Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-03/4160-11		

4. Title and Subtitle	5. Report Date
ENFORCEMENT ISSUES ON MANAGED LANES	September 2002 Resubmitted: January 2003
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
A. Scott Cothron, Douglas A. Skowronek, and Beverly T. Kuhn	Report 4160-11

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. Project No. 0-4160

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080	Research: September 2001 – August 2002
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Project Title: Operating Freeways with Managed Lanes

16. Abstract

This report provides an overview of enforcement issues for operating freeways with managed lanes. The role of enforcement is explored through identifying the available enforcement strategies and elements of enforcement area design. The state-of-the-practice for managed lane enforcement at various locations around the country gives insight of items to consider when developing an effective enforcement program. Lastly, this report acknowledges managed lane enforcement is becoming ever more dependent on technological advancements in presenting innovations in the area of automated enforcement technology, specifically, automated vehicle identification (AVI), license plate recognition (LPR), and electronic toll collection (ETC).

17. Key Words	18. Distribution Statement
Managed Lanes Enforcement, Managed Lanes Enforcement Strategies, Managed Lanes Enforcement Areas, Vehicle Identification (AVI), License Plate Recognition (LPR)	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	48	

ENFORCEMENT ISSUES ON MANAGED LANES

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Report 4160-11
Project Number 0-4160
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Sponsored by the
Texas Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The project was conducted in cooperation with the Texas Department of Transportation (TxDOT) and the U.S. Department of Transportation, Federal Highway Administration (FHWA). The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The engineer in charge was Douglas A. Skowronek, P.E., (Texas, # 80683).

NOTICE

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

The authors wish to acknowledge personnel from TxDOT who made this report possible. Special thanks are extended to the project program coordinator, Gary Trietsch, and project director, Carlos Lopez. Thanks are also extended to members of the project monitoring committee: Michael Behrens, Bill Garbade, John Kelly, Jim Randall, Jay Nelson, Mary Owen, Steve Simmons, Richard Skopik, and Robert Wilson.

In addition, Christy Harris of Texas Transportation Institute provided valuable support and technical assistance in seeing this report through to completion.

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INTRODUCTION

A managed lane facility requires effective enforcement policies and programs to operate successfully. Enforcement of vehicle-occupancy requirements, use by authorized vehicles, or proper toll collection is critical to protecting eligible vehicles' travel-time savings and safety. Visible and effective enforcement promotes fairness and maintains the integrity of the managed lane facility to help gain acceptance among users and non-users.

Development of enforcement policies and programs ensures that all appropriate agencies are involved in the process and have a common understanding of a project and the need for enforcement. Participation from enforcement agencies, the courts and legal system, state departments of transportation, and transit agencies is critical for enforcement success. This process begins by applying the appropriate enforcement strategy.

ENFORCEMENT STRATEGIES

Several strategies can be used to enforce managed lane facilities. The strategy chosen is influenced largely by the type of facility and its design. For example, high-occupancy vehicle (HOV) lane facilities require a different enforcement strategy than the strategy required for high-occupancy toll (HOT) lane facilities. Similarly, barrier-separated facilities would require a different enforcement strategy than the strategy required for buffer-separated facilities.

The enforcement strategy chosen for managed lanes usually can be described as one of the following: routine enforcement, special enforcement, selected enforcement, or self-enforcement. Routine enforcement uses existing freeway patrols to monitor managed lanes. Special enforcement uses dedicated equipment and manpower specifically to monitor the managed lanes. Selective enforcement is a combination of the other two strategies. This type of enforcement strategy may be used for specific events or concerns, such as the opening of a new managed lane facility or to combat high violation rates. The last enforcement strategy relies on the concept of self-enforcement. This involves promoting citizen monitoring and self-regulation by users of the managed lane and the motorists in adjacent general-purpose lanes.

Table 1 shows various locations of concurrent flow HOV lanes across the country, along with general information concerning the use of enforcement areas and procedures. Table 2 shows the state-of-the-practice for enforcement strategies from these states. Also shown is the required number of enforcement personnel, enforcement frequency, violation rates, and identified operational or safety concerns. Other managed lane facilities that incorporate pricing are described in detail later in the report.

Table 1. General Enforcement Information – Concurrent Flow Lanes.

Location	Routes	Enforcement Agency	Designated Enforcement Areas	Vehicles Pulled Over	Squad Cars or Motorcycles
Phoenix, AZ	I-10, SR-202, I-17	Lane not enforced	N/A	N/A	N/A
Vancouver, BC	H-99	Local police and Royal Canadian Mounted Police	None	Nearest corner	Cars
California	Many	California Highway Patrol	Median enforcement areas or inside shoulder	Enforcement area, inside or outside shoulder	Both
Hartford, CT	I-84, I-91	State Police	12 ft (3.66 m) buffer	Buffer on both sides of HOV lane	Cars
Ft. Lauderdale, Miami, FL	I-95	Florida Hwy Patrol	Pullover lane next to HOV lane	HOV enforcement lane	Both
Orlando, FL	I-4	Lane not enforced	N/A	N/A	N/A
Atlanta, GA	I-20, I-75, I-85	State police, local police, state transportation departments, certified police officers	I-20: 12 ft (3.66 m) inside shoulder. Spot areas of wider shoulder	Left-hand on and off ramps; follow violator to outside shoulder; I-20-inside shoulder	Cars
Honolulu, HI	Moanaloa Fwy, H-1, Kalanianaole Hwy, H-2	Honolulu Police Dept	H-1: Cutout on right shoulder	H-1: Outside shoulder	Motorcycles
Montgomery County, MD	I-270	Maryland State Police	12 ft (3.66 m) continuous shoulder and turnaround	Shoulder	Cars
Boston, MA	I-93 North	State Police	Median cutout	Median cutouts	Both
Minneapolis, MN	I-35W, I-394	State Police	None	Outside shoulder	Cars
Fort Lee, NJ	I-95	State Police	None	Outside shoulder	Cars
Morris County, NJ	I-80, I-287, NJ Turnpike	State Police	Wider locations on inside shoulder	Inside or outside shoulder	Cars
Suffolk County, NY	I-495	Suffolk County Police	Buffer zone between 2-directional HOV lanes separated by concrete median barrier	Buffer	Cars; summer-motorcycles also
Nashville, TN	I-40, I-65	Metropolitan National Police	I-40-in median I-65-none	Outside shoulder	Cars
Dallas area, TX	I-35E, I- 635	Dallas Area Rapid Transit	Enforcement station	Enforcement station	Both
Norfolk, Virginia Beach, VA	I-64, I-564, SR-44	State Police	Shoulder lane	Shoulder lane	Both
Northern Virginia, VA	I-66	State Police	Spot areas of wider shoulder	Follow vehicle - inside or outside shoulder	Both
Seattle, WA	I-5, I-90, I-405, SR-167, SR-520	Washington State Patrol	Shoulder widening	Enforcement area	Motorcycles mainly

Table 2. Enforcement Procedures – Concurrent Flow Lanes.

