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16. Abstract

This report provides the Texas Department of Transportation (TxDOT) with geometric guidance for the design of managed lane facilities. The report draws from the experiences of leading states in the development of managed lanes throughout the country. The report highlights the design and operation of managed lanes, and it includes additional information on planning, marketing, implementing, and enforcing managed lane facilities. It illustrates the critical design elements of managed lane facilities including geometric design criteria; the link between operations, design, and enforcement; and ingress/egress treatments.

This report is intended to be used as both an introduction to the managed lane concept and to provide design guidance. Throughout the report, schematics and photographs are included to illustrate the elements discussed in the text. These photographs include experiences and examples from across the country as well as in Texas.

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GUIDANCE FOR PLANNING, OPERATING, AND DESIGNING MANAGED LANE FACILITIES IN TEXAS

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Report 4161-1
Project Number 0-4161
Research Project Title: Entry-Exit and Intersection Design Criteria
for Barrier-Separated HOV Facilities

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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 contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. The engineers in charge of this report were William L. Eisele (TX-85445) and Angelia H. Parham (TX-87210).

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Ms. Pam Rowe: Report preparation; and
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CHAPTER 1

INTRODUCTION

1.0 BACKGROUND AND PROJECT OBJECTIVES

High-occupancy vehicle (HOV) lanes have provided a mobility option on congested corridors for eligible vehicles in many large metropolitan areas. In recent years, the Texas Department of Transportation (TxDOT) has revisited the definition of HOV lanes to ensure it provides the flexibility for changes in eligibility or variable pricing strategies. To reflect this flexibility, the term "managed lane" is increasingly replacing "HOV lane" terminology at TxDOT. As part of another TxDOT research project (0-4160), the following definition has been developed to serve as the official definition of a managed lane for TxDOT: "A managed lane facility is one that increases the freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals" (*1*). Figure 1-1 illustrates the different types of facilities that constitute managed lanes, including HOV lanes, truck lanes, toll highways, priced lanes, single-occupant vehicle (SOV) express lanes, or any combination of these facilities. Further, there is no absolute number or combination of these facility types needed to define a managed lane.

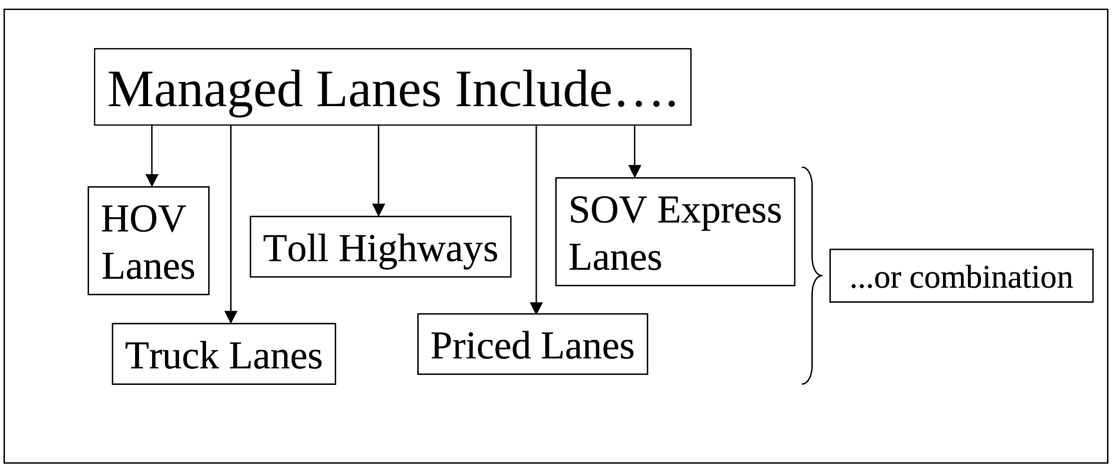


Figure 1-1. Definition of a Managed Lane.

The HOV facilities developed in Texas fall within the definition of a managed lane, and the term also describes projects that include a pricing element and/or other operational and design strategies. In Texas, managed lane facilities (which are HOV lanes in the way they operate) are currently located in Dallas and Houston, and the benefits of these facilities are well documented (*2*). Tables 1-1 and 1-2 list the operating characteristics of existing managed lane facilities in Houston and Dallas, respectively. Generally, experience suggests a few characteristics that are key to the success of managed lane facilities, and these include the following (*3*):

- metropolitan areas with more than one million people,
- work trips to major urban centers with 100,000 or more jobs,
- corridors with physical barriers (e.g., rivers, mountains),
- the potential for at least 25 busloads of transit passengers during the peak hour,
- high levels of traffic congestion,
- support programs and policies,
- ongoing marketing and public information activities,
- visible enforcement,
- strong working relationships among the responsible transportation agencies,
- travel time savings of at least one minute per mile for eligible vehicles,
- eight to ten minutes total travel time savings,
- more reliable travel time than mixed-flow lanes, and
- adequate truck usage for truck lanes.

Table 1-1. Operational Characteristics of Existing HOV Lanes in Houston (August 2001).

HOV Facility	Facility Type	Number of Lanes	Length mi (km)	HOV Operating Period	General Eligibility Requirements
I-10 Katy Freeway	Barrier-separated, reversible-flow	1 lane reversible	12.3 (19.8)	5 a.m. to 11 a.m. 2 p.m. to 8 p.m. Sat, outbound, 5 a.m. to 8 p.m. Sun, inbound, 5 a.m. to 8 p.m.	3+ peak periods[1] 2+ other times; Tolling $2.00 per trip during peak hours with two occupants
I-10 Katy Freeway	Concurrent flow, buffer-separated	1 each direction	6.3 (10.1)	5 a.m. to 11 a.m., inbound only. 2 p.m. to 8 p.m., outbound only. Sat, outbound, 5 a.m. to 8 p.m. Sun, inbound, 5 a.m. to 8 p.m.	3+ peak periods[1] 2+ other times
I-10 Katy Freeway	Barrier-separated, two-way, downtown connector. Elevated, opposing flow buffer-separated.	1 each direction	1.9 (3.1)	5 a.m. to 8 p.m.	2+
I-45 Gulf Freeway	Barrier-separated, reversible-flow	1 lane reversible	15.0 (24.1)	5 a.m. to 11 a.m. 2 p.m. to 8 p.m.	2+ other times
US 290 Northwest Freeway	Barrier-separated, reversible-flow	1 lane reversible	11.9 (19.2)	5 a.m. to 11 a.m. 2 p.m. to 8 p.m.	3+ peak period[2] 2+ other times; Tolling $2.00 per trip during peak hours with two occupants
I-45 North Freeway	Barrier-separated, reversible-flow	1 lane reversible	19.3 (31.1)	5 a.m. to 11 a.m. 2 p.m. to 8 p.m.	2+ other times
US 59 Eastex Freeway	Barrier-separated, reversible-flow	1 lane reversible	14.8 (23.8)	5 a.m. to 11 a.m. 2 p.m. to 8 p.m.	2+ other times
US 59 Southwest Freeway	Barrier-separated, reversible-flow	1 lane reversible	11.5 (18.5)	5 a.m. to 11 a.m. 2 p.m. to 8 p.m.	3+ peak hours 2+ other times
I-610/US 290	Barrier-separated, two-way. Elevated, opposing flow buffer-separated	1 lane reversible each direction	1.5 (2.4)	5 a.m. to 11 a.m. 2 p.m. to 8 p.m.	2+

[1]Peak periods are 6:45 a.m. to 8:00 a.m. and 5:00 p.m. to 6:00 p.m.
[2]Peak period is 6:45 a.m. to 8:00 a.m. only. There is no 3+ restriction in the afternoon.

Table 1-2. Operational Characteristics of Existing HOV Lanes in Dallas (August 2001).

HOV Facility	Facility Type	Number of Lanes	Length mi (km)	HOV Operating Period	General Eligibility Requirements
I-35E Stemmons Fwy	Concurrent flow, buffer-separated	1 each direction	SB 7.3 (11.7) NB 6.0 (9.7)	24 hours	2+
I-35E Stemmons Fwy	Reversible lane, queue bypass	1 each peak direction	0.7 (1.0)	6 a.m. to 9 a.m. 4 a.m. to 7 p.m.	2+
US 67 Marvin D. Love Fwy	Concurrent flow, buffer-separated	1 each direction	4.0 (6.4)	24 hours	2+
I-635 LBJ Freeway	Concurrent flow, buffer-separated	1 each direction	EB 6.8 (11) WB 6.1 (9.8)	24 hours	2+
I-30 East RL Thornton Freeway	Contraflow	1 each peak direction	5.2 (8.3)	6 a.m. to 9 a.m. 4 p.m. to 7 p.m.	2+

TxDOT project 0-4160 is entitled "Operating Freeways with Managed Lanes," and the objective of that project is to investigate the complex and interrelated issues surrounding the safe and efficient operation of managed lanes. A managed lanes manual is to be developed to help TxDOT make informed planning, design, and operational decisions when considering these facilities for their jurisdiction. In light of the objective of project 0-4160, the objective of the research presented in this report was to provide preliminary guidance for planning, operating, and designing managed lane facilities in Texas. This report documents the preliminary information that will provide a foundation for project 0-4160. Another objective of this report was the development of a new section on managed lanes for the *TxDOT Roadway Design Manual*. Chapter 6 if this report lists additional research needs in the area of managed lanes based upon this research effort, items identified in the *HOV Systems Manual* (*4*), and issues identified recently by the Transportation Research Board=s HOV Systems Committee.

This report provides TxDOT with preliminary geometric guidelines for the design of managed lane facilities. The *HOV Systems Manual* (*4*) provides the most recent and comprehensive summary of all aspects of HOV facility planning, operation, design, enforcement, and implementation as well as equally critical elements of marketing, support facilities (e.g., transit stations), and support programs. It forms a useful base for managed lane project guidance. Significant portions of this report are based upon the *HOV Systems Manual* (*4*) and are applied toward the design of managed lane facilities in Texas. Design manuals (principally HOV-related) from other states are also used to provide design criteria and practices that are relevant to Texas.

This report is intended to be used as both an introduction to the managed lane concept and to provide preliminary design guidance. Chapter 4 focuses on design and includes a discussion of geometric criteria, cross sections, access, enforcement, and the connection between operations and design. Throughout the report, schematics and photographs are included to illustrate the elements discussed in the text. These photographs include experiences and examples from across the country as well as Texas.

The “operational and design actions” stated in the managed lanes definition can include many different strategies. Operational actions include altering vehicle group eligibility or facility hours of operation, the decision to toll along the facility, or other operational controls (e.g., reversible lanes, ramp meters). In addition, physical control through barriers, limited access points, or gates can be used to control access. All of these strategies will affect the design of the facility. It should be noted that throughout this document, the term “eligible vehicles” refers to any user group that is allowed to use the facility. This may include high-occupancy vehicles (e.g., carpools, vanpools, buses), lower occupancy vehicles if tolling is planned, commercial vehicles and heavy trucks, motorcycles, low-emission vehicles (LEVs), taxis, emergency vehicles, or authorized vehicles. Chapter 3 describes these vehicle user groups in detail, along with other operational issues.

1.1 ORGANIZATION OF THE REPORT

This report is organized into six chapters as described below:

- Chapter 1, Introduction: Provides an introduction to the research topic, presents the definition of a “managed lane,” and describes the research objective.
- Chapter 2, Planning for Managed Lane Facilities: Provides an overview of the critical issues that should be considered in the planning of a managed lane facility. These issues include operations, design, enforcement, implementation, marketing, and the need for support facilities and programs.
- Chapter 3, Operating Managed Lane Facilities: Describes the issues involved in operating managed lane facilities and discusses the essential areas of hours of operation, vehicle eligibility, and incident detection and response.
- Chapter 4, Managed Lane Facility Design: Describes the primary design elements related to managed lane facilities including geometric criteria, cross sections, access, and enforcement. This chapter also describes the important link between design and operations.
- Chapter 5, Signs and Pavement Markings: Describes standard signing and markings for managed lane facilities.
- Chapter 6, Additional Research Needs: Describes areas of future research.

CHAPTER 2

PLANNING FOR MANAGED LANE FACILITIES

2.0 INTRODUCTION

This chapter provides a general overview of the planning process used for managed lane facilities. Managed lanes include the different types of facilities, or combinations thereof, shown previously in Figure 1-1. Regional, corridor, and facility-level planning are discussed, including the roles and responsibilities of the various agencies and groups that may be involved. Particular attention is given to the transit element of managed lane planning, as it is vital to a facility's success. Additional items of interest for planning managed lane facilities are discussed, including general-purpose lane conversion, priority pricing, commercial vehicle use, and environmental issues. The importance of public involvement during both the planning and implementation phases is described. The need for a thorough evaluation program, possibly in the form of a before-and-after study, is also included. The reader can find further information regarding the details of the material described here may be found in the *HOV Systems Manual (4)*.

2.1 OVERVIEW OF THE PLANNING PROCESS

2.1.1 General Planning Concepts in Transportation

The goal of the planning process is to develop a safe, efficient, and effective transportation system for the movement of people and goods. Several concepts and objectives should be considered to attain this goal. This requires addressing core issues related to the mobility, safety, and efficiency of a particular corridor. A thorough and comprehensive planning effort will also address different aspects of multimodal and intermodal systems, potential land uses, the environment, financing, and the surrounding area's economic vitality.

2.1.2 Typical Groups Involved when Planning Managed Lanes

Multiple agencies and groups are involved in the intricate process of planning managed lane facilities. State departments of transportation (DOTs) usually assume the role of lead agency for managed lanes consideration within a freeway setting, and their responsibilities include organizing, staffing, and chairing multi-agency project management teams. Transit agencies may assume the role of lead agency for managed lanes on separate rights-of-way or as co-sponsor when these facilities are provided in a freeway setting. Their responsibilities can range from overall project planning to a supporting role as a resource concerning bus services, bus facilities, and park-and-ride lots.

Numerous agencies and groups are involved in the process by providing general support in specific areas of expertise. Involvement by representatives from state and local police, or others responsible for enforcing managed lane regulations, is critical early in the planning process, and throughout the project to ensure that authorities can safely and efficiently enforce the facilities. Representatives from local metropolitan planning organizations (MPOs) and federal agencies provide input for the various policy issues for the planning of managed lanes. Private consulting firms often develop the design plans and can conduct specific studies related to travel forecasting and demand estimation. Public participation early in the planning process, and throughout the project, is critical to understanding the general opinions and travel issues surrounding the managed lane concept.

2.1.3 General Steps in Planning Managed Lane Facilities

There are 11 major non-sequential steps that project management teams should address when planning for any managed lane facility. Some of these steps continue through the entire project, such as Steps 1 and 3. The steps can be modified for a particular corridor depending on the scope of work tasks, the type of facility being considered, the location characteristics, and related policy issues. The reader can find additional discussion of these planning steps in the *HOV Systems Manual* (*4*).

Step 1. Identify and involve appropriate groups
Step 2. Identify issues and opportunities
Step 3. Initiate and continue public participation
Step 4. Identify objectives, analysis techniques, and data needs
Step 5. Identify alternatives
Step 6. Collect data
Step 7. Analyze alternatives
Step 8. Seek public input on alternatives
Step 9. Identify preferred alternative
Step 10. Provide for public review
Step 11. Select the preferred alternative

2.2 PLANNING MANAGED LANE FACILITIES ON FREEWAYS

2.2.1 Planning Managed Lane Facilities at the Regional Level

The planning process for managed lanes desirably begins at the regional level, and it focuses on the general needs, issues, and opportunities for transportation improvement within a metropolitan area. MPOs develop long-range regional plans that identify anticipated major travel corridors and areas. The inclusion of managed lane facilities in specific corridors is usually incorporated in the regional plans with the objective of developing a comprehensive managed lane system. The regional planning process may also consider busways, arterial street applications, park-and-ride lots, transit centers, and rideshare services. It is also possible that a managed lane project could begin as a project and evolve into a regional plan.

The Clean Air Act Amendments of 1990, ISTEA, TEA-21, and subsequent regulations issued by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Transportation require the use of transportation control measures (TCMs), such as managed lane facilities, in areas not meeting EPA air quality standards. Managed lane facilities, ridesharing, transit services, and transportation demand management (TDM) programs are all considered TCMs. Regions that must consider TCMs include: severe and extreme ozone non-attainment areas and serious, severe, and extreme carbon monoxide non-attainment areas.

2.2.2 Planning Managed Lane Facilities at the Corridor Level

Corridor-level planning for managed lane facilities requires a greater level of detail. Officials may consider the addition of general-purpose lanes or changes to roadway alignment at this level of the planning process.

The selection of a preferred alternative within a corridor may occur as the result of a Corridor Improvement Study (CIS), which was formerly termed a Major Investment Study (MIS). CISs are undertaken in corridors being considered for major transportation improvements. An MPO, state department of transportation, or transit agency may be responsible for conducting the CIS, along with ensuring that public participation occurs throughout the process. Typical criteria used in the evaluation of an alternative are included in the following categories, with specific measures of effectiveness determined as part of the local planning process:

- transportation system performance,
- mobility and/or accessibility,
- environmental and energy impacts,
- cost and financial viability,
- land use and development impacts, and
- equity and socioeconomic impacts.

2.2.3 Facility-Based Managed Lane Planning

Planning at the facility level requires the greatest level of detail and is initiated after the selection of a preferred alternative. It examines the specific elements associated with pre-design planning including demand projections, access treatments, bus services, and park-and-ride lots. The screening of such corridor characteristics or items of interest usually occurs at the facility-based planning level but may also occur earlier at the regional or corridor planning levels. The planning team can use the following criteria during the screening process for ranking or categorizing critical corridor characteristics:

- congestion levels,
- travel patterns,
- current bus and carpool volumes,
- travel time savings and travel time reliability,
- person throughput,

- projected demand,
- agency and public support,
- enforcement,
- cost effectiveness,
- physical characteristics of the corridor or roadway,
- support facilities and services,
- safety,
- system continuity,
- system staging and scheduling,
- operable segments, and
- environmental issues.

2.2.4 Transit Planning for Managed Lane Facilities

A successful managed lane facility will often incorporate bus services and bus facilities requiring the expertise of the local transit agency. Transit agencies have the overall responsibility for planning, financing, implementing, marketing, and operating bus services associated with managed lane facilities. The transit agency may also have a lead role or supporting role in planning, designing, and operating transit stations, park-and-ride lots, and other support facilities.

Other agencies and groups known to have interest or some level of responsibility for providing bus service and bus facilities on a managed lane facility should be considered in the various stages of planning. Private bus companies may provide service in a corridor with a new or existing managed lane facility. In some metropolitan areas, ride matching, vanpooling, and other rideshare programs may be the responsibility of an agency or organization other than the local transit agency.

Examining current transit routes and planning future bus service is an integral part of the managed lane facility planning process. The first step in the planning process is to review current transit services in the corridor or area. This information provides the starting point for the development of a future transit service plan, which will incorporate the goals and policies of the transit agency. Consideration should be given to the development of fixed facilities such as park-and-ride lots and transit stations and the impact of these elements on the service plan and operating strategy.

The two types of transit facilities usually associated with managed lane facilities on freeways are park-and-ride or park-and-pool lots and transit stations. Park-and-ride and park-and-pool lots provide commuters the opportunity to change between low- and high-occupancy vehicles. The location, the level of transit service provided, and the exclusive nature of the operation often categorize park-and-ride facilities. Park-and-ride lots are typically described as being remote, local, or peripheral with respect to their location and use along a managed lane facility. More guidance on the design of park-and-ride facilities can be found in the American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Design of Park-and-Ride Facilities* (*5*). This guide provides insight into locating park-and-ride lots, including a methodology for priority rating park-and-ride lot locations.

Transit stations or transit centers are used with many managed lane facilities. These facilities provide safe and sheltered locations for passengers to board buses or transfer between different bus routes or services. There are two standard designs for transit stations on a managed lane facility: 1) on-line stations that are located directly along a managed lane, or 2) off-line stations, which may be located adjacent to the freeway or at a point farther away from the managed lane facility.

Other facilities that should be mentioned include intermodal facilities and bus stops. Intermodal facilities serve multiple modes, providing travelers with the opportunity to change from one transportation service to another. Bus stops serve as basic points of access for passengers for buses that operate both on managed lane facilities and on local streets. Figure 2-1 illustrates the Addicks Park-and-Ride Lot along I-10 (Katy Freeway) in Houston, Texas. It shows how the lot is directly connected by a T-ramp to the barrier-separated reversible-flow managed lane. Figure 2-2 shows a photograph of an intermodal station at Mockingbird in Dallas, Texas, serving pedestrians, bicyclists, rail, and transit.

Figure 2-1. Addicks Park-and-Ride Lot along I-10W (Katy Freeway) in Houston, Texas.

