

DEVELOPMENT OF ARTERIAL HIGH - OCCUPANCY VEHICLE ENFORCEMENT TECHNIQUES

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EXECUTIVE SUMMARY

The single occupancy vehicle is the preferred mode of transportation for most Americans. The comfort, flexibility, and convenience of the single occupancy vehicle is unmatched by any other mode of transportation. However, with the increased use of the single occupancy vehicle, many cities are experiencing congestion.

In order to combat the congestion problem, there has been a shift from building more roadways to using the existing transportation system more efficiently, by increasing the person carrying capacity. Strategies to improve the capacity of the existing transportation system include Transportation Demand Management, Advanced Travelers Information Systems, and Transportation System Management. High occupancy vehicle (HOV) lanes are one TSM strategy to improve the person-carrying capacity of the existing roadway system. HOVs are generally defined to include buses, vanpools, and carpools with two, three, or more people. HOV priority treatments are generally in the form of either dedicated through travel lanes or queue bypass lanes at roadway constrictions. There are several benefits associated with HOV lanes including decreased travel time, trip time reliability, reduced vehicle emissions and increased travel speed.

In order to ensure that the HOV lanes operate as designed, the HOV restriction needs to be enforced. Police enforcement is the most basic HOV lane enforcement technique; however, there are also many automated techniques which are being developed. These automated techniques include video cameras, automated vehicle identification, and machine vision.

Much of research on HOV lane enforcement has been done on freeway HOV lanes. There has been little research on arterial HOV lane enforcement. Due to the functional and operational differences between freeways and arterial streets, the enforcement techniques which have been developed for freeway HOV lanes may not be effective enforcement techniques for arterial HOV lanes.

The objective of this paper is to develop effective enforcement techniques for arterial HOV lanes. In order to accomplish this objective, literature on freeway enforcement techniques was reviewed, arterial HOV lanes were classified to determine their operational characteristics, and cities with arterial HOV lanes were contacted in order to determine the enforcement techniques which they use on arterial HOV lanes.

Arterial HOV lanes can be divided into five categories: downtown curb lanes, downtown malls, longer distance arterials, queue bypasses, and signal control strategies.

It was determined that the enforcement of arterial HOV lanes depends upon the type of vehicles which are allowed to use the HOV lanes. Video tape is recommended to enforce arterial HOV lanes restricted to buses only. The video camera can cost effectively determine the type of vehicle on an arterial HOV lane. Police enforcement is recommended to enforce arterial HOV lanes restricted to carpools, vanpools, and buses. Video cameras can not accurately determine vehicle occupancy. Additional research is needed to determine machine

visions effectiveness in determining the vehicle occupancy before it can be used for arterial HOV lane enforcement.

The location of enforcement equipment (video camera or police officer) depends upon the type of facility. In general, the enforcement equipment should be located in areas with limited number of right turning vehicles. On downtown curb lanes, it is recommended that the enforcement equipment be located in blocks which prohibit right turns at the downstream intersection. On arterial streets, the enforcement equipment should be located downstream from driveways or intersections with significant right turn volumes, while on queue bypasses, the enforcement equipment should be located immediately past the intersection.

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INTRODUCTION

Traffic congestion was a problem experienced only in major metropolitan areas, but now is a problem in large metropolitan areas, small cities, and even suburban areas. Unlike many other American social problems - poverty, hunger, low-quality education, homelessness, drug addiction - traffic congestion is directly experienced every day by millions of American commuters of all income levels (1).

The congestion that many cities are facing is a result of the American's love with the private automobile and a reduction in the number of miles of roadway constructed. The single occupancy vehicle is the preferred mode of transportation for most Americans. The comfort, flexibility, and convenience of the single occupancy vehicle (SOV) is unmatched by any other transportation mode. Between 1981 and 1989, total highway mileage in the United States went from 3.853 million miles to 3.877 million miles, an increase of only 0.6 percent, while at the same time, the number of cars and trucks in use rose by 24.0 percent and total vehicle miles driven increased by 33.6 percent (1).

In order to combat the congestion problem, there has been a shift from building more roadways to using the current system more effectively by increasing the person-carrying capacity of the existing roadways (2). Strategies to improve the person-carrying capacity include Transportation Demand Management (TDM), Advanced Travelers Information Systems (ATIS), and Transportation Systems Management (TSM). High occupancy vehicle (HOV) lanes are one TSM strategy to improve the person-carrying capacity of the existing roadway system. HOV are generally defined to include buses, vanpools, and carpools with two, three, or more people.

In order for drivers of single occupancy vehicles (Lone Rangers) to change their current travel behavior to using HOV (carpool, vanpool, or public transit), the benefits associated with HOVs must outweigh the benefits of travelling alone. The priority treatments of high occupancy vehicle lanes, generally in the form of either dedicated through-travel lanes or queue bypass lanes at roadway capacity restrictions, provide HOVs travel time savings and trip time reliability (3). In addition, HOV lanes produce reduced vehicle emissions and increased travel speed.

Many times a driver in the general purpose lanes will be "stuck in traffic", while the drivers in the HOV lanes will be moving at the operating speed of the freeway. The driver in the general purpose lane may desire to gain the benefits of travelling in the HOV lanes, even though they are driving alone. SOVs in the HOV lanes reduce the benefits associated with HOV lane travel. In addition, the operational characteristics of the HOV lanes are greatly diminished, due to the presence of SOV in the HOV lanes. The enforcement of high-occupancy vehicle (HOV) lanes has a considerable impact on the operational and safety characteristics of HOV projects (4). In order to ensure that the HOV lanes operate as designed, to maximize *person-throughput*, the HOV restriction needs to be enforced.

Purpose

Most of the research on HOV lane enforcement has been on freeways. There has been very little research on the enforcement of arterial HOV lanes. Due to the functional and operational differences between freeways and arterial streets, HOV enforcement techniques that are effective on freeways may not be effective on the arterial street system. The purpose of this report is to determine effective HOV enforcement techniques to use on arterial HOV lanes.

Organization of Report

Following the introduction, there are four primary sections of the report. The first section of the report summarizes the enforcement techniques which are currently used on freeway high - occupancy vehicle (HOV) lanes. In this section, the strengths and weaknesses of each enforcement technique is outlined. The second section of the report summarizes the different designs of arterial HOV lanes. The design of arterial HOV lanes will be analyzed in order to obtain an understanding of the function that HOV lanes serve in the arterial street system. Several cities with arterial HOV lanes were contacted in order to determine the arterial HOV enforcement techniques which are currently employed. The third section of the report summarizes the survey of cities with arterial HOV lanes. This section includes the geometric and operational characteristics of the arterial HOV lanes, and the enforcement techniques which are currently employed. The final section of this report contains recommendations of arterial HOV enforcement techniques.

HIGH - OCCUPANCY VEHICLE ENFORCEMENT TECHNIQUES

To maintain the viability of HOV facilities, the number of violators must be minimized. There are several enforcement techniques which have been developed for HOV lanes. The five main types of HOV enforcement techniques are police enforcement, commuter enforcement, automated vehicle identification, video cameras, and machine vision. Each of these enforcement techniques will be discussed in the following section. The advantages and disadvantages of each technique will be identified, along with monetary issues involved with its use. The second part of this section identifies two case studies of current enforcement techniques on freeway HOV lanes.

Police enforcement

Police enforcement is the most basic HOV lane enforcement technique. A police officer, stationed at the entrance of the HOV lane or at a pulloff, monitors the number of occupants in each vehicle in the HOV lane. If a vehicle does not have the required number of occupants to use the HOV lane, then the police officer can radio to an officer at a downstream enforcement area, pursue the violator, or record the license plate number and mail the registered owner the ticket.

There are three strategies for assigning enforcement officers to the enforcement of HOV lanes: routine enforcement, special enforcement, and selective enforcement. Each of these strategies are described below (5):

Routine enforcement: enforcement of HOV lanes in conjunction with the normal assortment of uniformed police officer duties.

Special enforcement: specific planning and application of police activities to an HOV facility for a period of time, as when a patrol car is specifically assigned to enforce a particular mainline HOV lane.

Selective enforcement: a combination of both routine and special enforcement, which varies in terms of time, location, and level of effort, with the purpose of producing a high level of motorist compliance by applying routine and special enforcement tactics in an unpredictable manner.

Motorcycle officers are sometimes used for freeway HOV enforcement, because they can maneuver easier in congested traffic than a traditional police car. In addition, motorcycle officers are better able to determine the occupancy of vehicles while in motion (6). The two disadvantages with motorcycle officers are they can not be used during bad weather and their decreased conspicuity due to the smaller size of the motorcycles.

Advantages

HOV lane violations are low where police officers are highly visible (7). Because the best measure of the effectiveness of an enforcement program is the number of violations, highly conspicuous police officer enforcement is an effective method of HOV lane enforcement.

Secondary vehicle downstream. The secondary police officer is generally located in a pullover (enforcement) area downstream from the first police officer. An enforcement area is defined as all of those places along an HOV lane that officers can safely and conveniently direct a violator for a warning, citation or diversion to a mixed traffic facility (6). After receiving information on a potential HOV violator, the downstream officer can verify that the vehicle does not have the required number of occupants. The downstream officer can concentrate his efforts on checking the occupancy of the few vehicles expected to be in violation of the HOV lane occupant requirements, rather than checking the occupancy of each and every vehicle in the HOV lane. In addition, HOV enforcement pullover areas built into the HOV system can also serve as a pullover area for emergency stops or vehicle breakdowns.

Single police vehicle. HOV enforcement with a single vehicle reduces the cost of the enforcement program. The second police vehicle can be used for other police duties including speed monitoring and accident reporting and investigation.

Ticket by mail. Finally, the "ticket by mail" option reduces the amount of time that police officers need to pursue and stop violators (2). The police vehicle, with its lights flashing, does not need to pull the violator onto the shoulder. This decreases undesirable traffic operations, including reduced speed and rear end accidents, caused by "rubber-necking". "Rubber-necking" is the result of the passing motorists desire to observe the temporary roadside activity involving the police and the violator. In addition, this option also enhances the safety for both motorists and troopers, and eliminates the need to construct HOV enforcement pullover areas at locations with restricted right of way (2).

Due to the death of a police officer, who was hit by a vehicle while issuing an HOV citation, the state of Virginia has passed legislation which allows police officers to mail HOV citations to motorists that they see violating the HOV restrictions (8). With the ticket by mail approach, approximately 80 percent of motorists observed violating the HOV restrictions receive citations (9). Rental cars and out-of-state vehicles observed violating the HOV lane restrictions are generally not mailed citations, because they may not be familiar with HOV legislation. The fine for an HOV violation in Virginia is \$70, which includes a \$20 court fee.