Location	Stationary or Roving	Routine, Selective, or Random	Officer Numbers	How Often	Violation Rates	Operational or Safety Concerns
Phoenix, AZ	N/A	N/A	N/A	N/A	N/A	N/A
Vancouver, BC	Stationary	Special	2	Varies	Unknown	Shortage of enforcement officers.
California	Both	Selective	1-4	Typically peak periods	1% - 9%	Speed differentials/buffer violations, detecting occupancy, motorist confusion-peak vs. 24-hour operation and barrier vs. lane striping, safe stops.
Hartford, CT	Roving	Routine	Varies	Not seen anyone pulled over during off-peak	5% Peak hour	No problem with violations; mainlanes are good.
Ft. Lauderdale, FL Miami, FL	Stationary	Routine-Heavy	7-15	Peak periods only (when open)	20% Peak period (Orlando)	Enforcement reduces operations of HOV lane due to curiosity of other motorists.
Orlando, FL	Orlando (I-4) not enforced		0	Not enforced	90%	Discontinued due to public outcry.
Atlanta, GA	Roving	Selective	7	24 hours per day including weekends	Unknown	Place rumble strips or jiggle bars in buffer to discourage crossing.
Honolulu, HI	Roving	Routine	1	Peak periods only (when open)	20% Peak hour 20% Peak period	No adjacent shoulder to HOV lane; violators must cross mixed-flow lanes to outside shoulder.
Montgomery County, MD	Both; stationary is easier	Routine (1 day/week) & special (4 days/week)	3	Peak periods only (when open)	7% - 33% NB 6% - 16% SB	Rubbernecking
Boston, MA	Stationary	Selective	1 or 2	About 3 days/week	Under 5%	Cost - police coverage. Officers' lack of knowledge of HOV rules (motorcycles and babies) due to high turnover rate in police force.
Minneapolis, MN	Both	Selective	3-4	Sporadic	Higher than separated	Shortage of enforcement officers. Difficult to see inside vehicle-infants, reclining passenger, etc.
Fort Lee, NJ	Roving	Unknown	Unknown	Unknown	Unknown	
Morris County, NJ	Both	Routine	3	4 of 5 weekdays during peak period	Unknown	I-80 - weaving at the entrance to the HOV lane.
Suffolk County, NY	Roving	Special	1	Peak periods only (when open)	5% - 10%	Working well.
Nashville, TN	Stationary	Selective	Unknown	Peak periods only	33% - 40%	Safety of pulling people over on right shoulder.
Dallas area, TX	Both	Special	Varies	Peak periods & some off-peak	1% - 6%	
Norfolk, VA Virginia Beach, VA	Stationary	Routine	2-3	Peak periods only (when open)	Unknown	
Northern Virginia, VA	Both	Selective	Varies; 1-10	Peak periods only (when open); Full week then 2-3 days the next week	12% - 13%	Safety of officers exposed to traffic. Problem with courts-some of the HOV cases are dismissed. Government vehicles exempt from HOV restrictions.
Seattle, WA	Both	Selective	Varies	All day	Unknown	Difficult to enforce without wide shoulders.

ENFORCEMENT IN DESIGN

Traditional enforcement on managed lanes requires the specific design treatment known as dedicated enforcement areas. These areas are usually located immediately adjacent to the managed lane facility and allow enforcement personnel to monitor the facility, pursue violators, and apprehend violators to issue appropriate citations. However, recent advances in automated enforcement technology may lower the number of dedicated enforcement areas needed in the future, thereby shifting the focus of design to proper placement of electronic equipment. Enforcement areas are discussed further here with the topic of automated enforcement presented later in the chapter.

Classification identifies enforcement areas as either low-speed or high-speed and usually by type of separation from the general-purpose lanes. Low-speed enforcement areas are associated with facilities that offer some sort of barrier separation and are usually located near entrance or exit ramps. High-speed enforcement areas are associated with non-barrier separated or buffer-separated facilities, either concurrent flow or contraflow, and are located along the managed lane mainline. The next section discusses general characteristics for both types of enforcement areas, along with preferred design features for each.

LOW-SPEED ENFORCEMENT AREAS

Busways, managed lanes on separate rights-of-way, and barrier-separated freeway projects usually locate low-speed enforcement areas at access points. Specific locations may include ramps, reversible lane entrances, and queue bypasses where vehicle speeds are relatively slow, usually below 45 mph (75 kph). In the case of reversible-exclusive managed lane facilities, the geometric requirements for reversing a facility provide temporary enforcement areas within the ramp areas that serve the opposing peak-period direction.

Planners design areas to provide for monitoring, apprehension, and citing of violators and, where practicable, violator removal from the managed lane facility. The design feature of barrier-separation acts as a deterrent to potential misuse, as violators are confined in the lanes once the decision is made to enter the facility. The following design features may be considered with slow-speed enforcement areas.

- The enforcement area should be at least 100 feet (30 meters) in length and preferably up to 200 feet (60 meters) on high-volume facilities, not including approach and departure tapers.
- The enforcement area should be at least a width of 14 to 15 feet (4.3 to 4.6 meters).
- The enforcement area should have an approach taper of 2:1 or 30 feet (9.1 meters).
- The enforcement area should have a departure taper of 10:1 or 150 feet (45.7 meters) to allow for vehicle acceleration into the lane.

