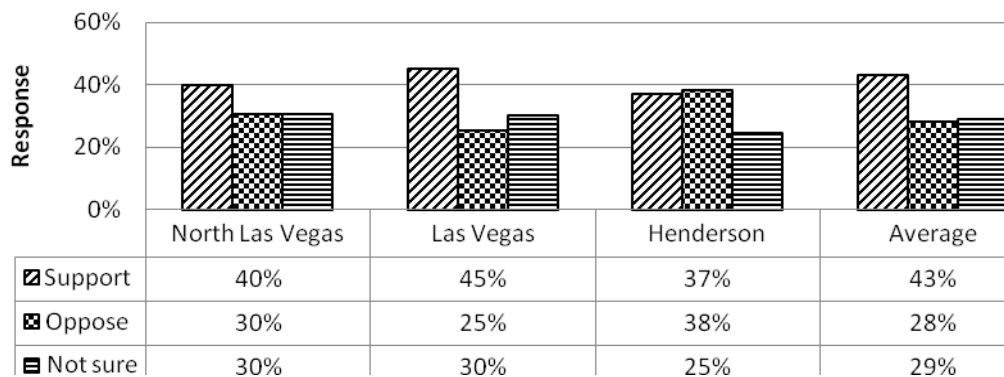


Figure 5.39 Opinions for Using Video Cameras in HOV Lanes

With regard to the reasons of supporting the automated enforcement, 35% of the respondents on average thought that photo-HOV occupancy enforcement could enhance HOV priority, while 36% of the respondents regarded “reduce violations” as a main reason and 28% of the respondents considered “increase efficiency” as a main reason (see Figure 5.40).

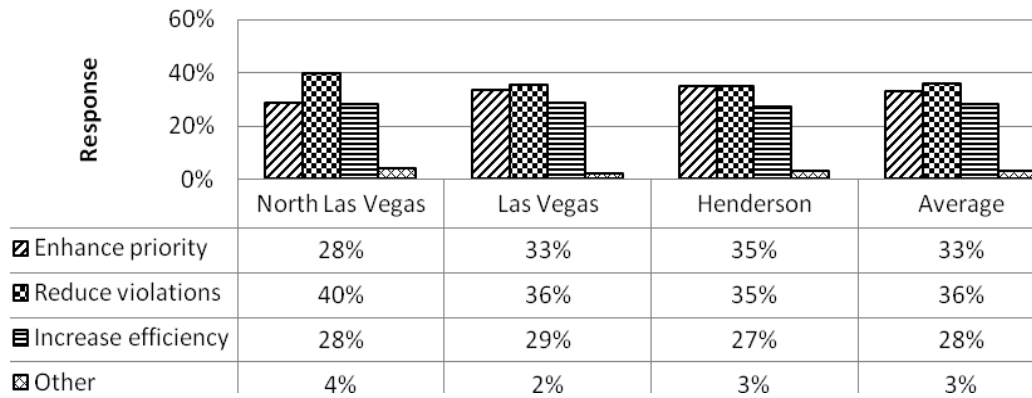


Figure 5.40 Reasons of Supporting the Automated Enforcement

As to the reasons of opposing the automated enforcement, 28% of the respondents on average regarded “privacy concerns” as a main reason, while 36% of the respondents regarded “not reliable” as a main reason and 27% of the respondents considered “unfair practice” as a main reason (see Figure 5.41).

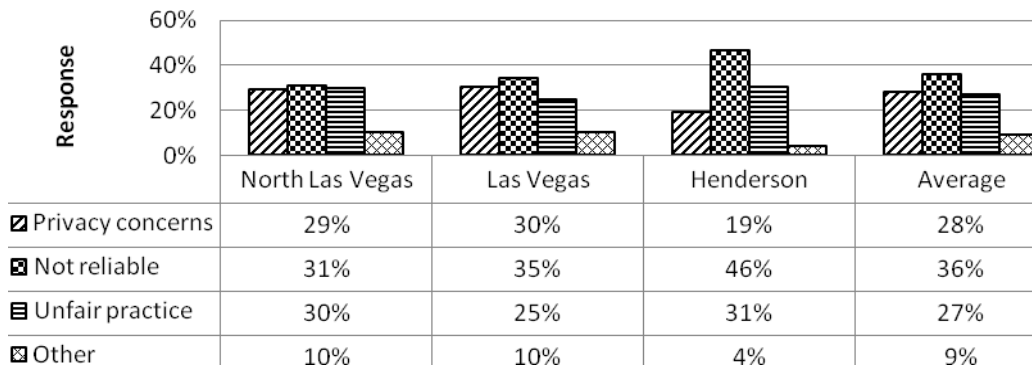


Figure 5.41 Reasons of Opposing the Automated Enforcement

In addition, support of using video cameras was greater among those who reported that vehicle occupancy requirement violation is a serious problem (approximately 57%) than among those who reported that it is not a serious problem (19%) (see Figure 5.42). Support was generally higher among older Nevadans (see Figure 5.43). Support was greater among those who reported annual incomes of below \$15,000 (47%) and at least \$50,000 (45%) (see Figure 5.44). Support was nearly even among men (40%) and women (37%) (see Figure 5.45).

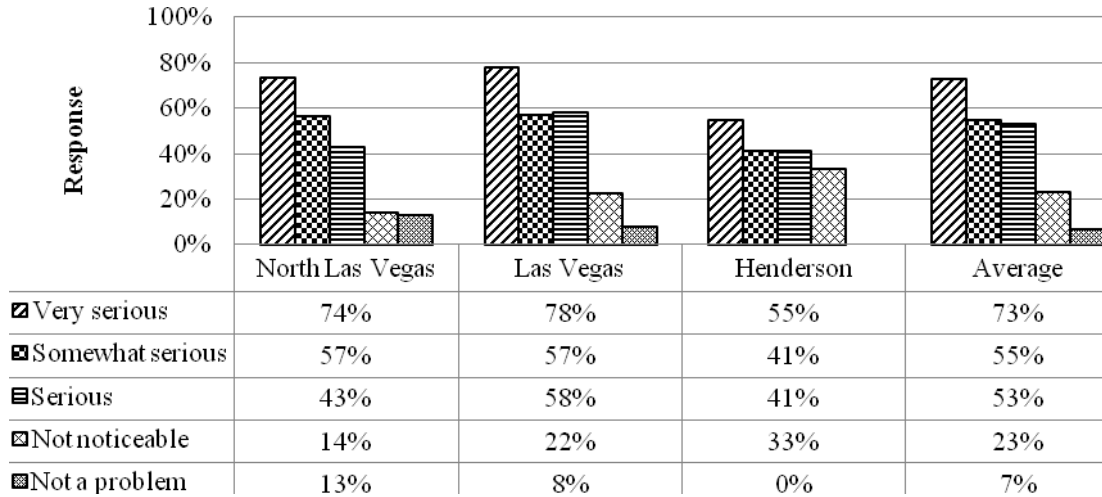


Figure 5.42 Support Video Cameras within Serious Groups

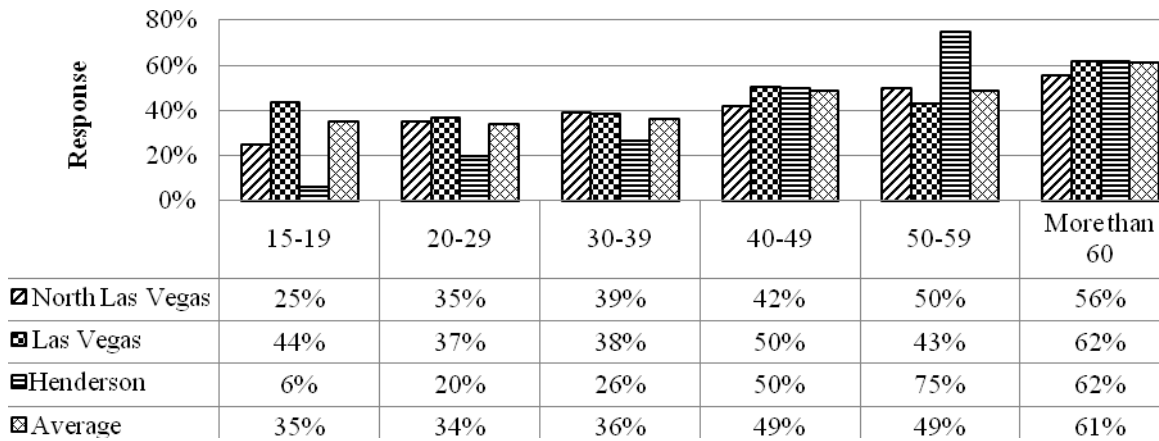


Figure 5.43 Support Video Cameras within Age Groups

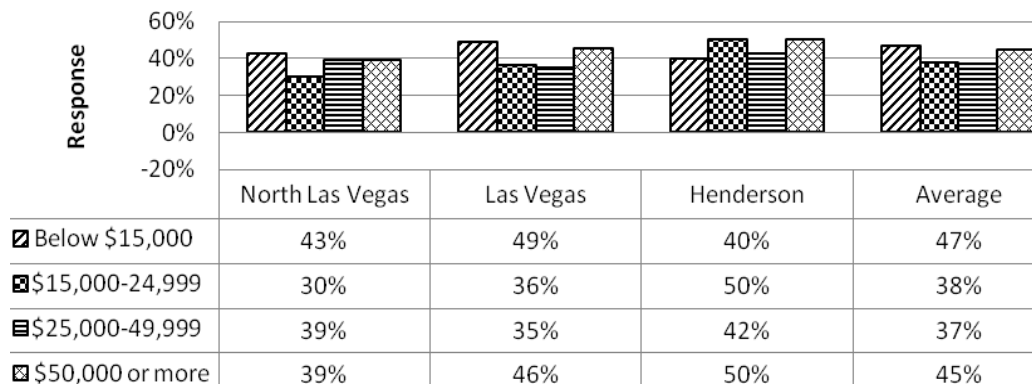


Figure 5.44 Support Video Cameras within Income Groups

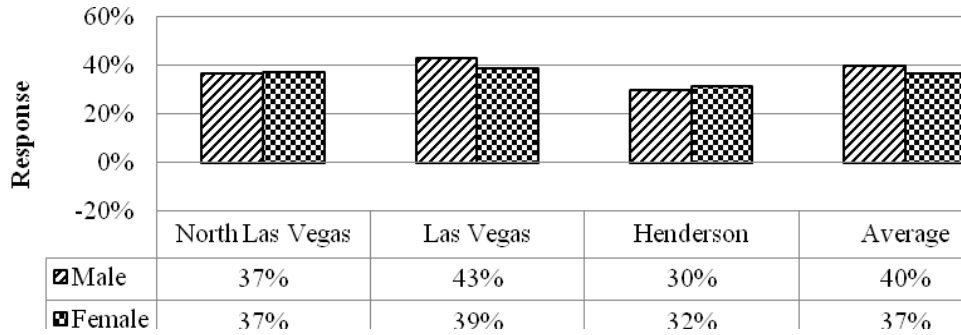


Figure 5.45 Support Video Cameras among Men and Women

Q: Would you support legislation permitting the issuance of citations based on automated enforcement of vehicle occupancy requirement violations in HOV lanes?

The number of respondents who would support or be against such legislation for HOV lane occupancy enforcement is almost even, with 40% support and 35% being against on average. Twenty-five percent of the respondents were unsure for support such legislation (see Figure 5.46).

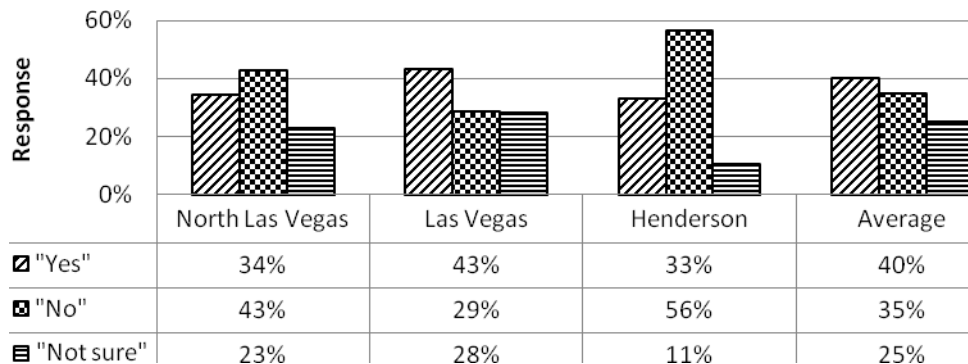


Figure 5.46 Opinions for Support Legislation in HOV Lanes

In addition, support of the legislation was greater among older respondents (see Figure 5.47). Support was greater among those who reported that vehicle occupancy requirement violation is a serious problem (approximately 48%) than among those who reported that it is not a serious problem (22%) (see Figure 5.48). Support was greater among those who did than those who did not support using video cameras in HOV lanes (see Figure 5.49). Support was nearly even among women (35%) and men (36%) (see Figure 5.50). Support was greater among those who reported annual incomes of below \$15,000 (44%) and at least \$50,000 (46%) (see Figure 5.51).