Disadvantages

All types of police enforcement of HOV lanes exposes police officers to traffic and weather (7).

Secondary vehicle downstream. After the downstream officer pulls the HOV lane violator onto the enforcement pullover, passing motorists "rubber-neck". As mentioned above, "rubber-necking" can increase congestion, reduce running speeds, and ultimately result in rear end accidents.

Single police vehicle. HOV enforcement by a single police officer also results in "rubber-necking". In addition, the single police officer method can also result in unsafe traffic operations when an enforcement area does not exist on HOV facility. For example, if the HOV lane is the median lane of the freeway, the violator would need to cross several congested general purpose lanes in order to reach the right shoulder.

Ticket by mail. Many states have legislation which prohibits issuing "tickets by mail" for moving traffic violations. There are four disadvantages associated with the "ticket by mail" enforcement method (2). First, by tracing the license plate, the police officer can determine the registered owner of the vehicle; however, the registered owner of the vehicle may not be the individual driving the vehicle. There has been some concern over the legality of making the registered vehicles owner responsible for an HOV violation. Second, a small number of motorists do not have their current mailing addresses recorded with the Department of Licensing. Third, "ticket by mail" procedure has created negative public support, especially in Virginia. Finally, ticket by mail reduces the positive effects of conspicuous police enforcement. Because the police officer is generally not conspicuous while recording the violators license plate, motorists may be more likely to violate the HOV restriction.

Monetary Issues

Due to the varying hours of operation (twenty four hours per day versus peak period) and intensity (once a week versus once a month) and type of enforcement (single vehicle, secondary downstream vehicle, or ticket by mail) it is difficult to determine an operational cost of police enforcement.

Commuter enforcement

An extension of police enforcement is commuter enforcement. Commuter enforcement allows disgruntled motorists to report HOV violations to a HOV hotline.

An example of commuter enforcement is the HERO program in Seattle, Washington, developed in 1984. The two purposes of the HERO program are to allow ridesharers an opportunity to vent their frustrations about violators and identify specific individuals who need an education on the purpose and operation of HOV lanes (10). The HERO program encourages people to call in HOV violators. Motorists observing the HOV lane violations are asked to report the license plate number, description of the violating vehicle, number of persons in the violating vehicle, and the time, date, and location of the violating vehicle (11). Between November 1988 and April 1989, the HERO hotline received between 100 and 200 calls per week (9). The phones are staffed between 8:00 a.m. and 5:00 p.m., and an answering machine records the calls during the remaining hours.

The first time that a vehicle is reported to be illegally using the HOV lane on the HERO hotline, the registered owner receives a brochure about the HOV system. The second time that a vehicle is reported on the HERO hotline, the registered owner receives the same brochure and a letter from the Washington State Department of Transportation stating that their vehicle was reported on the HOV lane without the required number of occupants and explaining the benefits of the HOV lane. The third time that a vehicle is reported to be illegally using the HOV lane,

the registered owner receives a more strongly worded letter from the Washington State Patrol asking the violator to refrain from using the HOV lane, unless they have the required number of occupants (12). For subsequent reported HOV violations, the registered owner of the vehicle receives the same letter from the Washington State Patrol. In addition, the Washington State Patrol may visit reported violators if they continue to be reported illegally using the HOV lane. The violator needs to be stopped in order to receive a ticket; there are not any tickets issued by mail. Studies done before and immediately after the HERO's implementation in 1984 determined that the HERO hotline reduced violations from 28.3 percent to 19.1 percent (a 33 percent reduction) on four mainline Interstate 5 locations (9).

There is also a similar program in Northern Virginia, which was implemented in 1989. For the first two offenses, the registered owner of the vehicle is mailed information on HOV lanes and is issued a warning. On the third offense, the violator is placed on the state police enforcement list. Warnings are not sent to out of state vehicles or rental cars, because they may not be familiar with HOV treatments.

Advantages

The most significant benefit of commuter enforcement is that individuals violating the HOV restrictions are given an opportunity to learn about the HOV facilities without being penalized. In addition, there is public involvement in the enforcement process, which is especially important on HOV projects (13). By being directly involved in the enforcement of HOV lanes, commuters gain a better understanding of the benefits associated with HOV lanes.

Disadvantages

With commuters having the power of the law, it becomes a battle of wits. In Northern Virginia, the HERO program had problems with motorists reporting vehicles that were not in the HOV in order to punish these motorists (8). It is hypothesized that this problem is due to the mindset of commuters in Virginia rather than the commuter enforcement program.

Automated vehicle identification (AVI)

Although automated vehicle identification (AVI) is currently not used in HOV lane enforcement, their use on toll facilities have proven them to be a technique for HOV enforcement in the future. The basic components on an AVI system are the vehicle mounted transponder (tag), the roadside reader and antenna array, a central computer system for processing and storing account data, and an enforcement and detection system (14).

Each carpool would have an AVI transponder mounted in their vehicle. The roadside reader broadcasts a signal which activates the AVI transponder in the vehicle. The central computer processes the interaction between the roadside reader and the transponder and stores the interaction. If the interaction between the transponder and the reader is not a valid interaction, then the enforcement system is activated and a photograph is taken of the vehicle in question.

Advantages

With the use of AVI technology, the upstream enforcement officer is no longer necessary. The downstream officer could monitor the enforcement system to identify potential violators. If ticket by mail is an option, there would not be a need for any enforcement officers to be exposed to traffic or weather.

Disadvantages

AVI technologies are currently not used as a method of HOV enforcement, because carpools can also be single occupancy vehicles on other trips. Many people feel that there is no correlation between a vehicle with a tag and the number of occupants in the vehicle. A study at Texas Transportation Institute, which surveyed AVI vendors, indicated that multiple transponders could be read from a single vehicle (each occupant in the vehicle would have their own tag) (11).

Requiring all occupants in a carpool to have a tag, becomes a problem of the "have" versus the "have not". Members of a carpool may decide it is not worth the price of a tag in order to participate in a carpool. Individuals in a carpool have to give up comfort, privacy, and flexibility in their schedule in order to participate in a carpool rather than drive alone. Requiring the members of a carpool to also purchase a tag to use the HOV lane facility, may reduce the benefits associated with carpooling and increase the use of the SOV. If the tags are provided free of charge, the members of the carpool need to apply and register for a tag. Again, the members of the carpool may feel that this inconvenience is not worth the benefits associated with carpooling.

Monetary Issues

For each enforcement location, the equipment costs for AVI enforcement is estimated to be \$108,000, while the operating costs are estimated to be approximately \$1,000 per month (11). The necessary AVI equipment includes the roadside reader, approximately 2,000 transponders or tags, and a video camera. The operating costs include the AVI and video equipment power and maintenance, in addition to the salary cost of an enforcement officer and technician (assuming one day per week) (11).

Video cameras

Video cameras are one example of an advanced technology for HOV lane enforcement. Video cameras are used to record both the number of occupants in the vehicle and the license plate of the vehicle in order to enforce the HOV lane requirements. A video camera set up for HOV enforcement, which has proven to be relatively effective, is shown in Figure 1.

SAMPLE CAMERA POSITIONS

1. Oncoming View
2. Oblique Oncoming View
3. License View
4. Eye-Level View

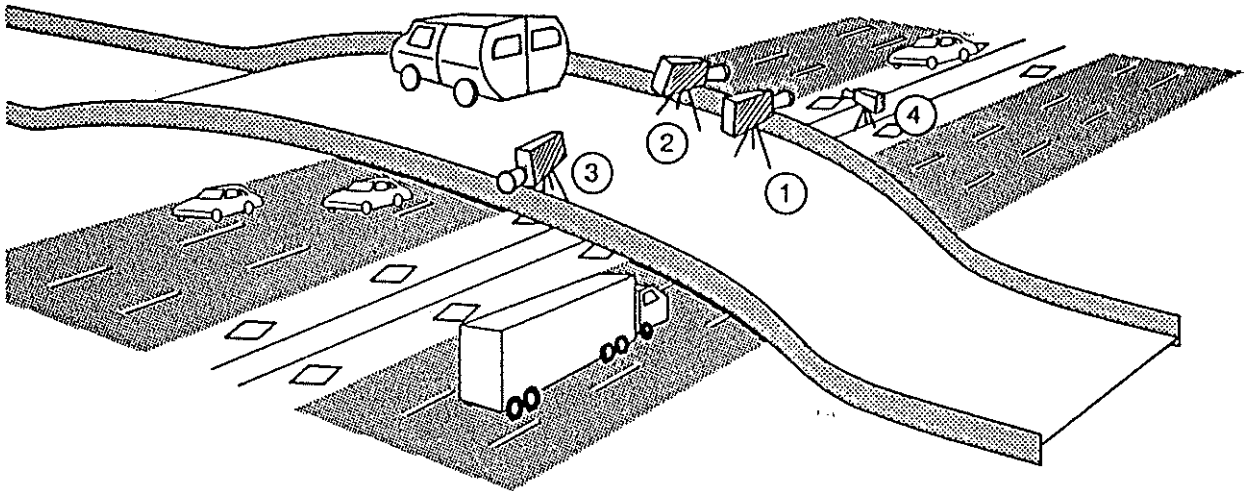


Figure 1. Video Camera Setup for HOV Enforcement (15).

There are four video cameras which can be used for HOV enforcement. These four views are:

1. An oncoming view;
2. A oblique oncoming view downward into the passenger seat;
3. A license view; and
4. An eye level camera view.

These are shown as video cameras 1, 2, 3, and 4, respectively in Figure 1. Camera 1 is used to provide a long range view of the vehicle, while camera 2 is used to view the interior of the vehicle. The third camera is used to document the license plate number. The eye level camera, camera 4, provided a view of the passengers in the back seat, along with a view of the passenger next to the driver. The eye level cameras must not be obvious to the driver; therefore, a micro-camera which is capable of being mounted on the median divider should be used (15).

The only video enforcement which has been evaluated consisted of two enforcement officer setups, which were approximately two miles apart. The upstream enforcement officer viewed the video tape to determine the vehicle occupancy, and would identify potential violators and radio the license plate and vehicle description to police officers located downstream (15). The two officer could pursue the potential violator and verify the violation (15). It is possible to eliminate the police officer who is viewing the video tape; however, cables must be placed in the corridor, which significantly increases the cost.

Advantages

Videotape with the capability of rewinding and reviewing questionable vehicles, has the capability of more accurate occupancy counts than those provided by roadside observers who must make decisions on the spot about vehicles moving past at 50 or 60 miles per hour (15). Video cameras also provide a permanent record of the driver, occupancy, and license plate which can be used in a court hearing.