HIGH-SPEED ENFORCEMENT AREAS

High-speed enforcement area design usually involves spacing multiple areas periodically along facilities that have multiple at-grade access locations or are lacking continuous shoulders wide enough for enforcement. These areas are usually designed for monitoring traffic and apprehending violators. Most apprehension activities occur at a downstream enforcement area or location with a wide left or right shoulder. The following design features may be considered with high-speed enforcement areas.

- The length of a high-speed monitoring area should be at least 100 feet (30 meters), not including the approach and departure tapers. For monitoring and apprehension, the preferable length is 1300 feet (396 meters).
- The enforcement area should be at least 14 to 15 feet (4.3 to 4.6 meters) in width.
- The enforcement area should have an approach taper of 20:1 and a departure taper of 80:1 or higher, or it may be controlled by general freeway criteria as required to fit in the design for proper acceleration to the design speed.
- Enforcement areas should be provided at a minimum interval of 2 to 3 miles (3.2 to 4.8 km) along the mainline managed lane facility.

Enforcement of two-way and reversible barrier-separated managed lane facilities is considered easier than with concurrent flow lanes due to limited access points. Violators may be stopped at entry and exit points where travel speeds are usually lower. A reversible facility allows enforcement personnel to monitor the facility from ramps that are not in use due to managed lane traffic moving in the opposing direction. Figure 1 provides examples of cross

sections using designated shoulders or other enforcement pockets located along the lane for facilitating enforcement activities.

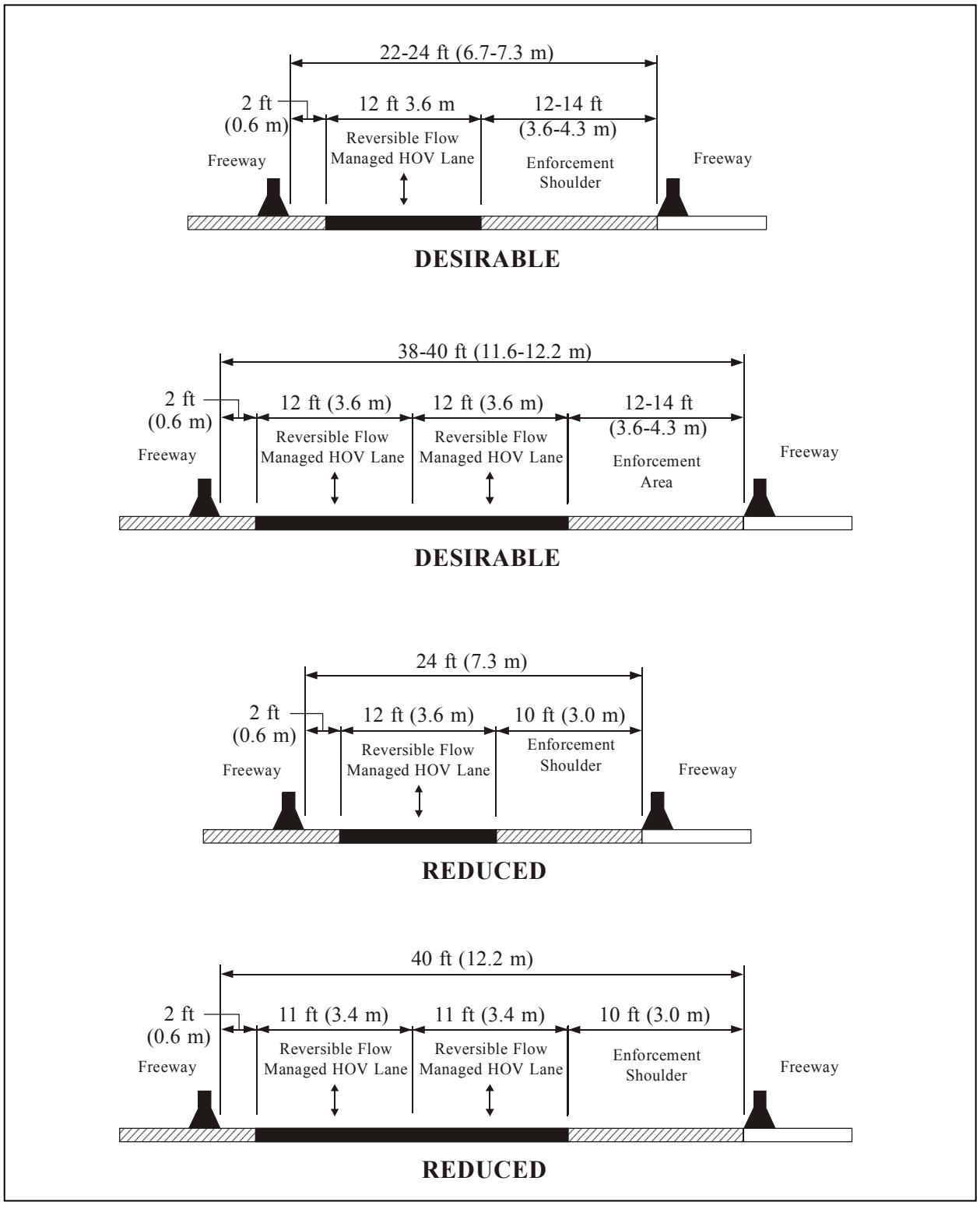

Figure 1. Examples of Cross Sections of Enforcement Areas along a Reversible Barrier-Separated Managed Lane
(Adapted from *NCHRP Report 414: HOV Systems Manual*).

Concurrent flow managed lanes are the most difficult to enforce due to motorists ability to enter and exit the lane at any time with relative ease. The maneuver is as simple as moving from one lane to another. Therefore, routine and consistent enforcement, whether perceived or seen by the public, is critical to managing lane violations. Figures 2 and 3 provide examples of cross sections and layouts for different types of enforcement techniques used with concurrent flow managed lanes.