(T-ramp transit center, local bus connections, ramp flow reversal section [lower left])

Figure 2-2. Intermodal Station at Mockingbird in Dallas, Texas.
(local bus parking [left] and rail tunnel)

2.3 SPECIAL PLANNING CONSIDERATIONS

2.3.1 Conversion of General-Purpose Lanes to Managed Lanes and Priority Pricing of Managed Lanes

The planning approaches described previously are generally appropriate for use on all managed lane facilities. However, some projects may require special consideration, and additional factors may need to be examined. Examples are conversions of an existing general-purpose lane to a managed lane or priority pricing of a managed lane facility that previously included occupancy restrictions. Additional factors that should be considered in these cases include: policy guidance, public perception, political support, transportation system connectivity, and environmental issues. Lane conversion projects are discussed in more detail in section 3.9.1.

The concept of priority pricing on freeways and roadways involves charging motorists for use of the facility during time periods of excessive traffic congestion. The intent of the approach is to price the use of a roadway facility so that sufficient capacity is provided for those willing to pay. Managed lane facilities may use priority pricing to control congestion on specific sections of lanes.

2.3.2 Commercial Use of Managed Lane Facilities

There is interest in the possibility of allowing commercial vehicles, particularly heavy trucks, onto managed lane facilities. A variety of different use scenarios have been suggested, including allowing trucks onto managed lane facilities during normal operating hours or providing trucks with exclusive use during off-peak periods. To accommodate commercial vehicles on managed lane facilities, additional elements should be considered in the planning process. These elements include projected managed lane eligible vehicles, truck origins and destinations, projected truck demand levels, design limitations, traffic operations, and safety and environmental issues. Further information related to truck use of managed lanes is shown in section 3.3.1 (operations) and 4.1.1 (design).

2.4 ASSESSING THE POTENTIAL ENVIRONMENTAL IMPACTS OF MANAGED LANE FACILITIES

2.4.1 Air Quality, Vehicle Emissions, and Energy Consumption

Assessing the environmental impacts of managed lane facilities is an important part of the planning process. An examination of air quality and environmental factors is required by federal legislation, and some states and local jurisdictions also have requirements relating to environmental considerations. Current techniques for modeling air quality and environmental elements are limited in assessing the overall impacts of managed lane facilities. However, there are studies of existing managed lane facilities identifying positive impacts on air quality, vehicle emissions, and energy consumption.

2.4.2 Other Potential Environmental and Social Impacts

Potential water quality issues with managed lane facilities are similar to those associated with general-purpose lanes, parking lots, and other related transportation components. The planning process should include an examination of possible water quality impacts and approaches to mitigate any identified problems. Specific issues relating to water quality should be coordinated with requirements and regulations of the EPA’s Office of Water Resources, the U.S. Corps of Engineers, state departments of transportation, state environmental agencies, and local jurisdictions.

Noise impacts may be a concern with managed lane facilities and with park-and-ride lots. This is less of an issue if managed lanes are being added to an existing freeway. The potential noise impacts on adjacent neighborhoods and land uses should be examined during the planning process. Noise modeling and monitoring techniques can be used to estimate the possible impact of managed lane facilities, and appropriate mitigation treatments can then be identified. The term "environmental justice" is frequently used to refer to the potential for a transportation project or the development of other major facilities to negatively impact low income and minority groups. The planning process for any transportation improvement, including managed lane facilities, should consider the impact on special groups. Any potential adverse effects should be identified along with strategies to mitigate these concerns.

The planning process should assess the impacts of the various alternatives on land use and development in the area. Elements to be considered in this assessment may include existing buildings that need to be demolished or relocated, compatibility with existing development and planned land uses, and potential joint development projects. Coordination with local jurisdictions and local business owners regarding land use is critical early in the planning process.

2.5 PLANNING PUBLIC INVOLVEMENT

Public involvement is an important part of the planning process for any transportation improvement. The participation of neighborhood groups, businesses, elected officials, and other interested individuals can help ensure that all interested parties have access to the planning process. Past experience has shown that successful managed lane projects have included comprehensive public involvement and marketing programs.

Key elements relating to public involvement during the planning process include background research, communication of general information, and public meetings. Background research can determine opinions or attitudes regarding alternatives being considered through literature searches, focus groups, surveys, or stakeholder interviews. During the various stages of a project, information can be communicated to the public through newsletters or the various media outlets. Public meetings and hearings are the traditional mechanism for securing input and responses from the public concerning specific issues.

2.6 PLANNING FOR IMPLEMENTATION OF MANAGED LANE FACILITIES

2.6.1 Planning for Group Involvement During Implementation of Managed Lane Facilities

Successful implementation of managed lane facilities requires the involvement of multiple agencies and groups. Planning a comprehensive and systematic approach to the implementation process will help ensure that the managed lane facility is constructed, tested, and opened to the public in a safe and efficient manner. It is critical that every entity involved has a common understanding of the implementation process and the operation of the facility.

Agencies and groups involved earlier in the planning process should remain involved throughout the implementation process. A special subgroup or committee, comprised of the operations personnel from the various agencies, may be formed to ensure that key individuals responsible for operating and enforcing the facility are involved in the planning and execution of the implementation plan. There should be an effort to include local policymakers and members of the judicial system who are responsible for enforcing fines or penalties. The selected contractor or contractors may participate to ensure that construction activities are well coordinated. Table 2-1 lists the agencies and groups that should be considered for inclusion on an implementation team or consulted during the development of an implementation plan.

2.6.2 Developing an Implementation Plan for Managed Lane Facilities

The extent of planning required and the process used for the implementation of managed lane facilities will relate to the regional experience for such projects. A new managed lane may be part of a region-wide system of similar facilities, or it may be the first of its kind for an area requiring a detailed implementation plan. In either case, the following are general steps that may be included in an implementation plan for a managed lane facility. These steps may be modified or deleted depending on the nature of the project and the characteristics of the area.

Step 1. Identify appropriate agencies and groups
Step 2. Organize multi-agency implementation team
Step 3. Review goals and objectives
Step 4. Identify key stakeholders
Step 5. Develop overall approach and schedule
Step 6. Construction and project phasing
Step 7. Public information, outreach, and marketing
Step 8. Bidding and contracting construction
Step 9. Managing traffic during construction
Step 10. Training operating personnel
Step 11. Pre-operational testing of facility equipment
Step 12. Special consideration (e.g., general-purpose lane conversion to managed lane or priority pricing)
Step 13. Monitoring and evaluating the implementation process

Table 2-1. Agencies and Groups Involved in Implementing Managed Lane Facilities (Adapted from Reference *4*).

Agency or Group	Potential Roles and Responsibilities
State department of transportation	• Overall project management • Bid preparation, bid letting, and contracting • Project phasing • Managing traffic during construction • Training operation personnel • Pre-operation testing • Public information, marketing, public relations • Funding support
Transit agency	• Overall project management • Bid preparation, bid letting, and contracting • Project phasing • Training bus operating personnel and field staff • Training bus support staff • Training transit police • Pre-operational testing • Public information, marketing, public relations • Funding support
State and local police	• Training enforcement personnel • Pre-operational testing of enforcement equipment • Coordination with judicial personnel • Pre-operational testing of enforcement personnel
Judicial system—state and local	• Enforcement of fines and penalties
Emergency personnel, EMS, and fire	• Training personnel on response to incidents and special situations • Pre-operational testing of emergency equipment and procedures
Tow truck operators	• Training personnel on procedures concerning disabled vehicles • Pre-operational testing of removing disabled vehicles
Trucking industry	• Provide information on trucking origins and destinations • Training of drivers on facility use for trucks
Toll authority	• Introduce tolling technologies and proper use • Pre-operational testing • Revenue generation
Local municipalities	• Project management including arterial streets and traffic signals • Bid preparation, bid letting, and contracting • Project phasing • Managing traffic during construction • Training operation personnel • Pre-operation testing • Coordination with other city departments • Public information, marketing, public relations
Rideshare agency	• Rideshare promotional activities • Public information, marketing, public relations
Metropolitan planning organization	• Facilitating meetings and multi-agency coordination • Ensure projects are in planning and programming documents
Transportation management organizations	• Employer support activities • Promotion of bus use and ridesharing • Specialized information and marketing
Special user groups (taxi, limousine)	• Training of operating personnel
Federal agencies (FHWA, FTA)	• Funding support • Overall approval of various steps
Elected and appointed officials	• Approve necessary contracts and actions • Participate in openings and meetings
Commuters and public groups	• Provide input to implementation process
Contractor	• Construction activities and schedules • Assisting with traffic management during construction • Assisting with project phasing

2.7 EVALUATION OF MANAGED LANE FACILITIES

2.7.1 Goals, Objectives, and Measures of Effectiveness

The evaluation of managed lane facilities may be conducted at different stages in the project development and implementation process. Before-and-after studies are usually conducted to determine whether the anticipated benefits of the facility have been realized. Ongoing monitoring and periodic evaluations ensure that the project continues to provide the desired results. Complete information on usage, violation rates, and traffic crashes are critical to the efficient and safe operation of the facility.

The evaluation process begins with identifying the goals and objectives of the managed lane facility. These goals and objectives were established early in the project planning and public participation. Project objectives should be stated clearly so that they are well-defined and measurable. For each objective, the appropriate measure(s) of effectiveness should be identified. Desirable threshold levels of change should also be identified that will be used to determine whether the facility has met the objective. Table 2-2 lists typical objectives and measures of effectiveness associated with managed lane facilities.

2.7.2 Identification of Data Needs

The team should identify the data needed to determine if the objectives have been realized for each measure of effectiveness. The appropriate methods to obtain and evaluate the information should also be determined, including identifying data collection locations and procedures. The following items are basic information needed for before-and-after studies of managed lane facilities:

- vehicle counts and occupancy counts, including counts of users in single occupant vehicles,
- travel time and speed information,
- safety and crash data,
- violation and enforcement data, and
- survey information concerning the perception of users, non-users, and the general public.

Table 2-2. Typical Objectives and Measures of Effectiveness for Managed Lane Facilities (Adapted from Reference *4*).

Objective	Measures of Effectiveness
Corridor	
Improve the capability of the congested freeway corridor to move more people by increasing the number of persons per vehicle	• Actual and percent increase in the person movement • Actual and percent increase in average vehicle occupancy rate • Actual and percent increase in carpools and vanpools • Actual and percent increase in bus riders
Increase the operation of bus service in the freeway corridor	• Improvements in vehicle productivity (operating cost per vehicle-mile, operating cost per passenger, operating cost per passenger mile) • Improved bus schedule adherence (on-time performance) • Improved bus safety (crash rates)
Have favorable impacts on air quality and energy consumption	• Reduction in emissions • Reduction in total fuel consumption • Reduction in the growth of vehicle miles traveled (VMT) and vehicle hours of travel
Revenue generation	• Revenue generated by tolling the managed lane facility
Be a cost-effective transportation improvement	• Benefit-cost ratio
Facility	
Provide travel time savings and a more reliable trip time to the vehicles using the facility (i.e., carpools, vanpools, buses, trucks, tolled vehicles, LEVs)	• The peak-period, peak-direction travel time in the managed lane(s) should be less than the travel time in adjacent general-purpose lanes • Increase in travel time reliability for vehicles using managed lane(s)
Increase the per lane volume of the total freeway facility	• Improvement in the peak-hour per lane volume of the total facility
Should not unduly impact the operation of the freeway general-purpose lanes	• Travel times in the freeway general-purpose lanes should not increase • The level of service in the freeway general-purpose lanes should not decline
Be safe and should not unduly impact the safety of the freeway general-purpose lanes	• Number and severity of crashes for managed lanes and general-purpose lanes • Crash rate per million vehicle miles traveled • Crash rate per million passenger miles traveled
Have public support	• Support for the facility among users, non-users, general public, and policymakers • Violation rates (percent of vehicles not meeting the occupancy requirement)

CHAPTER 3

OPERATING MANAGED LANE FACILITIES

3.0 INTRODUCTION

This chapter discusses the operation, enforcement, and incident management of various types of managed lane facilities. Figure 3-1 illustrates the different facility types, or combinations thereof, that comprise managed lanes. It is critical to understand the operating characteristics of managed lane facilities in order to identify elements in the design process. Operational alternatives will also influence the capital costs and the ongoing operating costs associated with different types of managed lane facilities. Additionally, various operation and enforcement issues may influence the potential for a successful project.

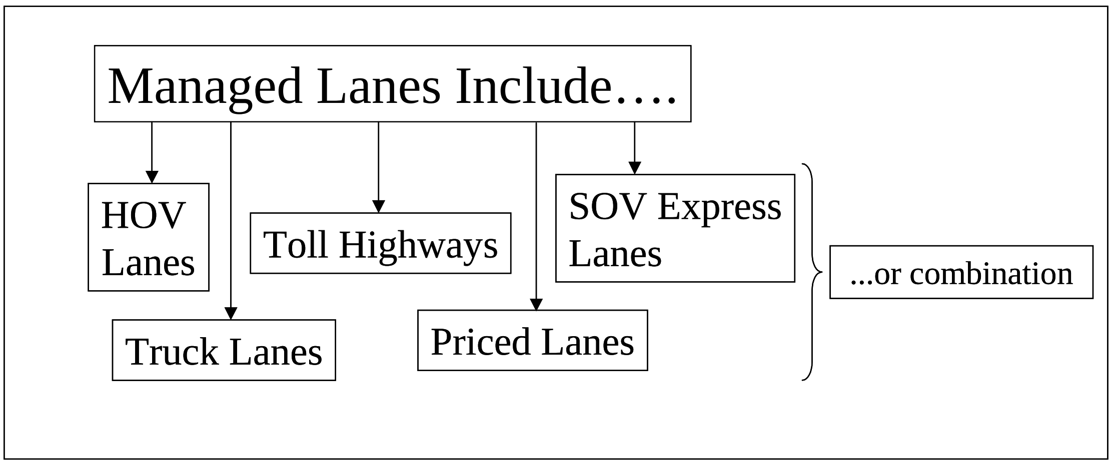


Figure 3-1. Definition of a Managed Lane.

There is a strong link between the operation and the design of a managed lane facility. The designer must consider operational strategies in conjunction with the design of the facility. Section 4.1 of Chapter 4 describes this link in more detail. A number of elements should be considered in the development plan for operating and enforcing a managed lane facility. This chapter discusses these factors and includes sections on the following areas:

- operational alternatives for managed lanes on freeways,
- ingress and egress alternatives for managed lanes,
- vehicle eligibility and vehicle-occupancy requirements,
- transit and support services and facilities,
- hours of operation,
- enforcement,
- incident management, and
- special operating considerations.

Portions of this chapter are excerpts from the *HOV Systems Manual* (*4*), and the reader is encouraged to review this reference and other references for additional information.

3.1 OPERATIONAL ALTERNATIVES FOR MANAGED LANES ON FREEWAYS

Three types of managed lanes are commonly found on freeways—exclusive, concurrent flow, and contraflow lanes. In addition, two different operating strategies are used with exclusive lanes—two-way and reversible. The following descriptions highlight the major characteristics, advantages, and disadvantages of these types of managed lane facilities. Chapter 4 presents more detailed information on the design considerations associated with the various treatments.

3.1.1 Exclusive Two-Way Managed Lane Facilities

Exclusive two-way facilities are constructed within the freeway right-of-way and are physically separated from the general-purpose freeway lanes. The term "two-way" in the description of these facilities refers to the fact that the facility operates in two directions all the time; however, unlike the reversible facility described in the next section, the operation of each direction of the two-way facility does not change. This means that the design and operation of each direction of an exclusive two-way facility, including cross-section and access design, can be developed without the consideration of the facility operation being reversed. The lanes are used exclusively by eligible vehicles the entire day or only during specific time periods. Most exclusive managed lane facilities are physically separated from the general-purpose freeway lanes through the use of concrete barriers; however, a few exclusive facilities are separated from the general-purpose lanes by a wide painted buffer.

Exclusive two-way managed lane facilities in freeway rights-of-way are usually open to all types of eligible vehicles. They often have limited access points and may include direct ramps and other exclusive ingress and egress treatments. Given the higher costs associated with this alternative, significant volumes of eligible vehicles traveling in both directions are needed to consider this approach. As illustrated in Figures 3-2 and 3-3, examples of exclusive two-way managed lane facilities include the San Bernardino Transitway in Los Angeles and the I-84 Freeway HOV Lanes in Hartford.

Figure 3-2. San Bernardino Transitway in Los Angeles, California.

Figure 3-3. I-84 Freeway HOV Lanes in Hartford, Connecticut.

Consider Exclusive Two-Way Managed Lane Facilities when:

- there are major job centers along or at the ends of the proposed lanes,
- corridors have fairly even directional splits, and
- there are large volumes of existing or projected eligible vehicles, usually in the range of 400 to 800 vehicles per hour.

Advantages of Exclusive Two-Way Managed Lane Facilities include:

- Travel time savings and travel time reliability benefits are available to a wider range of commuters and there is an enhanced operating environment for buses and managed lanes.
- Enforcement is easier than on non-exclusive facilities.

Potential Disadvantages of Exclusive Two-Way Managed Lane Facilities include:

- Right-of-way requirements are greater and associated costs are higher, and
- Cost of the barrier or other lane separation treatment is higher.

3.1.2 Exclusive Reversible Managed Lane Facilities

The other type of exclusive managed lane treatment is a reversible lane or lanes. Like a two-way facility, this approach involves a lane or lanes within the freeway right-of-way that are physically separated from the general-purpose freeway lanes and used exclusively by eligible vehicles for all or a portion of the day.

Exclusive reversible managed lane facilities usually operate inbound toward the central business district (CBD) or other major activity center in the morning and outbound in the afternoon. Reversible facilities require some type of daily operational setup. Steps in this process often include opening the lanes in the morning, closing the lanes to inbound traffic, reopening the lanes in the reverse direction of travel in the afternoon, and closing the lanes in the evening. Both manual and automated techniques are used to open and close these types of managed lane facilities.

The Houston, Texas, managed lanes represent the largest network of single-lane exclusive reversible managed lane facilities in the country. Currently, approximately 89 miles (143 km) of a planned 111-mile (179-km) system are in operation on five radial freeway corridors. Figure 3-4 illustrates a reversible lane on US 290 in Houston, Texas. Also, the I-395 (Shirley Highway) HOV lanes in Northern Virginia/Washington, D.C., area, the I-15 express lanes in San Diego, the I-25 express lanes in Denver, and a portion of the I-394 HOV lanes in Minneapolis all represent two-lane exclusive reversible managed lane facilities. A two-lane reversible facility on I-15 in San Diego is shown in Figure 3-5, and the I-10 (Katy Freeway) HOV lane in Houston is shown in Figure 3-6. The Shirley Highway HOV lanes in Northern Virginia/Washington, D.C., are illustrated in Figure 3-7.

Consider Reversible Managed Lane Facilities when:

- corridors have high directional splits of the target market of travelers. Substantially higher volumes of vehicles traveling in one direction are needed for this type of treatment. Unequal traffic distribution may exist in many radial corridors with large numbers of commuters traveling to the CBD or other major activity center.
- substantial congestion will exist in one direction and a low or tolerable congestion will be present in the other direction during the peak periods.

Advantages of Reversible Managed Lane Facilities include:

- Available right-of-way may exist in a freeway median to allow for the addition of an exclusive reversible managed lane.
- This lane may provide a cost-effective approach to add extra capacity during the peak hours since it operates in the peak direction of travel.
- Enforcement and operation are enhanced with the exclusive facility.

Potential Disadvantages of Reversible Managed Lane Facilities include:

- The capital and operating costs associated with the lane, access facilities, park-and-ride lots and other supporting components may be high.
- The availability of right-of-way may be limited.
- Consideration of expanding to a two-way facility may be needed if travel demand and traffic volume increases in the off-peak direction.

Figure 3-4. Reversible HOV Lane on US 290 in Houston, Texas.

Figure 3-5. Two-Lane Reversible Facility with Call Box on I-15 in San Diego, California.

Figure 3-6. I-10 (Katy Freeway) HOV Lane in Houston, Texas.

Figure 3-7. Shirley Highway HOV Lanes in Northern Virginia/Washington, D.C.

3.1.3 Concurrent Flow Managed Lane Facilities

Concurrent flow managed lanes are defined as freeway lanes in the same direction of travel that are not physically separated from the general-purpose traffic lanes. They are designated for exclusive use by eligible vehicles for all or a portion of the day. Concurrent flow managed lanes are usually open to all eligible vehicles. However, a few facilities are open only to buses, which allows transit vehicles to bypass specific bottlenecks.

Concurrent flow lanes are usually, although not always, located on the inside lane or shoulder. Pavement markings are a common means used to delineate these lanes. As discussed in Chapter 4, in some cases a 1-foot to 4-foot (0.3-m to 1.2-m) separation is provided between the managed lane and the general-purpose lane, while in other cases no additional separation is provided. Unlimited ingress and egress may be allowed with a concurrent flow managed lane or only specific access points may be provided.