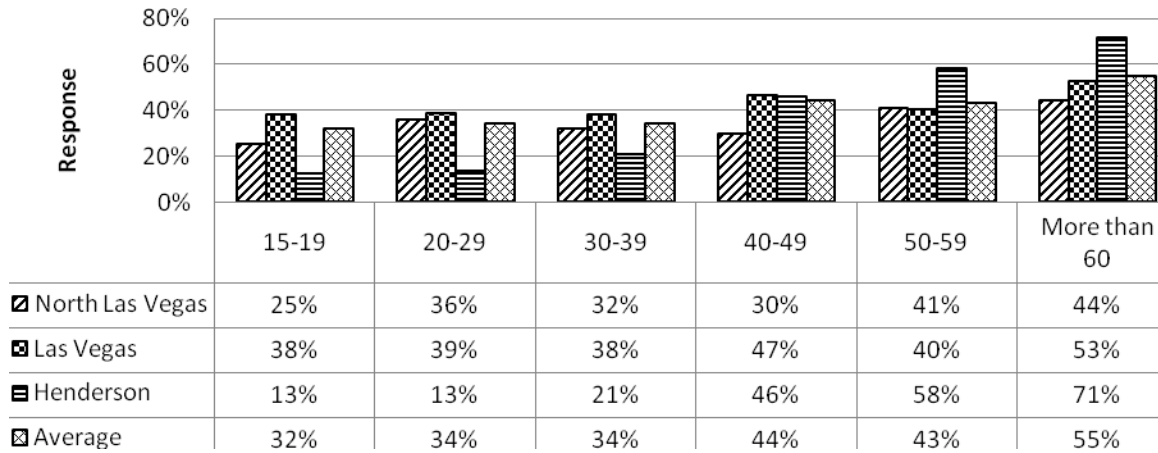


Figure 5.47 Support Legislation within Age Groups

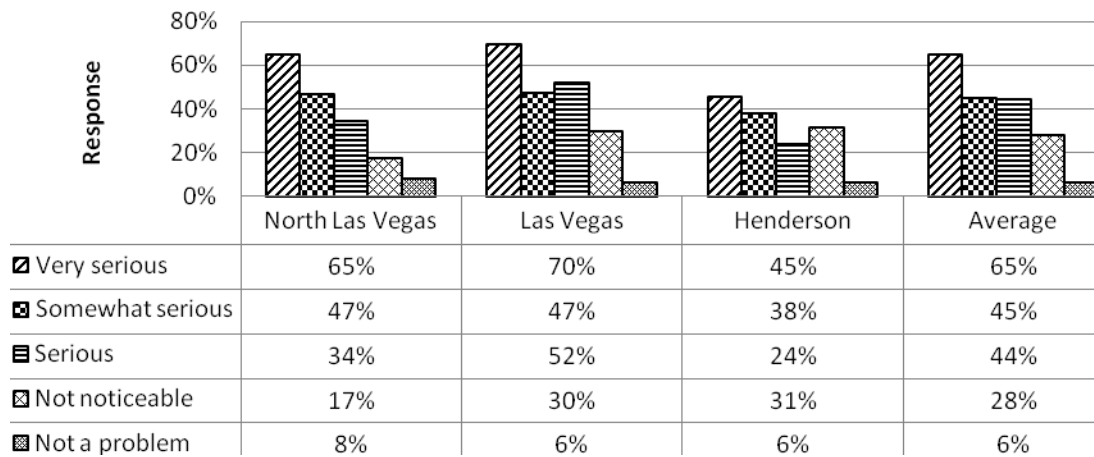


Figure 5.48 Support Legislation within Serious Groups

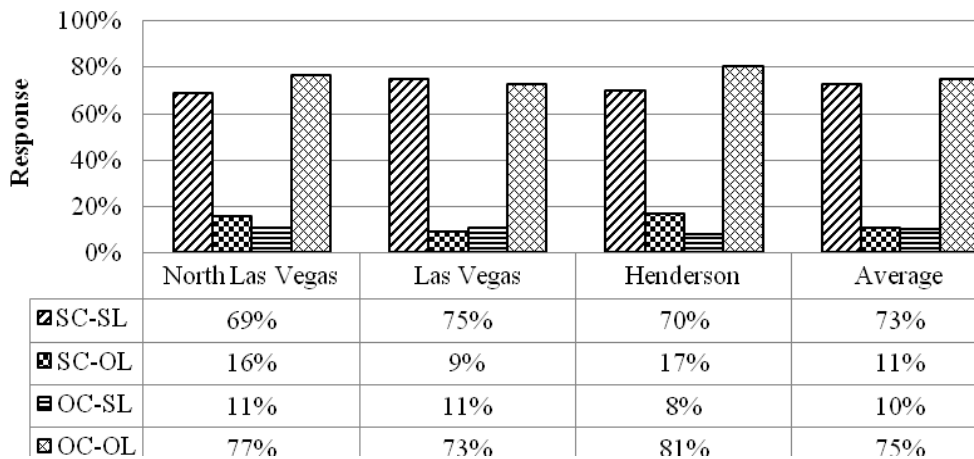


Figure 5.49 Support Legislation within Support Video Cameras

- Note: 1. SC denotes “support camera”;
 2. SL denotes “support legislation”;
 3. OC denotes “oppose camera”;
 4. OL denotes “oppose legislation”.

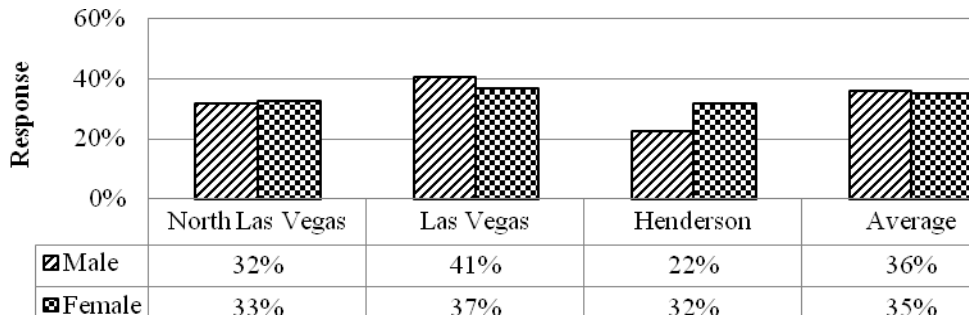


Figure 5.50 Support Legislation among Men and Women

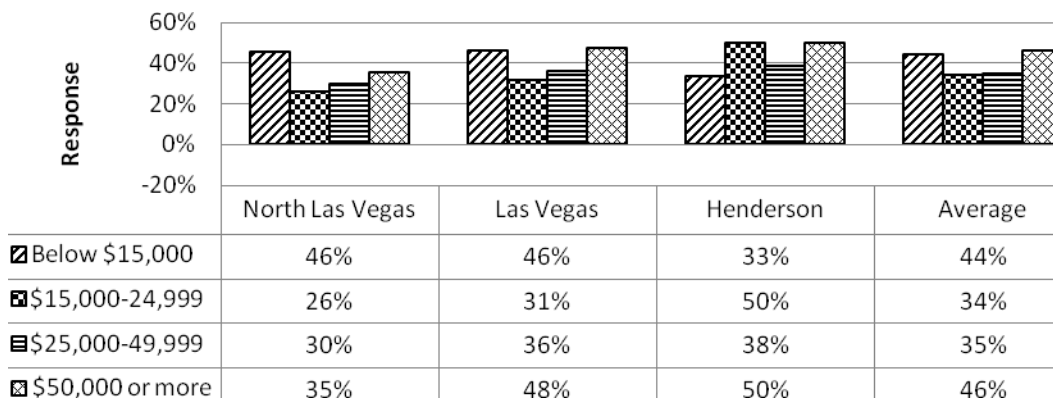


Figure 5.51 Support Legislation within Income Groups

Q: Have you received a ticket for violating vehicle occupancy requirement in HOV lanes during the past year?

Nearly 2% of the respondents on average reported that they had received tickets for violating vehicle occupancy requirement, while 98% of the respondents responded “no” (see Figure 5.52).

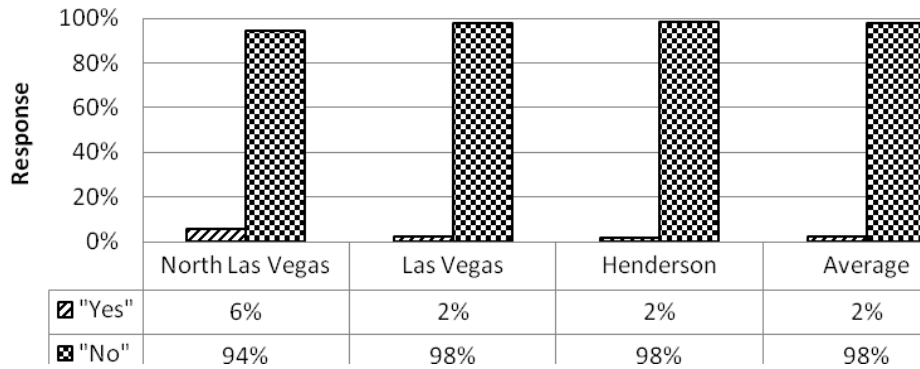


Figure 5.52 Experience of Receiving Tickets

5.3 Accident Analysis Related to Red-Light Running

Accident study related to red-light running primarily focuses on analyzing the number of red-light running violations, red-light running crash-rate, types and results of red-light running crashes, which can be used for assessing the seriousness and severity of red-light running problem. Since only a limited number of crash data related to red-light running was gathered from NDOT, so the data analysis just shows a glimpse at the seriousness of red-light running problem in some Nevada’s cities.

Three-year traffic accident data (between 2005 and 2008) was acquired from NDOT at some high crash intersections in the two major metropolitan areas: Reno-Sparks and Las Vegas. The data was used to investigate the seriousness of red-light running and how it related to traffic accidents. Since specific traffic crashes caused by red-light running cannot be exactly separated from the total accident data, the analysis was based on examination of the closest indicators such as recorded as disregarded traffic signs, signals, road markings; and failed to yield right of way. But the closest indicators do not necessarily imply that the driver ran a red light. In addition, it should be noted that not each violation resulted in a crash and there were unreported crashes. So these data do not truly reflect the seriousness of red-light running violation. As part of the research effort, field observation of red-light running violations needs to be conducted in the next step.

Table 5.3 shows the level of possible red-light running related accidents in Nevada’s major metropolitan areas. For the 52 high crash locations in Reno-Sparks, red-light running related accidents accounted for about 22%. For the 284 high crash intersections in Clark County, red-

light running related accidents are about 26%.

Table 5.3 Accident Data Related to Red-Light Running

City and County	Number of Intersections	Number of Red-Light Running Accidents	Total Accidents	Accident Portion
Reno and Sparks	52	292	1,334	22 %
Clark County	284	5,988	23,133	26 %

Note: Accident data provided by NDOT for the period of 2005-2008.

5.4 Agency Survey on Automated Enforcement

5.4.1 Agency Survey

In order to absorb the experiences and lessons from implementing red-light camera enforcement, an online agency survey was conducted throughout the U.S. in November 2009. Before conducting the survey, the research team developed a list of questions that should be critical for obtaining success in red-light camera enforcement. Survey questionnaire was approved by the research panel before formally conducting the surveys. The survey form is included in Appendix 4. An on-line survey site was created with the questionnaire posted. Agencies were contacted to inform the availability of the on-line survey. These agencies include Police Departments, many corporations, and other government agencies in many cities.

5.4.2 Agency Survey Results

Preliminary results and findings from the agency survey are provided next. A brief summary of the general findings is given first followed by detailed analyses of each survey question and response. The general findings are summarized as follows:

- Most respondents reported that the red-light running violation and traffic crashes could be reduced by red-light camera enforcement, while a quarter of respondents reported that rear-end crash might be increased.
- Most respondents (nearly 88% and 96%) indicated that digital still pictures and digital video were two camera types used extensively for red-light running enforcement, while over 30% of respondents reported that both camera types have been used since 2008.
- Nearly all of respondents ranked all items to be at least average and most respondents

ranked all items to be above average.

- Nearly 35% of respondents reported that the number of citations decreased by red-light camera enforcement, while most respondents (nearly 48%) reported that the number of citations increased. Nearly 17% of respondents answered “no change”.
- Most of respondents (nearly 82%) indicated that there was no public opinion polls conducted in their agencies, while nearly 18% of the respondents answered “yes”. The survey results provided by two respondents showed that nearly half of respondents would support red-light camera enforcement, while nearly a quarter of respondents would be against the enforcement.
- Educating the public is one of key steps in gaining success for red-light camera enforcement.
- A media campaign is encouraged to stress that photo enforcement is a traffic safety issue for the community rather than a revenue generator for the city.
- Local statistics for crashes caused by red-light running can be used as an important proof for supporting red-light camera enforcement.
- A comprehensive evaluation about accident history, the number of violations and constructability of the equipment, should be conducted in selecting intersections for red-light camera installation.
- A pre-determined designation for revenue sharing of the citations is necessary before implementing red-light camera enforcement.
- The selections of technologies and vendors are critical to ensure success in red-light camera enforcement.

The detailed analysis of each question is presented next.

Q: In your opinion, what are the key steps in gaining public support for using red-light camera enforcement?

There are 26 agencies who answered this question. Several issues are summarized by analyzing the specific results as follows:

- Extensive and advanced education for the public on the need for the program and what the goals are.
- An aggressive media campaign strongly stressing that photo enforcement is a traffic

safety issue for the community rather than a revenue generator for the city.

- Place the camera in a high accident/injury intersection to obtain the proof of the increased visibility, aggressive patrol of the area and increased level of enforcement.
- Show the local statistics for crashes at intersections where red-light violation was listed as the cause.
- Accident data with personal stories of loss of life due to red-light runners.
- Develop consistent policy regarding the application of penalty.
- Ensure the method for enforcement (photo/video) is clear and convincing.
- Conduct due diligence in selecting intersections for camera installation by 1) reviewing accident history for at least 3 years and determining where the highest numbers of accidents are; 2) conducting an audit at these locations to determine if there is a high number of violations; 3) inspect the location for constructability of the equipment.
- A pre-determined designation for where funds generated from the program will go.
- A 90 day warning period from the first day you activate the cameras, which allow the public to get used to the system.
- If all other countermeasures to red-light running intersections fail, install cameras.

Q: In your opinion, what are the key steps in gaining the legislature's support for using red-light camera enforcement?

There are 24 agencies who answered this question. Several respondents thought this question is basically the same as the previous one. Some issues are summarized by analyzing the specific results as follows:

- Use accident statistics as a reason for placement.
- Show success from other jurisdictions.
- Make it a civil penalty, with no points assessed to the license.
- Enlist community supporters of photo enforcement and organizations.
- Education regarding the financial and personal costs of red-light running crashes;
- Strong, consistent, and long lasting message from the police department supporting the use of red-light cameras.
- Financial gain for the state.
- Show supporting data that cameras have an impact on reducing red-light running

collisions.

- Proof to legislators that constituents support the cameras.

Q: Please indicate the effects of red-light camera enforcement on red-light running violations and traffic crashes in your jurisdiction.

There are 24 agencies totally who answered this question, as shown in Figures 5.53 - 5.55. Most respondents (approximately 92%) reported that the red-light running violation could be reduced by red-light camera enforcement. Nearly 17% of respondents indicated that the decreased percentage of the violation was up to 31-40%. Only one agency reported that the violation increased by 41-50%. Most respondents reported that traffic crashes were reduced in angle crash, rear-end crash, injury crash and fatal crash, while a quarter of respondents reported that rear-end crash might be increased. Nearly 13% of respondents indicated that injury crash could be reduced by 11-20%. Nearly 17% of respondents reported that fatal crash could be decreased by 91-100%. Nearly 17% of respondents reported that the increase of rear-end crash was less than 10%. In addition, one agency reported that accident calls for service were reduced by 20% and another agency reported that man hours and equipment utilized to work crashes were saved by 31-40%.