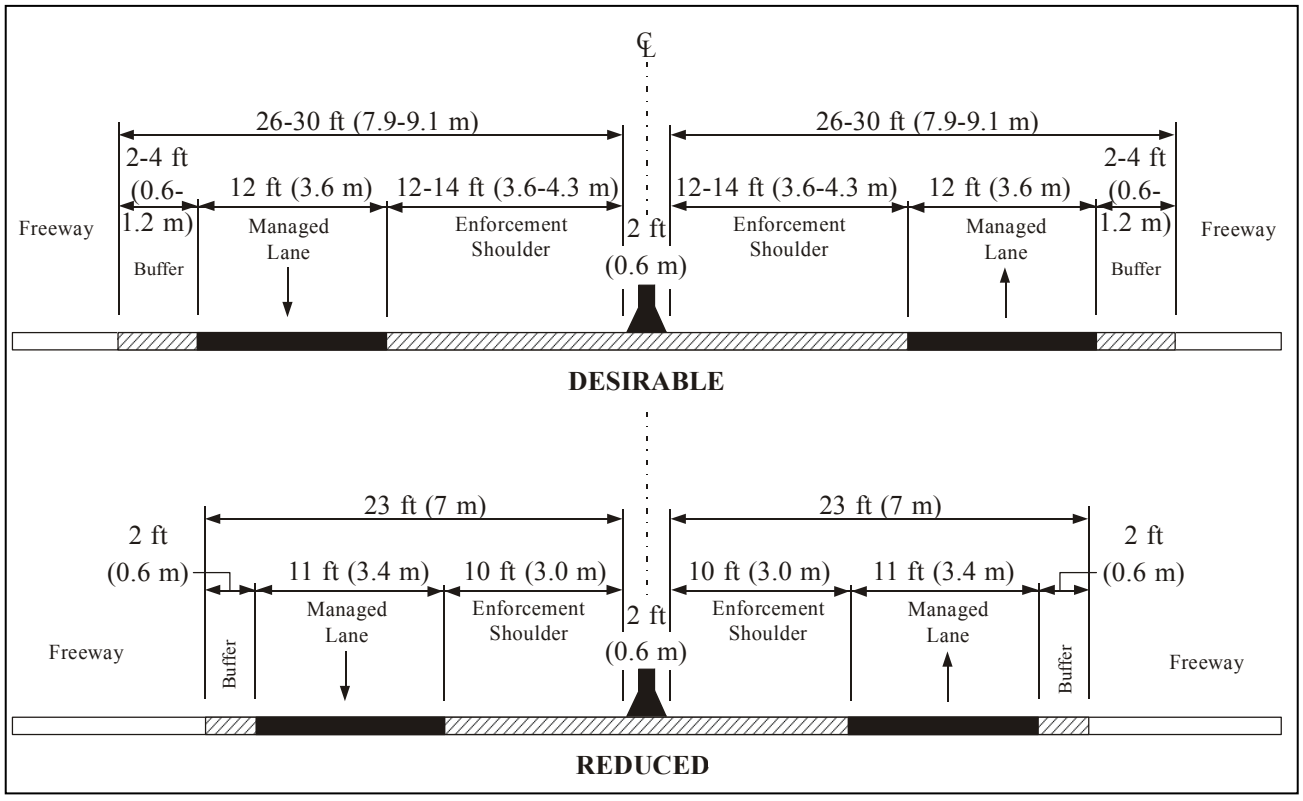

Figure 2. Examples of Cross Sections for Enforcement Areas along Concurrent Flow and Exclusive Buffer-Separated Managed Lanes (Adapted from *NCHRP Report 414: HOV Systems Manual*).