Concurrent flow managed lane facilities are the most common managed lane application in North America. Concurrent flow managed lanes are used extensively in Seattle and metropolitan areas in California, as well as other cities throughout the country. Figure 3-8 shows the concurrent flow lanes on the I-10 (Katy Freeway) in Houston, Texas. Other examples of concurrent flow lanes are I-635 and I-35E in Dallas, Texas; SR 520, I-405, I-5, and SR 167 in Seattle, Washington; SR 55, I-405, SR 91, SR 57, and I-5 in Los Angeles/Orange County, California; SR 101 in San Jose, California; I-280, I-80, and SR 237 in San Francisco, California; US 36 in Denver, Colorado; I-10 in Phoenix, Arizona; I-394 in Minneapolis, Minnesota; I-65 in

Nashville, Tennessee; I-4 in Orlando, Florida; I-95 and SR 112 in Miami, Florida; and SR 44 and I-564 in Norfolk/Virginia Beach, Virginia. Figures 3-9 and 3-10 provide examples of the concurrent flow HOV lanes in Seattle and Southern California, respectively.

Advantages of Concurrent Flow Managed Lane Facilities include:

- The cost of developing and implementing concurrent flow managed lanes is usually lower than other alternatives.
- Less right-of-way is required than with other alternatives.
- These lanes can often be implemented faster than other alternatives.

Potential Disadvantages of Concurrent Flow Managed Lane Facilities include:

- Violation of vehicle-occupancy requirements is more common than other alternatives.
- Travel time reliability may be lower due to the potential for incidents in the general-purpose lanes impacting the concurrent flow lanes.
- Users may have difficulty merging across the general-purpose lanes to enter and exit the concurrent flow lanes.

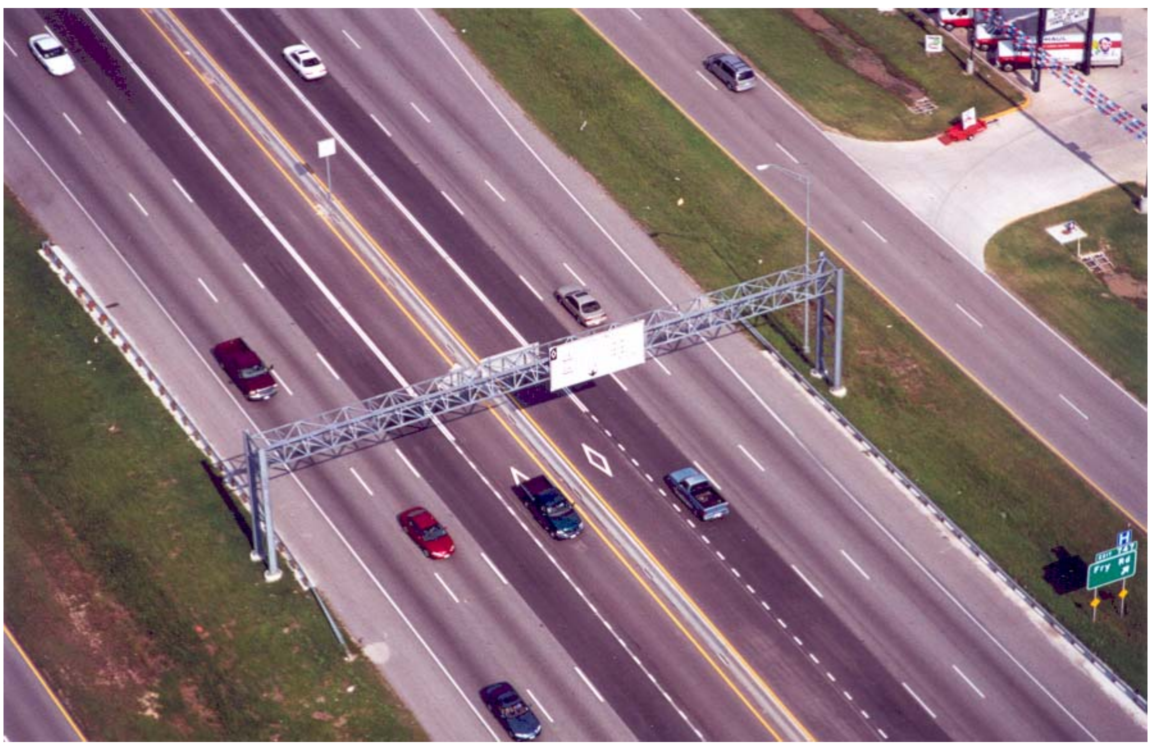


Figure 3-8. Concurrent Flow Lanes on I-10 (Katy Freeway) in Houston, Texas (at Mason Road Entrance).

Figure 3-9. I-5 North Concurrent Flow HOV Lanes in Seattle, Washington.

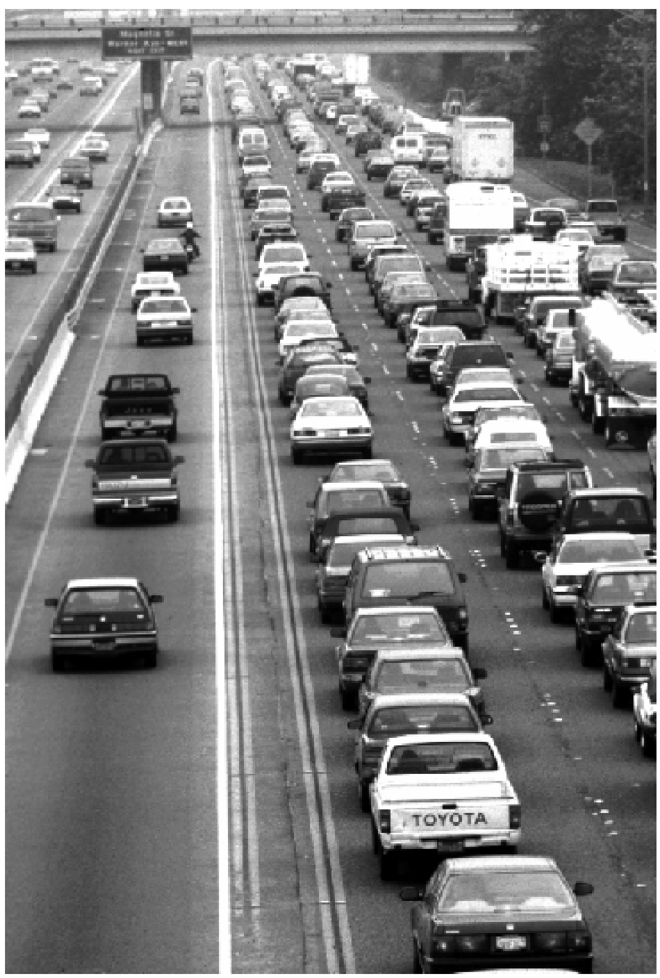


Figure 3-10. I-405 HOV Lane in Orange County, California.

3.1.4 Contraflow Managed Lane Facilities

This type of managed lane facility is a freeway lane in the off-peak direction of travel designated for exclusive use by eligible vehicles traveling in the peak direction. The lane is separated from the off-peak direction general-purpose travel lanes by some type of changeable treatment (i.e., plastic posts or pylons that can be inserted into holes drilled in the pavement or a moveable barrier). Contraflow lanes are typically the inside freeway lane, and they are usually operated only during the peak periods. Some operate only during the morning peak period. During other times of the day, the lanes revert back to normal use in the peak direction of travel. Some existing contraflow managed lanes are open to buses only, others are open to buses and vanpools, and others are open to all eligible vehicles.

Several examples of contraflow-managed lanes are located in the New York City area, including the eastbound approach to the Lincoln Tunnel and portions of the Long Island and Gowanus Expressways. These three facilities all use plastic pylons to create the managed lane, operate only in the morning peak period, and are restricted to buses-only or buses and vanpools. The contraflow lane on I-495 in Union City, New Jersey, approaching the Lincoln Tunnel is shown in Figure 3-11.

The I-30 (East R. L. Thornton Freeway) contraflow lane in Dallas and the Southeast Expressway contraflow lane in Boston use moveable concrete barrier technology to create the HOV lane. Figure 3-12 shows the moveable barrier creating the contraflow HOV lane on the East R. L. Thornton Freeway. Entrance and exit ramps to the contraflow lane at the downtown entrance to I-30 in Dallas, Texas, are shown in Figure 3-13. The barrier-transfer vehicle (“Zipper truck”) is also shown in Figure 3-13.

Consider Contraflow Managed Lane Facilities when:

- there is a high directional split of the target market of travelers and where the off-peak direction traffic speed will not be adversely affected by the loss of a lane.

Advantages of Contraflow Managed Lane Facilities include:

- They may provide a relatively low-cost way of addressing traffic congestion in some corridors, although significant costs may be involved in creating and removing the lane in response to peak-period traffic demands.

Potential Disadvantages of Reversible Managed Lane Facilities include:

- The ongoing operating costs may be higher than other approaches.
- Safety concerns may also be higher with contraflow facilities, requiring consideration of exclusive use by professional drivers.

Figure 3-11. Contraflow Lane on I-495 in Union City, New Jersey.

Figure 3-12. Moveable Barrier and Contraflow HOV Lane on I-30 (East R. L. Thornton Freeway) in Dallas, Texas.

Figure 3-13. Contraflow Lane at Downtown Entrance to I-30E (East R. L. Thornton Freeway) and "Zipper Truck" Used to Move Barriers.

3.1.5 Bypass Lanes (or Queue Bypass Lanes) for Eligible Vehicles

Bypass lanes (or queue bypass lanes) are typically used by eligible vehicles to provide priority treatment at metered freeway entrance ramps or at toll plazas. On freeway entrance ramps, a separate lane is provided adjacent to the general-purpose lane so that eligible vehicles do not have to stop at the ramp meter signal but can move around queued traffic and directly enter the freeway. Bypass lanes are in operation on freeways in the Minneapolis/St. Paul metropolitan area, Seattle, Washington, cities throughout California, and other areas.

In addition to freeway entrance ramps, bypass lanes have been incorporated at several bridge toll plazas across the country. The George Washington Bridge in New Jersey, the Coronado Bridge in San Diego, and various bridges in the San Francisco area provide examples of managed lane bypasses at toll plazas.

3.2 INGRESS AND EGRESS ALTERNATIVES FOR MANAGED LANES

A variety of treatments can be used to provide access to and from a managed lane. It is critical that all eligible vehicles can easily and safely merge into and out of managed lanes. In addition, in some areas the travel time savings provided by direct access ramps is as important as that provided by the managed lane. The following types of approaches can be used to provide ingress and egress to managed lanes.

3.2.1 Direct Access Ramps

Grade separated or direct access ramps provide exclusive ingress and egress for managed lanes and are usually combined with exclusive managed lane facilities. Design treatments may include drop ramps, T-ramps, Y-ramps, and flyover ramps. Direct ramps may provide access from adjacent roadways, park-and-ride lots, and transit stations. Direct access ramps are usually found with exclusive managed lane facilities. Direct connections can be the most efficient means of managing these conflicting movements at locations where there is substantial congestion in the general-purpose lanes and a large volume of vehicles accessing the managed lane.

A variety of direct ramp designs are in use. Figures 3-14 to 3-16 illustrate common direct access ramp designs including a T-ramp, drop ramp, and wishbone ramp, respectively. Direct access ramps may involve significant capital costs, but the travel time savings provided to eligible vehicles and the safety benefits may justify the additional costs associated with these types of treatments.

Advantages of Direct Access Ramps include:

- They have the ability to move high volumes of eligible vehicles into and out of a managed lane facility without disrupting flow in the freeway general-purpose lanes.
- They provide additional travel time savings.
- There is improved travel time reliability.
- There is enhanced safety.

Potential Disadvantages of Direct Access Ramps include:

- They create a need for additional right-of-way.
- There are additional capital costs associated with different design treatments.

3.2.2 Direct Freeway-Managed-Lane-to-Freeway-Managed-Lane Connections

These facilities provide direct connections from a managed lane on one freeway to a managed lane on another freeway. Freeway-to-freeway managed lane connections allow eligible vehicles to continue through regional highway interchanges without exiting the managed lane facility. This approach provides additional travel time savings and reduces potential conflicts with weaving movements into the general-purpose lanes. Examples of freeway-to-freeway HOV lane direct connections include the I-105/I-405, the I-105/I-110, and the I-105/I-710 interchanges in Los Angeles and the I-5/SR 55 interchange in Orange County, California. This type of connection involves significant capital costs, but it may be appropriate in areas with extensive networks of managed lane facilities where travel demand warrants. Due to the right-of-way requirements and the costs associated with this approach, there are probably few locations where these ramps are appropriate.

Figure 3-14. T-ramp in Houston, Texas.
(Main lane—right to left across photograph, local access ramp toward top)

Figure 3-15. Drop Ramp in Orange County, California.
(Managed flow main lane continues under overcrossing road)

Figure 3-16. Wishbone Ramp on I-45 (North Freeway) at Aldine-Bender in Houston, Texas.

3.2.3 Direct Merge or At-Grade Access

Direct merge approaches allow eligible vehicles to merge directly into and out of the managed lane from the adjacent general-purpose lane. Continuous ingress and egress may be allowed, or specific access points may be designated. Direct merges are usually used with concurrent flow managed lanes. These approaches are used on many concurrent flow managed lanes, including Seattle, San Francisco, San Jose, Los Angeles, Orange County, Phoenix, Nashville, Minneapolis, Miami, Orlando, Norfolk/Virginia Beach, Baltimore/Washington, D.C., and New Jersey/New York City. Figure 3-17 shows I-5 in Seattle where continuous access is allowed along the paint-separated concurrent flow lane.

Advantages of Direct Merge Approaches include:

- They represent the lowest capital cost alternative.
- They provide the greatest flexibility.
- Frequent and uncontrolled access can increase the number of potential users of a managed lane facility.
- Less frequent access points reduce the potential for conflict.

Potential Disadvantages of Direct Merge Approaches include:

- Conflicts may arise when vehicles merge across the general-purpose lanes in many locations.
- While less frequent access points reduce the potential for conflict, they may exclude some users.
- Enforcement of direct merge access is more difficult than with other treatments.

Figure 3-17. I-5 Concurrent Flow Lane Providing Continuous Access in Seattle, Washington.

3.2.4 Slip Ramps

Slip ramps may be used at the start, end, and intermediate points of an exclusive managed lane. Slip ramps provide a break in the barrier or buffer, allowing eligible vehicles to enter and exit the facility. In addition, slip ramps can be provided for either ingress or egress rather than both movements. Slip ramps are used with exclusive managed lanes in San Diego, Los Angeles, Houston, Minneapolis, and Washington, D.C./Northern Virginia. Figure 3-18 illustrates a slip ramp along I-45 (North Freeway) in Houston, Texas.

Advantages of Slip Ramps include:

- They have lower capital costs than direct access facilities.
- They provide a potential to serve more eligible vehicles.

Potential Disadvantages of Slip Ramps include:

- There are increased conflicts with non-merging vehicles.
- Enforcement is more difficult than with direct access facilities.

3.3 VEHICLE ELIGIBILITY AND VEHICLE-OCCUPANCY REQUIREMENTS

Managed lane facilities offer the benefit of matching vehicle eligibility criteria and vehicle-occupancy requirements to the demand for the lane. The types of vehicles allowed to use a facility and the vehicle-occupancy levels can be changed to maximize the person-carrying capacity of a facility, while preserving free-flow travel conditions and travel time advantages to eligible vehicles.

Figure 3-18. Slip Ramp along I-45 (North Freeway) in Houston, Texas.

This section identifies the types of vehicles usually considered for use on a managed lane facility and alternate vehicle-occupancy levels. The advantages of allowing various vehicles and vehicle-occupancy levels are highlighted along with some of the issues associated with various approaches. Other topics covered include variable requirements, volume operating thresholds, managing vehicle demand, and regional considerations.

3.3.1 Vehicle Eligibility Requirements

Establishing eligibility requirements that identify the types of vehicles that will be allowed to use a managed lane is a first step in developing an operation plan. Determining vehicle eligibility is important because it influences other decisions relating to the design and operations of the facility. The following types of vehicles may be considered to use a managed lane facility:

- buses,
- vans and vanpools,
- carpools in automobiles and light trucks,
- motorcycles,
- stickered vehicles,
- tolled vehicles,
- commercial vehicles and trucks,
- deadheading buses,
- taxis,

- airport shuttles and other special services,
- emergency vehicles, and
- low-emission vehicles.

The general characteristics of these vehicles are described next. Table 3-1 presents the advantages, disadvantages, and potential issues associated with allowing each type of vehicle to use a managed lane facility. Preference should be given to accommodating the widest variety of vehicles possible.

Buses. Buses are usually given first consideration in the use of a managed lane facility. High volumes of buses offer the greatest potential benefit for increasing the people-carrying capacity of a facility, as well as for energy savings and air pollution reductions. Buses may be the only vehicles allowed to use a facility, or buses may be one of many eligible users. Examples of the former include the busways in Ottawa, Pittsburgh, and Minneapolis-St. Paul; the contraflow HOV lane on Route 495 approaching the Lincoln Tunnel in New York City; and the bus-only shoulder freeway lanes on US 36 in Denver, Highway 99 in Vancouver, and freeway sections in the Minneapolis-St. Paul area. The bus facilities in Ottawa, Pittsburgh, and Minneapolis-St. Paul are all located in separate rights-of-way. These facilities were developed and designed to provide high-quality service to large numbers of buses. The other facilities are restricted to buses-only due to safety concerns or the desire to provide priority treatments for buses around specific freeway bottlenecks. Although buses provide the greatest person-carrying capacity, corridors in many metropolitan areas in North America do not have high enough current or projected transit vehicle volumes to warrant limiting the use of a facility to buses only. Thus, most managed lanes allow other vehicles to meet a vehicle-occupancy requirement along with buses.

Vans and Vanpools. Often, the next vehicles considered for managed lane use are vanpools. Although vans have operating characteristics similar to automobiles, vanpools have higher vehicle-occupancy levels than carpools. As a result, vanpools may be given preference over carpools in some situations.

Carpools. With the exception of the managed lanes noted under the previous two vehicle eligibility categories, all other managed lanes are open to carpools operating in automobiles or light trucks. Allowing carpools to use a managed lane can help avoid the "empty lane syndrome," add vehicles at no additional public cost, and enhance the person-carrying capacity of a facility. A potential disadvantage of allowing carpools is that too many vehicles may create congestion, which may negatively impact the travel time savings and travel time reliability of buses. Increasing the vehicle-occupancy requirement on a facility is one way to address this problem, and pricing is another solution.

Table 3-1. Vehicle Eligibility Considerations (Adapted from Reference *4*).

Vehicle Type	Advantages	Disadvantages
Buses	• Highest person-moving capacity • Greatest potential for increasing corridor throughput	• Unless there are high numbers of buses, the lane will look unused, creating an empty lane syndrome
Vanpools	• High person-moving capacity	• Unless there are high numbers of vanpools, the lane will look unused, creating an empty lane syndrome
Carpools using automobiles and pickup trucks	• Add users at no public cost • Add to person-moving efficiency • Help avoid empty lane syndrome	• Too many carpools may create congestion in the managed lane, reducing travel time savings and travel time reliability • May be safety concerns with some facilities
Motorcycles	• Add vehicles in lanes	• Potential safety concerns • Possible public perception problems of single-occupant vehicle
Stickered vehicles	• Maximize available capacity • Manage demand • Expand eligible user group • Address actual or perceived low use	• Make enforcement more difficult • Time and cost to administer program • Possible confusion among users • May add too many vehicles to the facility
Tolled vehicles	• Maximize available capacity • Manage demand • Expand eligible user group • Address actual or perceived low use • Generate new revenues	• Make enforcement more difficult • Time and cost to administer program • Possible confusion among users • May add too many vehicles to the facility • Cost of automated toll equipment • Public and policy maker concerns related to equity, double taxation, and use of revenues
Commercial vehicles and heavy trucks	• Exclusive use of managed lanes during off-peak hours by trucks may help reduce truck traffic in freeway lanes • Enhance good movement and economic development	• Potential safety concerns if trucks mixed with eligible vehicles • Safety concerns during transition period • Access points may not serve commercial origins and destinations • Geometric restrictions may not accommodate trucks • Do not provide incentive to use transit or rideshare • Do not enhance people-moving capability
Deadheading buses	• Enhance bus operating efficiencies	• Potential public perception problems if only operator • Reduce transit operating costs or allow more revenue service for the same cost
Taxis	• Add vehicles if meet occupancy requirements	• Potential public perception problems if only operator
Airport shuttles and other special services	• Add vehicles if meet occupancy requirements	• Potential public perception problems if only operator
Emergency vehicles	• Travel time savings and enhanced reliability to emergency vehicles	• Potential public perception problems if only operator
Low-emission vehicles (LEVs)	• May encourage use of LEVs • Add vehicles to managed lane	• Potential public perception problems if vehicles do not meet the occupancy requirements • Potential to make enforcement more difficult • May cause congestion on the facility if too many LEV with only the driver
Authorized vehicles	• May be appropriate if managed lane facility has physical design or operational constraints	• Add extra effort to train and register drivers • May not have enough authorized vehicles to make the lane looked used

Motorcycles. The advantages and disadvantages of allowing motorcycles to use managed lane facilities have been debated over the years. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 authorized the motorcycle use of managed lane facilities, regardless of the number of riders. Previous federal regulations provided some flexibility for states and other agencies in determining if motorcycles would be allowed to use a facility based on safety concerns. Several states, particularly Virginia, Pennsylvania, Florida, and Texas excluded motorcycles on managed lanes prior to the new regulations. There is a lack of good data on the safety impacts associated with motorcycle use of managed lanes. Figure 3-19 illustrates motorcycles using the concurrent flow lanes on I-635 (LBJ Freeway) in Dallas, Texas.