Video cameras are an alternative on HOV lanes which do not have an enforcement area for a police officer to pull over an HOV lane violator (11). An officer stationed downstream from the video camera can verify the number of occupants in vehicles which do not appear to have the required number of occupants in based upon viewing the videotape. The presence of police officers can also reduce the "Big Brother is watching" stigma which is present with the use of video camera alone (15). The successful implementation of such a system could save police officer time, reduce the number of hazardous pursuits needed to apprehend HOV lane violators, and improve traffic flow by eliminating much of the rubbernecking which follows ticketing activities on the roadside (15).

Video cameras which are used to monitor the HOV lane restrictions can also be used for the dual purpose of providing surveillance in corridors for incident detection.

Disadvantages

One of the biggest problems with the use of video cameras for HOV enforcement is opposition from civil liberty groups. These individuals argue that the cameras conjure the image of "Big Brother", and as a result infringe on the privacy of motorists (15).

The minimum carpool definition requirements do not state that all passengers must be visible from the exterior of the vehicle (4). Video camera alone can not currently identify the number of occupants in a vehicle with enough certainty to issue citations for HOV lane occupancy violations. A study by Systan, Inc. for California Department of Transportation had a 21% error rate in detecting HOV lane violations (21% of those vehicles identified as violators by videotape reviewers which had been checked by officers on site actually had the required number of occupants) (15). Tinted windows, headrests, windshield posts, sun glare, morning mist on the windshield and other environmental factors also could obscure the camera's view (15).

Monetary Issues

For each enforcement location, the estimated equipment cost for video enforcement is approximately \$108,000, which includes a control van, four cameras, and all necessary enforcement equipment (15). In addition to the equipment costs, there is also the cost of an individual to record and reduce the video tape data, which will vary depending on the level of enforcement effort.

Machine vision

Machine vision is the use of electro-optical infrared sensors and / or image processors with pattern recognition to remotely identify and distinguish individual vehicle occupants (11). This thermal imaging technology has proven to be successful in military surveillance and reconnaissance purposes and has just begun to be used in non-military applications. Using pattern recognition and heat differentials, machine vision can differentiate a live person from a mannequin or a sleeping occupant from a warm rear axle. Currently, machine vision is not used for HOV enforcement.

Advantages

The use of machine vision for HOV enforcement would reduce the enforcement officers exposure to traffic and weather. Because machine vision has the ability to differentiate between a mannequin and a sleeping occupant, many of the object recognition problems associated with video enforcement are corrected. In addition, videotape records can be kept for evidence in court cases or identification of violators for mailings of HOV information and warnings (11).

Disadvantages

Machine vision is currently not widely available for commercial use. In addition, the presence of window glass may severely limit the usefulness of machine vision for HOV applications, because infrared energy emitted by occupants in the vehicle would be dissipated by the window glass (11).

Monetary Issues

The initial equipment costs for machine vision are unknown, but probably would be relatively high since it would be a newly marketed product (11).

Freeway HOV Lane Case Studies

The following section describes the enforcement techniques which are currently used on two specific freeway sections. For both freeways the geometry, enforcement techniques, and violation rates are summarized.

East R.L. Thorton Freeway (Interstate Highway 30) Dallas, Texas

The East R.L. Thorton Freeway is a contraflow high occupancy vehicle (two or more occupants) lane. A contraflow HOV facility operates one or more lanes in a direction of travel opposite to the adjacent mixed-flow traffic (3). The contraflow HOV lane on East E.L. Thorton Freeway is the inside lane of the off-peak direction of traffic and is separated from the off-peak general purpose lanes by a moveable concrete barrier. During the morning peak period, 6:00 a.m. to 9:00 a.m., 8.4 kilometers (5.2 miles) of contraflow HOV lanes are in operation, while during the evening peak period, 4:00 p.m. to 7:00 p.m., 5.3 kilometers (3.3 miles) of contraflow HOV lanes are in operation. The violation rates in September 1993 for the peak periods can be determined from Table 1. The high average vehicle occupancy is due to a significant number of buses which use the facility.

It should be noted that during the morning peak period, enforcement personnel may be stationed at an HOV lane entrance, but do not try to redirect the vehicles that do not contain two or more individuals onto the general purpose lanes. The enforcement officer at the entrance spots a violator and radios ahead to alert an officer at a downstream enforcement area of the violating vehicle and description. During the evening operation, enforcement personnel at the eastbound HOV lane entrance attempt to prevent ineligible vehicles from entering the HOV lane, by guiding SOV into the general purpose westbound lanes (11).

Dallas Area Rapid Transit (DART) is responsible for the enforcement of the East R.L. Thorton Contraflow HOV lane. DART has contracted the enforcement duties of the facility to off-duty officers from the Dallas City Police. Due to the high visibility of Dallas City Police officers, violations have been low. Between three and five HOV citations are issued each day (7).

Enforcement officers monitor the facility just about every day. Due to the large number of vehicles which use the HOV facility, the enforcement officers believe that the operational

quality of the HOV facility will diminish unless enforcement officers are constantly visible. The enforcement of the facility costs between \$3,000 and \$5,000 per month (11).

Table 1. Summary of East R.L. Thorton Contraflow HOV Lane (11).

	Morning Operation		Evening Operation	
	Peak Hour 6:30-7:30 a.m.	Peak Period 6:00-9:00 a.m.	Peak Hour 4:30-5:30 p.m.	Peak Period 4:00-7:00 p.m.
Total Volume Vehicles	1,120	2,700	1,040	2,130
Persons	3,550	8,230	3,700	7,080
Avg. Vehicle Occupancy	3.2	3.0	3.6	3.3
Number of Violations	33	105	0	3
Percent Violations	2.9%	3.9%	0.0%	0.1%

Santa Clara 101 Santa Clara, California

The Santa Clara HOV lanes have been in operation since November 1986. Santa Clara 101 is a eight lane freeway, with the HOV lane as the median lane. The HOV is not physically separated from the general purpose lanes; therefore, access to the HOV is unlimited from the adjacent HOV lanes. The high occupancy vehicle lane, which is limited to vehicles with two or more occupants and motorcycles, is separated from the median barrier by a ten foot median shoulder. The facility is a peak hour facility which operates between the hours of 5:00 a.m. to 9:00 a.m. and 3:00 p.m. to 7:00 p.m., Monday through Friday. The HOV lanes operate in the northbound direction during the morning peak period, and in the southbound direction in the afternoon peak period. During the non peak periods, the HOV lane operates as a general purpose lane. The initial HOV lanes were in operation between Lawrence Expressway and Guadalupe Parkway, three miles in length. In December 1988 the Santa Clara 101 HOV lanes were extended to twelve miles. The following violation rates reflect the original three mile length.

In 1987, it was determined that during the morning operation, 711 vehicles per hour use the HOV lane and 1,664 vehicles per hour use *each* general purpose lane, while during the evening operation, 970 vehicles per hour use the HOV lane while 1,535 vehicles use *each* general purpose lane (5). The California Highway Patrol is responsible for the enforcement of the HOV lanes. Between two and three officers are assigned to routine enforcement on Santa Clara 101 during the morning and evening peak period. In addition, both motorcycle and ordinary patrol officers are assigned to overtime HOV enforcement two or three times a week

(5). In 1987, California Highway Patrol officers issued on average 18.1 citations per day for HOV occupancy violations, 11.3 citations per day for routine enforcement and 6.8 citations per day for special enforcement (5). The number of violations include ramp bypass citation, which are approximately four per day (5). In January 1989, the cost of a first HOV violation was raised from \$35 - \$65 to \$100. All subsequent HOV fines are based upon a graduated rate. The graduated fines can be determined from Table 2.

It is estimated that approximately 2.5% of the violators receive citations. With an apprehension rate of 2.5%, the typical violator could expect to use the lanes illegally forty times before being caught, so that a daily commuter using the lanes illegally morning and evening would expect to be caught within a month (5).

Table 2. Penalty for California HOV Violations (5).

Offense	Penalty	
	Minimum	Maximum
First Conviction	\$100	\$150
Second Conviction (within a year)	\$150	\$200
Third and Subsequent Convictions (within two years)	\$250	\$500

ARTERIAL HOV LANE DESIGNS

There are several characteristics which can be used to describe arterial HOV lanes. These characteristics are described in the following sections: (13)

- *Separated, non-separated:* The HOV facility may be a physically separated from the general purpose lanes or the HOV lanes may be separated from the general purpose lanes by a barrier such as plastic pylons or a movable concrete barrier. The HOV lanes may also be located adjacent to the general purpose lanes without any physical barrier separating the two facilities. Non-separated facilities are generally very difficult to enforce.
- *Unidirectional, reversible:* A unidirectional HOV facility operates in the same directions during the morning and evening peak period, while a reversible HOV facility operates in one direction during morning operation and the opposite direction in the evening peak period.
- *Concurrent flow, contra flow:* Concurrent flow HOV lanes operate in the same direction as the mixed flow traffic lanes, while contra flow HOV lanes operate in the opposite direction of the adjacent mixed flow traffic lanes (3). Generally, the contra flow lane is one of the lanes in the off peak direction of the general purpose traffic lanes. Because there is significantly less traffic in the off peak direction, the contra flow lane utilizes capacity that would otherwise be wasted.
- *Median lane, curb lane:* The two most frequent locations of the HOV lane are the median lane and the curb lane. The median lane is not applicable for facilities with local buses, which must load and unload passengers frequently, because the passengers would be entering the travel lanes. Vehicles parked in the HOV lane restrict the mobility in the HOV curblane.
- *Buses only, buses and carpools:* HOV lanes can be restricted to public transit (buses) only, or the HOV lanes can be restricted to buses and carpools. If a facility has infrequent bus use, and is restricted to buses only, generally the public views the facility as a wasted facility, even if the general purpose lanes are not at capacity. A low number of buses may require the facility to operate as buses and carpools, in order to receive positive public support.
- *Hours of operation:* An HOV facility can operate continuously (24 hours a day, seven days a week) or it can operate only during the morning and evening peak periods. HOV priority treatments such as reversible flow lanes and contra flow lanes can only operate during the peak period, because there needs to be time to clear the HOV lanes and reverse the direction of flow.

- *System wide, spot applications:* System wide HOV applications are generally in the form of dedicated through lanes of travel. Spot treatments are short distance lanes to detour HOV around isolated capacity restrictions or bottleneck locations (3). Examples of spot treatments include queue bypasses (queue jumpers) at high - volume intersections, and approaches to toll plazas, bridges, and tunnels.
- *Signal priority treatments:* Signal priority treatments re-allocate the green time at signalized intersections to provide more time for a particular movement when eligible buses are present in the traffic stream (16).