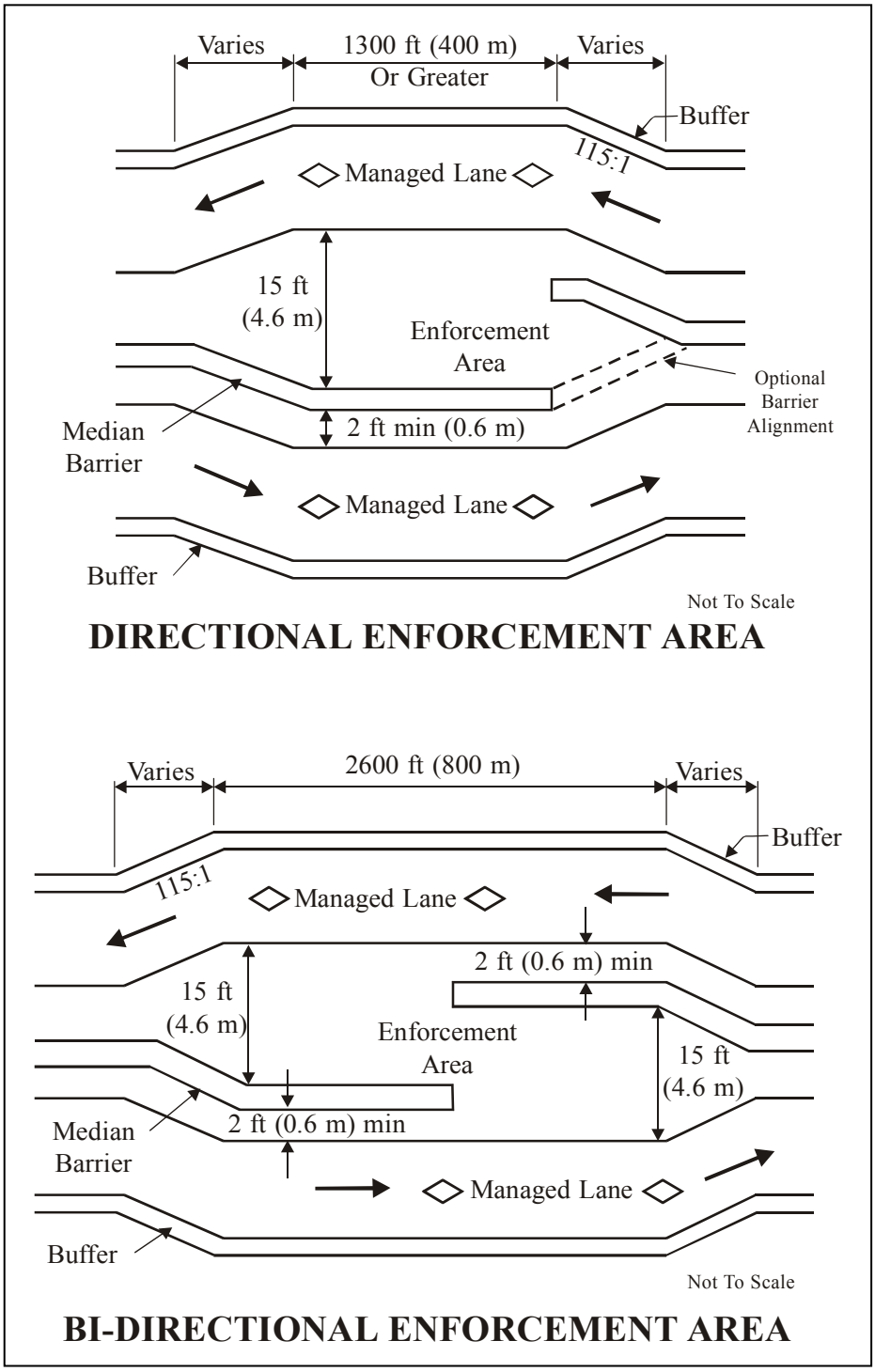

Figure 3. Examples of Directional and Bi-Directional Enforcement Area Layouts (Adapted from *NCHRP Report 414: HOV Systems Manual*).

ENFORCEMENT AGENCIES AND RESPONSIBILITY

Development of effective managed lane enforcement practices and procedures requires an understanding of existing managed lane enforcement programs and the responsible agencies. Examples of successful managed lane enforcement programs can be found in Orange County and San Diego County in California and in the Texas cities of Houston and Dallas. The "HERO" program of self-enforcement was first developed in Seattle, Washington, and has been successful as a public relations tool. The city of Minneapolis, Minnesota, is an example of an area that has had less than desirable results regarding its HOV lane enforcement program. An HOV lane enforcement program in the city of Toronto, Canada, offers a glimpse of the future of managed lane enforcement through the use of technology.

CALIFORNIA

The state of California has considerable experience with the managed lane concept. The California Highway Patrol (CHP) enforces HOV lane restrictions across the state. With the exception of SR-91 and I-15, CHP generally does not assign enforcement officers for the specific purpose of monitoring vehicle occupancies. Limited personnel resources must focus primarily on issues of safety and other law enforcement responsibilities with focused HOV lane enforcement being considered an overtime activity performed by off-duty officers.

The SR-91 express lanes in Orange County and the I-15 express lanes in San Diego County are two well-known managed lane facilities in California. Both of these facilities have contracted the enforcement services of CHP, which includes focused monitoring of vehicle occupancies. The SR-91 contract covers the costs for all CHP services 24 hours a day on what is otherwise not a state-owned roadway. The I-15 express lanes' contract covers the costs associated with CHP providing increased levels of enforcement daily. Prior to these agreements, CHP enforcement of the I-15 express lanes was limited to four days per month.

The SR-91 express lanes are privately funded and the nation's first implementation of variable tolling. Opened in 1995, the four-lane facility is located in the median of Riverside Freeway. Tolls are collected electronically with FasTrak transponders and overhead readers. The tolls vary by time of day to ensure the express lanes remain uncongested during peak travel times. Any transponder-equipped passenger vehicle may use the express lanes, and vehicles

without transponders are prohibited on the facility. Vehicles with a transponder and three or more occupants may use the express lanes for a reduced toll. A special traffic lane allows 3+ occupant vehicles to bypass automated toll-taking equipment. Video surveillance equipment verifies vehicle occupancy, and the proper reduced toll is assessed using photographic license-recording methods as vehicles pass spotter booths located at the midpoint of the facility. CHP issues citations with violation notices for vehicles without transponders being sent by mail, similar to the manner in which parking violations are handled.

In December 1996, the I-15 express lanes began operation as an HOV buy-in/HOT lane facility. Use of the two-lane, reversible facility had been previously restricted to carpools with two or more passengers, motorcycles, and emergency vehicles. CHP enforcement of the facility previously required visual identification of vehicles with two or more occupants, motorcycles, buses, and express pass vehicles with a visibly displayed permit. Permits issued early in the project were simply colored decals in which the color varied from one month to the next. Decals were later replaced with electronic transponders, and both were made available to express lane users for a flat monthly fee.

A visibly enhanced level of enforcement by CHP began on the first day of HOT lane operation. Enforcement was coordinated with the San Diego Association of Governments (SANDAG), who established a plan specifying varying levels of enforcement. Motorcycles are the preferred enforcement vehicle because of their ability to maneuver more easily with the barrier-separated, two-lane reversible facility. A noticeable reduction in single occupant vehicle (SOV) violations has occurred, most likely due to the dedicated CHP enforcement of the facility.

In March 1998, the FasTrak system fully automated dynamic pricing of the facility. Vehicles with two or more occupants and other authorized vehicles can use the facility free of charge, while SOVs are required to pay a fee. FasTrak transponders and overhead readers assess the required fees, which vary according to the level of congestion. CHP officers continue to be responsible for enforcement on the I-15 express lanes. Visual observation by highway patrol officers and electronic monitoring equipment determine whether a solo motorist is a qualified FasTrak customer who has paid the required toll.

WASHINGTON

The HERO program of self-enforcement was first developed in Seattle, Washington. It uses signs and other communication techniques to provide users and non-users with a telephone number they can call to report managed lane violators. Although the program has not had any impact on violation rates, it continues because of favorable public opinion. The HERO hotline is administered by King County Metro and funded by the Washington State Department of Transportation. The success of the HERO program has led to the development of similar programs in Houston, Texas, and the Washington, D.C. area, including Northern Virginia. The Northern Virginia program has since been discontinued due to funding issues.

TEXAS

Houston has 120 lane-miles (193 km) of HOV lanes, with nearly 5 percent of the city's workforce traveling in the reversible HOV lane facilities. During peak periods, the minimum vehicle occupancy of 2+ vehicle occupancies increases to 3+, with HOV lane buy-in available for 2+ on I-10 (Katy Freeway) and US 290 (Northwest Freeway).

As part of FHWA's value pricing program, pricing for 2+ HOVs on I-10 began in January 1998. Use of the HOV lane had previously been restricted to vehicles with 3+ occupants during the morning and evening peak hours. The buy-in program, known as QuickRide, is currently available only during the peak morning and evening operating hours. Users with varying commute patterns can insert their transponder in a shielding bag when using the facility as a 3+-occupant vehicle, so not to be assessed a toll.