Figure 3-19. Motorcycles on I-635 (LBJ Freeway) Concurrent Flow Lane in Dallas, Texas.
(Motorcycles shown in center of photograph)

Stickered Vehicles. One approach to managing demand on a managed lane facility is through the use of a sticker program. The basic concept of this technique is to allow vehicles with a valid sticker or electronic device like an automated vehicle identification (AVI) tag to use a managed lane facility. Currently, this approach is in use on the Southeast Expressway contraflow HOV lane in Boston. A three or more persons (3+) vehicle-occupancy requirement is in use on this facility, but two-person carpools with valid stickers may access the lane. The stickers were distributed by the Massachusetts Highway Department (MassHighway), which is responsible for the project. To ensure that the managed lane does not become too congested through this program, the stickers are color coded and use of the lane is regulated. Vehicles with license plates ending in an odd number have blue stickers and are allowed in the lane on odd numbered days. Vehicles with license plates ending in even numbers have red stickers and may access the lane on even numbered days. Potential advantages of this approach include maximizing available capacity in the managed lane, managing demand, expanding the eligible user groups, and addressing actual or perceived perceptions of low use. Potential disadvantages include making enforcement more difficult, adding extra administrative functions and costs to manage the program, and confusing users.

Tolled Vehicles. Another approach is to allow lower or single-occupant vehicles to use a managed lane facility for a fee. This technique may be referred to as priority pricing, value pricing, or high-occupancy toll (HOT) lanes. Potential advantages of this technique include maximizing available capacity, managing demand, expanding the eligible user groups, addressing real or perceived low use levels, and generating new revenues. Possible disadvantages include making enforcement more difficult, adding costs to administer the program, adding costs associated with automated toll collection, confusing users, and adding too many vehicles to the lane. This approach may also raise concerns from the public and policymakers relating to equity, double taxation, and use of revenues.

Commercial Vehicles. Commercial vehicles or semi-trucks are not allowed to use any managed lane facility in North America, regardless of the number of passengers. This restriction has been applied for safety reasons and because allowing trucks would not encourage ridesharing or reduce vehicle miles (km) of travel. Recently, groups in some areas have suggested providing commercial vehicles with exclusive use of managed lane facilities during off-peak periods or allowing trucks to share the lanes with other eligible vehicles during normal operating hours. These ideas have been raised partially to segregate commercial vehicles from general-purpose traffic, to provide commercial vehicles with travel time savings to increase their competitiveness, and to gain extended use of the managed lanes. Potential concerns with opening managed lane facilities to commercial vehicles during peak and off-peak periods include: lack of compatibility with policies and objectives to increase ridesharing and vehicle-occupancy levels, lack of access points to meet the origins and destinations of trucks, design limitations which may not accommodate truck movements, and conflicts between commercial vehicles and eligible vehicles.

Deadheading Buses. Deadheading refers to the operation of buses in non-revenue service. Deadheading usually occurs in the morning and evening as buses are going to and from the garage to the start or the end of a route. Deadheading also occurs with express services as buses travel back out to start another trip. Operating efficiencies may be realized by allowing deadheading buses to use the managed lanes. For example, allowing deadheading buses to use a managed lane facility may reduce transit operating costs or increase revenue service at no additional operating cost. However, buses with only an operator in a managed lane may create public perception problems if not properly described.

Taxis. Taxis meeting the vehicle-occupancy requirements are considered carpools and are allowed to use the managed lanes in North America open to carpools. Taxi operators in some areas have requested use of the managed lanes even when they are not carrying passengers to save time and increase their operating effectiveness. Concerns over public perception and increased difficulty in enforcement of the occupancy requirements more difficult for police are the two factors commonly cited for not allowing taxis with only the driver to use managed lane facilities. An additional factor considered in some areas is that they do not enhance people moving capabilities nor do they result in fewer vehicle trips.

Airport Shuttles and Other Special Services. Vans, buses, and limousine services that meet the vehicle-occupancy requirement are allowed to use many managed lane facilities. These services are often oriented toward airports or other major trip generators in an area. Like taxis, the operators of these services in some areas have requested authorization to use managed lane facilities even when they are not carrying passengers. Concerns over public perception and enforcement are the two factors commonly cited for not allowing these vehicles to use a managed lane facility with only a driver. An additional factor considered in some areas is that they do not enhance people-moving capabilities nor do they result in fewer vehicle trips.

Emergency Vehicles. Emergency vehicles are usually allowed on all managed lane facilities, even when not on an emergency trip. In most cases, emergency vehicles do not make extensive use of managed lanes due to access limitations, hours of operation, and other factors. The inclusion of emergency vehicles as an authorized user group should not significantly affect the design of the facility. It is suggested that emergency vehicles be properly identified because use of the lane by unmarked vehicles may raise public perception concerns.

Low-Emission Vehicles. Consideration has been given in some areas to allowing electric vehicles and other non-polluting or low-emission vehicles to use managed lane facilities without regard to the vehicle-occupancy requirements. ISTEA encourages the inclusion of these vehicles on managed lanes. Supporters of this approach suggest that providing low-emission vehicles with access to managed lane facilities would encourage more widespread use of these technologies. The major concern with allowing low-emission vehicles with only the driver to use a managed lane facility relates to enforcement. Alternatively fueled vehicles with only the driver are allowed to use the Houston managed lanes, and legislation allowing low-emission vehicles to use managed lanes came close to being approved by the California legislature in 1996. An additional factor considered in some areas for not allowing low-emission vehicles with only the driver to use the facility is that they do not enhance people-moving capabilities nor do they result in fewer vehicle trips.

Authorized Vehicles. Some managed lane facilities have physical designs or operational constraints that are severe enough to limit their use to trained drivers only. In these cases, a managed lane may be better suited to a smaller volume of users who are trained and authorized to use the lane. These could include bus drivers, taxi drivers, vanpool drivers, and, in some cases, authorized carpools. Different approaches may be used to identify authorized vehicles and to train drivers.

3.3.2 Vehicle-Occupancy Requirements

If carpools are allowed to use a managed lane facility, the vehicle-occupancy requirement will need to be considered. The planning process should include an analysis of the demand for a facility at different vehicle-occupancy levels and the impact these requirements will have on traffic flow. The goal is to set the occupancy requirement at a level that will encourage the use of carpooling, vanpooling, and taking the bus without creating too much demand to make the lane congested.

Operating managed lane facilities that allow carpools are almost evenly split between those requiring two or more persons (2+) per vehicle and those requiring 3 or more persons (3+) per vehicle (3+). Although no managed lane facility currently requires four or more occupants (4+), this level has been used in the past. Changing the occupancy requirement by time of day is another alternative. The characteristics, advantages, and disadvantages of the various vehicle-occupancy requirements are briefly described in this section and highlighted in Table 3-2.

Table 3-2. Vehicle-Occupancy Requirement Criteria (Adapted from Reference *4*)

Vehicle-Occupant Level	Advantages	Disadvantages
Two or more persons per vehicle	• Easiest level of carpools to form • Often significant numbers of existing 2+ carpools in a corridor	• May be too many 2+ carpools resulting in congestion in a managed lane
Three or more persons per vehicle	• Can address congestion problems at the 2+ level • Higher person-moving capacity	• Hard for individuals to form 3+ carpools • May not have enough 3+ carpools to make lane look used, causing the empty lane syndrome
Four or more persons per vehicle	• Can address congestion problems at the 3+ level • Higher person-moving capacity	• Hard for individuals to form 4+ carpools • Harder to operate on a regular basis due to individual travel needs and schedules • May not have enough 4+ carpools to make lane look used, causing the empty lane syndrome
Variable requirements by time of day (3+ peak hours, 2+ other operating hours)	• Can address main lane congestion problems during peak periods • Has been successfully used in Houston	• May be confusing for users, especially during transition periods • May make enforcement more difficult, especially during transition periods

Two or More Persons per Vehicle. Two or more persons per vehicle represents the lowest level of carpooling. Forming a two-person carpool is much easier than forming a three- or four-person carpool. Most two-person carpools are comprised of family members, co-workers, or friends. Corridors may have significant numbers of existing two-person carpools, providing a target market for a managed lane facility. Using a 2+ vehicle-occupancy requirement level initially provides the greatest opportunity to avoid the empty lane syndrome. On the other hand, if the number of 2+ carpools in the corridor is already relatively high, such as 30 percent on a four-lane facility, this designation may not improve the person-movement capacity of a facility. A managed lane facility should be initially opened at the 2+ occupancy level. If a managed lane becomes too congested at the 2+ occupancy level, the requirement can be increased to 3+ during the congested time. This allows the public to see the problem and then the solution to the problem when the restriction is changed to 3+. A general guideline used in many areas is that vehicle volumes at the 2+ level should not exceed 1,200 to 1,500 vehicles per hour per lane. The occupancy requirement should be examined and modified, if necessary.

Three or More Persons per Vehicle. The next level for defining a carpool is to require three or more persons per vehicle. Vehicle volumes at the 3+ level are significantly lower than at a 2+ requirement. It is more difficult for travelers to form three-person carpools, so some potential carpoolers may not be able to use a facility at a 3+ requirement. Others may form 3+ carpools from existing 2+ carpools, reducing vehicle volumes in the managed lane.

Four or More Persons per Vehicle. The highest carpool requirement used with a managed lane facility is four or more persons per vehicle. This requirement was used during the initial stages of the Shirley Highway HOV lanes in the Northern Virginia/Washington, D.C., area and on the I-10 (Katy Freeway) HOV lane in Houston.

It is difficult for most individuals to form carpools with four or more persons and also to operate those that are formed on a regular basis. Most metropolitan areas probably do not have enough demand at the 4+ level to make this a viable option, especially during the early stages of a project. Estimated volumes of 400 to 800 vehicles an hour per lane at the 4+ level should be present to consider this alternative. This is comparable to those identified for the 3+ level.

Variable Vehicle-Occupancy Requirements by Time of Day. Another approach is to change the managed lane occupancy requirement by time of day. This technique represents one approach to managing demand on a managed lane. For example, a 3+ requirement may be used during the morning and afternoon peak hours, with a 2+ level in effect during other operating hours. The I-10 (Katy Freeway) HOV lane in Houston currently uses a variable occupancy requirement.

3.3.3 Volume Operating Thresholds

As discussed previously, the goal of a managed lane facility is to provide travel time savings and travel time reliability to eligible vehicles. The vehicle-occupancy requirement should be established at a level that will encourage use of the facility and the formation of new carpools without creating too much demand to make the lane congested.

The number of vehicles using a lane on opening day and during the initial phases of a project should be high enough to justify the facility. Ensuring that the lane is well utilized will help build support among users, non-users, and the general public. If the public perceives a facility to be under-utilized, pressure may be exerted to change vehicle-occupancy requirements, operating hours, or to open the lane to mixed traffic.

A number of factors should be considered in assessing the minimum operating thresholds for a managed lane facility. The exact minimum threshold for a specific project will depend on the goals and objectives of the project, the type of facility, the vehicle eligibility and vehicle-occupancy requirements, the level of congestion in the general-purpose lanes, and local conditions and perceptions. Table 3-3 presents both minimum and maximum operating thresholds for different managed lane facility types. The minimum volume threshold generally range from 700 to 1,000 vehicles per hour per lane (vphpl) on opening day. Bypass lanes range from 100 to 200 vphpl. Freeway contraflow facilities for trained drivers (e.g., buses, vanpools) range from 200 to 400 vphpl. These facilities are not likely in Texas as they create a serious "empty lane syndrome" issue.

Traffic volumes on managed lanes must also be monitored to help identify when maximum flow rates are being approached so that appropriate actions can be taken. Table 3-3 shows general guidance for maximum flow rates. These flow rates generally range between 1,200 and 1,500 vphpl for different managed lane facility types. Freeway contraflow trained-driver (e.g., buses, vanpools) facilities range from 600 to 800 vphpl while bypass lanes range from 300 to 500 vphpl. The controlling factor for the capacity of a managed lane facility is the facility terminus design and interchange locations. Managed lane facilities that exit into the general-purpose lanes and continue as their own lane will handle higher operating thresholds than facilities that require motorists to merge back into the general-purpose lanes. The design of interchange locations also effects the vehicle capacity of the facility. For example, interchanges at a T-ramp that require vehicles to appreciably slow down at the access location will not handle as many vehicles as T-ramp interchanges that are designed to include bypass lanes for non-exiting vehicles.

Table 3-3. Volume Operating Thresholds for Different Managed Lane Facilities (Adapted from Reference *4*).

Facility Type	Volume Threshold (vphpl)	
	Minimum	Maximum
Freeway, exclusive two-way	700-1,000	1,200-1,500
Freeway, exclusive reversible	700-1,000	1,500-1,800
Freeway, concurrent flow	700-1,000	1,200-1,500
Freeway, contraflow, managed lane	700-1,000	1,200-1,500
Freeway, contraflow, Trained drivers (e.g., buses, vanpools)	200-400	600-800
Bypass lanes	100-200	300-500

3.3.4 Guidelines for Developing Vehicle Eligibility and Vehicle-Occupancy Requirements

A number of factors should be considered when establishing vehicle eligibility and vehicle-occupancy requirements for a managed lane facility. The exact factors and threshold levels will vary by metropolitan area depending on local goals and objectives, facility types, design treatments, system connectivity issues, local experience with main lanes, and local conditions. The elements discussed in this section can be used to help develop local criteria for vehicle eligibility and vehicle-occupancy requirements on managed lane facilities. These elements include the following:

- metropolitan area and project goals and objectives,
- type of managed lane facility,
- specific design or operating limitations,
- segment and area-wide continuity,
- existing vehicle-occupancy levels,
- travel time savings and travel time reliability, and
- carpool and vanpool formation and increased transit ridership.

Metropolitan Area and Project Goals and Objectives. The goals and objectives of a specific managed lane project or a managed lane system should be used in the development of the vehicle eligibility and vehicle-occupancy criteria. These may be reflected in the overall policies of the region or they may relate specifically to an individual project. The goals and objectives for a managed lane ramp meter bypass and a bus-only facility on a separate right-of-way may be different. For example, for a ramp meter bypass lane, the goal may be to ensure that the queue length of the general-purpose vehicles using the ramp does not become restrictive to bypassing traffic to ensure a travel time savings is provided to bypassing traffic. Whereas, for a bus-only facility the goal may be to ensure a travel time savings and trip reliability for eligible vehicles; thus, quick off-line access may be offered that allows buses to exit/enter the transit station and managed lane without mixing with other traffic once off the separated right-of-way. The vehicle eligibility and vehicle-occupancy requirements may also be different to reflect various goals and objectives.

Type of Managed Lane Facility. As previously noted, the type of managed lane facility being considered will influence the vehicle eligibility and vehicle-occupancy requirements. Bus-only lanes on separate rights-of-way obviously do not require consideration of vehicle-occupancy requirements. Most exclusive, concurrent, and contraflow freeway managed lane projects require consideration of both vehicle eligibility and vehicle-occupancy requirements. These facilities usually provide a good deal of flexibility in both vehicle eligibility and vehicle-occupancy criteria.

Specific Design and Operating Limitations. The vehicle eligibility criteria, and, to a lesser extent, the vehicle-occupancy requirement, may be influenced by design or operating constraints associated with a specific facility. For example, facilities with specific design or operating limitations may be restricted to buses, or to buses, vanpools, and 3+ carpools to maintain a lower volume of vehicles rather than being open to 2+ carpools.

Segment and Area-wide Continuity. If there is more than one managed lane facility in operation or in the planning stage in a metropolitan area, consideration should be given to uniform vehicle eligibility and vehicle-occupancy requirements. Maintaining the same requirements on multiple facilities can improve public understanding and simplify enforcement. This approach may not be appropriate if there are different types of managed lane facilities in an area or if significantly different travel and mode share characteristics exist in various corridors. Several metropolitan areas use different vehicle eligibility and vehicle-occupancy requirements on managed lane facilities, while other areas use the same regulations on all managed lanes.

Existing Vehicle-occupancy Levels. Vehicle-occupancy levels in a corridor or metropolitan area provide a good indication of the potential for use of a facility by existing carpools at different occupancy levels. A corridor with vehicle-occupancy levels of 1.4 persons per vehicle or higher indicates a strong existing carpool market. In this case, it may be appropriate to consider a 3+ vehicle-occupancy requirement. On the other hand, a corridor with average vehicle-occupancy levels of 1.1 to 1.2 suggest a 2+ requirement would be more appropriate. The number of existing or planned general-purpose lanes should also be considered. For example, if 25 percent of the existing traffic on a five-lane facility is comprised of 2+ carpools, a 2+

designation may not provide much of an incentive, whereas a 25 percent 2+ volume on a three-lane facility might provide more of an incentive.

Travel Time Savings and Travel Time Reliability. The travel time savings and travel time reliability provided to eligible vehicles using different vehicle eligibility and vehicle-occupancy levels should also be considered in establishing guidelines. Minimum speeds and speed reliability are often used in association with travel time savings and travel time reliability. The requirements should maximize the person-moving capacity of the facility, while not degrading operations. Lower vehicle-occupancy requirements usually mean increases in eligible vehicles, which may cause congestion on the lane. It is desirable to establish the vehicle eligibility and vehicle-occupancy requirements to accommodate growth in eligible vehicles without adversely affecting travel times and travel time reliability. Tolling the facility to allow lower occupancy vehicles to use the lane is another technique that can be used to balance the efficiency of the managed lane by avoiding underutilization while ensuring travel times are reliable.

Carpool and Vanpool Formation and Increased Transit Ridership. An objective of most managed lane projects is to encourage individuals to change from driving alone to riding the bus or forming carpools or vanpools. Vehicle-occupancy requirements should be set at levels that will encourage these shifts. If there are few carpools in a corridor, a 2+ requirement may be an appropriate starting point. The requirements should also allow for growth as more commuters switch to transit, carpooling, and vanpooling. This can be achieved through aggressive rideshare matching and transit incentives. As discussed next, vehicle-occupancy requirements can be increased if needed.

3.3.5 Guidelines for Changing Vehicle Eligibility and Vehicle-Occupancy Requirements

As noted previously, one of the advantages of managed lane facilities is the flexibility to change vehicle-occupancy or vehicle eligibility requirements in response to increasing demand. For example, if a managed lane becomes congested at a 2+ vehicle-occupancy level, consideration can be given to raising the vehicle-occupancy requirements to three or more persons. However, decisions on changing vehicle-occupancy and vehicle eligibility requirements should not be taken lightly. Careful consideration should be given to a number of factors before any decision is made to change vehicle eligibility or vehicle-occupancy criteria. Further, adequate public information and comment period should be provided to commuters prior to any actual change.

Consideration should be given to developing policies and criteria for use in guiding the decision-making process on changing vehicle eligibility and vehicle-occupancy requirements. These policies and criteria can serve a number of purposes. First, they can help focus the technical analysis on the key elements that should be examined in the decision-making process. Second, they can help communicate the factors that will be considered and the need for a change on a specific project to decision-makers and the public. This information is important to help develop an understanding among these groups about when changes may be needed and to build support for changes on a specific facility.

The guidelines developed by the Washington State Department of Transportation (WSDOT) provide one of the best examples of criteria for determining if changes are needed in vehicle eligibility and vehicle-occupancy requirements. The WSDOT policies focus on the minimum average speed and speed reliability on a managed lane facility. Thus, the policies support providing reliable travel speeds and travel time reliability to eligible vehicles. The measures used by WSDOT indicate that managed lane vehicles should maintain or exceed an average operating speed of at least 45 mph (72 kph) 90 percent of the time over a consecutive six-month period. If this criterion is not met, approaches for addressing the problem will be examined. These approaches may or may not include changing vehicle-occupancy or vehicle eligibility requirements.