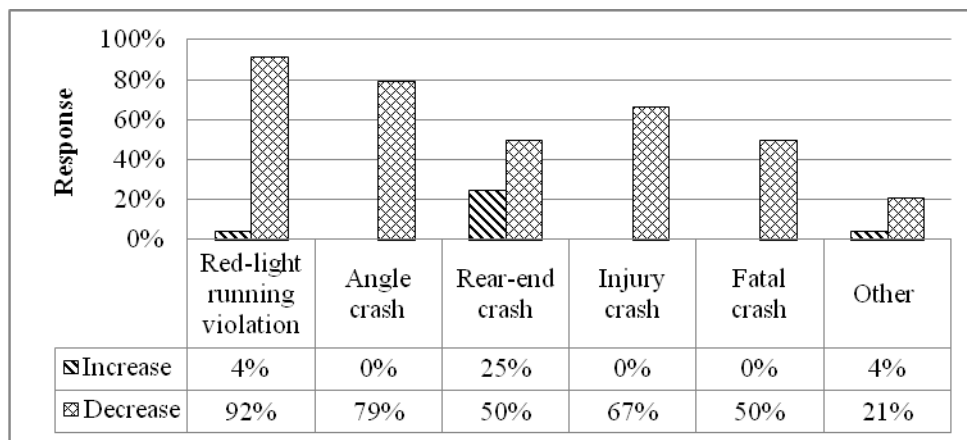


Figure 5.53 Effects of Red-Light Camera Enforcement

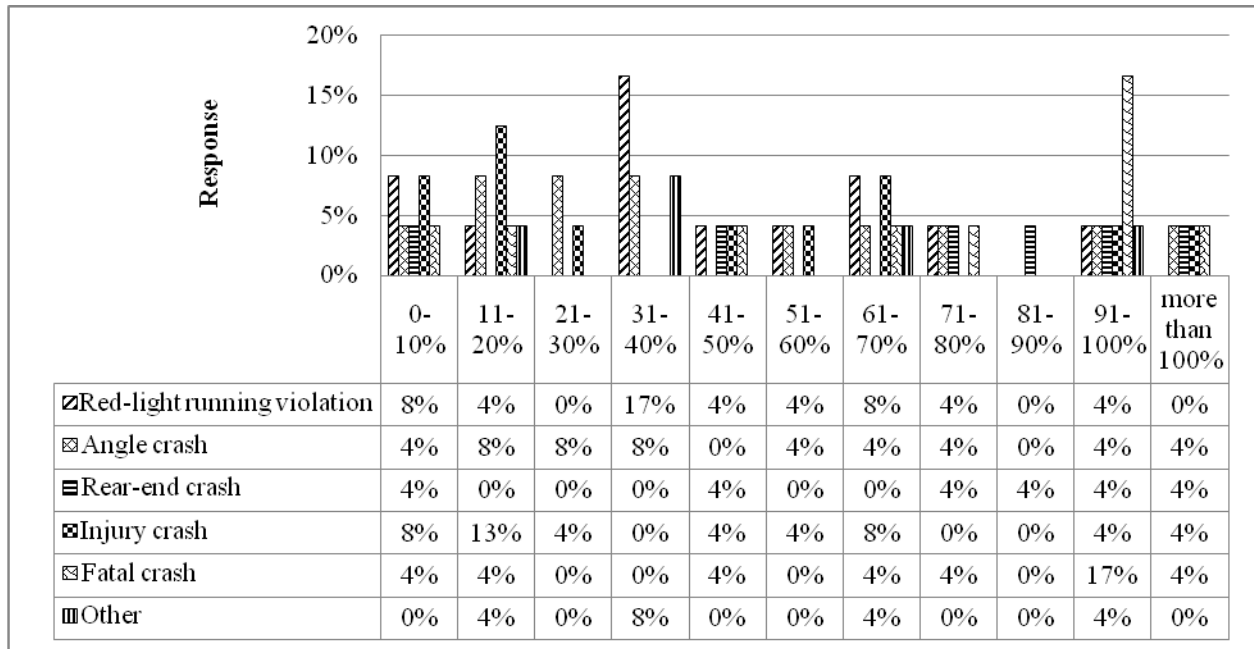


Figure 5.54 Decreases of Red-Light Running Violations and Traffic Crashes

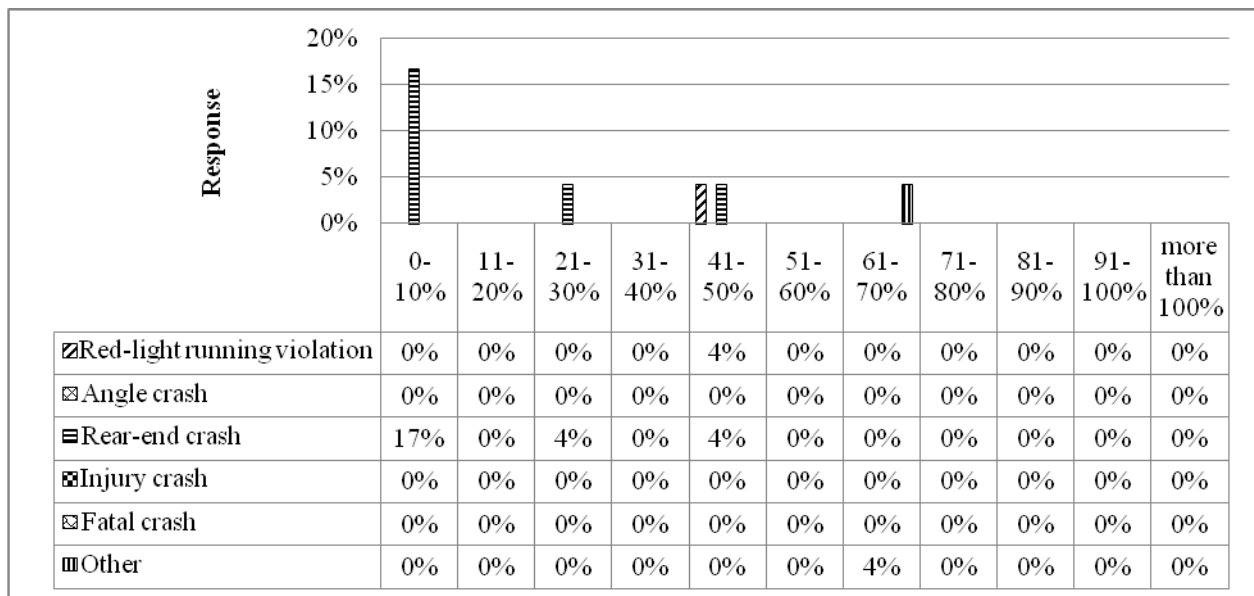


Figure 5.55 Increases of Red-Light Running Violations and Traffic Crashes

Q: Please indicate the camera types used by your jurisdiction for red-light running enforcement.

Most respondents (nearly 88% and 96%) of 26 agencies indicated that digital still pictures and digital video were two camera types used extensively for red-light running enforcement, as shown in Figure 5.56.

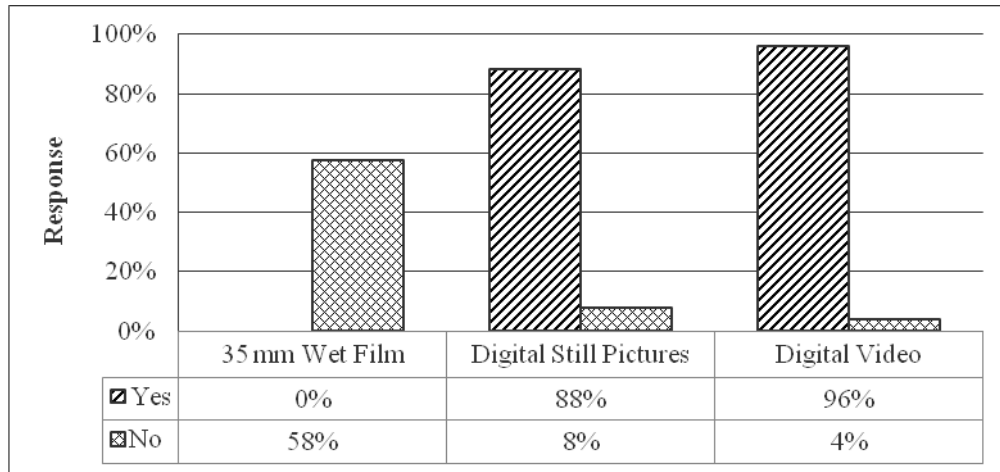


Figure 5.56 Camera Types Used for Red-Light Running Enforcement

Q: Please indicate the years of service of each camera type.

Over 30% of 26 respondents reported that both camera types of digital video and digital still pictures have been used since 2008. The earliest years of using digital still pictures and digital video can be traced back to 2001 and 2003 based on the survey results. There was a remarkable increase of using digital video in 2004 compared with using digital still pictures, as shown in Figure 5.57.

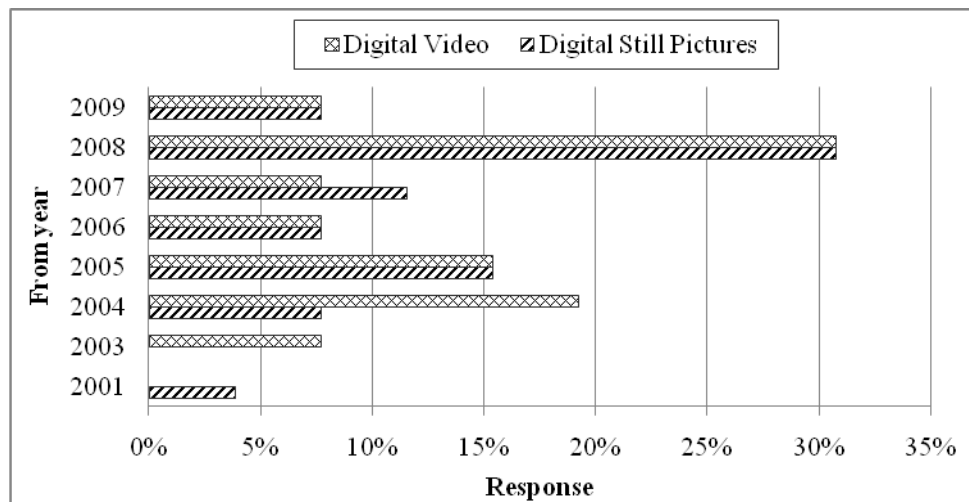


Figure 5.57 Years of Service of Each Camera Type

Q: Please rank the item from 1 to 5 with 1 representing easy or excellent and 5 representing difficult or poor.

Totally, all of 25 agencies responded this question, except for one respondent who ranked the

device installment to be below average, indicated that the ranks of all items are at least average, as shown in Figure 5.58. Most respondents ranked all items to be above average.

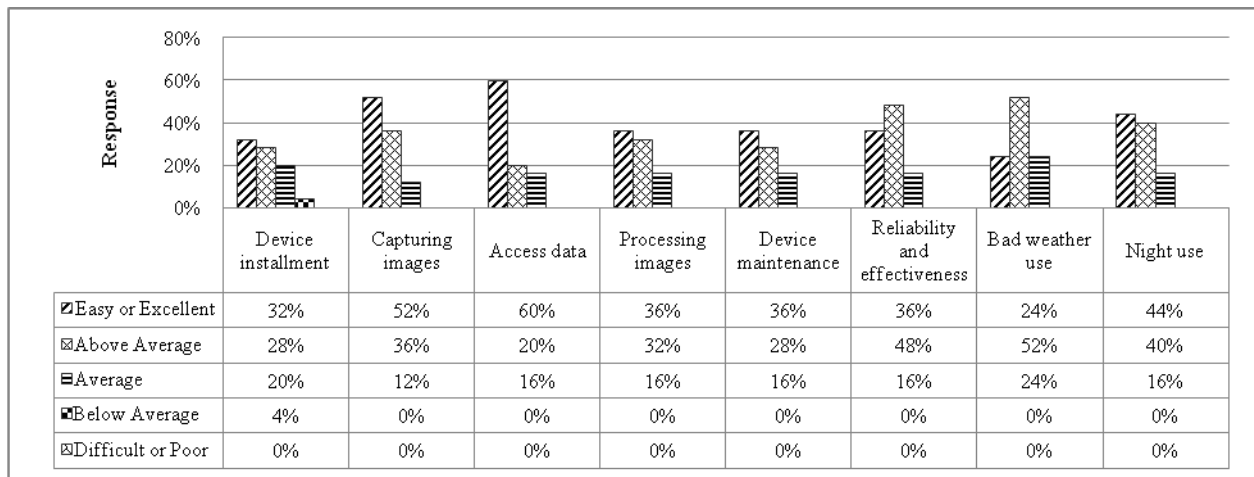


Figure 5.58 Ranks of the Items

Q: Please indicate how red-light camera enforcement has affected the number of citations in your jurisdiction.

Nearly 35% of 23 respondents reported that the number of citations decreased by red-light camera enforcement, while the range was different between 0 and 70%, as shown in Figures 5.59 and 5.60. Most respondents (nearly 48%) reported that the number of citations increased, while nearly 17% of respondents answered “no change”. Most respondents (nearly 22%) indicated that the increase of the number of citations ranged from 41% to 60%.

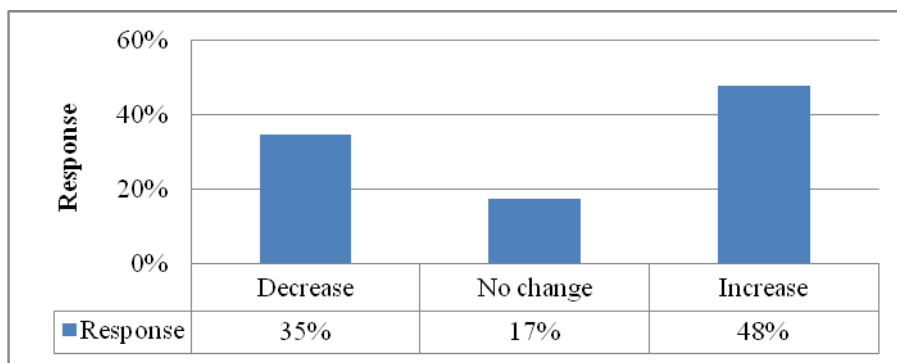


Figure 5.59 Effects of Red-Light Camera Enforcement on the Number of Citations

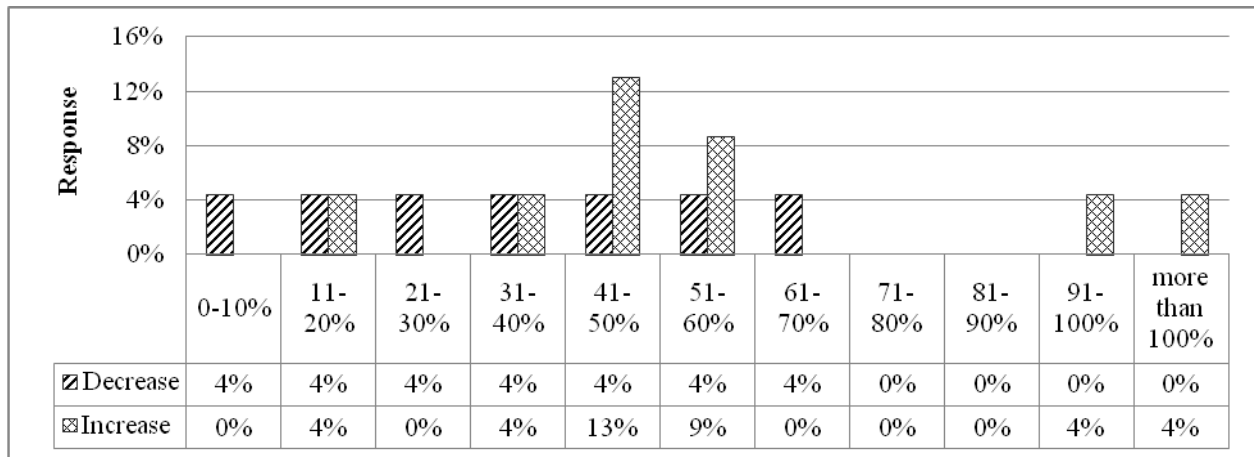


Figure 5.60 Effects of Red-Light Camera Enforcement on the Number of Citations

Q: Has your agency conducted a public opinion poll regarding red-light running camera enforcement? If yes, please indicate the percentage of public that would support, oppose, or are neutral on red-light camera enforcement.