The QuickRide program allows a limited number of travelers to participate. A pre-paid user account is established for accepted applications, and vehicle transponders are issued. The transponder, known locally as an EZ-Tag, also operates on the other toll roads in the area. Violation rates are less than 10 percent on I-10 using manual observation to verify 3+ occupant vehicles.

The QuickRide program is a smaller program relative to the other HOT lanes operating throughout the country. However, the program has achieved its primary goal for the corridor of improving HOV lane utilization by increasing person movement and average vehicle occupancy. The success of the program led to its expansion and implementation on the US 290 corridor in November 2000 during the morning peak period.

METRO police officers provide enforcement on Houston area HOV lanes. Enforcement ensures the safe and efficient operation of the HOV lane. At least one METRO police officer is present in the HOV lane corridor during hours of operation. They are responsible for patrolling and monitoring the corridor for violators of the HOV lane rules and regulations. Enforcement action is taken at specified enforcement areas that do not interfere with the flow of traffic.

A HERO program of self-enforcement has been operational in the Houston area for over 10 years. The program consists of a dedicated phone number that is available for motorists to call and report a violator on any of the HOV lanes. It is an automated system that requires motorists to leave a message about the reported violator. METRO transit police mail a letter to the reported violator warning them of the consequences of violating the HOV lane requirements.

Dallas has 47 lane-miles (76 km) of interim HOV lanes operating as barrier-separated and buffer-separated facilities. Dallas Area Rapid Transit (DART) transit police are responsible for enforcement of the HOV lanes. Although the number of enforcement personnel varies, enforcement on buffer-separated facilities is a combination of roving and stationary vehicles during peak periods and sporadic monitoring during off-peak periods. Facilities are monitored for the required number of vehicle occupants, as well as vehicles crossing the buffer at a non-designated area. The barrier-separated facility is effectively monitored with a minimum number of enforcement personnel, resulting from its design restricting movement of occupancy violators out of the lane.

MINNESOTA

The Twin Cities Metropolitan Area HOV lane network consists of concurrent flow lanes and barrier-separated, reversible lanes. HOV lanes on I-35W and I-394 are underutilized and suffer from excessive occupancy violations. The Golden Valley police and state patrol officers provide enforcement on these lanes. Earlier attempts to provide effective enforcement on the I-394 managed lane resulted in severe congestion on the general-purpose lanes due to onlooker delay. The induced congestion was so severe that the Minnesota Department of Transportation's (MnDOT) Traffic Management Center activated their changeable message signs to warn drivers: "Congestion ahead; use alternate routes." This warning may have prompted even more drivers to use the HOV lane illegally. Such enforcement problems have led to increased research on the use

of value pricing in these corridors. Value pricing would provide a level of traffic management on the HOV lanes. Vehicles that are now using the facility illegally on a routine basis, whether they need the travel-time savings or not, would probably pay the required fee to use the facility legally, and only when a travel-time savings is really needed.

CANADA

The opening of the Highway 407 express toll route (ETR) has credited Toronto, Canada, as a world leader in the field of electronic tolling and enforcement. The 407 ETR is a completely electronic toll highway stretching over 67 miles (108 km) across the north side of the Greater Toronto area. The most unusual feature of this facility is the ability to collect tolls from transponder-equipped vehicles, as well as cash customers, without using toll plazas.

Overhead tolling gantries are positioned to record transponder-equipped vehicles as they enter and exit the facility. Tolls vary by vehicle class and distance traveled on the facility. Vehicles exceeding 5 tons (4500 kg) are assessed an additional fee for using the facility. Additionally, since close to 30 percent of the vehicles using the facility are not equipped with transponders, their license plates are recorded electronically so that they may be billed through the mail. An additional processing fee is applied at the time of billing.

Non-local vehicles, not equipped with transponders, can also be billed by mail because of agreements developed with neighboring Canadian provinces and some states in the United States. Those vehicle owners with outstanding accounts for failure to pay their bill will have their information forwarded to the Registrar of Motor Vehicles, where renewal of vehicle registration can be denied until toll charges and fees are paid in full.

A license plate recognition (LPR) system is able to identify about 80 percent of vehicles not equipped with transponders. Digital images of the other 20 percent are reviewed by human eyes in an effort to identify vehicles for billing. Approximately 6 percent may not be billed at all, due to an inability to read license plates or the lack of an extradition agreement with the vehicle owner's home province or U.S. state.

The 407 ETR is patrolled seven days a week by dedicated safety and security vehicles. The Ontario Provincial Police (OPP) and Ministry of Transportation (MTO) enforcement officers also patrol the facility. Toll collection and enforcement is a completely automated process with enforcement of traffic offenses, such as speeding, still enforced by OPP.

AUTOMATED ENFORCEMENT TECHNOLOGY

The role of technology for managed lane enforcement is growing at an ever-increasing rate. For many years, intelligent transportation system (ITS) technologies have been available for use in monitoring roadways as part of various traffic demand management (TDM) programs. Early detection and quick response times have been vital for incident management and effective use of emergency services. Such advances are the precursor for the use of technology in monitoring and enforcement of managed lane facilities.

Automated enforcement of managed lanes may use many of the same technologies as ITS including speed sensors, road-imbedded vehicle detectors, surveillance cameras, and centralized traffic management centers. Successful enforcement of managed lane facilities requires that enforcing agencies have the ability to identify specific vehicles and, when necessary, determine the number of vehicle occupants. This success is possible through innovations such as license plate recognition and video-imaging technologies.

Today, approximately 30 private companies offer license plate recognition systems (LPRS). This technology is used widely for automated enforcement of managed lane facilities that assess tolls. Toll collection is usually done with electronic transponders or manual toll payments. When a toll violation occurs, the LPRS system is activated. A violator's license plate number may be stored locally, or it may be transmitted to a management center via standard dial-up telephone lines, cellular links, radio transmitters, and Ethernet networks. More advanced systems can interface with the image-capture system at the remote enforcement site to process digital images of the violator's license plate, access motor vehicle registration data, and print and issue violation tickets by mail. This technology excels in reliability with reportedly near perfect recognition rates up to 99.5 percent. Such results can be expected during severe weather conditions, including lightning storms.