Consideration of other elements may also be of help in determining when changes need to be made in vehicle eligibility and vehicle-occupancy criteria. Four factors that should be used in the development of guidelines include:

- vehicle volumes,
- vehicle speeds,
- travel time savings, and
- travel time reliability.

Vehicle Volumes. The number of vehicles using the facility is one criterion that can be used to help identify changes needed in vehicle-occupancy requirements and vehicle eligibility criteria. Vehicle volume guidelines should be matched to the type of facility, design and operating concerns, project goals and objectives, and local conditions. The general ranges provided in Table 3-3 can be used to assist with the development of a project.

Vehicle Speeds. The speed of vehicles traveling in a managed lane can be used as another criterion to help identify the need to change vehicle eligibility requirements or to increase vehicle-occupancy levels. The desired operating speed for a facility should first be identified based on the speed limit for the facility, the general travel speeds in the corridor or freeway, and any special design and operating characteristics. Speeds on the managed lane facility can then be monitored. Recurring speeds that fall below the desired level may indicate the need to re-evaluate the existing vehicle-occupancy requirements and possibly the vehicle eligibility criteria.

Travel Time Savings.   This criterion relates to both vehicle volumes and travel speeds in the general-purpose lanes as well as those on the managed lane facility. Providing travel time savings to managed lane vehicles is critical to the ongoing success of a project. It is possible, however, for travel speeds to decrease slightly on a managed lane while still maintaining significant travel time savings over the general-purpose lanes. To use this criterion, a desired travel time advantage for managed lanes should first be established, and a program to monitor travel times on both the managed lane and general-purpose lanes should be established. If this level is not maintained on a regular basis, consideration can be given to changing the vehicle-occupancy requirements or vehicle eligibility.

Travel Time Reliability.   Surveys of carpoolers, vanpoolers, and bus riders indicate that the travel time reliability provided by managed lane facilities is as important as the travel time savings in the decision to change from driving alone to using a managed lane. Therefore, travel time reliability should be considered in developing criteria for changing vehicle eligibility and vehicle-occupancy requirements. Once a desired level of reliability has been established for a managed lane project or a managed lane system, changes and degradations in the level can be monitored and appropriate action can be taken as needed.

3.3.6 Other Techniques for Managing Demand

Other techniques may also be appropriate for consideration in managing demand on a managed lane facility. These approaches focus on managing demand on the facility and on alternative operational strategies. It may be appropriate to consider these strategies before focusing on changing vehicle eligibility or vehicle-occupancy requirements. These strategies include:

- ♦ encouraging voluntary higher vehicle-occupancy levels,
- ♦ encouraging alternative work or commute schedules,
- ♦ metering access points, and
- ♦ adding managed lane capacity.

Encouraging Voluntary Higher Vehicle-Occupancy Levels. Prior to changing to a higher vehicle-occupancy level, it may be appropriate to first encourage the voluntary formation of carpools at the higher level. Marketing and public information campaigns could be undertaken to encourage the formation of carpools with higher occupancy levels. If a 2+ vehicle-occupancy requirement is in effect, the campaign could focus on encouraging the formation of 3+ carpools. Further, supporting programs and policies could be used to encourage higher vehicle-occupancy levels. For example, providing free parking for 3+ carpools, while charging 2+ carpools a reduced rate over single-occupant vehicles, may encourage an increase in 3-person carpools. This approach may result in enough 3+ carpools to reduce congestion in the managed lane. The limited experience with this approach indicates that significant numbers of carpoolers are not likely to increase vehicle-occupancy levels voluntarily.

Encouraging Alternative Work or Commute Schedules. A second approach focuses on encouraging commuters to shift their travel to less congested time periods. If congestion is occurring during the peak hour or the peak period, managed lane users could be encouraged to shift their travel to the shoulders of the peak-period or outside of the peak. Greater use of alternative work schedules by employers can help facilitate this shift.

Metering Access Points. Freeway ramp metering has been used in many areas to improve the flow and increase the capacity of freeways. This approach could also be used on managed lane facilities to help manage demand. For example, vehicles entering a managed lane from a direct ramp at a park-and-ride lot could be metered, or 2+ carpools could be metered with 3+ carpools allowed to bypass the meter. This approach may have limited application due to the design of most managed lane projects; however, it may be appropriate for consideration in specific cases.

Adding Managed Lane Capacity. Another approach is to add managed lane capacity along the corridor. Depending on available right-of-way, the characteristics of the existing managed lane facility, and projected demand, options include adding a lane to a single-lane facility, developing a managed lane on an adjacent freeway or roadway, and adding exclusive access treatments.

3.4 TRANSIT AND SUPPORT SERVICES AND FACILITIES

3.4.1 Transit Service Orientation

A variety of bus services and bus operating strategies can be used with managed lane facilities. The wide range of operating scenarios indicates the flexibility in service orientation and service levels offered by managed lane facilities. For example, bus services can be tailored to the specific travel patterns and travel needs of residents and the unique characteristics of an area. In addition, modifications to route structures and service levels can easily be made in response to changing conditions. The five bus operating strategies most often found with managed lane facilities are summarized next.

Dedicated Services. Dedicated bus service operates only on a busway or a managed lane. The route is dedicated to the managed lane facility and does not deviate off of the lane. Routes of this nature provide service similar to light rail transit (LRT) or a heavy rail line. Passengers generally access dedicated routes by walking to a station, using a connecting route, driving to a station or park-and-ride facility, or being dropped off at a station. Operating speeds are usually in the range of 35 to 40 mph (55 to 70 kph) but may reach 50 to 55 mph (80 to 90 kph) on longer segments. Service is offered on these routes throughout the day with frequent buses operating during the peak hours. Dedicated services are usually found with bus-only facilities.

Express and Park-and-Ride Services. Express services—or park-and-ride routes as they are called in some areas—are routes that initiate from park-and-ride lots or other areas close to the managed lane and then operate as express service to major activity centers. This type of route provides high-speed service using the managed lane. Most express or park-and-ride service is oriented toward the downtown or other major activity center. Speeds for the line-haul portion of the trip on the managed lane usually average 50 to 55 mph (80 to 90 kph). These services are usually oriented toward peak-period commuters. Thus, many areas provide express or park-and-ride services only during the peak periods, with little or no off-peak service. Express transit service is found with all types of managed lanes.

Neighborhood-Oriented Routes. These routes offer local service in neighborhood areas and then access the managed lane for the trip to the downtown area or to another major activity center. Operating speeds in the neighborhood areas tend to be in the range of 5 to 10 mph (10 to 15 kph), while speeds on the managed lane segment average between 45 to 55 mph (70 to 90 kph). Neighborhood routes provide commuters with the advantage of not having to drive to a park-and-ride lot or to transfer from a local feeder route. Further, neighborhood-oriented routes may serve areas with concentrations of transit dependents. Neighborhood routes may operate only during the peak periods or throughout the day.

Reverse Commute and Suburb-to-Suburb Routes. The transit routes described focus primarily on serving trips oriented toward the downtown or to other activity centers. This network structure reflects the traditional orientation of transit services, which has historically provided service from suburban areas to central cities and downtown areas. Less service has been focused on providing residents of central cities with access to suburban areas or serving trips between suburbs. Reverse commute and suburb-to-suburb services have been implemented in some areas to meet these travel needs. Reverse commute routes provide central city residents with access to jobs, shopping, and other opportunities in suburban areas. Suburb-to-suburb routes provide service between suburban communities.

Timed-Transfer Services. Timed-transfer systems are oriented around a network of transit routes designed to facilitate fast and convenient transferring between different routes. Timed-transfer systems are set up so that routes and buses are linked at major interchange points, which are usually major transit centers. Buses on all routes serving the transfer points operate on the same headways or service frequencies. Buses are scheduled to arrive at the interchange point at the same time to allow passengers to transfer between routes. The advantage of this system is that passengers do not have to go downtown to transfer, as in a traditional radial system, allowing riders to reach more destinations more conveniently and quickly.

3.4.2 Supporting Facilities

Four general types of support facilities are commonly found with managed lanes on freeways and in separate rights-of-way. These are park-and-ride and park-and-pool lots, transit stations, intermodal facilities, and bus stops and shelters. A general description of these facilities is provided in this section, and Figures 3-20 through 3-23 highlight examples of these facilities.

Park-and-Ride Facilities. Park-and-ride and park-and-pool lots are integral parts of most managed lane facilities in North America. Although the size, location, and design of park-and-ride facilities vary among different managed lane projects, all share a common purpose. Park-and-ride and park-and-pool lots provide users with the opportunity to change to eligible vehicles, affording an effective combination of automobile and bus, vanpool, and carpool use. Park-and-ride lots are usually oriented toward commuters changing from an automobile to a bus or a rail system, while park-and-pool facilities assist in the formation of carpools and vanpools. Access to the lots may also be accomplished by walking or bicycling, and some park-and-ride facilities provide bicycle storage lockers or bicycle racks. In addition, some travelers may be dropped off and picked up rather than leaving their vehicles in the lot all day.

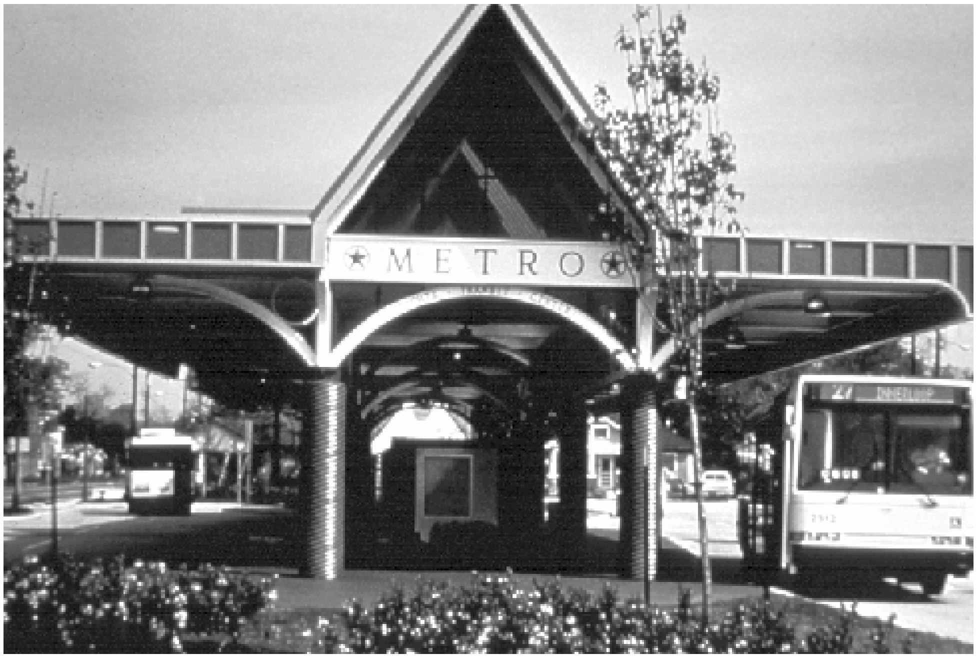


Figure 3-20. Transit Station in Houston, Texas.

Figure 3-21. Westpark Park-and-Ride Lot along US 59 (Southwest Freeway) in Houston, Texas.

Figure 3-22. Richardson Transit Center near US 75 in Dallas, Texas.

Figure 3-23. Fuqua Transit Station and Park-and-Ride Lot along I-45 (Gulf Freeway) in Houston, Texas.

Transit Stations. Transit stations or transit centers are used with many managed lanes. Transit stations provide convenient, safe, and sheltered locations for passengers to wait for buses and to transfer between different routes or services. Most transit centers include enclosed waiting areas for passengers and multiple bus bays. Route and schedule information is usually provided, and some facilities include amenities such as bus pass sales outlets, newspaper racks, small convenience stores, and other services. Many transit stations—although not all—associated with managed lane facilities are incorporated into park-and-ride lots. The type and design of a transit station is related to the nature of the managed lane facility and the bus operating concept to be served. The two basic types of stations are on-line centers, which are located on the managed lane, and off-line stations, which are located adjacent to the lane or freeway.

Intermodal Facilities. Intermodal facilities serve multiple modes, providing travelers with the opportunity to change from one transportation service to another. Intermodal facilities enhance the connectivity of all modes and make it easier for individuals to transfer between different services. Intermodal facilities are usually relatively large, providing amenities such as waiting areas, ticket sales and passenger information, convenience services, and other activities.

Bus Stops and Shelters. Bus stops are the basic point of access for passengers. Transit stops are thus integral parts of managed lane facilities, especially those located along arterial streets. Proper location, design, and maintenance of bus stops are important factors in the development of a comprehensive managed lane system.

3.5 HOURS OF OPERATION

3.5.1 Factors Influencing Managed Lane Operating Hours

In general, the operating hours of managed lane facilities can be characterized by three scenarios: continuous 24-hour use, extended morning and afternoon operating hours, and peak-period only operation. In addition, some facilities are open additional hours for sporting events or other special activities. Factors to be considered in determining the most appropriate operating schedule include the project goals and objectives, the type of managed lane facility, the level of congestion in the corridor, system or regional connectivity, and enforcement and safety concerns. Each of these considerations is described briefly, followed by a discussion of the characteristics associated with the various operating scenarios. The various alternatives available for consideration during non-managed lane operating periods are also described.

Metropolitan Area and Project Goals and Objectives. The goals and objectives contained in the transportation plan for a metropolitan area and those related to the specific project may influence the hours of operation. For example, areas such as Seattle and Southern California have policies relating to providing eligible vehicles with low and reliable travel times during all times of the day and night. As a result, managed lanes in these areas operate on a 24-hour basis.

Type of Managed Lane Facility. Although no one specific operating scenario necessarily equates to a certain type of managed lane facility, the orientation and design of a facility will influence the operating hours. For example, projects designed to provide managed lanes with priority treatment around a specific bottleneck may operate only during congested time periods, as may contraflow facilities. Reversible lanes also require some time to open, close, reverse the direction of traffic flow, reopen, and close.

Congestion Levels in the Corridor. The level of traffic congestion on the freeway and in the travel corridor may also influence the hours of operation for a managed lane facility. In some areas, such as Southern California, congested freeway conditions extend over long periods of the day. As a result, the managed lanes operate on a 24-hour basis. In other areas, managed lane facilities may operate only during the most congested periods of the day.

System or Regional Connectivity. If there are multiple managed lanes in an area, consideration should be given to coordinating the operating hours of the various facilities. Uniform operating hours simplify the concept for commuters and enforcement personnel. Similar operating hours may not always be possible, however, depending on the type of managed lane facilities in an area.

Enforcement and Safety. The need for enforcement during all operating periods may influence the hours a managed lane facility is open. Safety concerns, such as the potential for vehicles to enter a lane in the wrong direction of travel, need to be considered in assessing alternative operating scenarios.

3.5.2 Alternative Managed Lane Operating Hour Scenarios

The characteristics of the three general operating hour scenarios—24-hour, extended hours, and peak-only—for managed lane facilities are described on the following pages, along with the use of managed lanes during special events. Examples of the use of different operating hours are provided along with advantages, limitations, and issues associated with different scenarios.

24-hour Operation. This approach maintains the managed lane designation and operation of a facility on a 24-hour basis. In these cases, the managed lane is open during all operating periods. Continuous 24-hour operation tends to be found with managed lanes in separate rights-of-way and with freeway concurrent flow and exclusive two-way facilities. This approach is not used with contraflow or exclusive reversible managed lane facilities. Examples of managed lane facilities operating on a 24-hour basis include the exclusive two-way managed lanes on I-84 in Hartford, the San Bernardino Transitway in Los Angeles, and the concurrent flow lanes in Seattle and Southern California.

The 24-hour operating scenario is based on the premise that eligible vehicles should be provided with priority treatment at all times. Since congestion or incidents may occur at any time, the 24-hour designation provides managed lanes with travel time savings and travel time reliability throughout the day and night. This operating scenario also allows travelers to use the managed lane facility during non-commute hours. For example, recreational trips often include more than one person in a vehicle. The 24-hour operating scenario allows these individuals to use the managed lanes, which may promote wider acceptance of the facility. Off-peak use by travelers may also help encourage peak-period use by commuters. Figure 3-24 shows the I-635 (LBJ Freeway), which operates 24 hours with limited access.

Figure 3-24. 24-Hour Concurrent Flow Operation along I-635 (LBJ Freeway) in Dallas, Texas.

The 24-hour designation may also help to minimize potential confusion on the part of motorists as to whether or not the managed lane designation is in effect. Since the vehicle-occupancy requirement is always in effect, motorists know they should not use the lane unless they have the correct number of occupants. As a result, the continuous managed lane designation can also make enforcement easier, as there is no question on the operational requirements. Twenty-four hour operation may simplify signing and lane markings. Also, there may be no need for additional capacity in the general-purpose lanes during the off-peak time periods if the facility is not congested. If congestion does exist, priority may be given to managed lanes to satisfy specific transportation goals and objectives in an area.

Limitations and issues associated with 24-hour operation of a managed lane facility include possible negative public perception if the facility is not well used during off-peak time periods, the need for ongoing enforcement, and potential safety concerns. The advantages and limitations should be examined to determine the appropriate operating scenario for a specific facility.

Extended Peak Operating Hours. Extended operating hours encompass a major portion, but not all, of the day. In most cases, managed lanes using extended hours are open for major portions of the morning and afternoon. Although the exact hours of operation vary by facility, this scenario often encompasses the time periods from 6:00 a.m. to 11:00 a.m. and 3:00 p.m. to 7:00 p.m. These times correspond to the major commuting periods when traffic congestion is heaviest.

Extended operating hours are currently in use with exclusive reversible managed lanes, concurrent flow lanes, and contraflow lanes. Examples of specific facilities using this operating approach include the exclusive reversible HOV lanes in Houston, San Diego, Denver, Minneapolis, and the Northern Virginia/Washington, D.C. area; the concurrent flow HOV lanes in Miami, Orlando, and Minneapolis; and the contraflow lanes in Dallas and Boston.

Extended peak operating hours provide managed lanes with travel time savings and travel time reliability during the periods when the general-purpose freeway lanes are most likely to be congested. This approach may also represent the most logical or the only realistic scenario for some types of managed lane facilities. For example, extended hours are often the most appropriate approach with exclusive reversible facilities and contraflow lanes using a separation that allows access to all managed lanes.

Potential limitations of extended operating hours include confusion on the part of motorists, which makes enforcement more difficult, and the need for additional signing and pavement markings. The use of the facility during non-managed lane operations may influence the level of these concerns. If a managed lane facility is closed during non-managed lane operating hours, which is usually the case with exclusive reversible lanes, these may not be major problems. A concurrent flow managed lane that is open to general traffic during non-managed lane operating periods will probably require the planning team to address these concerns.

Peak-Period Only Operation. The final operating scenario is to use the managed lane only during the peak-periods in the morning and afternoon. Peak-period operation is defined more narrowly than the extended hours, usually encompassing the hours from 6:00 A.M. to 9:00 A.M. and 4:00 P.M. to 7:00 P.M., although variations are found in these hours. Some facilities use the managed lane restriction only in the peak direction of travel, while others may operate only in the morning peak period in the peak direction. Figure 3-25 shows the signage for the outbound operation of I-30 (East R. L. Thornton Freeway) in Dallas, Texas.

Peak-period operating hours are used primarily with concurrent flow and contraflow managed lanes. Currently, concurrent flow lanes in Minneapolis, Miami, Orlando, San Francisco, and San Jose are restricted to eligible vehicles only during the peak hours. The concurrent flow HOV lanes on US 36 in Denver, the contraflow lanes on Route 495, the Long Island Expressway, and the Gowanus Expressway in New York operate only in the morning peak period in the inbound direction.

Peak-period only operations present many of the same advantages, disadvantages, and issues as extended operations. Advantages include providing priority to managed lanes at critical times of the day and addressing specific bottleneck problems. Depending upon the use of the facility during non-managed lane operating periods, possible disadvantages include confusion on the part of commuters, more difficult enforcement, safety issues, and increased signing needs.

Extended Operating Hours for Special Events and Other Activities. A few managed lane facilities throughout the country are open on a periodic basis outside the normal operating hours for special events and other activities. A number of examples highlight the use of managed lanes to help traffic during special events. The I-394 HOV lanes in Minneapolis are open in the evening and on weekends for professional baseball, football, and basketball games and University of Minnesota football games at facilities in downtown Minneapolis. Vehicles using the managed lanes must meet the 2+ vehicle-occupancy requirement. The I-279 HOV lane in Pittsburgh is open extended hours in the outbound direction after baseball and football games at PNC Park in the downtown area and after football games at Heinz Field. All traffic is eligible to use the facility to exit the stadium.

Opening these and other managed lane facilities for special events can provide a number of benefits. First, the managed lanes can help manage traffic during major events and can improve the traffic flow into and out of the sports stadium or other facility. Second, opening a managed lane for special events provides opportunities for travelers who might not be able to use the lanes during their regular commute to use the facility. Using a managed lane during a special event can be a good way to introduce the facility to non-users and to build public acceptance and support.