Most of 34 respondents (nearly 82%) indicated that there was no public opinion polls conducted in their agencies, while nearly 18% of the respondents answered “yes”, as shown in Figure 5.61. Only two respondents provided the survey results of public opinion polls as shown in Figure 5.62. The results showed that nearly half of respondents would support red-light camera enforcement, while nearly a quarter of respondents would be against the enforcement.

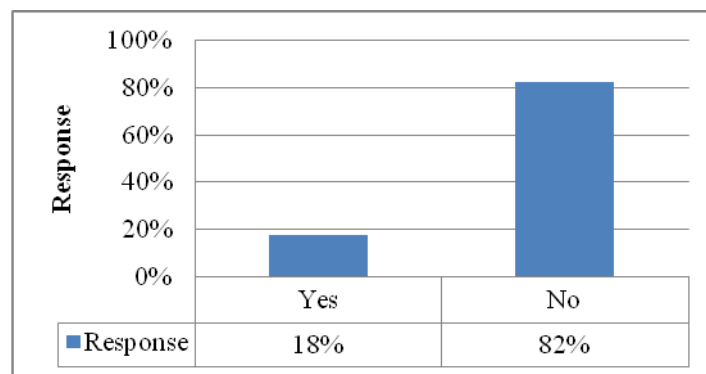


Figure 5.61 Public Opinion Polls Regarding Red-Light Camera Enforcement

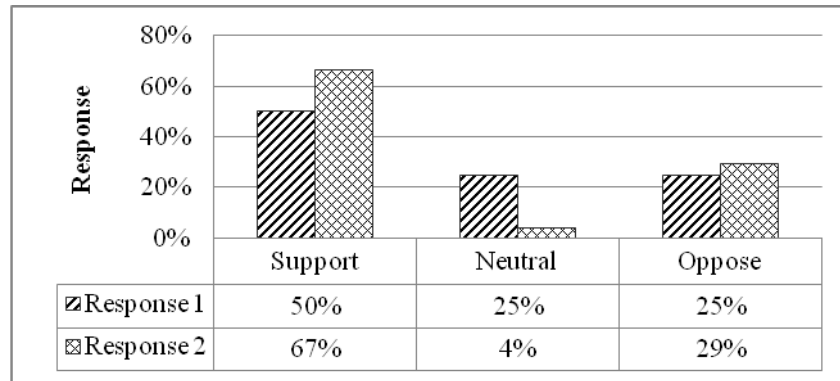


Figure 5.62 Public Opinion Polls Regarding Red-Light Camera Enforcement

Q: Please provide any suggestions and lessons learned from your experiences using red-light camera enforcement.

There are 20 agencies who answered this question. Several issues are summarized by analyzing the specific results as follows:

- Educate the public on the need and reason for the system is very important.
- Make sure all your yellow timing and speed limits are correct.
- Be prepared for the State to suggest revenue sharing of the violations in the form of add-ons for trauma centers etc.
- Place the devices in high accident area and publish yearly accident statistics.
- Use digital video and including the ability for viewing still images and video for the violator.
- Make sure that the money from the citations goes back into the jurisdiction.
- Avoid the temptation to put cameras up at high-violation locations and concentrate on high accident locations.
- Use the city website to post example videos for the public to view.
- Determine how the court system wants the cases presented in the court; what is admissible, what is not and why.
- Have a good media campaign to educate the public on automated enforcement.
- Keep updating the press on changes in accident rates.
- Concern the yellow light timing and the use of the term “Cost Neutrality”.
- Show that the program is open for review.

- Make saving lives the priority and not revenue generation.
- With a strong plan for what the municipality wants to accomplish, let the vendors tailor to that.
- The administration of the enforcement program is more time consuming than one might think or be lead to believe.
- The ordinance must be very specific and the permitted legal defenses must be in the ordinance.
- It is much easier on the agency to have a private company do all the work and simply have police review the violations.
- The agency must decide how to deal with non paying offenders.

5.5 HOV Violation Rate Survey

5.5.1 Data Collection

The vehicle-occupancy violation rate referred to as the violation rate, which reflect the number of vehicles not meeting the minimum HOV lane occupancy requirements, provide a general indication of the degree of public understanding and support for the facility (91). Violation rates are usually expressed as a percentage by dividing the number of vehicles not meeting the occupancy requirement, excluding exempt vehicles, by the total number of vehicles in the lane (91).

An on-site survey for assessing the violation rate was conducted in November 2009 in the Las Vegas metropolitan area. Manual method can be used to count the number of vehicles not meeting the occupancy requirement. The total number of vehicles can be obtained by videos tapping the traffic in both northbound and southbound HOV lanes along the US-95 corridor. The survey location is shown in Figure 5.63. The survey had been conducted for few days between Tuesday and Thursday during the AM peak period (6:30 a.m. - 8:30 a.m.) and PM peak period (3:30 p.m. - 5:00 p.m.). The original data of violation rate survey is provided in Appendix 5.

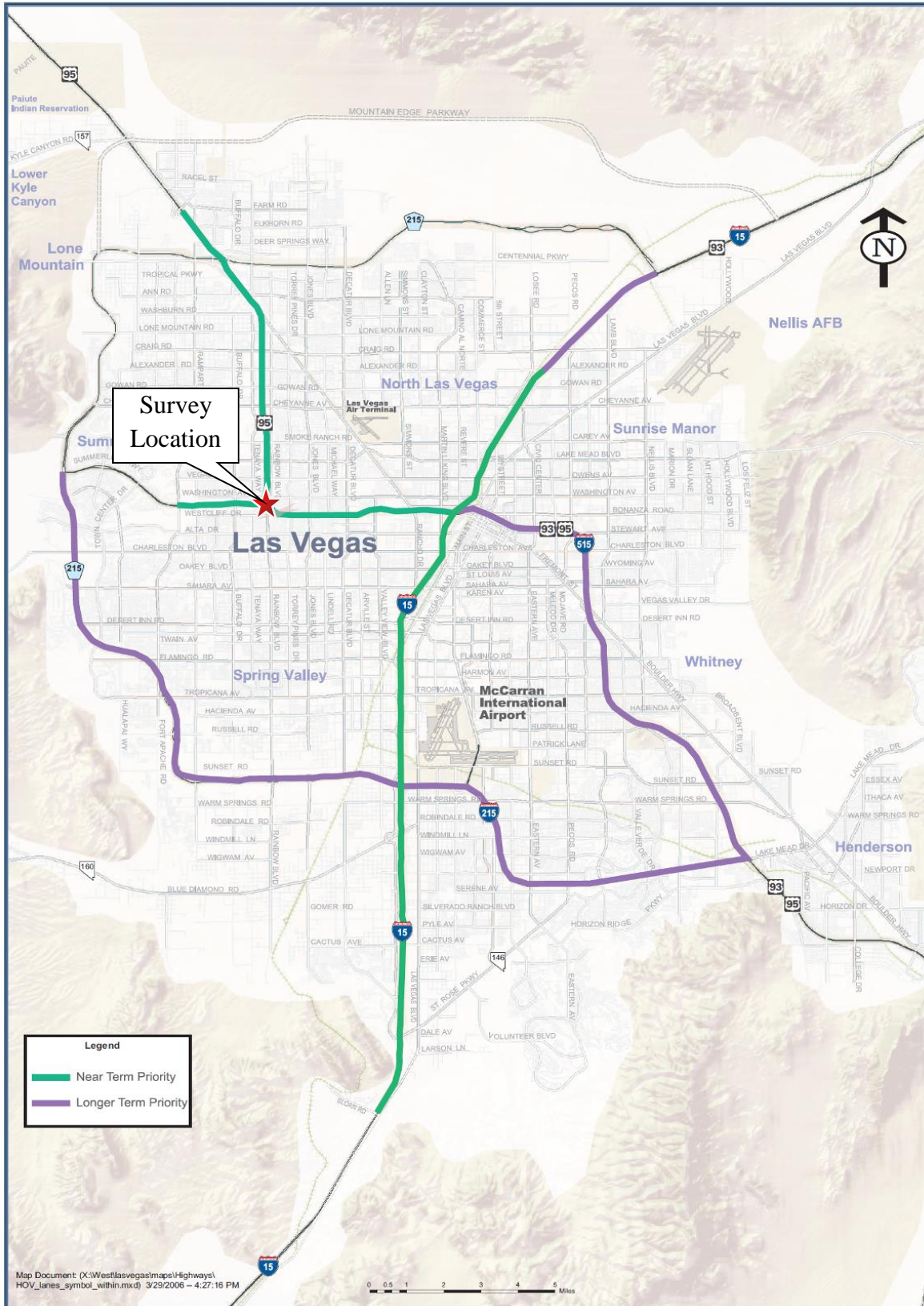


Figure 5.63 Location of Violation Rate Survey on US-95

5.5.2 Survey Results

On average, the violation rates in the northbound HOV lane were 34 percent during the AM peak hours and 53 percent during the PM peak hours. The violation rates in the southbound HOV lane were 28 percent during the AM peak hours and 24 percent during the PM peak hours. Based on the secondary research, typical national violation rates on non-barrier separated concurrent HOV lanes are about 12 percent (91). Thus, the violation rates in both HOV lanes were much higher than national experience, particularly in the northbound HOV lane during the PM peak hours. Violation rates in both HOV lanes are summarized in Table 5.4. The survey results of violation rates in both HOV lanes during the AM and PM peak hours are shown in Figures 5.64 – 5.71.

Table 5.4 Violation Rate in the HOV Lanes on US-95

Time	Northbound HOV lane			Southbound HOV lane		
	1	2	Average	1	2	Average
AM peak hours	39%	28%	34%	29%	27%	28%
PM peak hours	55%	50%	53%	27%	20%	24%
Average	44%			26%		