There are many functional and operational differences between arterials and freeways. One of the main differences between freeways and arterials is design speed. Freeways generally have design speeds of 70 mph, while arterials have design speeds of 40 mph to 50 mph. In addition, access is more limited on freeways than on arterial streets. Access on freeways occurs only at ramps, while on arterials access is provided at intersections and driveways. Trips are generally shorter and more disrupted on arterials due to traffic signals, turning vehicles, and loading and unloading transit buses. Finally, pedestrians and bicyclists also use the arterial street system, and they are generally not found on freeways.

The enforcement techniques which are used on freeway HOV lanes, can not be directly applied to the arterial street system, due to the functional and operational differences which exist. It is necessary to determine the different types of arterial HOV lane designs which exist, in order to determine the enforcement technique which is most effective for different arterial lane designs.

There are five basic priority treatments which can be applied to arterial HOV lanes: downtown curb lanes, downtown malls, longer distance arterials, queue bypass, and signal control strategies. Each of these treatments will be discussed in detail in the following section.

Downtown curb lanes

Downtown curb lanes can either be concurrent flow or contraflow HOV lanes and are generally restricted to buses only. Due to the number of land access points and intersections in the downtown environment, they are generally not barrier separated from the general purpose lanes. The only separation between the HOV lanes and the general purpose lanes is generally a wide paint stripe. The typical downtown curb lane is shown in Figure 2.

The HOV in the downtown environment are generally located adjacent to the curb, in order to allow the safe loading and unloading of passengers on transit buses. When the HOV lane is located adjacent to the curb, there are conflicts with right turning vehicles and vehicles stopped or parked in the HOV lane.

Downtown malls

Downtown malls, or bus streets, are an entire segment of roadway exclusively used by HOV's (3). Most downtown malls in operation are reserved for transit buses exclusively, and are located in central business district areas which rely heavily on bus transportation.

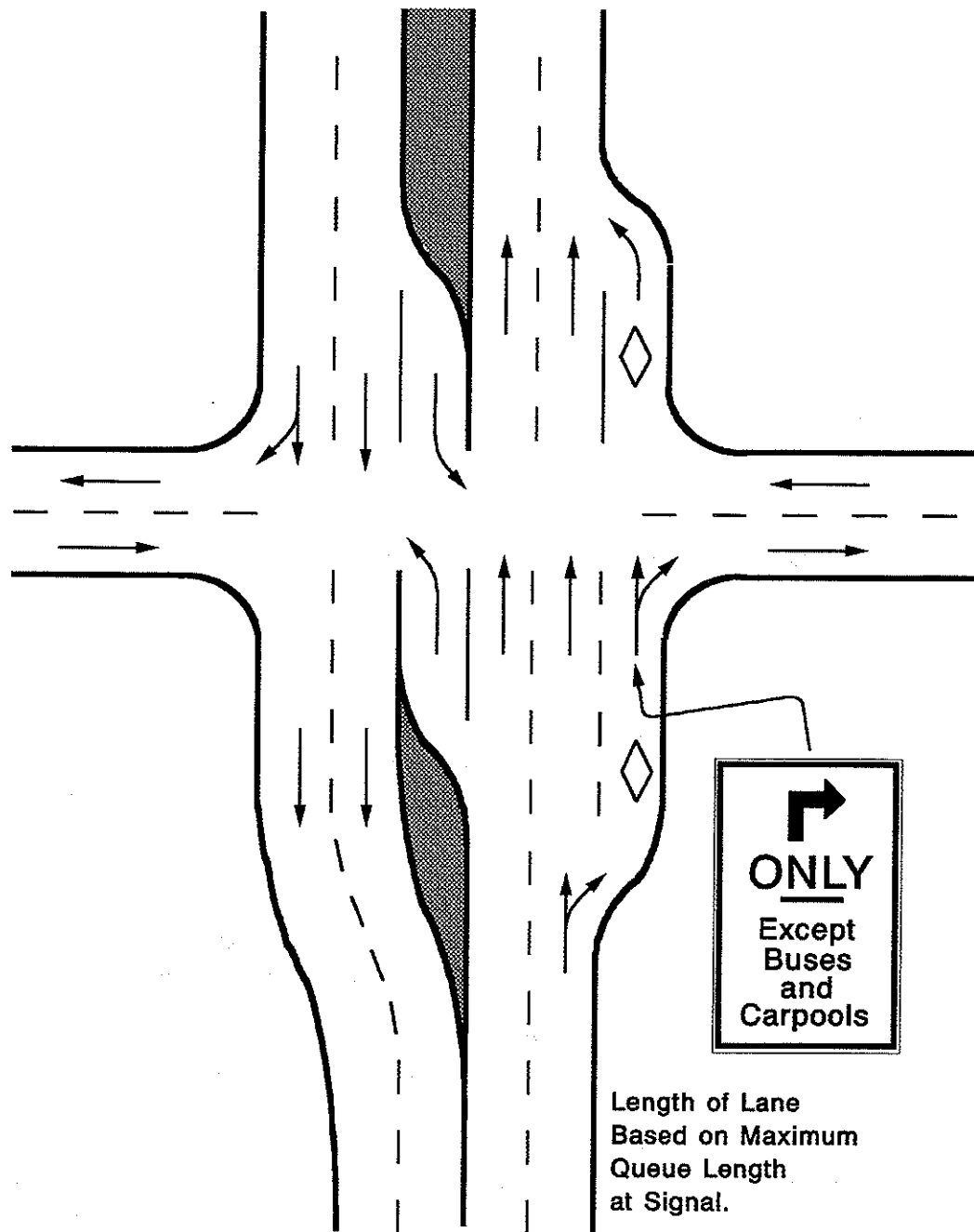


Figure 2. Downtown Curb Lane (16).

Bus streets and transit malls solve the problem of internal circulation, but bus exclusive facilities do not significantly reduce the line-haul congestion common on suburban arterial streets (3). There are many bus streets which currently are in operation including Nicollet Mall in Minneapolis, State Street in Chicago, and Chestnut Street in Philadelphia (17). A typical bus street design is depicted in Figure 3.

As seen in Figure 3, when there are greater than 60 buses per peak hour each way, a passing lane for buses should be provided at bus stops (17). This additional lane improves the operation of transit operations in congested corridors. In addition, a passing lane should also be provided when the bus lane extends for greater than one half mile (17).

Longer distance arterials

Unlike downtown curb lanes which are located in the downtown central business district, longer distance arterials are generally located in the suburbs. The longer distance arterial HOV lanes can be concurrent flow or contra flow, and they can be restricted to buses only or restricted to buses and HOV's. The longer distance arterial HOV lanes can be the curb lane, the middle lane, or the median (left) lane. Longer distance arterial HOV lanes are generally not used by local buses; therefore, they do not need to be located adjacent to the curb in order to pick up and drop off passengers. A typical concurrent flow left (median) side HOV lane is shown in Figure 4.

Queue bypass

A queue bypass, or queue jump, is a spot treatment which is short distance concurrent flow facility which enables HOV to bypass a congested location or bottleneck. The most common type of queue bypass locations are at bottlenecks, congested intersections, and approaches to toll plazas, tunnels, and bridges.

Figure 5 is the typical design for a queue bypass or queue jump. In the arterial street environment, queue bypasses are generally located at congested intersections. A special lead green signal phase may be provided for through movement vehicles in the queue jump, and a merge lane is provided downstream of the intersection (16).

Signal control strategies

Signal control strategies re-allocate green time at signalized intersections to provide more time for a particular movement when eligible high-occupancy vehicles are present in the traffic stream (16). Two different control strategies can be employed: unconditional and responsive. Unconditional preemption gives the HOV green, no matter the phase the traffic light is on. When unconditional preemption is used, there is a great deal of wasted cycle time (18). A more sophisticated system is the schedule responsive system. A bus can be programmed with its schedule for the day. As the bus is monitored by each intersection controller along the route, the on-time performance of the bus can be calculated, and preemption can be given to the bus only when the bus is behind schedule (18).

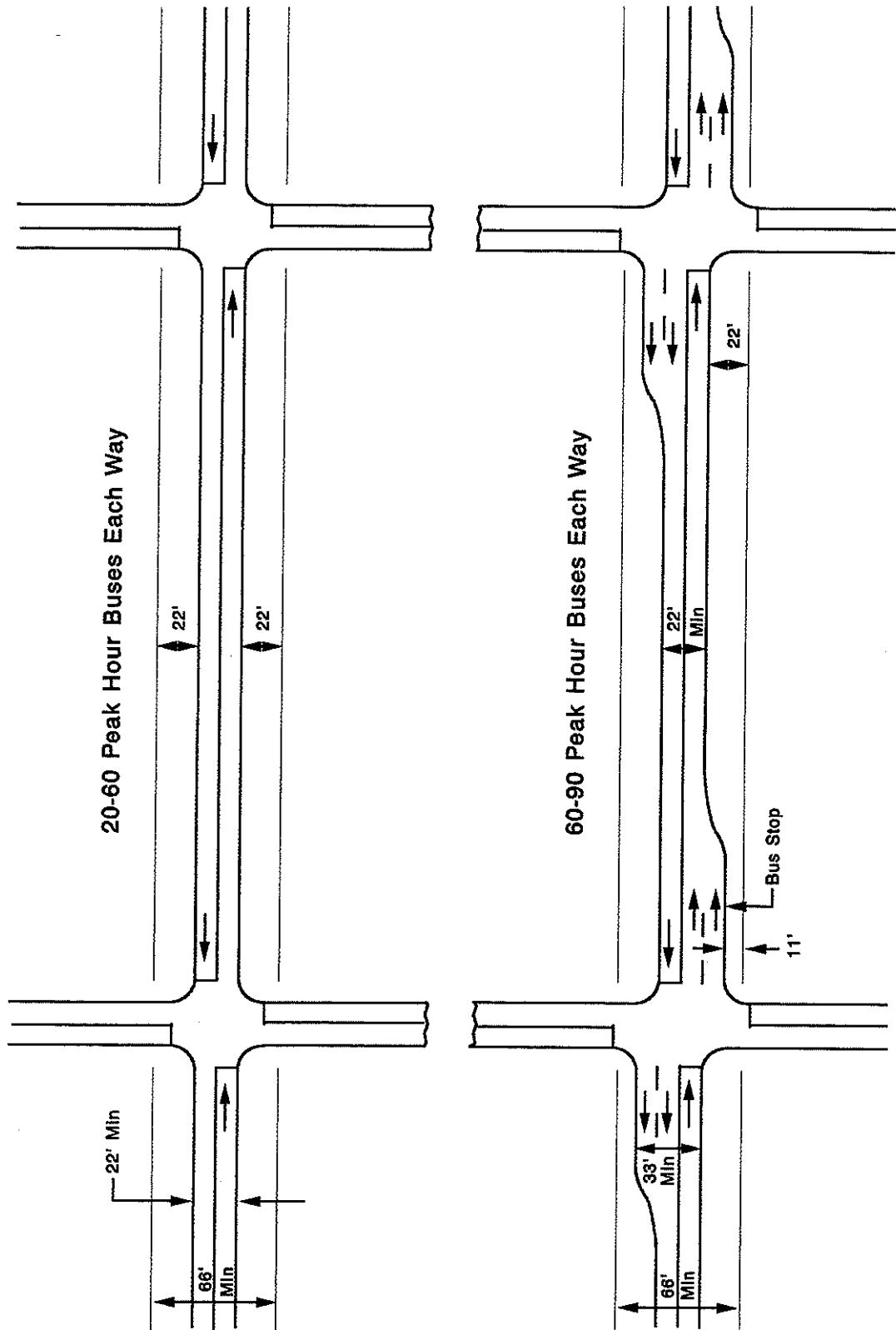


Figure 3. Typical Bus Street Design (16).