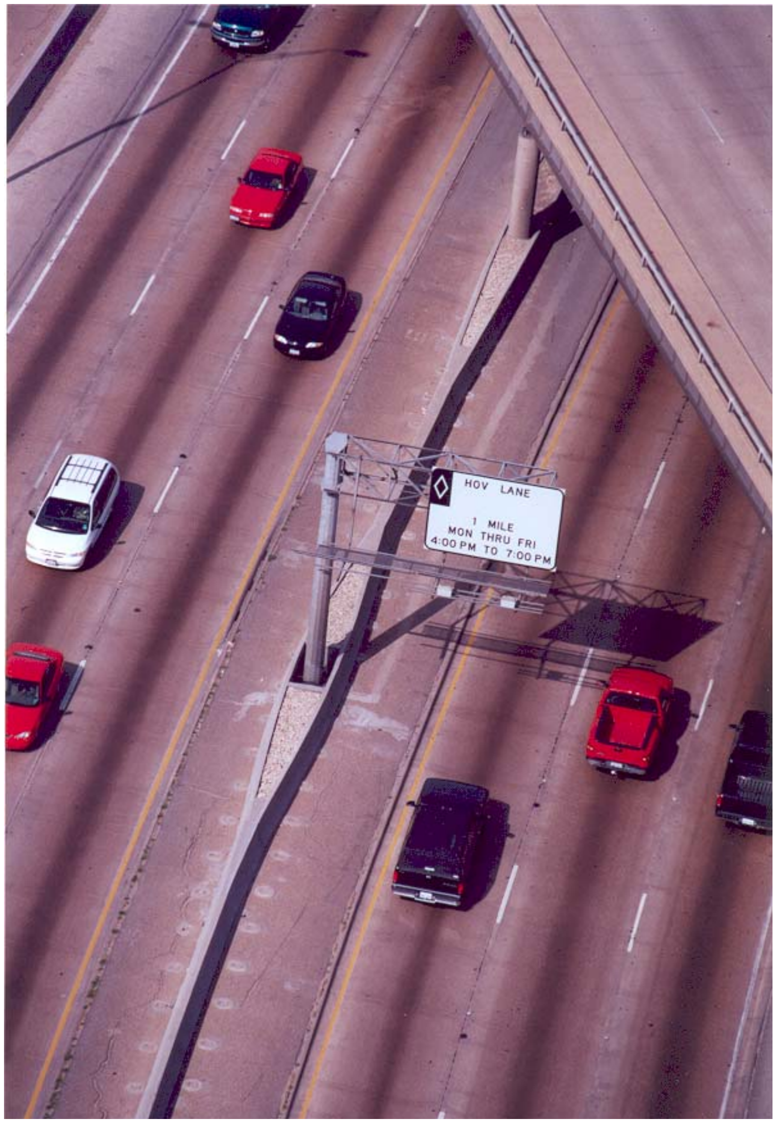


Figure 3-25. Contraflow Lane Signage for I-30E (East R. L. Thornton Freeway) at Downtown Entrance in Dallas, Texas.

However, opening a managed lane for special events is not without possible concerns. Since many travelers may be first-time users, care should be taken to provide advance information on access points, vehicle-occupancy requirements, and other operating instructions. The managed lanes may need additional or special signs and enforcement to ensure safe operation of a managed lane facility during special events.

3.5.3 Use of Facility During Non-Managed Lane Operating Periods

The operating hour scenarios discussed in the previous section correspond to two general operating philosophies. One approach, which equates to 24-hour operation, is a dedicated facility that is reserved for managed lanes at all times. The other general approach, which covers both extended hours and peak-period operation, provides eligible vehicles with priority use only during specific times of the day. These facilities may be open for general-purpose vehicles, revert to shoulders, or be closed to all traffic during non-managed lane operating hours.

The planning process should assess the demand for a managed lane facility over all operating hours, as well as the opportunities for providing managed lanes with priority during the peak periods. The alternatives for use of a managed lane facility during non-managed lane operating hours relates to the type of facility as well as to the goals and objectives of the project and potential operating, enforcement, and safety concerns. The current practices associated with different types of managed lane facilities, along with elements to be considered in assessing alternatives for non-managed lane operating periods, are described in this section.

Exclusive Facilities on Freeways. All of the exclusive lanes on freeways, with two exceptions, are typically reserved for eligible vehicles on a 24-hour basis or are closed during non-managed lane operating periods. These include both the two-way managed lane facilities that operate on a 24-hour basis and the reversible lanes, which have extended opening hours or are open only during peak periods.

The two exceptions are the I-279 HOV lanes in Pittsburgh and the Shirley Highway HOV lanes in the Northern Virginia/Washington, D.C., area. As noted previously, the I-279 managed lanes operate in the outbound direction for all traffic after sporting events and other activities at PNC Park and Heinz Field. The Shirley Highway HOV lanes are open to general traffic during non-managed lane operating hours. On weekdays the lanes are open to general-purpose vehicles in the inbound direction in the morning and the outbound direction in the afternoon. On weekends the lanes are open in the outbound direction to all traffic to help accommodate many of the weekend special events in Washington, D.C.

Concurrent Flow Managed Lanes. A mix of operating philosophies is found with existing concurrent flow managed lanes. In some areas, such as Seattle and Southern California, the concurrent flow lanes are dedicated for eligible vehicle use on a 24-hour basis. In other cases, the managed lanes revert back to mixed-flow lanes or shoulders during non-managed lane operating periods. For example, the concurrent lanes in Miami, Orlando, Minneapolis, Nashville, Phoenix, San Francisco, San Jose, and Honolulu are open to general traffic during non-HOV periods. The concurrent flow managed lanes on US 36 in Denver and Highway 99 in Vancouver revert back to shoulders.

Contraflow Managed Lanes. All of the contraflow managed lanes revert back to general-purpose use during non-managed lane operating hours. These facilities utilize available capacity in the off-peak direction for managed lanes moving in the peak direction of travel. The lanes are needed for general-purpose traffic when the off-peak direction becomes the peak direction of travel during other times of the day.

A number of factors should be considered in assessing fully dedicated or part-time managed lane facilities. Part-time facilities provide eligible vehicles with priority treatment during the critical times of the day. As congestion increases in many areas, however, it may be desirable to provide eligible vehicles with priorities during all operating periods. For example, midday use on some HOV lanes in Southern California is approaching 70 percent of the peak-period volumes.

Issues relating to informational signs and pavement markings, enforcement, and safety should also be examined with part-time facilities. Signs providing information on operating hours and vehicle-occupancy requirements should be clearly visible and easily understood. Enforcement may be more difficult with part-time facilities, and a grace period at the beginning of the managed lane restricted period may be needed for exiting vehicles that entered the lane prior to the start of the restricted time period. Safety may be a concern with the use of shoulder lanes for managed lanes.

Different approaches have been used with shoulder managed lanes. In Seattle, HOV lanes are in operation on a 24-hour basis on the outside lanes of SR 520. This project has effectively served bus operations. Minimal conflicts have been experienced with general-purpose traffic merging and diverging from local access ramps.

A major safety concern with shoulder use is that motorists may continue to stop in the shoulders in an emergency, creating a dangerous situation. Providing adequate signing for these situations is important. Enforcement may also be more difficult with the part-time use of shoulders.

3.6 ENFORCEMENT

3.6.1 Role of Enforcement Policies and Programs

Enforcement is a critical element to the successful operation of a managed lane facility. The role of a managed lane enforcement program is to ensure that operating requirements, including vehicle-occupancy levels, are maintained to protect eligible vehicles' travel time savings, to discourage unauthorized vehicles, and to maintain a safe operating environment. Visible and effective enforcement promotes fairness and maintains the integrity of the managed lane facility to help gain acceptance of the project among users and non-users. However, there may be a perception on the part of some motorists that enforcement is greater on managed lanes than on the general-purpose lanes, which may discourage use by some eligible groups.

Enforcement policies and programs perform a number of important roles. First, the development of enforcement policies and programs will help ensure that all of the appropriate agencies are involved in the process and that all groups have a common understanding of the project and the need for enforcement. Thus, the participation of representatives from enforcement agencies, the courts and legal system, the state department of transportation, the transit agency, and other groups throughout the development and implementation of enforcement policies and programs is critical.

Second, this same information can be provided to the public, especially travelers in the corridor, to help introduce the managed lane facilities and to communicate the guidelines for use of the lanes. Third, the enforcement policies and programs should be followed to maintain the integrity of the facility by deterring possible violators and to promote the safe and efficient use of the lane.

Representatives from a number of agencies and groups should be involved in the development of managed lane enforcement policies and programs. These groups include the state department of transportation, transit agencies, state and local police, state and local judicial systems, local municipalities, the metropolitan planning organization, rideshare agency, and federal agencies including the Federal Highway Administration (FHWA) and the Federal Transit Agency (FTA).

3.6.2 Elements of a Managed Lane Enforcement Program

An effective enforcement program should include a number of components. The six general elements that should be considered in developing an enforcement program include:

- legal authority to enforce a facility,
- nature of citations for violations and the level of fines,
- general enforcement strategies,
- specific enforcement techniques,
- funding, and
- communicating the program elements to users, non-users, and the public.

This section summarizes each of these elements.

3.6.3 Legal Authority

The agency responsible for enforcing the operating requirements of a managed lane facility must have the legal authority to do so. This authority must include the ability to issue citations to individuals violating vehicle eligibility regulations, vehicle-occupancy requirements, hours of operation, speed limits, and other operating regulations. Existing statutes should be reviewed during this task, and the need for changes in current regulations or new legislation should be identified.

Although the agency charged with enforcement of managed lane facilities may have specific authority related to many of these violations, others may need additional legal definition. For example, police have the authority to enforce posted speed limits. Enforcing vehicle-occupancy requirements on a managed lane facility, however, may not be specifically identified in the statutes outlining the powers and authority of the state or local police.

Ensuring that the enforcement agency has the power to issue citations that the court system will uphold is a critical first step in developing an enforcement program for a managed lane facility. New or modified legislation has been needed in some areas to address enforcement of managed lane facilities. For example, in Houston, a city ordinance was revised to give METRO police the authority to issue citations to drivers of vehicles violating the vehicle-occupancy requirements and other managed lane regulations. In other areas, these violations have been included under the broad heading of “moving vehicle violations” or “failure to obey posted signs” that the state patrol or police have regulatory authority over.

3.6.4 Citations and Fines

The type of citation that will be issued for various infractions and the fine associated with these violations are related to the legal authority to enforce the operating requirements of a managed lane. Generally, higher fines for non-compliance with managed lane facility operating requirements equate to lower violations. Ensuring that the appropriate classification is used will help ensure that citations are upheld in the court system. Establishing fines at levels high enough to deter possible violators is also important.

Some areas use a graduated scale, with fines increasing for repeated offenses. In other areas, additional penalties, such as payment of court costs or demerits on the driver’s record, are part of the fine. Posting the fines for violating the managed lane facilities can be an effective technique for self-enforcement. Also, consideration should be given to uniform and consistent citations and fines for managed lane facilities within a state.

3.6.5 General Enforcement Strategies

Enforcement strategies for managed lane facilities can generally be categorized into four basic approaches. These are routine enforcement, special enforcement, selective enforcement, and self-enforcement. All of these strategies may be appropriate for consideration with the various types of managed lane projects. The most effective approaches and techniques will vary somewhat for different facilities. For example, enforcement of barrier-separated facilities is easier than for buffer-separated facilities. The four general enforcement approaches are described in this section. Figures 3-26 through 3-29 illustrate examples of different enforcement techniques used with HOV lane facilities. Figure 3-26 shows a bi-directional enforcement zone with a police car present along I-35E (North Stemmons) in Dallas, Texas. Figure 3-27 shows a police car that has a violator pulling a trailer on the concurrent lanes on I-635 (LBJ Freeway) in Dallas, Texas. Figure 3-28 shows enforcement on concurrent flow lanes in Southern California. Figure 3-29 shows enforcement of the 3+ occupancy requirement at the entrance to the I-10 (Katy Freeway) HOV lanes in Houston, Texas, in the afternoon.

Routine Enforcement. Routine enforcement represents the normal level of police patrols in an area, regardless of the presence of a managed lane facility. This approach does not include extra patrols or other special activities because of the managed lane. Rather, the normal level of policing in a corridor is provided, and monitoring managed lane use is just one of many responsibilities of the enforcement personnel.

Figure 3-26. Enforcement Zone with Police Vehicle Showing Gate for Bi-Directional Enforcement on I-35E (North Stemmons) in Dallas, Texas.

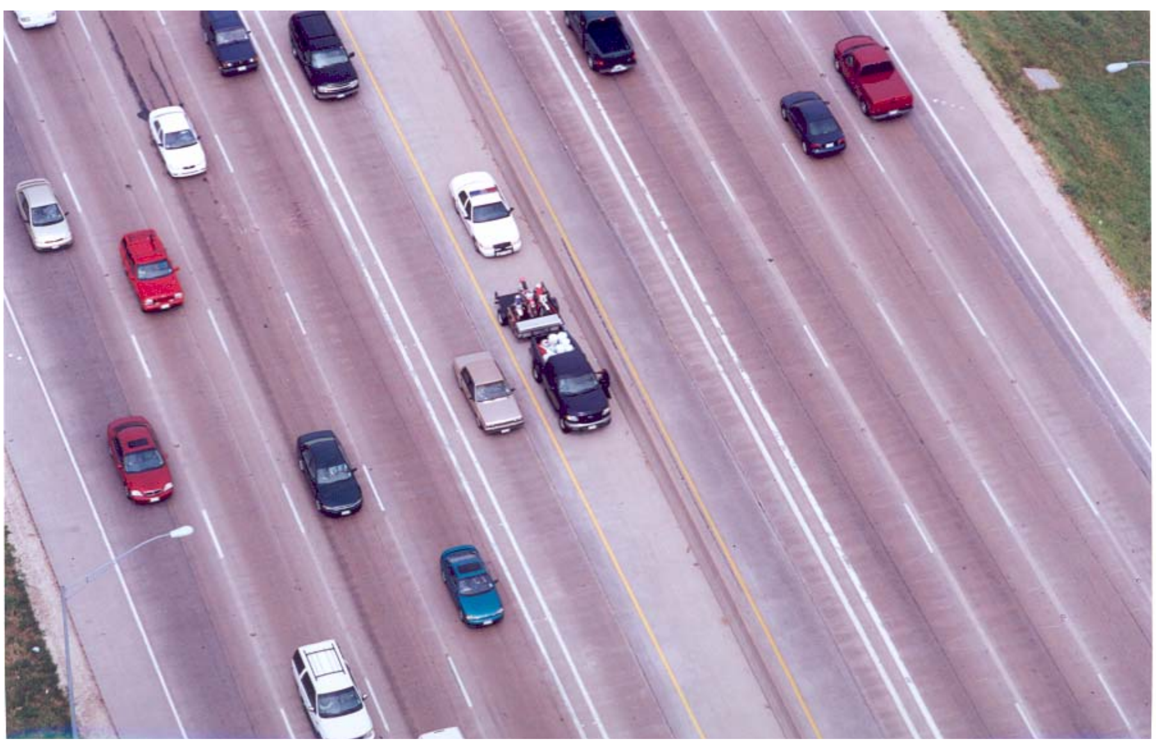


Figure 3-27. Enforcement on Concurrent Flow Lanes on I-635 (LBJ Freeway) in Dallas, Texas.

Figure 3-28. Examples of Enforcement on Concurrent Flow HOV Lanes in the Los Angeles, California Area.

Figure 3-29. Enforcement of 3+ Operation at Entrance to I-10 (Katy Freeway) HOV Lane in Houston, Texas.
(Officer manually checking 3+ occupancy outside vehicle, violator pulled over)

Routine enforcement may be considered in a number of situations. First, this approach may be appropriate once a managed lane has become well established and the violation rate is at a low or locally accepted level. Second, routine enforcement may be used when the design or operation of a facility makes it relatively easy to monitor. Finally, if resources are not available to fund other approaches, routine enforcement may be the only alternative available.

Special Enforcement. Special enforcement involves the dedication of additional personnel and resources to monitoring and policing a managed lane facility. Approaches may include assigning a patrol car specifically to a managed lane, adding extra patrols in a corridor with a managed lane facility, or locating enforcement personnel along a facility during all operating hours. Special enforcement activities may be accomplished by reallocating existing personnel or by adding additional enforcement during key operating periods.

Selective Enforcement. Selective enforcement may be undertaken in response to a number of different factors or it may be scheduled on a somewhat regular basis to provide periodic saturation of a managed lane facility. As with special enforcement, selective enforcement may be an appropriate approach to utilize when a new managed lane facility is opened. It may also be used when other significant operating changes have been made, such as increasing the vehicle-occupancy requirements or extending operating hours. Selective enforcement may also be used in response to high violation rates or to target problems in a specific area or section.

Self-Enforcement. The last general approach is self-enforcement. This strategy involves self-regulation by managed lane users and motorists in the general-purpose lanes. Self-enforcement is usually used with other approaches, rather than as the only enforcement strategy. The HERO program provides the best example of a self-policing managed lane enforcement effort. This approach was first developed in Seattle and has subsequently been used in other areas including Houston and the Northern Virginia/Washington, D.C. area.

The HERO program uses signs and other communication techniques to provide users and non-users with a telephone number they can call to report managed lane violators. The individuals, who remain anonymous, report the sighting of a violator and give the license number, time of day, location, and any other supporting information to the HERO telephone operator. The vehicle data are checked for accuracy in the vehicle registration files, and, if they are correct, an information brochure providing information on proper use of the managed lane facility, along with notification that the vehicle was seen violating these requirements, is mailed to the vehicle owner. Figure 3-30 shows HERO sign in Seattle, Washington.

If the same vehicle is reported a second time, another brochure and a personalized letter is sent along with information regarding the reported offense. A third reported violation results in a warning from the enforcement agency. After the fourth report, the license number, description of the vehicle, and information on violation pattern are forwarded to the police officers who may target the vehicle in subsequent routine, special, or selective enforcement activities.

This strategy has been considered successful and is believed to have reduced dependency on other enforcement strategies and to have contributed toward lowering the violation rates. In addition, repeat offenders appear to be few. Public opinion has also been favorable toward these programs, which provide both an ongoing informational as well as an enforcement focus.

**Figure 3-30. Example of Self-Enforcement Technique—
HERO Sign in Seattle, Washington.**

3.6.6 Specific Enforcement Techniques

A variety of enforcement techniques can be used to monitor managed lane facilities. These techniques focus on providing surveillance of the lanes, detecting and apprehending violators, and issuing citations or warnings to violators. The following enforcement techniques are summarized in this section. Most areas use a combination of these enforcement techniques:

- stationary patrols,
- roving patrols,
- team patrols,
- multipurpose patrols, and
- electronic monitoring.

Stationary Patrols. Stationary patrols involve the assignment of enforcement personnel at specific locations along a managed lane facility. These may be dedicated enforcement areas or locations that provide the necessary vantage points and space for enforcement personnel. As discussed in Chapter 4, enforcement areas should provide adequate space and a safe environment for enforcement personnel to perform all necessary duties. These duties include monitoring the facility, pursuing a violator, and stopping the violator to issue a citation. Enforcement areas may be located at the beginning or end of a facility or at specific locations along the lane. Stationary enforcement may be used during all operating hours or on a selective or special basis. Stationary enforcement may be provided with patrol cars, motorcycles, or other types of vehicles. In addition, monitoring and surveillance may be performed visually by enforcement personnel or with the aid of advanced technology.

Roving Patrols. This technique involves enforcement vehicles patrolling the length of the managed lane facility. Patrol cars—either marked or unmarked—or motorcycles may operate either on the managed lane facility or on the adjacent freeway. Further, patrols may cover the total facility or they may be assigned to specific segments or zones. Enforcement personnel can monitor the use of the lane and the vehicle-occupancy requirements, and apprehend violators. A safe area to pull violators over to issue citations is needed with this technique, and advanced technologies can be used to enhance roving enforcement.

Team Patrols. This technique uses various combinations of stationary and roving patrols working in unison to monitor a managed lane facility and to apprehend violators. Potential combinations may include multiple stationary patrols, multiple roving patrols, or a combination of stationary and roving patrols. In one example, a stationary patrol located at the beginning or mid-point of a managed lane facility is responsible for monitoring vehicle-occupancy requirements. Vehicle and license plate information on potential violators is radioed to a stationary patrol located downstream, where the actual apprehension takes place. As with other techniques, advanced technology may be used to enhance the monitoring function with team patrols.

Multipurpose Patrols. This technique utilizes patrols or personnel that are assigned multiple functions, including managed lane enforcement. Responsibilities of these groups may include incident detection and response, operation of the managed lane facility, general policing, and enforcement. This approach may be used in combination with other techniques and may be supported by advanced technologies to monitor a facility.