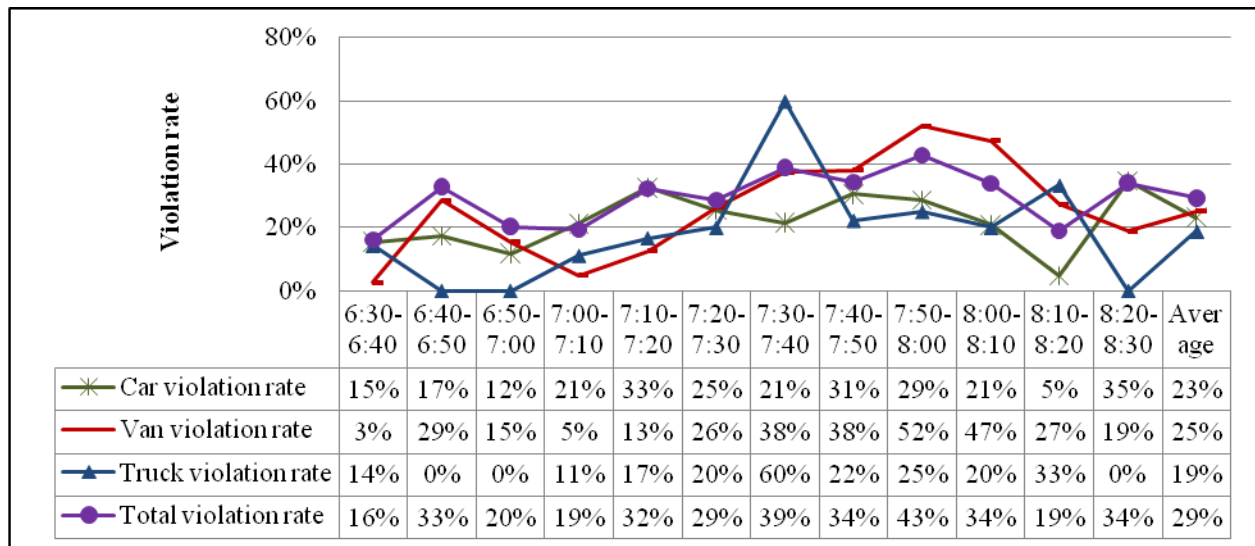


Figure 5.64 Violation rate in the southbound HOV lane during AM peak hours

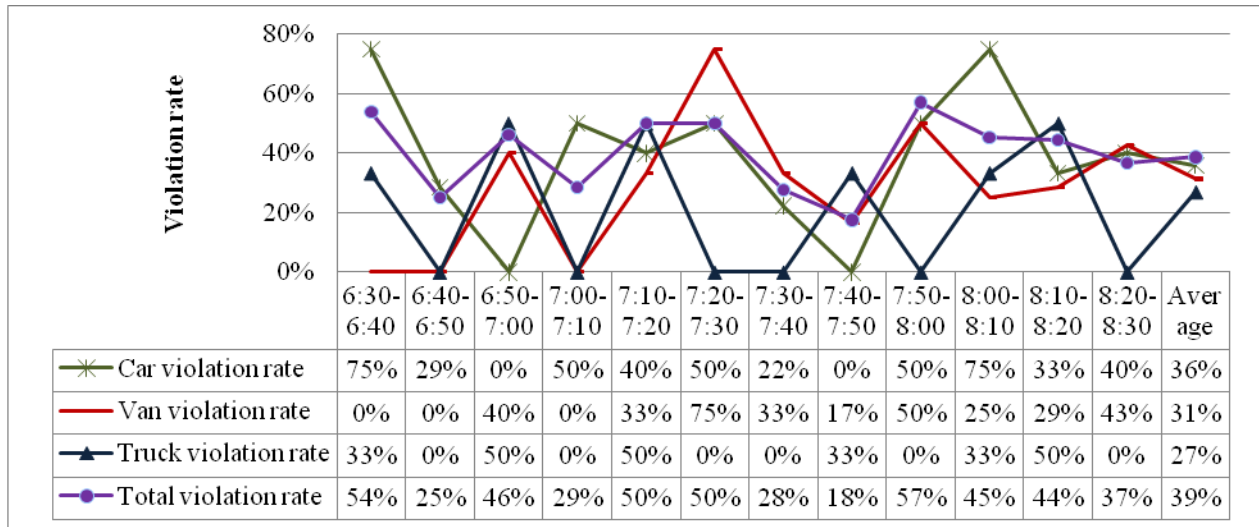


Figure 5.65 Violation rate in the northbound HOV lane during AM peak hours

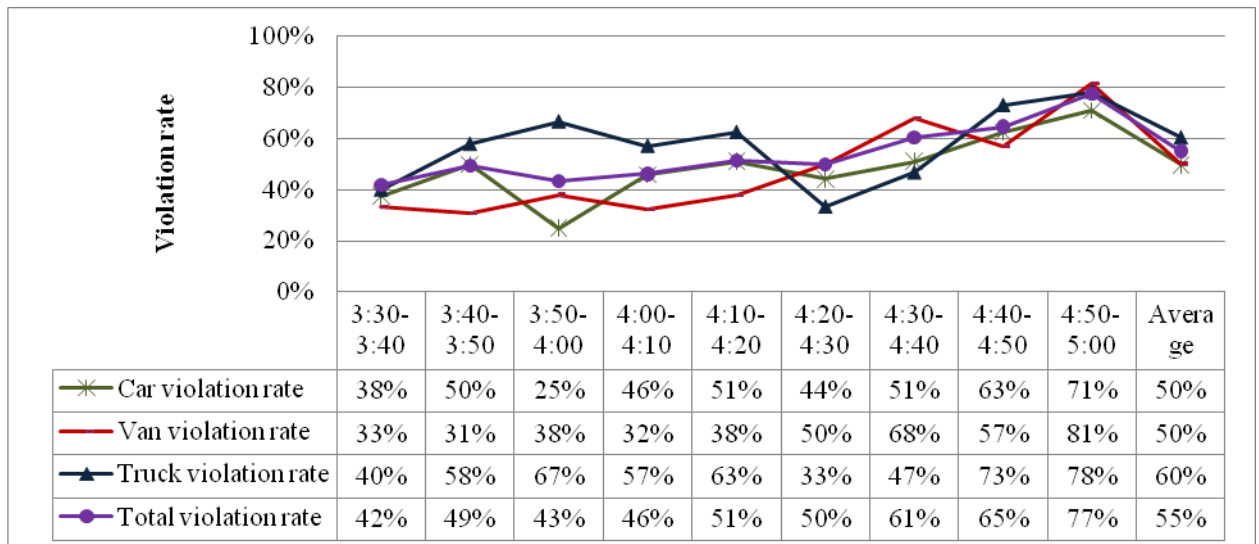


Figure 5.66 Violation rate in the northbound HOV lane during PM peak hours

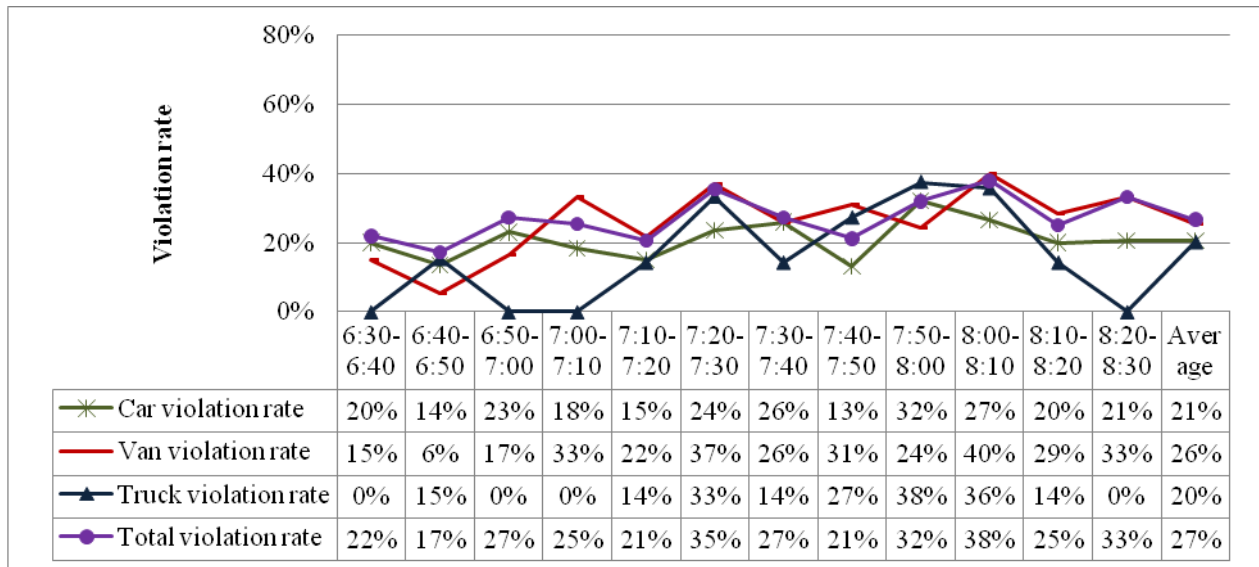


Figure 5.67 Violation rate in the southbound HOV lane during AM peak hours

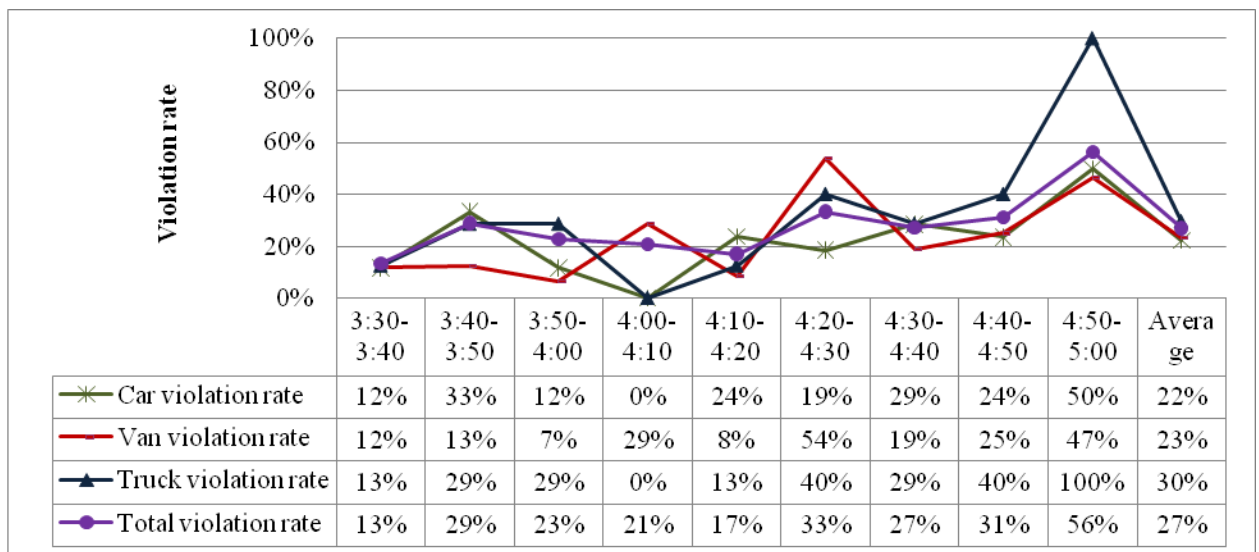


Figure 5.68 Violation rate in the southbound HOV lane during PM peak hours

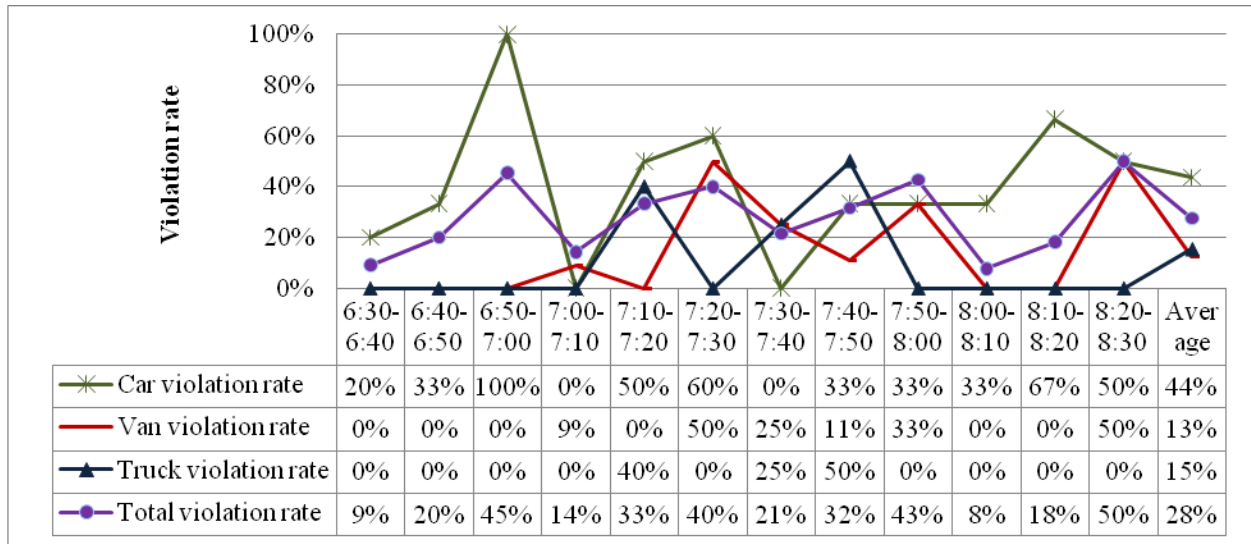


Figure 5.69 Violation rate in the northbound HOV lane during AM peak hours

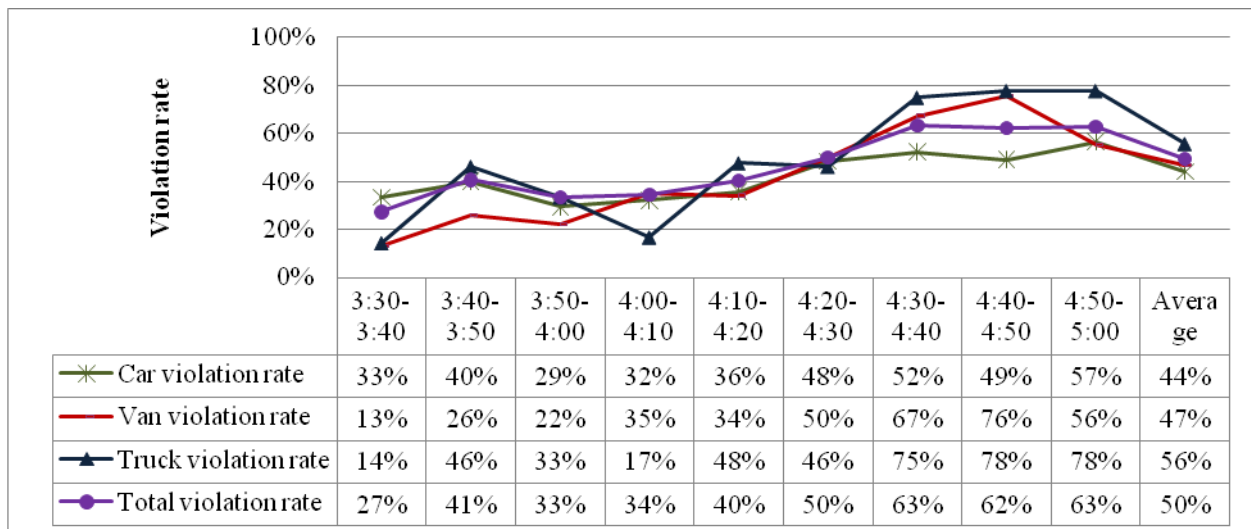


Figure 5.70 Violation rate in the northbound HOV lane during PM peak hours

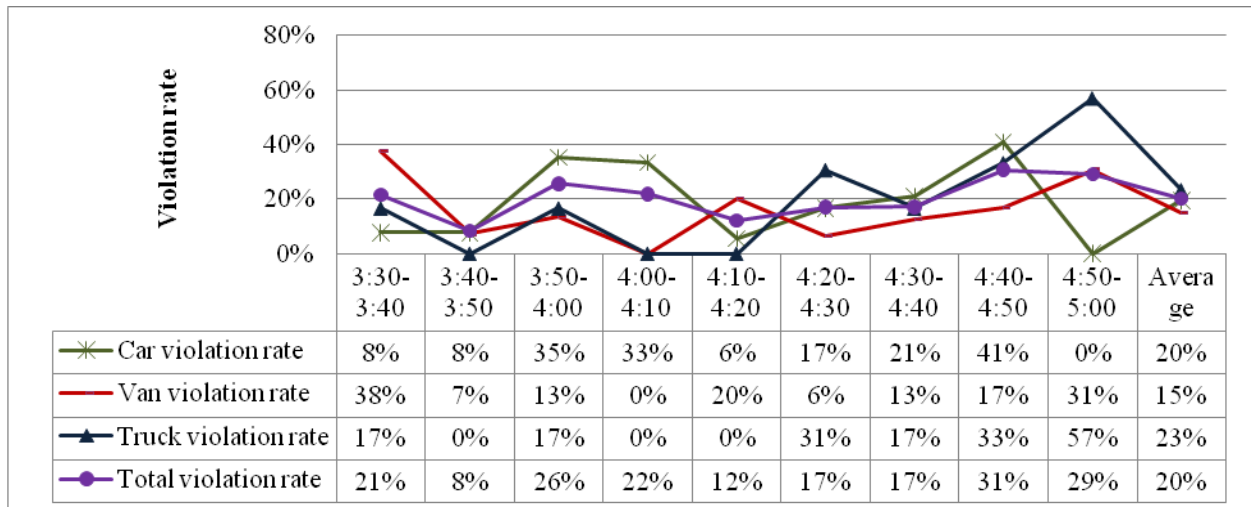


Figure 5.71 Violation rate in the southbound HOV lane during PM peak hours

6. LEGAL AND PUBLIC ACCEPTANCE ISSUES

6.1 Legal Issues

Legal issues related to automated enforcement are myriad and complex. Basic constitutional issues, evidentiary requirements, and the need to revise state and/or local laws should be considered before implementing automated enforcement programs. The constitutional issues presented here deal primarily with the following (19):

- *Right to privacy (First and Fourth Amendments),*
- *Due process and equal protection (Fifth and Fourteenth Amendments),*
- *Right to present a defense (Sixth Amendment),*
- *Admissibility of evidence, and*
- *Enabling legislation.*

6.1.1 Right to Privacy

The Fourth Amendment provides that “the right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures, shall not be violated.” Privacy has also traditionally been protected through four common-law torts: unreasonable intrusion on an individual’s seclusion; public disclosure of true, embarrassing facts; untruthful publicity; and misappropriation of an individual’s name or likeness for commercial purposes is recognized as an actionable claim for invasion of privacy (20).