Electronic transponders used for automated vehicle identification (AVI) systems provide a high reliability with rates up to 99.995 percent for accurately receiving and transmitting information to highway vehicles, even those vehicles traveling at excessive speeds. Advanced error detection and correction ensures that information is transferred accurately. Lane discrimination technology ensures that transponders ignore signals from AVI readers in adjacent travel lanes.

Technology also exists for determining compliance with vehicle occupancy requirements on HOV/HOT lanes. HOT lane facilities allow vehicles not meeting the occupancy requirement to use the facility for a fee. Enforcement requires observation of the interior of vehicles for the appropriate number of occupants. A typical strategy for this 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 semi-automatic review process notes 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 semi-automated HOV enforcement and review system, known as HOVER, has been tested in Dallas, Texas, using the strategy discussed above.

The system developed by Transformation Systems, Inc., in cooperation with Computer Recognition Systems, Inc., was installed on the I-30 (East R.L. Thornton Freeway) contraflow HOV lane. It proved to be effective for mailing HOV educational information to suspected violators. The test results noted that 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.

Additional camera views would enhance the system. However, there would still be some difficulty in capturing images of small passengers or children in car seats. Obviously, vehicles with tinted windows would pose a problem to the system as well.

Research in the area of automated vehicle identification has resulted in the development of a new technology known as a high-speed bar code reader by Pearpoint, Inc. Pearpoint, known for their innovations in automatic license plate recognition (ALPR) hardware and software, has conducted trials of their new high-speed bar code reader for the Federal Motor Carrier Safety Administration (FMCSA). Tests determined whether this technology would function well for identifying and tracking commercial vehicles. It was initially conceived as a potential replacement for AVI tags used for tolling passenger vehicles on managed lane facilities.

The Pearpoint system uses a technologically advanced camera with pulsed infrared illumination combined with an extremely fast shutter speed allowing crisp images to be captured at highway speeds. Computer software has been developed to examine each field of video, at a rate of 60 frames per second, and determines if a bar code image exists. When a bar code image is detected, the image is electronically cut out of the larger field of view and read by the bar code

reader. A bar code system of vehicle identification could provide the same information as other available AVI systems.

The previous discussion provided a general overview of some uses of technology within a managed lanes environment for the purpose of enforcement. Actual application of enforcement products requires an understanding of the technology categories and the viability of particular product name brands, which are available from various vendors around the world. Managed lane enforcement technology includes such categories as AVI systems, electronic toll collection systems (ETC), LPR systems, and video occupancy enforcement. Table 3 provides a list of potential vendors for the various technologies discussed.

Table 3. Enforcement Product Vendor Information.

Vendor Name	Telephone / Fax	Address	Website
Aselsan AS	90-312-385-19-00 90-312-354-13-02	P.O. Box 101 Yenimahalle, Ankara, Turkey 06172	www.aselsan.com
Asia Vision Technology, Ltd.	852-2319-2648 852-2319-2665	Unit 1107, 11/F., Tower III Enterprise Square 9 Sheung Yuet Rd. Kowloon Bay, Kowloon, Hong Kong	www.asiavision.com.hk
Belgian Advanced Technology Systems	32-04-367-08-88 32-04-367-13-14	Parc industriel de recherches du Sart Tilman Avenue des Noisetiers B-4031 Angleur (Liège) BELGIUM	www.bats.be
Combitech Traffic Systems AB	46-36-194300 46-36-194300	P.O. Box 1063 SE-55110 Jonkoping, Sweden	www.trafficsystems.com
EFKON AG	43-0-316-69-56-75 43-0-316-69-56-75	Andritzer Reichsstrassee 66 8045 Graz, Austria	www.efkon.com
Golden River Traffic, Ltd.	44-0-1869-362800 44-0-1869-246858	Churchhill Road Bicester, Oxfordshire, UK OX26 4XT	www.goldenriver.com
Mark IV IVHS	905-624-3020 905-238-3141	6030 Ambler Dr. Mississauga, Ontario, Canada L4W 2PI	www.ivhs.com
Micro Design ASA	47-73-82-65-00 47-73-82-65-01	P.O. Box 3974 Leangen N-7443 Trondheim, Norway	www.microdesign.no
Monitron Int.	44-0-1562-825556 44-0-1562-822256	Birchen Coppice Trading Estate Stourport Rd. Kidderminster, Worchestershire, UK DY11 7QY	www.monitron.com

Table 3. Enforcement Product Vendor Information (continued).

Vendor Name	Telephone / Fax	Address	Website
Neurodynamics, Ltd.	44-0-1223-488540 44-0-1223-488540	Cowley Rd. Cambridge, UK CB4 0WZ	www.neurodynamics.com
Optasia Systems Pte., Ltd.	65-6-744-6863 65-6-776-0157	20 Ayer Rajah Crescent #9-16/17 Singapore 139964	www.singaporegateway.com/optasia
Perceptics	865-671-9353 865-966-9330	9737 Cogdill Rd. Knoxville, TN 37932	www.perceptics.com
PIPS Technology, Inc. (formerly Pearpoint)	865-777-9064 865-777-2925	11728 Kingston Pike Knoxville, TN 37922	www.pipstechnology.com
Pulnix American, Inc.	800-445-5444 408-747-0880	1330 Orleans Dr. Sunnyvale, CA 94089	www.pulnix.com
TDC Inc.	516-484-3333 516-484-5161	111 Mineola Ave. Roslyn Heights, NY 11577	www.csroute.com
TransCore-Amtech Systems	800-923-4824 972-733-6486	19111 Dallas Parkway, Suite 300 Dallas, TX 75287	www.transcore.com
Transport Data Systems	619-226-2534 619-26-2534	1261C Rosecrans Street San Diego, CA 92106	www.transportdatasystems.com
Redflex Traffic Systems, Inc.	480-607-0705 480-607-0752	15029 North 74th St. Scottsdale, AZ 85260	www.redflex.com
SAIC Transportation Technology	800-430-7629	10260 Campus Point Dr. San Diego, CA 92121	www.saicttg.com
Sirit	800-498-8760 905-940-4405	250 Shields Court, Unit 12 Markam, Ontario, CA L3R 9W7	www.sirit.com
Tadiran Telematics	972-3-557-5725 972-3-557-5753	26 Hmelacha Street P.O. Box 267 Holon, Tel Aviv, Israel 58102	www.tadiran-telematics.com
Tecnicon International	703-754-0449 703-754-0432	1981 Mountain Rd. Haymarket, VA 20169	www.tecnicon.com

CONCLUSIONS

Successful enforcement of managed lanes requires appropriate application of available resources. This project identified the various enforcement strategies concerning the amount of enforcement required to ensure that the rules and regulations of managed lanes are maintained. This amount ranges from continuous enforcement to the simpler process of self-enforcement. A review of the various enforcement practices across the country indicates that there are multiple variations for the enforcement of managed lanes with varying levels of success.