Electronic Monitoring. Electronic and other advanced technologies may be used to help monitor a managed lane facility and to assist in detecting violators. Closed circuit television cameras (CCTV), infrared cameras, photographs of vehicles and license plates, and other technologies may help identify potential violators. Although various technologies have been tested to assist with the identification of vehicles not meeting the occupancy requirements, to date no approach appears to provide adequate coverage during all times. Specifically, technology is currently not available that can overcome problems associated with seeing inside a vehicle with tinted windows, seeing inside a vehicle prior to and after daylight hours, and seeing passengers in a reclining position or young children. These problems have limited the widespread use of advanced technologies to assist with enforcement. There continues to be a good deal of interest in the use of advanced technology to help enforce vehicle-occupancy requirements, however, and systems that can overcome the current problems may be available in the future.

3.7 INCIDENT MANAGEMENT

This section discusses incident management on managed lane facilities on freeways. The role of incident management is reviewed first, followed by a description of the agencies and groups that should be involved in the development and implementation of an incident management program. The elements associated with incident management are described, and general guidelines for developing an incident management plan are presented.

3.7.1 Role of Incident Management

There are two aspects related to incident management on managed lane facilities. The first is the development of plans and procedures that can be implemented to respond to accidents, incidents, or special situations on the managed lane facility. The second relates to the use of managed lanes to assist with incident management on the freeway or in the travel corridor.

A variety of incidents may occur on managed lane facilities and freeways. Incidents can cause major problems, especially if they are not dealt with quickly. A general guideline for general-purpose lanes is that the congestion behind the incident takes three to four minutes to return to normal for each minute of delay. Thus, responding quickly to incidents is important. Common incidents include traffic crashes, disabled vehicles, spilled loads, and adverse weather conditions. These incidents usually result in a single lane or multiple lanes being blocked, thereby slowing traffic on the facility. In addition, drivers on portions of the facility not directly affected by the incident often slow down to look at the problem, causing further delays.

Responding quickly and efficiently to accidents or incidents on a managed lane facility is important for a number of reasons. First, an incident response program is critical to help ensure the safety of users of the managed lane facility. Responding quickly to crashes can help save lives. Second, clearing problems quickly can help ensure that the travel time savings and the travel time reliability provided by a managed lane facility are maintained. Since these benefits are critical factors in influencing commuters to change from driving alone to using a managed lane, incident management programs represent an important element in the overall operation of a facility. Managed lane facilities should include retractable barriers to allow for emergency entrance/exit to the facility for vehicle breakdowns, if needed.

Managed lane facilities can play a role in incident management on the freeway or in the corridor. For example, managed lanes may be used to help manage traffic when a major incident or accident has occurred on the freeway general-purpose lanes. Most managed lane facilities are used to help with incident management on the freeway and may be opened to general traffic in the case of major accidents (i.e., total closures) on the freeway, snowstorms, flooding, or other significant incidents.

Representatives from a number of agencies and groups should be involved in the development and implementation of incident management plans and programs. The various groups to be included in these activities include the state department of transportation, transit agency, state and local police, emergency medical services, fire departments, other emergency personnel, tow truck operators, local municipalities, and federal agencies.

3.7.2 Elements of an Incident Management Program

An effective incident management program should detect, respond, clear, and communicate information about an incident quickly to return a facility to its normal operation. These four elements—detecting, responding, clearing, and communicating—are summarized next.

Detection. An accident or incident must be reported for a response to be initiated. Detection refers to the ability to identify that an incident has occurred and to obtain accurate information on the location, nature, and scope of the problem. The sooner an incident can be identified and the proper responses initiated, the faster the problem can be cleared and the facility returned to normal. A wide variety of methods and technologies can be used to help detect an incident. These include more traditional approaches as well as advanced technologies. Table 3-4 highlights potential approaches.

Table 3-4. Surveillance and Detection Techniques with Managed Lane Facilities (Adapted from Reference *4*).

Level of Technology	Technique
Low/manual	• Visual detection by police, bus operators, motorist assistance patrols, or agency personnel • Calls from motorists using cellular telephones • Reports from roadside call boxes • Information from commercial traffic reporters
Mid level/semi-automated	• Loop detectors • Closed-circuit television cameras
High/automated	• Automated vehicle identification (AVI) and Automatic Vehicle Location (AVL) • Full advanced transportation management systems (ATMS) or integrated transportation management systems (ITMS)

Visual Detection by Enforcement and Operation Personnel. Police officers, bus drivers, and other operating personnel in the corridor usually provide a basic level of monitoring for incidents and accidents. These individuals can report problems by radio to the appropriate group to initiate the incident response program. In addition, some areas have implemented motorist assistance or courtesy patrols. These programs provide vans or trucks that regularly patrol a section of freeway and can assist motorists with flat tires and other routine problems. The patrols can also call tow trucks and emergency personnel for more serious incidents.

Calls from Motorists Using Cellular Telephones. The proliferation of cellular telephones has provided another technique for detecting traffic problems. In many metropolitan areas, the state department of transportation, commercial traffic reporting services, or other groups publicize toll free numbers for travelers to report accidents or other problems on the roadways. This approach is a relatively inexpensive way of obtaining information on the status of highway conditions and accidents. The accuracy of the information may not always be the highest, as motorists may not always know the exact location of an incident; however, the number of calls and/or the ability to verify the problem with a camera means this method is the way most accidents are reported.

Roadside Telephone Call Boxes. Some metropolitan areas have installed roadside telephone call boxes for motorists to use to report accidents, incidents, or other problems. Calls made from these boxes are received by state or other operating personnel, and the appropriate responses can be initiated.

Commercial Traffic Reports. Most metropolitan areas have one or more commercial traffic reporting services. These businesses may use a variety of techniques, including helicopters, roving patrols, cameras, and calls from motorists to monitor the flow of traffic on major travel routes. This information is provided in regular traffic reports on radio and television stations. The same information can be provided to the state department of transportation and other agencies. As described in more detail later in this section, many metropolitan areas are developing advanced transportation management systems. In many cases, the commercial traffic services are either located in these facilities or information is shared among the groups.

Loop Detectors. Loop detectors, usually induction loops located in the roadway pavement, are used in many metropolitan areas to obtain vehicle volume, lane occupancy, and speed data. In many cases, this information is analyzed at a later date rather than being used for real-time traffic monitoring. However, these systems can be used to help with detection capabilities by monitoring traffic speeds and stopped traffic on a real-time basis.

Closed-Circuit Television Cameras. The use of CCTVs and other advanced technologies is becoming more common in large and medium-sized metropolitan areas. Cameras are usually placed at regular intervals along a freeway or corridor and monitored from a remote location. CCTVs are integral parts of an ATMS and are monitored by agency personnel in a control center. CCTV provides an excellent technique for monitoring freeways and managed lane facilities. Operating staff obtain a continuous picture of the situation along a facility, allowing them to take appropriate action to respond to a situation.

Automatic Vehicle Identification and Automatic Vehicle Location. AVI and AVL technologies can also assist in monitoring the status of managed lane and freeway facilities. For example, AVI tags and readers are being used to provide a real-time traffic information map in Houston. Operators monitoring this map and CCTVs can check on potential problems in areas that register stopped or stop-and-go traffic conditions. A bus AVL system could also be used to help monitor the status of vehicles and the general traffic flow on a managed lane. The AVL system can help identify when buses have stopped unnecessarily or when travel speeds have slowed to levels that indicate a problem.

Advanced Transportation Management Systems or Integrated Transportation Management Systems. These systems focus on the deployment of advanced transportation surveillance, monitoring, and communication systems using a wide range of advanced technologies. Surveillance systems transmit information on facility conditions to a central control center. This information is constantly monitored by operating personnel and appropriate responses, including dispatching emergency vehicles and communicating with motorists in the corridor, can be taken to incidents and accidents.

The use of these surveillance and detection techniques are not mutually exclusive. In most areas, multiple strategies and technologies are used in a corridor and throughout a metropolitan area. The various approaches can compliment rather than duplicate each other.

Response. Once an accident or incident has been identified, the proper response can be initiated. A variety of approaches can be used, depending on the nature, severity, and scope of the problem. The key is to match the response to the specific situation. Table 3-5 provides examples of response strategies that may be appropriate for different types of situations. The general types of response vehicles and personnel include Highway Helper or Courtesy Patrols, dedicated agency tow trucks, commercial towing services, police, EMS, fire, and specialized response teams. Figure 3-31 illustrates the response equipment used on the HOV lanes in Houston.

Clearing. This step in the incident response process involves removing the disabled vehicle or clearing the incident scene and returning the facility to normal operations. The types of vehicles and personnel highlighted in Table 3-5 are usually involved in both responding to and clearing an incident or accident. For example, tow trucks will be needed to remove disabled vehicles, while a Highway Helper Patrol may be able to assist with a vehicle that has run out of gas. Traffic control and site management are also important elements of this process. The roles and responsibilities of personnel from the various agencies should be established to allow for the safe, efficient, and coordinated management of an accident or an incident site.

Communication. This element of an incident management program focuses on communicating information on the status of the managed lane and freeway facilities to other agencies and the motoring public. A variety of techniques and technologies can be used to provide current or real-time information to managed lane users, motorists in the general-purpose lanes, and other agencies. This step is important to provide commuters and travelers with information on major problems and significant delays on a facility, as well as on alternate routes that they may wish to take. The following approaches and technologies can be used to communicate with the traveling public.

Commercial Radio and Television Stations. Information updates on the status of managed lane, freeway, and other facilities can be provided to commercial radio and television stations. Many radio and television stations in metropolitan areas provide regular traffic updates during the morning and afternoon peak periods. The information for these updates may be obtained from public agencies, commercial traffic reporting services, or station personnel using the detection technologies described previously.

Figure 3-31. METRO Tow Truck and Response to Incident in Houston, Texas.
(Short tow truck wheelbase can turn around in 20-foot [6.1 m] lane)

Table 3-5. Response Strategies to Incidents or Accidents (Adapted from Reference *4*).

Incident	Potential Response Strategies
Disabled vehicle (flat tire, out of gas, etc.)	• Highway Helper or Courtesy Patrol • Dedicated tow truck • Commercial towing service • Police to manage traffic
Disabled bus	• Transit operator tow truck and replacement bus • Highway Helper or Courtesy Patrol • Police to manage traffic
Accident/no injuries	• Highway Helper or Courtesy Patrol • Dedicated tow truck • Commercial towing service • Incident response team • Police to manage traffic
Accident/injuries	• Emergency Medical Services (EMS) and ambulance • Highway Helper or Courtesy Patrol • Dedicated tow truck • Incident response team • Commercial towing service • Police to manage traffic
Accident/special problems (toxic substance, etc.) or hazardous waste	• Highway Helper or Courtesy Patrol • Dedicated tow truck • Commercial towing service • Police to manage traffic • Fire truck access • Incident response team
Snow, ice, flooding or other weather-related emergency	• Snow plows and other service vehicles • Highway Helper or Courtesy Patrol • Incident response team • Dedicated tow truck • Commercial towing service • Police to manage traffic

Highway Advisory Radio. Highway Advisory Radio (HAR) provides a dedicated radio channel for information on roadway and travel conditions. HAR is operated by a public agency, usually the state department of transportation, and is often broadcast out of an ATMS control center. HAR may cover a specific freeway or a portion of a metropolitan area. HAR broadcasts may be provided during the peak periods or reports may be provided throughout the day. A low-frequency AM bandwidth is usually used for most HAR stations.

Changeable Message Signs. Changeable message signs are used in many metropolitan areas to communicate with motorists on freeways and on managed lane facilities. A variety of signs and technologies are commercially available. These signs can be used to provide short, concise messages to motorists on traffic conditions, major incidents, alternate routes, and other critical information. Operation of changeable message signs is usually from the ATMS control center. The signs can be preprogrammed so that an operator only has to push a button to activate a message or an operator may type in a specific message in response to a situation. The location of changeable message signs should be carefully considered if they are intended to help divert or re-route traffic in response to incidents. Ensuring that the signs are located well in advance of points where motorists can take alternate routes or actions is important.

Advanced Traveler Information Systems. More emphasis is being placed on communicating real-time information to commuters on the status of different travel modes to allow for more informed travel choices. Advanced traveler information systems (ATIS) focus on providing real-time information to individuals prior to starting a trip, en route, or in-vehicle. Various technologies can be used to accomplish this objective. Monitoring and surveillance technologies used by an ATMS are often the source of real-time information.

3.8 USE OF MANAGED LANE FACILITIES TO ASSIST WITH INCIDENT MANAGEMENT

As noted previously, managed lane facilities can be used to assist with managing incidents and accidents on the general-purpose freeway lanes or responding to other special circumstances. Most managed lane facilities are used to assist with incident management under certain circumstances including traffic accidents on the freeway, snowstorms, flooding, and other major incidents. The use of a managed lane to help with incident management will depend on the type of facility, access points, and other factors.

The incident management plan should address the use of managed lanes to help with incident management on other facilities. It is important that the plan clearly identify when and under what conditions the managed lane facility will be used to help manage traffic, how it will be used, the specific procedures that will be followed, and the responsibilities of the various agencies.

These elements are critical to help ensure the safe operation of the managed lane facility during an incident on the freeway or other condition. For example, additional signing or information may be needed for motorists who normally use the general-purpose lanes and may be hesitant to enter a managed lane. In addition, in order to maintain the integrity of the managed lane facility, consideration should be given to using the managed lane only in response to extreme problems or specific situations.

The following examples illustrate the use of managed lane facilities to assist with incident management on the freeway general-purpose lanes.

Shirley Highway HOV Lanes. The Shirley Highway HOV lanes have been open to all traffic during normal HOV-only periods on a few occasions such as when major snowstorms have hit the Northern Virginia/Washington, D.C., area. For example, this procedure has been used when federal offices have closed early and workers have been sent home during major snowstorms. Opening the HOV lanes to all traffic has helped expedite the movement of people out of Washington, D.C. The Virginia Department of Transportation (VDOT) is responsible for making the decision on when to open the lanes to non-HOV vehicles.

Houston HOV Lanes. The Houston HOV lanes are used periodically to assist with incident management on the freeways. The HOV lanes have been opened to mixed traffic in response to heavy rainstorms and flooding, as well as for major accidents that have blocked the freeway general-purpose lanes. However, these situations have been infrequent. The Texas Department of Transportation and the Metropolitan Transit Authority of Harris County (METRO) are responsible for the decision on when to open the lanes to non-HOV travelers.

3.9 SPECIAL OPERATING CONSIDERATIONS

Current initiatives and special operational elements being considered and implemented with managed lane facilities in North America are highlighted in this section. Information on converting general-purpose lanes to managed lanes, priority pricing on managed lane facilities, ITS and managed lane facilities, truck use of managed lanes, converting managed lanes to fixed guideway transit facilities, and addressing concerns with slow-moving vehicles in managed lanes are presented. Potential issues that may need to be examined in considering these approaches are described along with relevant examples.

Additionally, special consideration must be given to the existing traffic flow while lanes are being added or reconstructed to provide managed lanes. Construction phasing and detailed traffic control plans are critical in maintaining smooth traffic operations. This may also influence public reaction, which can ultimately impact the future success of the managed lane project. Drivers in the mixed flow lanes should not experience a reduction in the number of lanes available for their use after construction of the project.

Another consideration is staging the opening of managed lane facilities. Experience has shown that opening sections of a managed lane for mixed flow use before an entire facility is completed can have detrimental results. As discussed further in the following section, future HOV lanes of the Dulles Toll Road were opened to all traffic as the various segments were completed. There was a very negative vocal response when HOV lane requirements were implemented, and the HOV lane requirement was eventually rescinded.

3.9.1 Converting a General-Purpose Lane into a Managed Lane

The few experiences with converting a general-purpose lane to an HOV facility have had mixed results. In some cases, negative response resulted in the projects being discontinued. In other cases, the projects have gained public and political acceptance and continue to operate successfully.

There has been a good deal of interest recently in many metropolitan areas related to converting general-purpose lanes to managed lanes. Further, studies have been conducted in some areas to better gauge public reaction to this concept and to identify the critical factors that should be considered in assessing the potential for converting a general-purpose lane.

Assuming that the planning process has indicated that a project is viable, a number of operational elements should be included in any assessment of converting a general-purpose lane to a managed lane: ensuring that extensive public information and marketing programs are undertaken, adequate signing and pavement markings are used, and visible enforcement is provided at the initiation of the project and on an ongoing basis. Other factors may need to be considered based on local conditions. The following case studies provide examples of the experience with lane conversion projects.

Santa Monica HOV Lanes, Los Angeles. The Santa Monica HOV lanes are usually referred to in the discussion of converting a general-purpose lane to an HOV lane. This project, which was in operation for only seven weeks in 1976, converted approximately 7 miles (12 km) of a general-purpose lane on the Santa Monica Freeway in Los Angeles to an HOV lane. Although the lane worked from an operational standpoint, the public reaction was negative and the project was discontinued. There appear to be numerous reasons for the failure of this project. The lack of an adequate public involvement and marketing program may be partly to blame. Although radio, newspaper, and television advertising and other techniques were used, these approaches were unable to overcome the large volume of negative publicity that was generated on the project. As a result, the California Department of Transportation (Caltrans) discontinued the operation of the HOV lanes after seven weeks.

I-80 HOV Lanes, Morris County. In the early 1990s, the New Jersey Department of Transportation (NJDOT) was widening a 10-mile (16-km) segment of I-80 to add general-purpose travel lanes in Morris County. NJDOT conducted a feasibility study examining the potential for HOV lanes in the area. The study recommended that HOV lanes were needed in the area. Although segments of the project had been completed, and the new lanes had been opened to general-purpose traffic, NJDOT converted the lanes to HOV lanes in 1994. An extensive marketing and public information program was used to build support for the project. This facility was opened to general-purpose vehicles in 1998 along with the HOV lanes along I-287 in New Jersey.

Dulles Toll Road HOV Lanes, Northern Virginia. The 12-mile (20-km) Dulles Toll Road links Dulles International Airport to Tyson Corner. In 1992, the Virginia General Assembly approved legislation to add one lane in each direction to the facility and stipulated that these lanes be reserved for HOV lanes during the morning and afternoon peak hours. A 6-mile (10-

km) segment was completed in 1991, one year in advance of the completion date for the full 12 miles (20 km) and the anticipated implementation of the peak-period HOV lane restrictions. The lanes were opened to all traffic as the various segments were completed. When the HOV lane requirements were implemented, there was a vocal negative response, which included the formation of the Citizens Against Dulles HOV (CAD HOV) group. The efforts of this group were supported by the local congressman. As a result of these activities, the VDOT rescinded the HOV lane requirement.

State Route 85 HOV Lane, Santa Clara County. In 1995, Caltrans converted a segment of SR 85 through the I-280 interchange in Santa Clara County from a general-purpose lane to an HOV lane. The project, which is approximately 1 mile (1.6 km) in length, was initiated to provide an important link to the 18-mile (30-km) HOV lanes on SR 85. Keys to the success of this project included public support, no adverse impacts on the remaining general-purpose lanes, local understanding of the managed lane concept, and a general consensus that it was a logical change.

I-90 HOV Lanes, Seattle. In 1993 and 1994, WSDOT converted a general-purpose lane in each direction along a 7-mile (11-km) section of I-90 between Issaquah and Bellevue in the Seattle area HOV lane. The HOV lane facility connects to the HOV lanes on the Lake Washington Bridge, which were in operation when consideration of the lane conversion project was initiated. The project converted one of the four general-purpose lanes in each direction to an HOV lane. A number of elements contributed to the success of this project. The biggest element may have been selective lane additions in the bottleneck sections so traffic congestion did not harm operations. Other elements include a revision of the WSDOT policy on when lane conversion projects would be considered, a consensus building effort, a public involvement program, and a marketing and public information program.

3.9.2 Sticker Programs with Managed Lane Facilities

One approach to managing demand on a managed lane facility is through the use of a sticker program. This technique allows vehicles with a valid sticker, AVI tag, or other electronic device to use a managed lane. Unlike the priority pricing projects discussed in the next section, there is no charge for stickers. The use of this approach on the Southeast Expressway contraflow managed lane in Boston is described in this section.

Southeast Expressway, Boston, Massachusetts. The I-93 (Southeast Expressway) HOV lane was opened in November 1995. The 6-mile (9.6-km) contraflow HOV lane is located on the southeast side of Boston and utilizes a moveable barrier system to create and remove the contraflow lane during the morning and afternoon peak periods. The Massachusetts Highway Department (MassHighway) is responsible for the design and operation of the facility.

A 3+ vehicle-occupancy designation is used on the project. Concerns by some commuters that the facility was underutilized at the 3+ level resulted in support by state elected officials to reduce the vehicle-occupancy requirements. MassHighway was concerned that opening the lane to unrestricted 2+ carpools would overburden the facility. Working with the legislature, MassHighway developed a compromise approach, which was signed into law by the Governor in 1996. The resulting sticker program was implemented in September 1996.