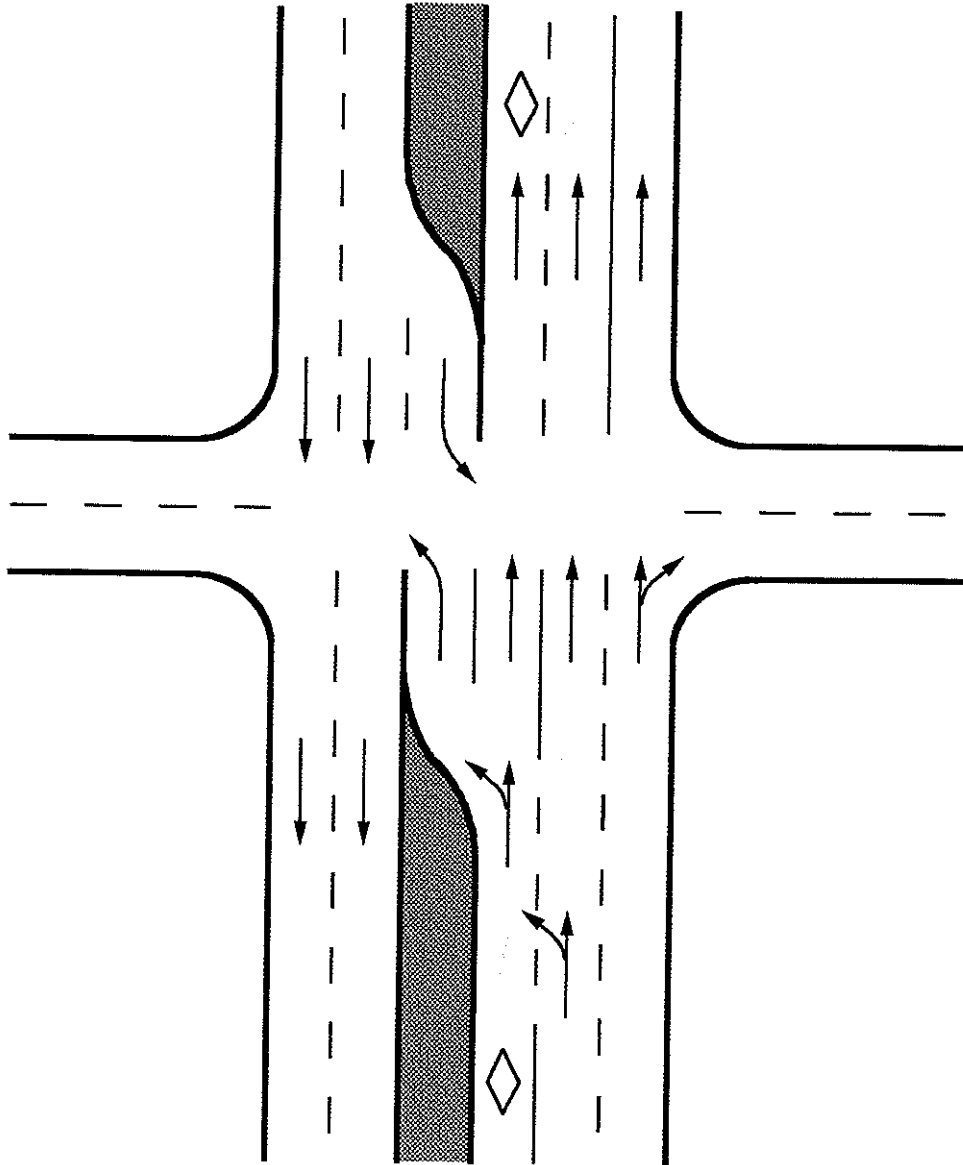


Figure 4. Typical Concurrent Flow HOV Median Lane (17).

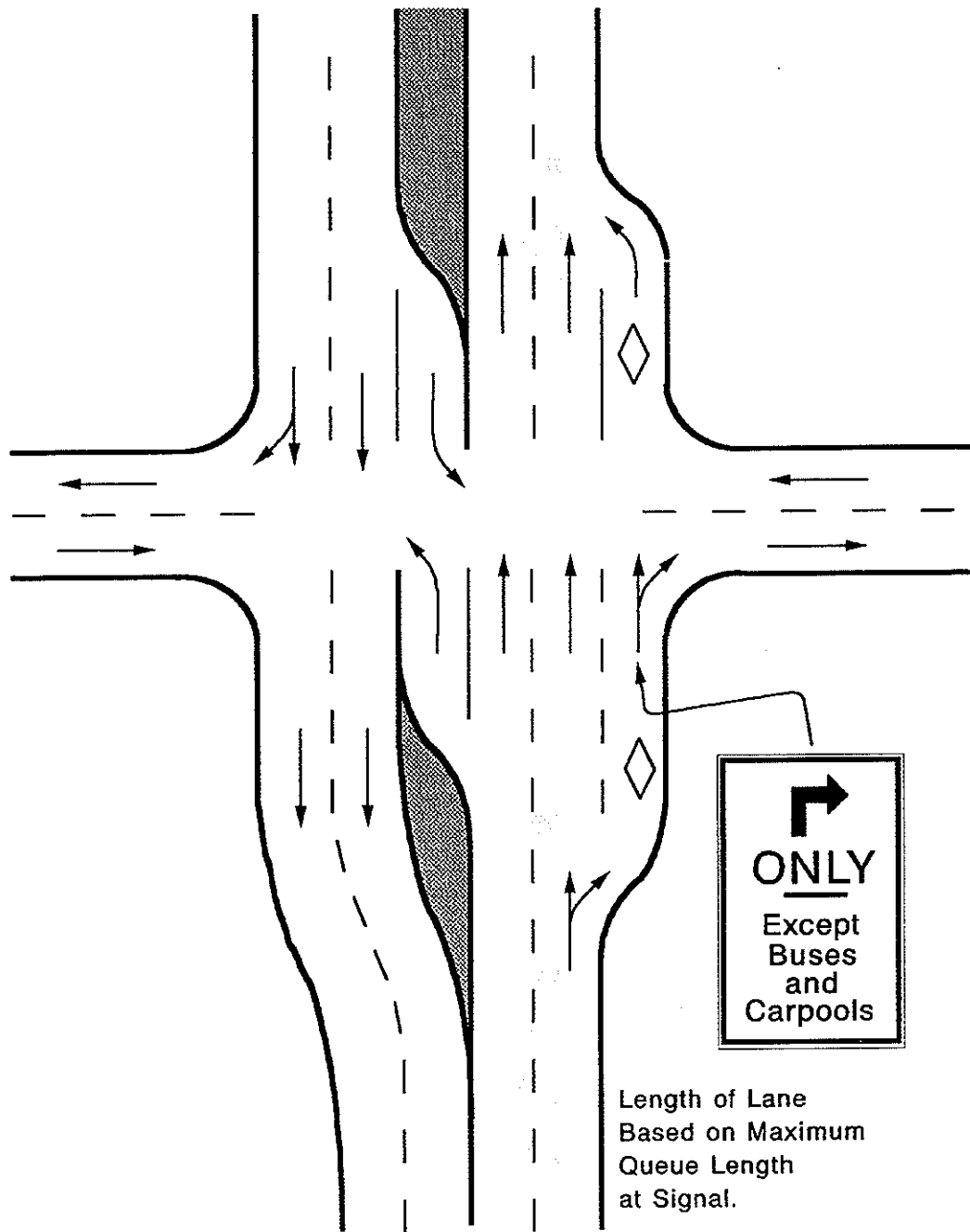


Figure 5. Signal Queue Jump (16).

Signal control strategies must be able to recognize the HOV in the traffic stream, in order for the signal control strategies to operate. Methods of identifying vehicles include strobe lights, loop detectors, and transponders. Strobe lights are typically used to provide emergency vehicles preemption at intersections. A receiver, which is activated by a strobe light in a vehicle requesting preemption, ensures that the green indication is displayed when the vehicle requesting preemption arrives at the intersection. Loop detectors can be placed at the bus stops to monitor when a bus is leaving a bus stop, in order to provide priority treatment at the adjacent intersection. A third type of vehicle identification, transponders, is shown in Figure 6. A transponder can be mounted on the underside of the HOV and is detected by a traffic loop in the roadway (16).