There is currently no court case that has specifically defined an individual's right to privacy under the First Amendment with respect to operating a vehicle. Although the Supreme Court has protected an individual's right to privacy in matters relating to marriage, family, and sex, the act of driving does not appear to be protected. Because driving is considered a privilege that is not guaranteed to everyone and because driving takes place in view of the public, it is not logical to believe that an individual's right to privacy while operating a vehicle would be protected by the Constitution (19).

6.1.2 Due Process and Equal Protection

Concerns regarding due process and equal protection deal primarily with the differences that arise between officer-issued citations and automated enforcement-issued citations. These differences occur in the level of public notification and awareness, officer discretion, establishment of jurisdiction, and cost of issuing citations. For violation notifications by mail to be considered reasonable, they must be sent in a timely manner. Additionally, the level of advance notification (e.g., signs, media coverage) that alerts the driving public to the potential of receiving automated enforcement citations should be sufficient to be considered reasonable by the courts (19).

Some constitutional challenges to photo enforcement have also been based on the claim that they violate the equal protection doctrine of the Fourteenth Amendment, which mandates uniform penalties for similar classes of law violations. Opponents claim that because the penalties associated with photo enforcement citations differ from those issued directly by an officer, photo enforcement is a violation of a citizen's right to equal protection. This argument has also been rejected by the courts. The County Court of Denver ruled in 2002 that, "Different classes of persons may be treated differently without violation of equal protection when the classification is reasonable, not arbitrary, and bears a rational relationship to legitimate state objectives." A few states — Arizona, California and Colorado — have addressed this issue by making driver liability the basis for photo enforcement violations. California state law, in particular, considers red-light camera violations to be criminal violations and assesses the same penalty in fines and driver license "points" for red light violations issued by patrol officers." However, in order to establish driver liability, the burden of proof is on law enforcement to determine that the driver at the time of the violation was also the registered owner. This usually requires additional camera placement to photograph the driver's face, as opposed to the owner liability standard of only photographing the rear of the vehicle and the license plate. As a result, driver liability camera programs require significantly more time to process in order to establish who was driving, and the idea of photographing drivers, even ones blatantly violating the law, has not been widely embraced by many policy makers. As a result, the vast majority of red-light camera programs in America operate under owner liability and process red-light camera violations as civil infractions, which have a lower burden of proof (29).

6.1.3 Right to Present a Defense

Concerns regarding the right to present a defense primarily deal with the lag time in notifying the alleged violator after the offense occurred, and the resulting possibility of the driver forgetting salient facts. One of the complaints frequently made against automated enforcement by its opponents is that the alleged violators have forgotten the specific circumstances of the alleged violation by the time they receive a notice in the mail. This is especially true when the driver is unaware that they have been photographed. In practice, the lag time is relatively short and most automated enforcement programs mail notices within two weeks of the alleged violation. In *United States v. Delario*, the Fifth Circuit Court ruled that a delay of one year did not constitute a denial of due process, so long as the delay was not deliberate (19).

6.1.4 Admissibility of Evidence

Evidence obtained from automated enforcement devices may be introduced in court in one of two ways: from unmanned devices (typically red light enforcement) and manned devices (typically speed limit enforcement). The admissibility of photographic evidence from unmanned devices is based upon the silent witness theory, whereas that from manned devices is based upon the pictorial testimony theory. These principles are discussed further in the following paragraphs (19):

1. *Manned Operation - "Pictorial Testimony" Theory*: If the automated enforcement system is manned, such as many early speed enforcement systems, the photograph of the alleged violation is admitted under the "pictorial testimony" theory. Under this theory, photographic evidence is admissible only when a witness has testified that it is an accurate representation that was personally observed by the witness. However, the witness does not necessarily have to be the photographer.

2. *Unmanned Operation - "Silent Witness" Theory*: Unmanned enforcement systems, such as red-light cameras, must rely on the "silent witness" theory. Under this theory, photographs constitute substantive evidence, meaning that photographic evidence alone can support a finding by those evaluating the truth or falsity of an allegation. Photographs and other visual evidence can be admitted if testimony is given to establish the following:

- *The photograph has not been altered or manipulated;*
- *The date, time, and place the photograph was taken; and*
- *The identity of the people participating in the activities depicted in the photograph.*

Several conditions should be met for photographs taken by unmanned automated enforcement systems to be admissible in court:

- *The instrument must be periodically certified in accordance with any performance specifications/test protocols set forth by the appropriate state agency,*
- *Evidence will need to be recorded that the instrument was working properly at the time of the offense, and*
- *The officer or technician maintaining the instrument is well-trained and experienced.*

3. Service of Citation by Mail: For any evidence to be considered in court, proper service must be achieved. Notices of violation or citations mailed to registered vehicle owners by the agency operating the automated enforcement program constitute service of process. Such notice must be timely and sufficient to bring a person to the issuing agency or to the courts.

4. Mailing Photograph(s) of Alleged Violation with Citation: A debate exists among implementers of automated enforcement systems about whether or not to mail the photograph of the alleged violation along with the citation.

In New York City's automated red light enforcement program, photographs of the alleged violation are mailed along with a Notice of Liability to the registered owner of the vehicle. New York City automated enforcement staff recommend the practice, especially in cases where only rear license plate photographs are taken and the vehicle clearly can be seen committing the violation. In the case of red-light running, a photograph of the vehicle in the intersection and the red light illuminated provides evidence that is difficult to refute (19).

6.1.5 Enabling Legislation

Up to four pieces of enabling legislation may be necessary before implementing an automated enforcement program. The enabling legislation is necessary to meet constitutional standards, state legal standards, state vehicle code standards, and local jurisdiction standards. The need for

each of these pieces must be determined by the jurisdiction proposing the automated enforcement program working together with the courts, state transportation and motor vehicle departments, and any other group or agency deemed necessary. A major decision that must be made when develop enabling legislation is whether identification of the driver must be made to enforce a violation or if the registered owner of the vehicle can be held responsible for the violation (19).

1. State Legislation: State enabling legislation should address the broad constitutional issues (federal and state) within a framework that includes the following elements:

- definitions of acceptable automated enforcement devices,*
- any restrictive uses (e.g., manned, unmanned),*
- description of acceptable photographic evidence,*
- description of the admissibility of such evidence,*
- a registered owner liability section including provisions for rebuttable presumptions,*
- description of any required corroborating testimony (e.g., technical, eyewitness),*
- determination of the nature of the infraction (e.g., civil or criminal),*
- provisions for summons by mail, and*
- penalty provisions.*

2. Local Legislation: Local legislation should cover requirements that address local needs for an automated enforcement program in more detail, such as:

- specific automated enforcement devices, operating criteria, and data to be collected for that jurisdiction;*
- the specific agency (e.g., police, traffic department) empowered to operate the program;*
- restrictive uses particular to that jurisdiction (e.g., expressways, local streets, schools);*
- requirement for advance notification (e.g., signs);*
- requirement of expert witness and/or operator testimony in court;*
- any sunset and/or review clauses regarding the life of the program; and*

- *any criteria that must be satisfied before automated enforcement can be used at a particular location or area.*

6.2 Public Acceptance

Public acceptance of automated enforcement varies throughout the world due to different cultures, legal processes, and past experiences. The use of automated enforcement in North America elicits differing responses from the public, depending upon the traffic law being enforced and how the program is implemented. Public opinion surveys have shown that most people have strong opinions about automated enforcement (some positive, some negative). Very few people aware of automated enforcement programs are neutral on the issue. Several public opinion surveys have been conducted in the United States that show approximately two-to-one or greater respondents in favor of using automated enforcement. The convictions of automated enforcement opponents, although they are typically outnumbered two-to-one by, supporters of automated enforcement tend to be deeply held. Most opposition to photo enforcement is related to the constitutionality of the programs. Critics of automated enforcement programs for red light violation often claim that the technology is unconstitutional or infringes on basic rights (19).

Citizens concerned about the use of automated enforcement generally express their concerns from two perspectives: one from an ethical standpoint, and the other from the way enforcement is deployed and used. The following concerns are expressed most frequently by the public regarding automated enforcement (19):

- *It is an invasion of privacy;*
- *The wrong person can get a citation;*
- *Vehicle owners are wrongly assumed to be guilty until proven innocent;*
- *Some violators escape prosecution while the honest citizen pays;*
- *It is a dishonest form of enforcement (i.e., citizen may not be aware of its presence);*
- *Does not give the driver a chance to tell his or her side of the story;*
- *Notification lag time causes forgotten circumstances and reduces legal defenses;*
- *Citations can come as a surprise in the mail, causing anxiety;*

- *Citation instructions can be confusing and difficult to follow for some;*
- *Enforcement is done solely to generate revenues;*
- *Automated enforcement program costs outweigh benefits; and*
- *Automated enforcement is not effective in achieving safety goals.*

In some extreme examples of adverse citizen reaction to red-light cameras, cities have been sued, cameras have been “shot up” and the technology [electronic enforcement] has been labeled a devious tactic meant to pad cities=coffers. Perhaps the fiercest opposition to automated enforcement has been in San Diego, where lawyers, seeking dismissal of 398 tickets, blasted the cameras in court as an intrusion on citizens=rights. As a result, the San Diego red-light running program has been suspended pending a complete “audit” of the system. In a highly publicized attack on red-light running technology and programs, the office of House Majority Leader Dick Arney (R-TX) has published a report that contends the transportation profession has modified vehicle signal change and clearance intervals for the purpose of increasing revenue to local agencies from red-light running enforcement fines. Agencies interested in implementing automated enforcement programs should be prepared to respond to these and other potential concerns (19).

6.3 Law Enforcement Acceptance

The support of local law enforcement agencies is another essential element for automated enforcement programs. The reasons generally given by law enforcement personnel in support of automated enforcement are (19):

- *increased use of radar detectors by motorists that warn of down-the-road radar,*
- *difficulty making traffic stops on high speed facilities,*
- *general safety concerns over making traffic stops,*
- *high resource demand to issue citations using conventional enforcement, and*
- *ability to respond (without deploying officers) to speeding concerns on local streets and near schools where traffic volumes are low.*

The opinions of law enforcement personnel are sometimes split over the issue of automated enforcement, even within agencies that have run automated enforcement programs. Those law enforcement personnel who oppose automated enforcement typically give the following reasons (19):

- Officers do not wish to be considered "sneaky,"*
- The motorist is deprived of the officer's discretion to cite when making a stop,*
- Automated enforcement is very inefficient on high-volume freeway facilities,*
- Automated enforcement may not take into account artificially low speed limits, and*
- Law enforcement unions are generally opposed due to image and job security.*

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the review of current practices and experiences in other states, the results of public polls and agency survey, traffic accident analysis, and HOV violation rate survey, several preliminary conclusions can be made concerning the feasibility of using video cameras for automated enforcement on red-light running and managed lanes in Nevada.

Preliminary conclusions regarding the feasibility of automated red-light running enforcement in Nevada can be summarized below:

- The literature reviewed shows there is a preponderance of evidence indicating that red-light camera enforcement is highly effective in reducing red light violations and right-angle injury crashes associated with red-light running despite the results are not yet conclusive due in part to the methodological weaknesses of the studies, while the number of rear-end crashes could increase.
- Public polls of Nevada residents indicated that most of 1,833 respondents (approximately 63%) would support automated red-light running enforcement, while a smaller percentage of the respondents (21%) would oppose it. A majority (58%) of the respondents reported that they would support legislation to permit giving traffic tickets for drivers running red lights based on video evidence, while a smaller percentage of the respondents (24%) would be against such legislation.
- The recent three-year traffic crash data between 2005 and 2008 in Nevada's urban areas indicated that red-light running related crashes account for a significant portion of the total crashes. At the 52 high crash intersections in the Reno-Sparks area, about 22% of the total crashes were related to red-light running. At the 284 high crash intersections in Southern Nevada, red-light running related crashes were about 26% of the total crashes.
- Most agencies indicated that key steps for gaining success in red-light camera enforcement include several issues, such as public education, media campaign, accident statistics, revenue sharing, selecting intersections, selecting technologies and vendors.

Preliminary conclusions regarding the feasibility of photo-HOV occupancy enforcement in Nevada can be summarized below:

- The results of relevant research indicated that video cameras have proven to be effective at determining compliance with vehicle occupancy requirements in HOV and HOT lanes, though the use of video cameras for actual enforcement would still require various enhancements.
- None of the research to date has identified a system that is effective and reliable enough to be implemented as a primary HOV occupancy enforcement strategy due to the inherent difficulties.
- Public polls indicated that 43% of 1,163 respondents on average would support photo-HOV occupancy enforcement, while 28% of the respondents would oppose it. The number of respondents who would support or be against such legislation for HOV lane occupancy enforcement is almost even, with 40% support and 35% being against.
- On average, the violation rates in the northbound HOV lane were 34 percent during the AM peak hours and 53 percent during the PM peak hours. The violation rates in the southbound HOV lane were 28 percent during the AM peak hours and 24 percent during the PM peak hours. The violation rates in both HOV lanes were much higher than national experience (about 12 percent).

7.2 Recommendations

Based on evidence from numerous automated enforcement studies in the United States, the following general recommendations are presented for evaluating the feasibility of automated red-light running enforcement and photo-HOV occupancy enforcement in Nevada.

- Pilot installation and test of red-light running camera systems are recommended at selected intersections where high-violation and high-crash rates exist. This is based on the overwhelming success of other states and good support from Nevada's residents.
- Considering the inherent difficulty of photo-HOV occupancy enforcement technology and the relatively low support from Nevada's residents, video camera systems are recommended as supplemental countermeasures for reducing HOV occupancy violations.

- Automated enforcement systems are recommended only if all other viable low-cost engineering countermeasures have been tried without success in eliminating red-light running and HOV occupancy requirement violation problems. Such engineering countermeasures may include traffic operational improvements, geometric improvements, signal control parameters, signal conspicuity.
- Only if traditional enforcement has proven to be ineffective or inefficient may automated enforcement technology be considered under the conditions that video camera system has proven to be reliable, properly installed and maintained in technology, and processing of images and issuance of citation have proven to be accurate, efficient and fair.
- Video cameras should not be implemented on a widespread basis without detailed scrutiny. On the contrary, red-light cameras should only be considered at specific locations where the characteristics that lead to an increase in rear-end crashes can be understood.
- The State should enact provisions permitting the temporary use of red-light cameras at certain intersections so that the safety effects can be further studied. At the same time, the State should conduct a detailed, perpetual public information and educational effort regarding the automated enforcement.
- A pre-determined designation for revenue sharing of the citations is necessary before implementing red-light camera enforcement.
- The selections of technologies and vendors are critical to ensure success in red-light camera enforcement.