Barrier-separated facilities obviously experience less violation than buffer-separated facilities due to the more restrictive nature of the design. The level of importance that responsible enforcement agencies place on managed lane facilities also dictates the restrictive nature of the facility. The enforcement practices at several of the more well-known managed lane facilities from around the country are presented in the research to show the level of commitment to enforcement of several of the agencies. The most notable of these is the California Highway Patrol that has been contracted for the specific purpose of monitoring the SR-91 express lanes in Orange County and the I-15 express lanes in San Diego County.

This project also focused on the concurrent flow and barrier-separated, reversible HOV lanes in Minneapolis, Minnesota. Underutilization and excessive occupancy violations characterize HOV lane operation on both I-35W and I-394 because of limited enforcement. Previous attempts to enforce these facilities resulted in severe congestion on the general-purpose lanes due to onlooker delay. Perhaps other enforcement techniques are in order that do not interrupt the flow of traffic. This is the case with automated enforcement technology.

The use of automated enforcement technology is growing at an ever-increasing rate. This project acknowledges the use of automated vehicle identification, license plate recognition, and electronic toll collection as the way of the future concerning enforcement of managed lanes.

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APPENDIX:
TRAFFIC OPERATIONS MANUAL
CHAPTER 11

Chapter 11
Enforcement Procedures and Design

Section 1:
Procedures

Role of Enforcement on Managed Lanes

A managed lane facility requires effective enforcement policies and programs to operate successfully. Enforcement of vehicle-occupancy requirements, use by authorized vehicles, or proper toll collection is critical to protecting eligible vehicles' travel-time savings and safety. Visible and effective enforcement promotes fairness and maintains the integrity of the managed lane facility to help gain acceptance among users and non-users.

Enforcement Strategies

Several strategies can be used to enforce managed lane facilities. The strategy chosen is influenced largely by the type of facility and its design. For example, HOV lane facilities would require a different enforcement strategy than that used for HOT lane facilities. Similarly, barrier-separated facilities would require a different strategy than buffer-separated facilities. The type of enforcement strategy used can usually be classified as one of the following:

- Routine enforcement uses existing freeway patrols to monitor managed lanes.
- Special enforcement uses dedicated equipment and manpower specifically to monitor the facility.
- Selective enforcement may be used during special events or at the opening of a new facility.
- Self-enforcement involves the promotion of citizen monitoring and self-regulation of the facility.

Section 2:
Design

Enforcement Areas

Traditional enforcement on managed lanes requires the specific design treatment known as dedicated enforcement areas. These areas are usually located immediately adjacent to the managed lane facility and allow enforcement personnel to monitor the facility, pursue violators, and apprehend violators to issue appropriate citations. These enforcement areas are often classified as either low-speed or high-speed.

Low-speed enforcement areas are usually located at access points on busways, managed lanes on separate rights-of-way, and barrier-separated freeway projects. Specific locations may include ramps, reversible lane entrances, and queue bypasses where vehicle speeds are relatively slow, usually below 45 mph (75 kph). In the case of reversible-exclusive managed lane facilities, the geometric requirements for reversing a facility provides temporary enforcement areas within the ramp areas that serve the opposing peak period direction.

These areas are often designed to provide for monitoring, apprehension, and citing of violators, and where practicable, violator removal from the managed lane facility. The design feature of barrier-separation acts as a deterrent to potential misuse, as violators are confined in the lanes once the decision is made to enter the facility. The following design features may be considered with slow-speed enforcement areas.

- The enforcement area should be at least 100 (30 meters) in length and preferably up to 200 feet (60 meters) on high-volume facilities, not including approach and departure tapers.
- The enforcement area should be at least a width of 14 to 15 feet (4.3 to 4.6 meters).
- The enforcement area should have an approach taper of 2:1 or 30 feet (9.1 meters).
- The enforcement area should have a departure taper of 10:1 or 150 feet (45.7 meters) to allow for vehicle acceleration into the lane.

High-speed enforcement area design usually involves spacing multiple areas periodically along facilities that have multiple at-grade access locations or are lacking continuous shoulders wide enough for enforcement. These areas are usually designed for monitoring traffic and apprehending violators. Most apprehension activities occur at a downstream enforcement area or location with a wide left or right shoulder. The following design features may be considered with high-speed enforcement areas.

- The length of a high-speed monitoring area should be at least 100 feet (30 meters), not including the approach and departure tapers. For monitoring and apprehension, the preferable length is 1300 feet (396 meters).

- The enforcement area should be at least a width of 14 to 15 feet (4.3 to 4.6 meters).
- The enforcement area should have an approach taper of 20:1 and a departure taper of 80:1 or higher, or it may be controlled by general freeway criteria as required to fit in the design for proper acceleration to the design speed.
- Enforcement areas should be provided at a minimum interval of two to three miles (3.2 to 4.8 km) along the managed lane facility.

Section 3:
Automated Enforcement Technology

The role of technology for managed lane enforcement is growing at an ever-increasing rate. For many years, intelligent transportation system (ITS) technologies have been available for use in monitoring roadways as part of various Traffic Demand Management (TDM) programs. Early detection and quick response times have been vital for incident management and effective use of emergency services. Such advances are the precursor for the use of technology in monitoring and enforcement of managed lane facilities.

Successful enforcement of managed lane facilities requires that enforcing agencies have the ability to identify specific vehicles and, when necessary, determine the number of vehicle occupants. The latest technologies with documented application on managed lane facilities included the following:

- Automated Vehicle Identification (AVI),
- License Plate Recognition (LPR),
- Electronic Toll Collection (ETC), and
- Surveillance Cameras.