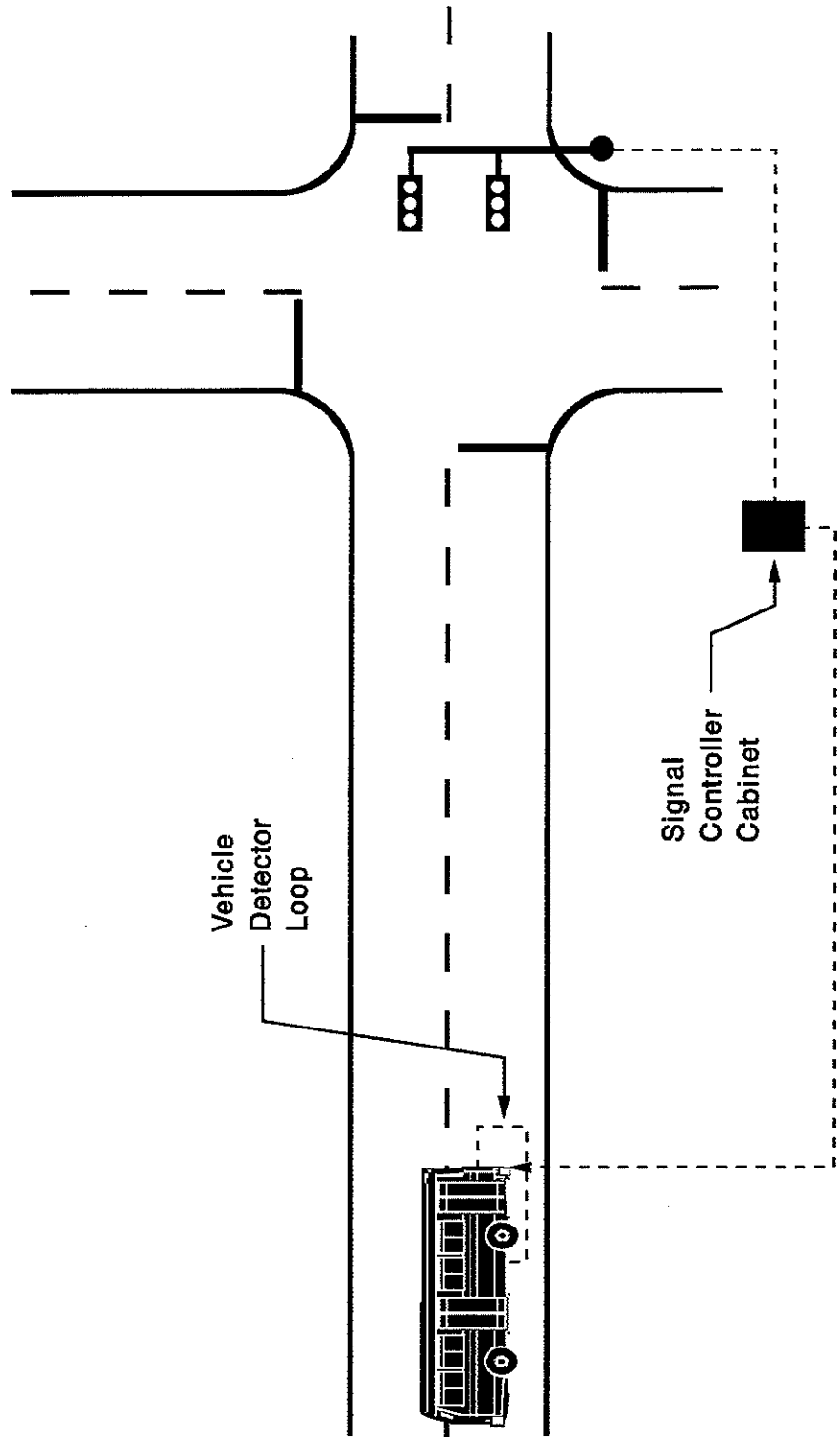


Figure 6. Transponder and Loop Detector used for HOV Enforcement (16).

SURVEY OF ARTERIAL HOV LANE ENFORCEMENT TECHNIQUES

Several cities with arterial HOV lanes were contacted to determine the HOV enforcement techniques which are currently used. The following section summarizes the enforcement techniques which are currently employed. This section describes the type of facility and the type of enforcement technique which is used. For most of the HOV lanes, it was not possible to obtain a HOV violation rate for the facility, because the violation rates are determined for all of the HOV facilities in the city rather than a specific facility.

Lincoln Broadway Bus Lanes. Denver, Colorado

The Lincoln Broadway Bus Lanes corridor is 2.3 miles in length and connects Interstate 25 to the downtown central business district (CBD). The location of this HOV lane is shown in Figure 7. Broadway is a five lane arterial street which operated in the southbound direction, with curb parking on both sides of the street. The bus lane is the right lane adjacent to the curb parking. Lincoln operates in the northbound direction. The 1.7 mile section south of Speer Boulevard is a four lane arterial, with the right lane as the bus lane. The section of Lincoln, north of Speer Boulevard, is a five lane arterial, with the bus lane the second lane from the curb. Curb parking is permitted on both sides of Lincoln north of Speer Boulevard.

The Lincoln Broadway bus lanes are a peak hour facility which operate between the hours of 7:00 a.m. to 9:00 a.m. and 3:00 p.m. to 6:00 p.m. During the non peak hours, the bus lanes operate as curb parking. When the bus lane is the right lane, cars and other vehicles turning right can travel in the bus lane for one block prior to their right turn as long as their right turn signal is operating (19). This facility is enforced by the City of Denver Police and court system. The type of violations present on this facility are (19):

- Those who drive in the HOV lane for several blocks, and claim that they were unaware of the HOV restrictions.
- Those individuals who understand the HOV restrictions, but violate the restrictions by either using the lane to pass a queue or by driving in the lane for several blocks with their right turn signal on.
- Those who leave a parked vehicle in the HOV lane during the restricted period.

During the first few years of operation, the courts in Denver did not honor HOV tickets. The defense of the violators was whether or not they knew what time it was (19). The violators would argue that they did not know the time, and claimed that there was nothing in the requirements of operating a motor vehicle in Colorado which stated that the driver needed to own a clock! This problem was solved in 1987 by adding flashing lights to the overhead signs. The lights flash on the overhead signs which state: "Buses and Right Turns Only When Flashing". The cost of an HOV violation is currently \$35 in Colorado.

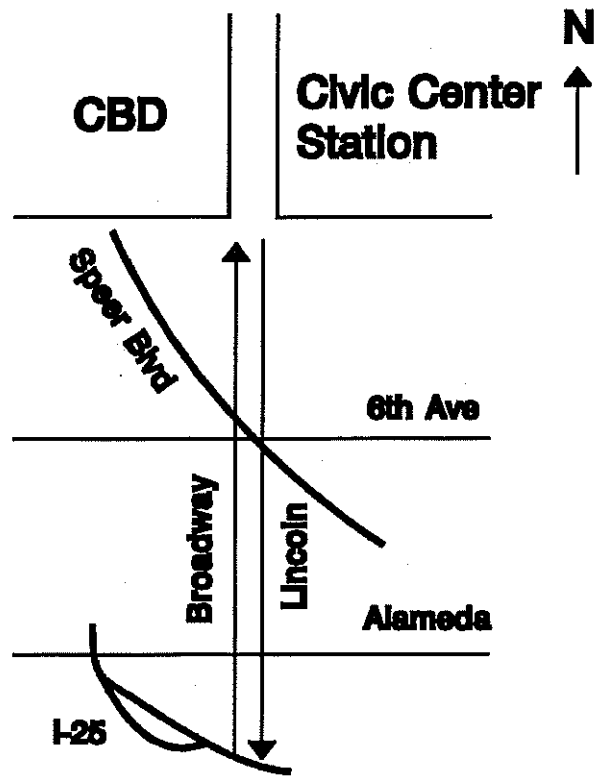


Figure 7. Broadway Lincoln Bus Lanes (19).

Louisiana Street. Houston, Texas

Louisiana Street is a five lane one-way arterial located in the central business district (CBD) of Houston, Texas. The HOV lane is nine blocks long and is restricted to buses only. The bus lane is not barrier separated from the adjacent general purpose lanes. The bus lane operates in the same direction as the adjacent general purpose lanes and is located adjacent to the curb.

The Louisiana Street is a peak period facility which operated between the hours of 7:00 a.m. and 6:00 p.m. Monday through Friday. During the off-peak hours, the bus lane operates as a general purpose lane. Due to the downtown grid system of one way streets in Houston, right turning vehicles are allowed to enter the bus lane every other block. The Metro Transit Police enforce the bus lane on Louisiana Street. The Metro Transit Police generally enforce the facility every few days; however, they will ticket a violator during routine enforcement. Every few weeks the Metro Transit Police run a task force on HOV street enforcement and spend more time monitoring the bus lane. The main violation is vehicles stopped or parked in the HOV lane (20). The Metro Transit Police have loud speakers attached to the top of their vehicles so they can pull up behind a vehicle parked in the bus lane and inform the driver to move his vehicle to the next cross street to receive a ticket. Because the bus lane is heavily used by buses, there is not any time saving benefits of passenger cars using the bus lane (20). The current cost an HOV ticket on the first citation in Houston in \$100. The fine for subsequent violations is up to the judge.

Spring Street. Los Angeles, California

Spring Street is a contra flow bus lane located in Los Angeles. The bus lane is located adjacent to the curb in operates in the northbound direction, while the three adjacent general purpose lanes operate in the southbound direction. The bus lane runs from 5th Street to 9th Street and is not barrier separated from the general purpose lanes.

The HOV lane on Spring Street operates as a bus lane twenty four hours a day. The Metropolitan Transit Authority (MTA), formerly Rapid Transit District is responsible for the enforcement of the bus lane. There are two or three mobile police units which are responsible for the enforcement of the facility, along with several officers on foot between the hours of 10:00 a.m. and 7:00 p.m.. The types of HOV violations include parking in the HOV lane, vehicles traveling in the HOV lane which are not buses, and vehicles traveling the wrong way. The MTA enforcement vehicles have bull horns attached to the top of their vehicle so that they can drive up behind a parked vehicle on the HOV facility and request the operator to move his vehicle off the HOV facility in order to be apprehended. In addition, part of the facility consists of two HOV lanes. The double HOV lanes provide space for buses to pass those buses that have stopped to pick up or drop off passengers. The enforcement officers can also use the second HOV lane to apprehend the violator and not affect the operations of the HOV facility. To improve the safety in the corridor, the buses operate with their headlights on at all times, so they are easier seen by the pedestrians (17).

Most of the violators are immigrants who are not intentional HOV violators (21). The signs for the HOV facility are in English only, but have international symbols on them.

Third Street. Minneapolis, Minnesota

Third Street is a four lane arterial which operates between Hennepin Avenue and Second Avenue North and is two blocks in lengths. The HOV lane, which is restricted to buses and HOV (two or more occupants), is located adjacent to the curb. The concurrent flow HOV lane is not barrier separated from the adjacent general purpose lanes. This HOV facility has been in operation for approximately one year.

The Third Avenue HOV lane is a peak period facility which operates between the hours of 4:00 p.m. and 6:00 p.m.. During the non peak hours, the HOV lane operates as a parking lane. The City of Minneapolis Police are responsible for the enforcement of the facility. There is heavy police enforcement of the facility. Upon spotting a violator, the police will apprehend the violator on the cross street. Due to the short length of the HOV segment, violations are not a problem, with violation rates estimated to be one percent (22). In Minneapolis, an HOV violation ticket costs \$25.

Third Street is the only arterial HOV facility which is enforced in the city of Minneapolis. All of the other HOV facilities are generally bus only, and violations are not a problem (22).