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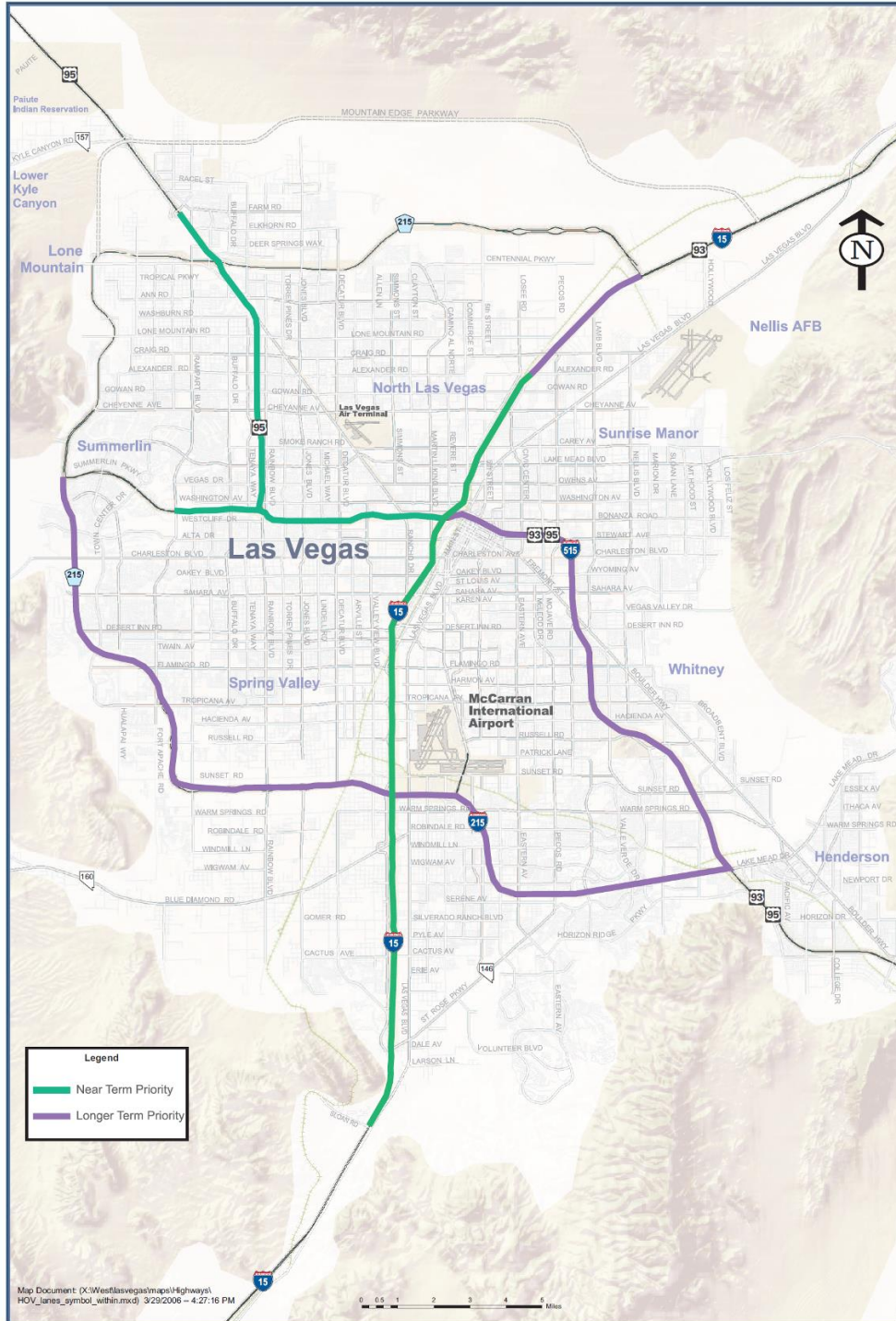
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APPENDIX 1. HOV FREEWAY FACILITY

Near and long term implementation for HOV freeway facility [source: Parsons, et al., 2007]



APPENDIX 2. RED-LIGHT RUNNING ENFORCEMENT PROGRAMS

Summary of automated red-light running enforcement programs [source: Washington and Kangwon Shin, 2005]

Reference	City	Camera Site	Comparison/Reference Group	Crash Type Studied and Estimated Effects (negative indicates reduction)		Comment
Hillier et al. (1993)	Sydney, Australia	Installed at 16 intersections	16 signalized intersections	Right-angle and left-turn opposed	-50%	RTM, spillover and adjusted signal timing in middle of study period are a factor in results
				Rear-end	+25-60%	
South et al. (1988)	Melbourne, Australia	Installed at 46 intersections	50 signalized intersections	No significant results, looked at Right Angle, Right Angle (Turn), Right Against Thru, Rear End, Rear End (turn), other, All crashes, No. of casualties, No Significant results		RTM possible, no accounting for changes in traffic volumes. Comparison sites may have been affected by spillover and other treatments.
Andreassen (1995)	Victoria, Australia			No significant results		Lack of an effect may be due to the fact that the sites studied tended to have few red-running related accidents to begin with (author). Comparison sites may have been affected by spillover.
Kent et al. (1995)	Melbourne, Australia	3 intersections approaches at different intersections	Non-camera approaches	No significant relationship between the frequency of crashes at RLC and non-RLC sites and differences in red light running behavior		Cross-sectional design is problematic and there were likely spillover effects to the non-camera approaches at the same intersections.
Mann et al. (1994)	Adelaide, Australia	Installed at 13 intersections	14 signalized intersections	Reductions at the camera sites were not statistically different from the reductions at the comparison sites.		RTM and spillover a factor
London Accident Analysis Unit (1997)	London, U.K.	RLC at 12 intersections and 21 speed cameras	City-wide effects looked at.	No significant results.		The results are polluted by the fact that two programs are being evaluated.
Hooke et al. (1996)	Various cities in England and Wales	Installed at 78 intersections		All injury	-18%	A simple before-after comparison, not controlled for effects of other factors, regression to the mean and traffic volume changes.
Ng et al. (1997)	Singapore	Installed at 42 intersections	42 signalized intersection	All	-7%	RIM and spillover effects likely affect results.
				Right-angle	-8%	
Retting and Kyrychenko (2001)	Oxnard, California	Installed at 11 intersections	Unsignalized intersections in Oxnard and signalized intersections in 3 similarly sized cities	All	-7%	Looked at city-wide effects, not just at RLC sites. 29 months of before and after data used.
				All Injury	-29%	
				Right-angle	-32%	
				Right-angle Injury	-69%	
SafeLight, Charlotte	Charlotte, North	Installed at 17 intersections	No comparison group	Angle - all approaches	-37%	Probable RTM in site selection
				Angle - camera approaches	-60%	

	Carolina			All - camera approaches	-19%	
				Rear-end - camera approaches	+4%	
				All	< -1%	
Maryland House of Delegates (2001)	Howard County, Maryland	Installed at 25 intersections		Rear-end	-32%	Probable RTM in site selection
				Right-angle	-42%	
				Other	-22%	
Fleck and Smith (1998)	San Francisco, California	Installed at 6 intersections	City-wide effects looked at	City-wide injury collisions caused by red-light violators. It is not clear how these were defined.	-9%	Question on definition of RLC crashes. Did not examine specific effects at treated sites.
Vinzant and Tatro (1999)	Mesa, Arizona	6 intersections with RLC only 6 with RLC plus photo speed enforcement	6 signalized intersections	Total crash rates – crashes per million entering vehicles at each intersection		It is not clear whether the assignment of treatment/no treatment to the four quadrants was random.
				Combined-treatment quadrant	-15.9%	
				Photo-radar quadrant	-7.5%	
				RLC quadrant	-9.7%	
				Control quadrant	-10.7%	
Fox (1996)	Glasgow, Scotland	Installed at 8 intersections and 3 pelican crossings.	Area-wide effects on injury crashes looked at	Crossing Carelessly	-54%	RTM effects likely. Because the decreases in non-RLR crashes are greater than the RLR decreases at times, it is difficult to say what citywide effect the cameras have.
				Unsafe Right Turn	-29%	
				Fail to keep Distance	+8%	
				Other	-29%	
				All per month	-32%	
Winn (1995)	Glasgow, Scotland	6 locations on 1 approach	Various	Injury crashes related to RLR violations	-62%	Probable RTM effects.

APPENDIX 3. PUBLIC OPINION POLL FORMS

Public Opinion Poll of Automated Enforcement (Red-Light Running)

The Nevada Department of Transportation is surveying citizens regarding automated enforcement of red-light running violations (see details in the accompanying brochure). Please complete the survey by checking the boxes. All questions are voluntary, and the responses will be kept confidential and used for research purposes only. If you have questions about the study, please contact Dr. Zong Tian at the University of Nevada Reno by phone at 775-784-1232 or by email at zongt@unr.edu.

1. Do you have a driver's license?

- Yes No

If yes, since when (e.g., 1985): _____.

2. How serious do you believe the problem of red light running is in your community?

- Very serious Somewhat serious Serious Not noticeable Not a problem at all

3. Please answer the following questions based on your observations in your community?

a. How many times (on average) per week do you observe drivers running red lights?

- Never 1 to 5 6 to 10 11 to 15 More than 15

b. How many of these result in accidents?

4. In your opinion, why do drivers run red lights? (Check all that apply)

- Yellow light is too short Conscious decision not to stop
 Driving too fast to stop Other, please specify

5. Were you aware of automated enforcement programs in other communities before you took this survey?

- Yes No

6. Do you support or oppose using red-light running cameras to improve traffic safety in your community?

- Support Oppose Not sure

a. If you support, please indicate why you support the automated enforcement on red-light running (Check all that apply).

- Reduce crashes Reduce violations Reduce speeds Other, please specify _____.

b. If you oppose, please indicate why you oppose the automated enforcement on red-light running (Check all that apply).

- Privacy concerns Not reliable Unfair practice Other, please specify _____.

7. Do you support initiatives such as using red-light cameras to provide for a safer driving experience?

- Yes No Not sure

8. Would you support legislation permitting the issuance of citations based on automated red-light running enforcement?

Yes No Not sure

9. Have you received a ticket for running a red light during the past year?

Yes No

10. Please indicate your zip code and gender.

Zip Code: _____.

Gender: Male Female

11. Please indicate the ranges of your age and annual income.

Age: 15-19 20-29 30-39 40-49 50-59 More than 60

Income: Below \$15,000 \$15,000-24,999 \$25,000-49,999 \$50,000 or more

12. Do you have any other comments regarding initiatives to make our roads safer?

_____.

Thank you for your time and assistance!

Public Opinion Poll of Automated Enforcement (Red-Light Running and HOV)

The Nevada Department of Transportation is surveying citizens regarding automated enforcement on red-light running and vehicle occupancy requirement violations in High Occupancy Vehicle (HOV) lanes (see details in the accompanying brochure). Please complete the survey by checking the boxes. All questions are voluntary, and the responses will be kept confidential and used for research purposes only. If you have questions about the study, please contact Dr. Zong Tian at the University of Nevada-Reno by phone at 775-784-1232 or by email at zongt@unr.edu.

1. Do you have a driver's license?

Yes No

If yes, since when (e.g., 1985): _____.

2. How serious do you believe the problem of red light running is in your community?

Very serious Somewhat serious Serious Not noticeable Not a problem at all

3. Please answer the following questions based on your observations in your community?

a. How many times (on average) per week do you observe drivers running red lights?

Never 1 to 5 6 to 10 11 to 15 More than 15

b. How many of these result in accidents?

4. In your opinion, why do drivers run red lights? (Check all that apply)

Yellow interval is too short Conscious decision not to stop

Driving too fast to stop Other, please specify

5. Were you aware of automated enforcement programs in other communities before you took this survey?

Yes No

6. Do you support or oppose using red-light running cameras to improve traffic safety in your

community?

- Support Oppose Not sure

a. If you support, please indicate why you support the automated enforcement on red-light running (*Check all that apply*).

- Reduce crashes Reduce violations Reduce speeds Other, please specify_____.

b. If you oppose, please indicate why you oppose the automated enforcement on red-light running (*Check all that apply*).

- Privacy concerns Not reliable Unfair practice Other, please specify_____.

7. Do you support initiatives such as using red-light cameras to provide for a safer driving experience?

- Yes No Not sure

8. How serious do you believe the problem of violating vehicle occupancy requirements is in HOV lanes?

- Very serious Somewhat serious Serious Not noticeable Not a problem at all

9. How many times (on average) per day do you observe vehicles violating occupancy requirements in HOV lanes?

- Never 1 to 5 6 to 10 11 to 15 More than 15

10. Do you support or oppose using video cameras to reduce vehicle occupancy requirement violations in HOV lanes?

- Support Oppose Not sure

a. If you support, please indicate why you support the automated enforcement on violating vehicle occupancy requirements (*Check all that apply*).

- Enhance HOV priority Reduce violations Increase efficiency Other, please specify_____.

b. If you oppose, please indicate why you oppose the automated enforcement on violating vehicle occupancy requirements (*Check all that apply*).

- Privacy concerns Not reliable Unfair practice Other, please specify_____.

11. Would you support legislation permitting the issuance of citations based on automated red-light running enforcement?

- Yes No Not sure

12. Would you support legislation permitting the issuance of citations based on automated enforcement of vehicle occupancy requirement violations in HOV lanes?

- Yes No Not sure

13. Have you received a ticket for running a red light during the past year?

- 3Yes No

14. Have you received a ticket for violating vehicle occupancy requirement in HOV lanes during the past year?

- 4Yes No

15. Please indicate your zip code and gender.

Zip Code:_____.

Gender: Male Female

16. Please indicate the ranges of your age and annual income.

Age: 15-19 20-29 30-39 40-49 50-59 More than 60

Income: Below \$15,000 \$15,000-24,999 \$25,000-49,999 \$50,000 or more

17. Do you have any other comments regarding initiatives to make our roads safer and more efficient?

_____.

Thank you for your time and assistance!

APPENDIX 4. AGENCY SURVEY FORMS

The Nevada Department of Transportation (NDOT) is studying the feasibility of using automated enforcement by camera monitoring of red-light running violations. NDOT is conducting an agency survey for the purpose of gaining experience and acquiring lessons learned using automated enforcement systems. If you have questions about the study, please contact Dr. Zong Tian at the University of Nevada, Reno by phone at 775-784-1232 or by email at zongt@unr.edu.

1. Please provide your contact information (optional).

Name: _____.

Agency: _____.

Address: _____.

City/Town: _____.

State: _____.

ZIP/Postal Code: _____.

Country: _____.

Email Address: _____.

Phone Number: _____.

2. In your opinion, what are the key steps in gaining public support for using red-light camera enforcement?

_____.

3. In your opinion, what are the key steps in gaining the legislature's support for using red-light camera enforcement?

_____.

4. Please indicate the effects of red-light camera enforcement on red-light running violations and traffic crashes in your jurisdiction.

	Increase or Decrease	Percentage
Red-light running	_____	_____
Violation	_____	_____
Angle crash	_____	_____
Rear-end crash	_____	_____
Injury crash	_____	_____

Fatal crash _____

Other (specify below) _____.