Aurora Avenue North. Seattle, Washington

Aurora Avenue North is a four lane arterial with a center two-way left-turn lane located in Seattle, Washington. The HOV lane is located adjacent to the curb. The concurrent flow HOV lane is located adjacent to the curb and is not barrier separated from the general purpose lanes. The adjacent land use is described as industrial / commercial with a lot of driveways (23). The HOV facility is restricted to buses and HOV (two or more occupants).

The HOV lane on Aurora Avenue North is a peak hour facility which operates between the hours of 3:00 p.m. and 6:00 p.m.. The City of Seattle police are responsible for the enforcement of the facility. The police generally apprehend the violators on the adjacent cross streets. Most of the enforcement is done by a police officer during routine enforcement. However, once a week there is scheduled enforcement of the facility. A violator is observed driving in the HOV lanes for a few blocks. An HOV ticket costs \$ 66 in Washington state.

Airport Road. Snohomish County, Washington

The Airport Road HOV lane operates between Interstate 5 and the Boeing plant. The HOV lanes were implemented to handle the increased traffic demands when the Boeing plant expanded from Boeing 747 to Boeing 777. The concurrent flow HOV lane is located adjacent to the curb on the majority of the facility. There is one section in which the HOV lane is the center lane due to intersection of an adjoining arterial. There is a high directional split, because the majority of the drivers are Boeing employees.

The HOV lane on Airport Road is a peak hour facility, which is limited to vehicles with two or more occupants. The Snohomish County police are responsible for the enforcement on the HOV lane. There is not a significant amount of enforcement of the HOV lanes, due to the cost of enforcement. In addition, it is difficult to enforce due to the amount of adjacent land access. The second phase of the Airport Road project will begin shortly, and one of the goals of the second phase is to determine a method to reduce the number of HOV violations.

Eglington Avenue. Toronto, Canada

Eglington Avenue is a six lane arterial, with 11 to 12 kilometers of HOV lanes. The concurrent flow HOV lane is located adjacent to the curb and is not barrier separated from the adjacent two general purpose lanes. The land use in the area can be described as suburban / commercial with a fair amount of land access.

Eglington Avenue HOV lanes are a peak period facility which operate between the hours of 7:00 a.m. to 10:00 a.m. and 3:00 p.m. to 7:00 p.m.. The Metro Toronto Police Force are responsible for the enforcement of the HOV lanes. Special enforcement is generally used on the facility. When a violator is identified, they are apprehended either on a side street or in one of the adjacent parking lots. Vehicles parking in the HOV lane is not a problem on this facility because parking is prohibited. An HOV ticket in Toronto costs \$14.75 and is scheduled to increase to \$62.

CONCLUSIONS AND RECOMMENDATIONS

As can be seen, the design and operation of arterial HOV lanes are significantly different than freeway HOV lanes. Some of the main differences in enforcement between the two types of facilities include:

- In the arterial HOV street design, HOV and other road users access to adjacent property must be an integral consideration.
- The lower speeds on arterial HOV lanes, along with the significant number of parking lots and driveways adjacent to the facility, does not make the safety of enforcement officers the prime concern on arterial HOV lanes enforcement.
- On the freeway HOV lanes, enforcement is primarily concerned with violations of the number of occupants in the vehicle, while on arterial HOV lanes, HOV violations must address vehicles stopped or parked in the HOV lane in addition to the number of occupants in the vehicle.
- State police officers are generally responsible for the enforcement of freeway HOV lanes, while city police officers or transit agencies are responsible for the enforcement of arterial HOV lanes. Police officers must deal with violent crimes along with non-violent crimes such as enforcement. Because transit agencies are concerned with the security of their customers, enforcement efforts may be more significant on facilities enforced by transit officers.

Adequate traffic enforcement is a key factor in the development of a viable, safe, and successful HOV preferential treatment project (4). Based upon the review of freeway enforcement techniques, arterial street design, and enforcement techniques which are currently used on arterial HOV lanes, recommended enforcement techniques were developed for each type of arterial HOV lane. A summary of the recommended enforcement techniques can be found in Table 3. Each of the recommended techniques are described in the following sections.

Commuter enforcement should not be used on any arterial HOV facility, because vehicles which do not have the required number of occupants are allowed to use the HOV lane for right turns at intersections and driveways. It would be very difficult for commuters to distinguish HOV violators from commuters using the HOV lane for right turns. Commuters would report all vehicles in the HOV lane without the required occupancy, even if the identified violator was legally in the HOV lane to make a right turn.

Table 3. Recommended Arterial HOV Enforcement Techniques.

Legend ○ Strongly recommend ■ Recommend – Do Not recommend ✓ Conditionally recommend	Police	Video camera	AVI	Machine vision
Facility				
Downtown curb lane				
Buses only	■	○	–	–
Buses and HOVs	○	–	–	✓
Downtown malls				
Buses only	■	○	–	–
Buses and HOVs	○	–	–	✓
Longer distance arterials				
Queue Bypass				
Intersections	○	–	–	✓
Toll Plaza				
Automated Collection	○	–	–	✓
Toll Booth Operator	○	–	–	–

Downtown curb lanes

On all downtown curb lanes, the presence of parked vehicles in the curb lane is one restriction that must be enforced. As stated earlier, several cities use a police vehicle equipped with a loud speaker attached to the top of their vehicle so they can pull up behind a vehicle parked in the curb lane and inform the driver to remove his vehicle to the next cross street to receive a citation. At first it may seem as though, the loud speaker would be a nuisance to pedestrians and business owners in the downtown area. However, when HOV violators are apprehended, the non-violating operators are psychologically reminded that their behavior is being monitored, and will be less likely to violate an HOV restriction in a subsequent trip. The recommended enforcement techniques of downtown curb lane enforcement depends on the type of HOV on the facility.

Downtown curb lanes restricted to buses

On downtown curb lanes restricted to buses only, the violation rate is generally low due to the conspicuity of a non-bus in the HOV lane. The violation of the HOV lane restriction is a result of the type of vehicle rather than the number of occupants in the vehicle; therefore, a single video camera mounted on a signal pole, pedestrian bridge, or other existing feature would suffice in the enforcement of the HOV requirement. In addition, this camera can be used for surveillance and incident detection purposes. This video camera should have a zoom feature which is capable of recording the license plate of the violator. The video camera should be placed directly overhead the center of the HOV lane, to obtain the clearest view of the license plate. The video camera should be focused to record the license plate of vehicles beyond the back of the queue from the intersection. If the video camera is focused closer to the intersection, the queue of vehicles may block the camera's view of the license plate.

Vehicles, other than buses, need to use the HOV lane to make right turns. The video cameras should be mounted at locations with minimal right turn maneuvers, so the right turning vehicles are not mistakenly identified as violating the HOV restriction. In most downtown areas, the streets form a network grid of alternating one way streets. Therefore, drivers desiring to turn right can enter the HOV lane every other block, as long as their right turn signal is activated. Therefore, the video cameras should *not* be placed in the blocks that allow right turning vehicles to use the HOV lane. A recommended video camera setup for downtown curb lanes restricted to buses only is shown in Figure 8.

It is important that the video cameras are not obvious to the motorists and pedestrians. Passing motorists and pedestrians may vandalize or steal the video cameras if they are conspicuous and easily accessible.

Generally, only one camera is needed for a downtown curb lane restricted to buses only, due to the low violation rate. A single camera can be relocated to record vehicles on different sections of the HOV facility on different days of the week. Due to the low violation rate, vehicles in the HOV lane do not need to be recorded during all hours in which the HOV lane is in operation; however, selective enforcement should be used to view vehicles at different times of the day, as well as, days of the week.

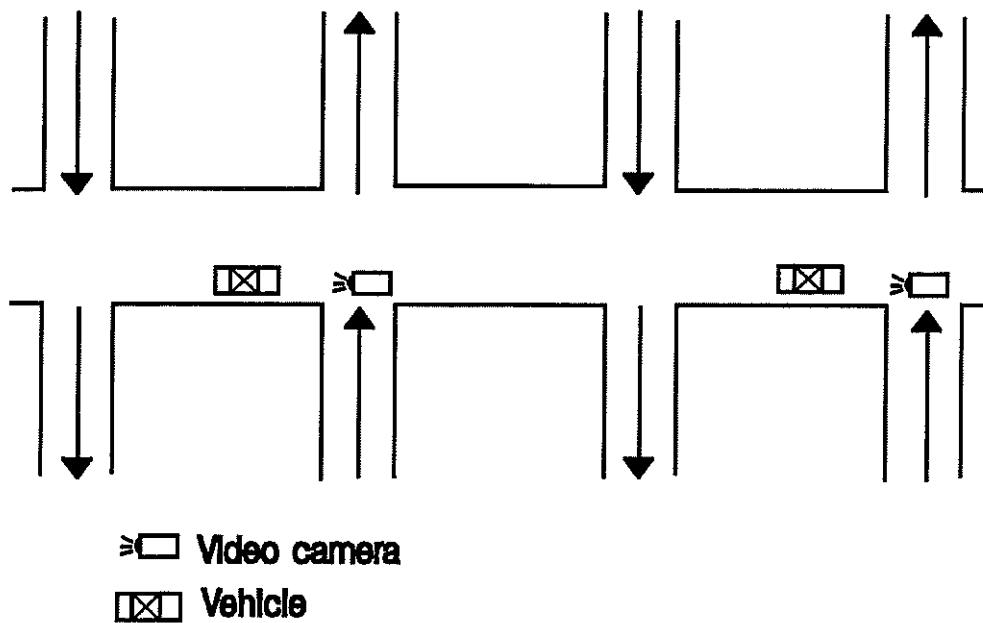


Figure 8. Recommended Video Camera Placement for Downtown Curbs Lanes - Buses Only.

The video tape should be reviewed by a technician. During the first few weeks that HOV lanes are opened or substantial enforcement is applied, the video tape can be used to identify motorists who need additional education on HOV facilities. Pamphlets on HOV facilities can be mailed to the registered owner of the reported vehicle. This will give motorists a chance to learn about the HOV facilities, without being penalized. Police officers should be present on the facility, although no citations are written so the general public observes the officers monitoring the facility. These officers can warn motorists of the new HOV restrictions, although no tickets will be written. The visual presence of police officers will help improve the compliance with the HOV restrictions.

After the first few weeks of operation, citations should be issued to the motorists illegally using the HOV lane. Technicians should view the video tapes in "real time", and radio to a police unit to pursue the potential violators. The citation process should take place on a minor cross street to minimize the adverse affect to traffic.

Downtown curbs lanes restricted to buses only can also be enforced by police officers; however, police enforcement is not as strongly recommended as the use of video camera. The police officers should not be located in the blocks which allow right turns at the downstream intersection, so there will be a minimum number of vehicles turning right in the HOV lane. When police officer enforce downtown curbs lanes restricted to buses, it does not use the officers time efficiently, because there is a low violation rate. The police officers could spend their time on more serious law infractions, including ticketing speeding drivers and investigating crime scenes.

The use of Automated Vehicle Identification (AVI) for downtown HOV curb lanes restricted to buses is not recommended, due to the cost of the enforcement system and the number of violators. As stated above, an AVI system consists of vehicle mounted transponders (tags), a roadside reader and antenna array, a central computer system for processing and storing account data, and an enforcement and detection system (14). The central computer system and enforcement system would probably be more expensive than a single video camera which can be used for enforcement.

It is not recommended that machine vision be used for the enforcement of downtown HOV lanes restricted only to buses. Because machine vision is not currently available, it will probably be expensive. Vehicle type can be identified with other enforcement methods at a significantly lower cost.

Downtown curb lanes for buses, carpools, and vanpools

On downtown curb lanes which are reserved for all high occupancy vehicles (transit buses, carpools, and vanpools), the number of occupants in the vehicle is the primary concern in determining if a vehicle is violating the HOV restriction. It appears that machine vision is the most promising technology for determining the number of occupants in a HOV. However, machine vision is not readily available. Because machine vision has not been evaluated as a HOV lane enforcement method, it is recommended that additional research be performed in order to determine if machine vision can be used to accurately determine the occupancy of vehicles. Until this additional research is conducted, machine vision can only be conditionally recommended to enforce HOV lanes restricted to buses, carpools, and vanpools.

Police enforcement should be employed on downtown HOV curb lanes which are restricted to carpools, vanpools, and buses. With the technology that is currently available, police officers are the most capable of determining the occupancy of vehicles in the HOV lane. With the reduced speeds on downtown curb lanes, the vehicle will be in the view of the police officer longer than on the higher speed freeways; therefore, it may be easier for the police officer to determine the occupancy of the vehicles. It must be noted that the safety of the enforcement officer should not be compromised during the enforcement procedure.

Due to the reduced speeds on downtown arterial streets, an effective enforcement technique may involve enforcement officers stationed midblock to record the license number of violators. As with the downtown curb lanes for buses only, enforcement officers should be located in the city blocks that do not permit right turning vehicles. This will minimize the number of cars and vans that the occupancy must be determined in. If parking is permitted along the facility, the police officer can be located in a parking space along the HOV lane. The police officers will be out of the way of traffic, while at the same time, will be conspicuous to the passing motorist. During the first few weeks of enforcement, the violators should receive brochures about HOV lanes in the mail. During this time, the public will have the opportunity to learn about HOV lanes without being penalized. After the first few weeks, citations should be given to the motorists violating the HOV restriction. When the enforcement officer issues a citation to the violator on the facility, the arresting procedure should be performed in a minor cross street, in order to mitigate the adverse affects to through traffic.

Due to the inadequacy of video camera of determining the number of occupants in a vehicle, it can not be used for HOV enforcement on downtown curb lanes for carpools, vanpools, and buses. The percentage of inaccurate HOV violations determined from video tape does not make it a viable alternate for downtown curb lane HOV enforcement. In addition, motorists who are incorrectly identified as violating the HOV restrictions and are pulled over by police officers, may create a negative attitude toward high-occupancy vehicle lanes. Until video cameras can more accurately determine the occupancy of vehicles, other techniques should be used for the enforcement of downtown curb HOV lanes reserved for all HOVs.

It is not recommended that Automated Vehicle Identification (AVI) be used to enforce downtown HOV curb lanes restricted to buses, carpools, and vanpools, because there is not any correlation between the number of occupants in the vehicle and a vehicle having a transponder. In other words, single occupancy vehicles can have transponders located in their vehicles, as well as high-occupancy vehicles. Police officers would be needed to determine the vehicle occupancy, if single occupancy vehicles could obtain transponders. It would be more cost effective to have police officers determining the occupancy of vehicles, rather than enforcing arterial HOV curb lanes restricted to buses, carpools, and vanpools with police officers *and* AVI technology. Therefore, AVI is not recommended for downtown curb lanes restricted to buses, carpools, and vanpools, because single vehicles can have transponders and AVI is not cost effective.

Downtown malls

Because downtown malls are limited to transit buses only, they are the easiest type of priority HOV treatment to enforce. Violations on bus only restrictions are uncommon because bus volumes can be high and this provides a self-enforcing feature and a non bus in the bus lane is very conspicuous to an enforcement officer (4). Downtown malls with a high volume of bus traffic will have a limited number of violations, because there is not any time savings associated with traveling in the downtown mall. In downtown malls with low bus volumes, some enforcement will be necessary in order to prevent automobiles from using the excess capacity on the bus lanes. Because bus malls operate similarly to downtown curb lanes restricted to buses only, the enforcement techniques recommended for downtown curb lanes restricted to buses only are recommended for downtown malls.

Because automobiles are generally not permitted in downtown malls, the problems associated with vehicles parking in the HOV lane do not present a problem on downtown transit malls.

Longer distance arterials

Longer distance arterial HOV lanes are generally used by carpools, vanpools, and public transit. The enforcement techniques which were recommended for downtown curb lanes are recommended for longer distance arterial HOV lanes.

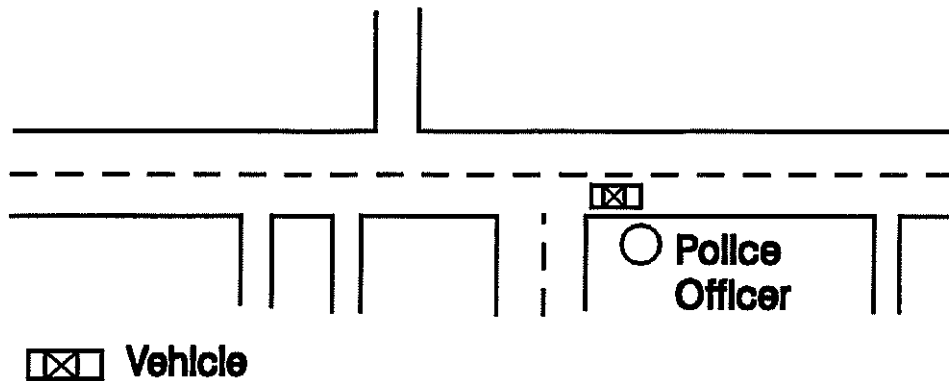


Figure 9. Recommended Police Officer Location for Longer Distance Arterial Streets - Buses, Carpools, and Vanpools

On longer distance arterials restricted to buses, carpools, and vanpools, the location of police officers is important in determining the effectiveness of arterial HOV lane enforcement. The police officers should be located where there would be a minimum number of vehicles in the HOV lane making a right hand turn. Therefore, the police officers should be located downstream from any major intersections or driveways. Figure 9 depicts a typical arterial street. Most of the vehicles in the HOV lane upstream from the intersection, will turn right at the intersection. As shown in Figure 9, the police should be located past the major intersection. However, the driveway downstream from the intersection should be analyzed to determine if there is a significant number of vehicles using this driveway. If there is a significant number of vehicles entering this driveway, the police officer should be stationed downstream from this driveway.

On longer distance arterial restricted to buses only, the video cameras should be located downstream from all major intersections and driveways. If the video cameras were located upstream from major intersections or driveways, there may be a significant number of non-buses legally in the HOV lane to make a right turn. Therefore, the right turning vehicles would be inaccurately identified as violating the HOV lane restriction.

Queue bypass

Queue bypasses generally occur at congested intersections or approaches to toll plazas or bridges. Queue bypasses are short distance arterial streets. Therefore, the enforcement techniques which were recommended for longer distance arterials are recommended for queue bypasses. From Figure 10, it can be seen that the police officer should be located past the intersecting cross street. If an enforcement officer was located prior to the intersection, single occupancy vehicles in the queue bypass could argue that they were turning right at the intersection.

A slightly different HOV enforcement technique is recommended for toll plazas and bridges without automated toll collection. On toll plazas and bridges without automated toll collection, the toll collectors can monitor the number of occupants in each vehicle entering the

facility. Vehicles which are in violation of the HOV restriction can be routed to an enforcement area to receive a citation from an enforcement officer. In addition, machine vision is not recommended on toll facilities without automated collection. A toll collector can determine vehicle occupancy at a significantly lower cost than machine vision.

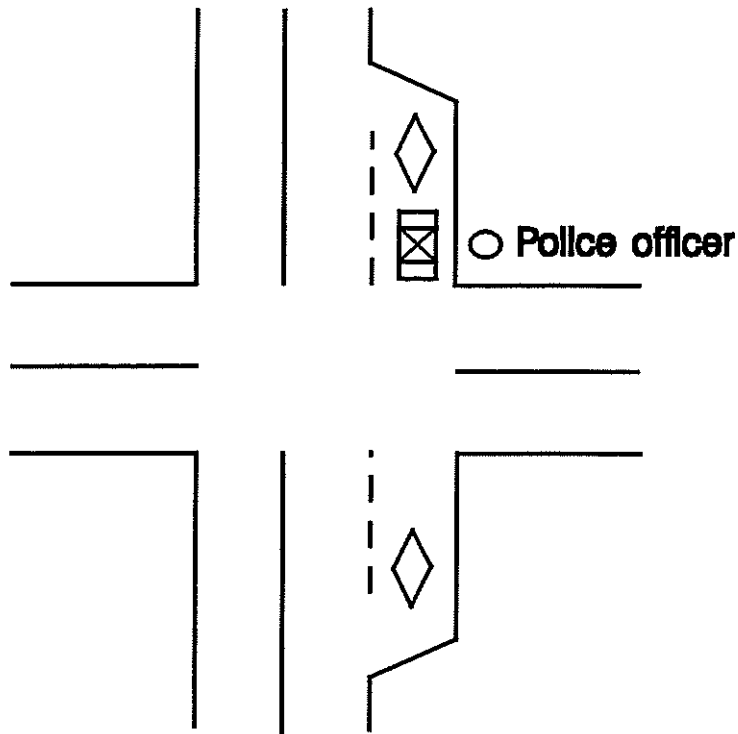


Figure 10. Location of Police Officers at Queue Bypass.

Signal control strategies

If transponders are only available to buses, the violations of signal control strategies are unauthorized vehicles having and utilizing the signal preemption transmitter and motorists unknowingly running the red light due to a change in signal phasing due to a HOV requesting preemption (4). Due to the nature of the HOV violations, there are not any enforcement techniques recommended.

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