5. Please indicate the camera types used by your jurisdiction for red-light running enforcement.

35 mm Wet Film Yes No

Digital Still Pictures Yes No

Digital Video Yes No

Other (please specify) _____.

6. Please indicate the years of service of each camera type.

	From	To
35 mm Wet Film	_____	_____

Digital Still Pictures	_____	_____
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Digital Video	_____	_____
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Other (as specified previously) _____.

7. Please rank the item from 1 to 5 with 1 representing easy or excellent and 5 representing difficult or poor.

- Device installment Easy or Excellent Above Average Average Below Average Difficult or Poor
- Capturing images Easy or Excellent Above Average Average Below Average Difficult or Poor
- Access data Easy or Excellent Above Average Average Below Average Difficult or Poor
- Processing images Easy or Excellent Above Average Average Below Average Difficult or Poor
- Device maintenance Easy or Excellent Above Average Average Below Average Difficult or Poor
- Reliability and effectiveness Easy or Excellent Above Average Average Below Average Difficult or Poor
- Bad weather use Easy or Excellent Above Average Average Below Average Difficult or Poor
- Night use Easy or Excellent Above Average Average Below Average Difficult or Poor

8. Please indicate how red-light camera enforcement has affected the number of citations in your jurisdiction.

Number of Citations Increase/No Change/Decrease Percentage: _____

9. Has your agency conducted a public opinion poll regarding red-light running camera enforcement?

Yes No

10. If yes, please indicate the percentage of public that would support, oppose, or are neutral on red-light camera enforcement.

Support Neutral Oppose

11. If your public opinion poll and/or report is available, please email document to zongt@unr.edu or please provide link in box below.

_____.

12. Please provide any suggestions and lessons learned from your experiences using red-light camera enforcement.

_____.

Thank you for your time and assistance!

APPENDIX 5. HOV VIOLATION RATE SURVEY RESULTS

Survey data in the southbound HOV lane during AM peak hours (Survey date: 11/03/2009)

Types of Vehicles	Car				Van				Truck				Motorcycle		Total		
	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation	Violation	Total	Violation	Violation rate
Time	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Number	Percentage
6:30-6:40A.M	33	6	39	15%	38	1	39	3%	12	2	14	14%	0	7	99	16	16%
6:40-6:50A.M	24	5	29	17%	15	6	21	29%	4	0	4	0%	0	10	64	21	33%
6:50-7:00A.M	30	4	34	12%	22	4	26	15%	3	0	3	0%	0	6	69	14	20%
7:00-7:10A.M	26	7	33	21%	20	1	21	5%	8	1	9	11%	0	4	67	13	19%
7:10-7:20A.M	27	13	40	33%	14	2	16	13%	5	1	6	17%	0	6	68	22	32%
7:20-7:30A.M	38	13	51	25%	14	5	19	26%	8	2	10	20%	0	4	84	24	29%
7:30-7:40A.M	22	6	28	21%	20	12	32	38%	2	3	5	60%	0	7	72	28	39%
7:40-7:50A.M	41	18	59	31%	13	8	21	38%	7	2	9	22%	0	4	93	32	34%
7:50-8:00A.M	25	10	35	29%	12	13	25	52%	3	1	4	25%	0	6	70	30	43%
8:00-8:10A.M	19	5	24	21%	10	9	19	47%	8	2	10	20%	0	3	56	19	34%
8:10-8:20A.M	20	1	21	5%	8	3	11	27%	2	1	3	33%	0	2	37	7	19%
8:20-8:30A.M	15	8	23	35%	13	3	16	19%	3	0	3	0%	0	5	47	16	34%
Total	320	96	416	23%	199	67	266	25%	65	15	80	19%	0	64	826	242	29%

Survey data in the northbound HOV lane during AM peak hours (Survey date: 11/05/2009)

Types of Vehicles	Car				Van				Truck				Motorcycle		Total		
	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation	Violation	Total	Violation	Violation rate
	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Number	Percentage
6:30-6:40A.M.	1	3	4	75%	3	0	3	0%	2	1	3	33%	0	3	13	7	54%
6:40-6:50A.M.	5	2	7	29%	2	0	2	0%	2	0	2	0%	0	1	12	3	25%
6:50-7:00A.M.	2	0	2	0%	3	2	5	40%	2	2	4	50%	0	2	13	6	46%
7:00-7:10A.M.	2	2	4	50%	2	0	2	0%	1	0	1	0%	0	0	7	2	29%
7:10-7:20A.M.	3	2	5	40%	2	1	3	33%	1	1	2	50%	0	2	12	6	50%
7:20-7:30A.M.	1	1	2	50%	1	3	4	75%	2	0	2	0%	0	0	8	4	50%
7:30-7:40A.M.	7	2	9	22%	4	2	6	33%	2	0	2	0%	0	1	18	5	28%
7:40-7:50A.M.	7	0	7	0%	5	1	6	17%	2	1	3	33%	0	1	17	3	18%
7:50-8:00A.M.	2	2	4	50%	1	1	2	50%	0	0	0	0%	0	1	7	4	57%
8:00-8:10A.M.	1	3	4	75%	3	1	4	25%	2	1	3	33%	0	0	11	5	45%
8:10-8:20A.M.	4	2	6	33%	5	2	7	29%	1	1	2	50%	0	3	18	8	44%
8:20-8:30A.M.	6	4	10	40%	4	3	7	43%	2	0	2	0%	0	0	19	7	37%
Total	41	23	64	36%	35	16	51	31%	19	7	26	27%	0	14	155	60	39%

Survey data in the northbound HOV lane during PM peak hours (Survey date: 11/05/2009)

Types of Vehicles	Car				Van				Truck				Motorcycle		Total		
	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation	Violation	Total	Violation	Violation rate
	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Number	Percentage
3:30-3:40P.M.	20	12	32	38%	10	5	15	33%	9	6	15	40%	0	5	67	28	42%
3:40-3:50P.M.	20	20	40	50%	18	8	26	31%	8	11	19	58%	0	6	91	45	49%
3:50-4:00P.M.	27	9	36	25%	13	8	21	38%	7	14	21	67%	0	5	83	36	43%
4:00-4:10P.M.	13	11	24	46%	19	9	28	32%	3	4	7	57%	0	6	65	30	46%
4:10-4:20P.M.	22	23	45	51%	23	14	37	38%	6	10	16	63%	0	7	105	54	51%
4:20-4:30P.M.	24	19	43	44%	25	25	50	50%	8	4	12	33%	0	9	114	57	50%
4:30-4:40P.M.	22	23	45	51%	15	32	47	68%	8	7	15	47%	0	7	114	69	61%
4:40-4:50P.M.	15	25	40	63%	19	25	44	57%	7	19	26	73%	0	6	116	75	65%
4:50-5:00P.M.	13	32	45	71%	5	22	27	81%	5	18	23	78%	0	7	102	79	77%
Total	176	174	350	50%	147	148	295	50%	61	93	154	60%		58	857	473	55%

Survey data in the southbound HOV lane during AM peak hours (Survey date: 11/10/2009)

Types of Vehicles	Car				Van				Truck				Motorcycle		Total		
	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation	Violation	Total	Violation	Violation rate
	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Number	Percentage
6:30-6:40A.M.	24	6	30	20%	28	5	33	15%	12	0	12	0%	0	7	82	18	22%
6:40-6:50A.M.	32	5	37	14%	34	2	36	6%	11	2	13	15%	0	7	93	16	17%
6:50-7:00A.M.	20	6	26	23%	10	2	12	17%	2	0	2	0%	0	4	44	12	27%
7:00-7:10A.M.	31	7	38	18%	14	7	21	33%	5	0	5	0%	0	3	67	17	25%
7:10-7:20A.M.	34	6	40	15%	18	5	23	22%	6	1	7	14%	0	3	73	15	21%
7:20-7:30A.M.	26	8	34	24%	17	10	27	37%	8	4	12	33%	0	6	79	28	35%
7:30-7:40A.M.	37	13	50	26%	26	9	35	26%	6	1	7	14%	0	3	95	26	27%
7:40-7:50A.M.	46	7	53	13%	20	9	29	31%	8	3	11	27%	0	1	94	20	21%
7:50-8:00A.M.	21	10	31	32%	25	8	33	24%	5	3	8	38%	0	3	75	24	32%
8:00-8:10A.M.	22	8	30	27%	18	12	30	40%	9	5	14	36%	0	5	79	30	38%
8:10-8:20A.M.	24	6	30	20%	15	6	21	29%	6	1	7	14%	0	2	60	15	25%
8:20-8:30A.M.	23	6	29	21%	14	7	21	33%	1	0	1	0%	0	6	57	19	33%
Total	340	88	428	21%	239	82	321	26%	79	20	99	20%	0	50	898	240	27%

Survey data in the southbound HOV lane during PM peak hours (Survey date: 11/10/2009)

Types of Vehicles	Car				Van				Truck				Motorcycle		Total		
	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation	Violation	Total	Violation	Violation rate
	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Number	Percentage
3:30-3:40P.M.	30	4	34	12%	15	2	17	12%	7	1	8	13%	0	1	60	8	13%
3:40-3:50P.M.	18	9	27	33%	14	2	16	13%	5	2	7	29%	0	2	52	15	29%
3:50-4:00P.M.	15	2	17	12%	14	1	15	7%	5	2	7	29%	0	5	44	10	23%
4:00-4:10P.M.	14	0	14	0%	15	6	21	29%	5	0	5	0%	0	3	43	9	21%
4:10-4:20P.M.	16	5	21	24%	11	1	12	8%	7	1	8	13%	0	0	41	7	17%
4:20-4:30P.M.	22	5	27	19%	6	7	13	54%	6	4	10	40%	1	1	51	17	33%
4:30-4:40P.M.	10	4	14	29%	17	4	21	19%	5	2	7	29%	0	2	44	12	27%
4:40-4:50P.M.	13	4	17	24%	6	2	8	25%	3	2	5	40%	0	2	32	10	31%
4:50-5:00P.M.	9	9	18	50%	8	7	15	47%	0	4	4	100%	0	2	39	22	56%
Total	147	42	189	22%	106	32	138	23%	43	18	61	30%	1	18	407	110	27%

Survey data in the northbound HOV lane during AM peak hours (Survey date: 11/12/2009)

Types of Vehicles	Car				Van				Truck				Motorcycle		Total		
	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation	Violation	Total	Violation	Violation rate
	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Number	Percentage
6:30-6:40A.M.	4	1	5	20%	4	0	4	0%	2	0	2	0%	0	0	11	1	9%
6:40-6:50A.M.	2	1	3	33%	1	0	1	0%	1	0	1	0%	0	0	5	1	20%
6:50-7:00A.M.	0	4	4	100%	3	0	3	0%	3	0	3	0%	0	1	11	5	45%
7:00-7:10A.M.	1	0	1	0%	10	1	11	9%	1	0	1	0%	0	1	14	2	14%
7:10-7:20A.M.	3	3	6	50%	4	0	4	0%	3	2	5	40%	0	0	15	5	33%
7:20-7:30A.M.	2	3	5	60%	1	1	2	50%	3	0	3	0%	0	0	10	4	40%
7:30-7:40A.M.	2	0	2	0%	6	2	8	25%	3	1	4	25%	0	0	14	3	21%
7:40-7:50A.M.	4	2	6	33%	8	1	9	11%	1	1	2	50%	0	2	19	6	32%
7:50-8:00A.M.	4	2	6	33%	4	2	6	33%	0	0	0	0%	0	2	14	6	43%
8:00-8:10A.M.	2	1	3	33%	8	0	8	0%	2	0	2	0%	0	0	13	1	8%
8:10-8:20A.M.	1	2	3	67%	6	0	6	0%	2	0	2	0%	0	0	11	2	18%
8:20-8:30A.M.	2	2	4	50%	1	1	2	50%	1	0	1	0%	0	1	8	4	50%
Total	27	21	48	44%	56	8	64	13%	22	4	26	15%	0	7	145	40	28%

Survey data in the northbound HOV lane during PM peak hours (Survey date: 11/12/2009)

Types of Vehicles	Car				Van				Truck				Motorcycle		Total		
	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation	Violation	Total	Violation	Violation rate
	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Number	Percentage
3:30-3:40P.M.	22	11	33	33%	20	3	23	13%	6	1	7	14%	0	3	66	18	27%
3:40-3:50P.M.	27	18	45	40%	17	6	23	26%	7	6	13	46%	0	5	86	35	41%
3:50-4:00P.M.	24	10	34	29%	14	4	18	22%	8	4	12	33%	0	5	69	23	33%
4:00-4:10P.M.	19	9	28	32%	13	7	20	35%	10	2	12	17%	0	4	64	22	34%
4:10-4:20P.M.	36	20	56	36%	25	13	38	34%	11	10	21	48%	0	6	121	49	40%
4:20-4:30P.M.	32	30	62	48%	24	24	48	50%	14	12	26	46%	0	4	140	70	50%
4:30-4:40P.M.	40	44	84	52%	16	33	49	67%	10	30	40	75%	0	7	180	114	63%
4:40-4:50P.M.	27	26	53	49%	8	25	33	76%	2	7	9	78%	0	3	98	61	62%
4:50-5:00P.M.	23	30	53	57%	16	20	36	56%	6	21	27	78%	0	5	121	76	63%
Total	250	198	448	44%	153	135	288	47%	74	93	167	56%	0	42	945	468	50%

Survey data in the southbound HOV lane during PM peak hours (Survey date: 11/17/2009)

Types of Vehicles	Car				Van				Truck				Motorcycle		Total		
	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation 2+	Violation	Total	Violation rate	No violation	Violation	Total	Violation	Violation rate
Time	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Percentage	Number	Number	Number	Number	Percentage
3:30-3:40P.M.	12	1	13	8%	5	3	8	38%	5	1	6	17%	0	1	28	6	21%
3:40-3:50P.M.	24	2	26	8%	13	1	14	7%	7	0	7	0%	0	1	48	4	8%
3:50-4:00P.M.	11	6	17	35%	13	2	15	13%	5	1	6	17%	0	1	39	10	26%
4:00-4:10P.M.	10	5	15	33%	12	0	12	0%	3	0	3	0%	0	2	32	7	22%
4:10-4:20P.M.	17	1	18	6%	8	2	10	20%	4	0	4	0%	0	1	33	4	12%
4:20-4:30P.M.	20	4	24	17%	15	1	16	6%	9	4	13	31%	0	0	53	9	17%
4:30-4:40P.M.	15	4	19	21%	14	2	16	13%	5	1	6	17%	0	0	41	7	17%
4:40-4:50P.M.	13	9	22	41%	15	3	18	17%	8	4	12	33%	0	0	52	16	31%
4:50-5:00P.M.	10	0	10	0%	9	4	13	31%	3	4	7	57%	0	1	31	9	29%
Total	132	32	164	20%	104	18	122	15%	49	15	64	23%	0	7	357	72	20%



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