Analysis conducted by the Department estimated that an additional 2,000 vehicles a day could use the managed lane without degrading the level of service. Rather than issuing just 2,000 stickers, the agency developed a program to issue 4,000 stickers and to control use of the lane by the color of the sticker.

After an extensive education and commuter program, stickers were issued free on a first come, first served basis. Of the 4,000 available stickers, half blue and half red, individuals with license plates ending in odd numbers received blue stickers and those ending in even numbers received red stickers. Travelers with blue stickers and two people in a vehicle can use the managed lane on odd numbered days, while travelers with red stickers are able to use the lane on even numbered days.

MassHighway has conducted an extensive monitoring and evaluation effort of the sticker program. The volume of vehicles in the HOV lane has increased steadily since the program was implemented. For example, in December 1995, an average of 2,080 3+ vehicles a day used the lane. In December 1996, 2,392 3+ and 2+ carpools used the lane. By March 1997, some 2,724 carpools were using the lane, representing a 35 percent increase over the 1995 levels, and by June 1997, 3,284 carpools were using the lane.

3.9.3 Priority Pricing on Managed Lane Facilities

Congestion pricing involves charging motorists for the use of freeways and roadways during periods of heavy use. The technique is based on the economic concept of charging users (in this case motorists) the “price” that represents the cost they create by using a roadway. For example, the addition of a vehicle to a congested freeway creates further delay to vehicles already using the facility. The intent of this approach is to price the use of a roadway facility so that a sufficient capacity is provided for those willing to pay.

A related approach that is being considered and implemented in some areas is being called priority pricing, value pricing, or high-occupancy toll lanes. This concept focuses on the use of congestion or priority pricing on a managed lane facility. Examples of this technique include charging two-person carpools to use the lane but allowing 3+ carpools to use the facility for free, or charging single-occupant vehicles a fee but allowing two-person carpools to travel for free. Further, the use of advanced technologies, including AVI and electronic toll collection, provide the opportunity to use variable pricing techniques and other approaches.

ISTEA contained a congestion pricing demonstration program. As a result of this program and other initiatives, congestion and priority pricing projects are being considered and implemented in a few areas. As highlighted next, some of these projects focus on priority pricing or other related applications.

SR 91 Express Lanes, Orange County, California. The SR 91 express lanes are located between the SR 91/55 intersection near Anaheim and the Orange County/Riverside County line in the median of the existing Riverside Freeway. The 10-mile (16.1-km) facility provides two extra lanes in each direction, separated from the adjacent main lanes by a "soft" barrier of a painted buffer with plastic pylons. Access is provided only at the ends of the facility. The project was one of four special toll facilities authorized by the California Legislature in 1989. A franchise agreement, creating the California Private Transportation Company, was signed in December of 1990 and construction began in July of 1993.

The lanes are unique in that they were built and are operated by a private company. The lanes opened for operation on December 27, 1995, as the world's first fully automated variable toll facility. The SR 91 express lanes also use the marketing name *FasTrak* to refer to their electronic toll collection (ETC) system, which enables a motorist to drive on the SR 91 express lanes without stopping to pay tolls. The system is compatible with other Southern California facilities that use the *FasTrak* technology. Each user of the facility must be registered, have an active account, and have a transponder attached to the windshield of the vehicle. The *FasTrak* program offers a 50 percent discount off the full toll to motorists with three or more people in the vehicle. The same discount is also given to motorcyclists, zero-emission vehicles, and vehicles with a disabled person's license plate. The toll varies relative to demand and the level of congestion expected on the main lanes. Currently, the toll schedule varies from a low of $0.75 to a high of $4.25 in the eastbound p.m. peak. Initially, when the project was authorized, carpools and vanpools with three or more persons were allowed to use the facility for free during the first two years of operation.

The express lanes typically carry 1,400 to 1,600 vehicles per hour per lane at the height of the peak. By September 1998, the lanes were carrying approximately 14 percent of the total SR 91 traffic on a typical weekday. The express lanes have succeeded in more evenly distributing the traffic across the facility, reducing congestion in the parallel freeway lanes, while maintaining free-flow conditions on the toll road.

Enforcement of the occupancy requirements is done visually as carpools enter the facility. Enforcement of the toll offense is done electronically. In both cases, tickets are issued by mail, and the offenses are similar to a parking ticket. The fine is $100 for the first offense and goes up to $500 for repeated offenses.

I-15 Express Lanes, San Diego, California. The I-15 express lanes are located approximately 10 miles (16.1 km) north of downtown San Diego. The I-15 Express Lane Congestion Pricing project is one of the congestion pricing demonstrations funded as a result of ISTEA. The project included two phases called *Express Pass* and *FasTrak*.

This project began as a three-year pilot program on an 8-mile (12.9-km) stretch of two reversible HOV lanes on I-15 between SR 52 and SR 56. The HOV lanes are barrier-separated from the main lanes of I-15. *FasTrak* allows buy-in for single-occupant vehicles. Access is only available at the northern and southern termini; there is no intermediate access on this 8 mile (12.9 km) stretch. This route serves commuters from the suburban communities known as the

“Inland North” area to employment centers in central San Diego. Certain parameters established at project implementation include the following:

- Solo drivers on the express lanes could not adversely affect the current level of service (LOS), which was determined to be no worse than LOS C.
- Revenue generated from the demonstration project would be used for capital and operating expenses for transit improvements and HOV facilities in the corridor.
- Enabling legislation that was required for the project would expire after three years (the length of the federal demonstration project).

The project began in December 1996 with Phase I, known as *Express Pass*. *Express Pass* sold a limited number of monthly passes for SOV use at a fee ranging from $50.00 to $70.00. These passes were windshield stickers that identified SOV users on the express lanes as *FasTrak* participants. In June 1997, the windshield stickers were replaced with electronic transponders to allow for automatic vehicle identification.

On March 30, 1998, the project transitioned to Phase II, known as *FasTrak*, where *FasTrak* customers used electronic toll collection and a debit system to pay on a per-trip basis for use of the express lanes. The tolls are set dynamically, based on real-time traffic data and can change every six minutes depending on congestion on the express lanes. Congestion is monitored through information collected by loop detectors and transmitted to a traffic management center. The San Diego Association of Governments (SANDAG) Board of Directors set the initial toll schedule, which varies from $0.50 to $4.00 per trip. The fee can be as high as $8.00 if major incidents on the express lanes cause the LOS to dip below C. Some adjustments have been made to the toll schedule to more fully distribute the traffic in the peak. For instance, the tolls have been lowered during the peak-period shoulders to create an incentive for motorists to adjust their travel times out of the heaviest of the peak hours. Carpools and motorcycles are free; commercial trucks are not allowed on the express lanes.

By the end of the federal demonstration project in December 1999, over 11,000 transponders had been issued to 7,500 account holders. Almost 11,000 HOVs were using the express lanes and an additional 3,000 SOV drivers were participating in the *FasTrak* program. In February 2000, the express lanes averaged 16,900 daily vehicles, and 20 percent of the vehicles were SOV *FasTrak* customers.

The results of the three-year demonstration show that the project goals have been met. Existing capacity is being better utilized and the HOV lanes have maintained free-flow conditions. The revenue generated is approximately $1.2 million annually; approximately $430,000 is spent annually for operating costs, and $60,000 is spent annually on enforcement by the California Highway Patrol. The remainder is used for transit and HOV facility improvements. In fact, the *Inland Breeze* bus service (Route 980 and 990) is completely funded by *FasTrak* revenue. Bus service in the corridor has increased by approximately 9 percent over the study period from fall 1996 to fall 1999. The maximum ridership was reached in spring 1999. San Diego State University conducted the Phase II, Year Three Bus Study. Their findings indicate that most of the ridership on the *Inland Breeze* consists of riders that used other modes of transit for the same trip. However, the proportion of riders that were former solo drivers has increased from fall

1998 to fall 1999. Greatest impact from the *Inland Breeze* service will come from attracting non-traditional bus riders.

In September 1999 the California legislature extended the enabling legislation for an additional two years. In January 2000 the project became fully self-supporting and has continued without federal funding. Recently, the California legislature, in SB 252, extended the legislation until January 2002.

The project team is continuing to work with other toll authorities to ensure interoperability of transponders allowing for access on other toll roads and bridges in Southern California. Pricing is seen as a planning solution on the I-15 corridor. There are plans to create a 20-mile (32-km) managed lane facility in the median of I-15 between SR 163 and SR 78. The plan calls for a four-lane HOV facility with a moveable barrier, multiple access points to regular highway lanes, and direct access ramps for buses. Bus Rapid Transit will be operated in the managed lanes.

I-10 (Katy Freeway) and US 290 (Northwest Freeway) QuickRide, Houston, Texas. The I-10 (Katy Freeway) HOV lane is a 13-mile (20.9-km), one-way, reversible lane that is barrier-separated with limited access. Beyond the western end of the facility is a newly opened non-barrier HOV section extending for 6 miles (9.7 km). The HOV lane was underutilized with a 3+ occupancy requirement during the morning and evening peak hours. However, allowing 2+ HOVs during those peak hours resulted in congestion in the HOV lane.

As part of FHWA's Value Pricing program, the facility began pricing for two-person HOVs in January 1998. The program, known as *QuickRide*, is in operation only during the peak hours when the HOV lane has a 3+ occupancy (6:45 to 8:00 a.m. and 5:00 to 6:00 p.m.).

QuickRide allows a limited number of travelers to register for the program. When an application is accepted, a pre-paid account is established and the applicant is issued a transponder. The transponder, known locally as an EZ-Tag, also operates on the other toll roads in the area. When HOV-2s use the Katy HOV lane during the peak hour, the registered motorist is debited $2.00 from the established account.

The *QuickRide* program is a smaller program relative to the other HOT lanes operating throughout the country. The primary goals of improving HOV utilization by increasing person movement and average vehicle occupancy have been achieved. The majority of users does not use the *QuickRide* every day but are occasional users. In December 2000, approximately 140 people were taking advantage of the *QuickRide* program during the morning and evening peak.

In November 2000, the *QuickRide* program was expanded to US 290 (Northwest Freeway). This facility is also a single-lane, reversible HOV lane. The 15.5-mile (24.9-km) HOV lane offers limited access and is barrier-separated from the main lanes. The *QuickRide* program is in operation on US 290 during the morning peak, when the 3+ restriction is in effect on this roadway. In December 2000, the average use was 51 vehicles per day.

The success of the *QuickRide* program on both the Katy and Northwest Freeways has prompted the Houston Metropolitan Transit Authority to apply for a planning grant from the Federal Highway Administration to study I-45.

New Jersey Turnpike. The New Jersey Turnpike is a 148-mile (238-km) limited access facility that uses a variety of management strategies to optimize flow. The turnpike is a divided toll road that varies from four to 14 lanes. There are only 28 interchanges on the facility. From Interchange 8A to Interchange 14, a distance of approximately 31 miles, the Turnpike is a dual-dual roadway. This means there are both inner and outer travel lanes in each direction. The inner lanes are reserved for passenger cars only while the outer lanes are open to cars, trucks, and buses. In December 1996, two new lanes, one in each direction, were added to the outer roadway between Interchanges 11 and 14, a distance of approximately 14 miles. The new lanes are HOV lanes during the peak period and access is restricted to cars or vans, buses or motorcycles. The peak period is defined as 6:00 to 9:00 a.m. northbound and 4:00 to 7:00 p.m. southbound.

The Turnpike Authority participates in a regional consortium with four other transportation agencies, including the Delaware Department of Transportation, the New Jersey Highway Authority, the South Jersey Transportation Authority and the Port Authority of New York and New Jersey. The consortium is also part of a larger Interagency Group (IAG) that consists of 16 northern toll agencies across seven states. The IAG has committed to offering a fully interoperable electronic toll collection system known as *E-ZPass*. This system will allow motorists seamless transition to more than 700 toll lanes on 415 miles (668 km) of roads, tunnels, and bridges in the Northeast.

Tolls on the Turnpike are calculated according to the cost of maintenance and construction of the toll road between the point of entry and the point of exit, and the type of vehicle being driven. Vehicles are divided into classes determined by the number of axels. All the toll lanes, at each of the 344 toll plazas on the Turnpike, are equipped with toll tag readers, and motorists are encouraged to participate in the *E-ZPass* program although manual toll collection is still available throughout the Turnpike. The Turnpike Authority has recently implemented a value pricing incentive to shift travel out of the peak. *E-ZPass* customers traveling in the off-peak hours (hours other than 7:00 to 9:00 a.m. and 4:30 to 6:30 p.m. Monday through Friday) will receive a 20 percent discount off the new increased toll rate. *E-ZPass* customers who travel in the peak period will have an 8 percent increase in the toll rate.

E-ZPass demand was originally projected at 35 percent of motorists. In actuality, 58 percent of motorists are taking advantage of the program on the state’s toll roads, and at some toll plazas that number is as high as 70 percent.

3.9.4 Pricing Project Implementation Issues

Based on the limited experience with these projects, it appears a number of issues should be examined when pricing strategies are being considered on a new or an existing managed lane. As described next, these issues include the project objectives, target markets, pricing alternatives, potential impact on managed lanes, use of revenues, public and policymaker perceptions, and operational approaches.

Project Objectives. Pricing or sticker programs may be considered for a number of reasons. Determining the specific goals and objectives of a project is a critical first step. Possible objectives for a pricing project include improving managed lane utilization or maximizing available capacity by allowing lower-occupancy vehicles, restoring free flow to managed lanes by charging lower-occupancy vehicles, generating additional revenues, introducing another travel option, and supporting other secondary impacts such as air quality.

Target Markets. The potential market or markets being considered for the pricing project should be examined. Possible target markets include drivers of lower-occupant vehicles and single-occupant vehicles.

Pricing Alternatives. Examining the amount the target market may be willing to pay to use a managed lane should also be considered. A number of factors may be considered in this assessment, including the estimated demand at various pricing levels and quality of service. In addition to the traditional cost-to-demand relationship, other factors to consider include the bus fares in the corridor and the cost of other transit alternatives.

Impact on Existing or Projected Managed Lane Users. The impact of a pricing strategy on existing or projected managed lane users will also need to be considered. There should be no impact on managed lane users that are to be favored. A number of negative impacts might result from pricing, however. For example, increased congestion in the managed lane might occur if tolls are set too low or if too many stickers are distributed, resulting in too many lower- or single-occupant vehicles using the facility. This situation could result in slower travel speeds, reduced travel time savings, and lower levels of travel time reliability. Current managed lane volumes may decline if existing bus riders, carpoolers, and vanpoolers decide to change to driving alone for a fee. On the other hand, if revenues generated from the project are used to enhance bus service in the corridor, to reduce bus fares, subsidize vanpool fares, or to make other improvements benefiting managed lanes, then bus ridership, carpool, and vanpool use may increase.

Level and Use of Revenues. The level of revenues generated and the use of the revenues should also be considered. The funds generated by the pricing project and the cost to operate and administer the program should be carefully examined along with how any excess revenues will be spent. The focus groups conducted during the planning process for the I-10 (Katy Freeway) demonstration, as well as findings from other congestion pricing studies around the country, indicate that public reaction to a possible project is influenced by how the revenues are anticipated to be used. Public support appears to be higher if the revenues are used for transit and transportation improvements than if they are used for other purposes. The revenues for the I-15 project in San Diego are funding additional transit services in the corridor.

Public Reaction. The reaction of the public toward a pricing project should be considered. Motorists and current managed lane users may have a negative reaction to the concept of pricing, since freeways and roadways have already been paid for through tax dollars. In addition, equity issues or concerns that only the rich will be able to afford to use the lanes have been voiced in many areas, although survey data from the SR 91 express lanes shows that these concerns can be addressed (*3*).

Operational Strategies. A number of operational strategies can be used with pricing projects. The two general types of approaches are a manual or static technique and the use of automated vehicle identification or toll tags. There are several elements that should be considered in comparing manual and automated techniques. The first is the payment method. In most cases, motorists will pay a specific amount for a manual tag regardless of how often they use the facility. The automated method allows individuals to pay just for the times they actually use the facility. Manual approaches can be implemented for lower costs; however, they may be more difficult to enforce.

3.10 POTENTIAL TRUCK USE OF MANAGED LANES

The potential use of managed lanes by trucks during all operating hours or just the off-peak periods has been suggested in some areas. In many instances, these comments have focused on providing commercial vehicles with exclusive use of managed lane facilities during all or a portion of the off-peak periods, although use during peak periods has also been suggested. Segregating trucks from general-purpose traffic for safety reasons, providing goods movement and commercial vehicles with travel time savings to increase their competitiveness, and gaining additional use of the lanes all represent reasons for these suggestions.

Determining the feasibility of allowing trucks to use a managed lane facility involves considering the type of managed lane facility, safety issues, and the potential benefits to commercial vehicle operators. The following elements are suggested for consideration in any feasibility assessment of truck use in managed lanes:

- type of managed lane facility,
- travel time benefits to goods movement,
- managed lane access points and origins and destinations of commercial vehicles,
- safety, and
- additional operating costs.

Type of Managed Lane Facility. For the most part, consideration of allowing trucks to use managed lanes will be limited primarily to exclusive and concurrent flow managed lanes. Contraflow lanes, which operate only during the peak periods in the peak direction of travel, may be less logical candidates. Bus-only facilities on exclusive rights-of-way may also not be appropriate given significant bus volumes throughout the day and limited access points, which are often through transit facilities.

Travel Time Benefits to Goods Movement. Consideration should be given to the travel time savings and travel time reliability that the managed lanes may provide to commercial vehicles. Determining the potential benefits to the movement of goods and comparing these to the person-moving benefits of a managed lane facility should be part of the assessment process. During the off-peak periods, the managed lane may not provide any travel time advantage over the general-purpose lanes.

Managed Lane Access Points, and Origins and Destinations of Commercial Vehicles. The origins and destinations of commercial vehicles should be compared to the managed lane facility access points. In some cases, the limited access points of exclusive facilities may not match the origins and destinations of commercial vehicles. For example, a study conducted in Houston in the 1980s found that the access points on the managed lanes did not meet the needs of commercial operators and that little if any benefits would be realized by allowing trucks to use the facilities.

Safety. Safety concerns should also be considered. Potential safety issues that should be examined during a feasibility assessment include conflicts between commercial vehicles and managed lanes, trucks weaving across the general-purpose lanes to enter and exit a facility, and design geometrics that may not accommodate trucks.

Additional Operating Costs. Any extra resources associated with goods movement on a managed lane facility should also be identified and analyzed. For example, off-peak use by commercial vehicles on a facility normally closed during these times may require added resources. Additional operating personnel, enforcement officers, incident response personnel, and maintenance personnel may be needed to accommodate commercial vehicles on a managed lane facility.

3.11 POTENTIAL FOR CONVERTING MANAGED LANES TO FIXED GUIDEWAY TRANSIT FACILITIES

It may be appropriate to consider the potential for converting a managed lane to some type of fixed guideway transit system at some point in the future. Ideally, the possible need to convert a managed lane facility to a higher capacity transit alternative will be identified during the planning process. If a corridor is forecast to experience travel patterns and demands that warrant a fixed guideway system, the facility can be designed so that conversion can occur in the future or is at least not precluded.

A variety of fixed guideway transit systems may be appropriate for future consideration. These include the guided bus system, such as those in operation in Adelaide, Australia, and Essen, Germany, as well as light rail transit and other rail systems. From an operational perspective, a number of issues should be examined if conversion is being considered. These include assessing the origins and destinations of managed lane users, access points, feeder services, travel times of different modes, and other elements. Further, all of the basic elements needed to sustain a fixed guideway system should be assessed, and public perception related to taking lanes away from motor vehicles should be considered. Design issues that may need to be considered include travel patterns (i.e., where trips are going), availability of right-of-way, the physical envelope, infrastructure design (LRT weight), control requirements, power requirements, the need for on-line or off-line stations, existing and planned feeder bus services, and connections to major activity centers.

Although these issues are not insurmountable, there are probably only limited cases where conversion to a fixed guideway transit system is a realistic alternative. For example, the downtown bus tunnel and the I-90 HOV lanes in the Seattle area were designed to allow for conversion to rail in the future if a LRT system is implemented in the area. The Ottawa Transitway system has also been developed so as not to preclude the use of rail at a future date.

3.12 SLOW-MOVING VEHICLES

In order to maintain free-flow conditions on a managed lane, vehicles should travel at the posted speed limit. Providing a free-flow condition is important for managed lanes in order to maintain the travel time savings and the travel time reliability. As discussed previously, congestion in the lane can reduce the operating speeds. In addition, problems may be experienced on some facilities with slow-moving vehicles or vehicles that do not maintain the posted speed limit.

Slow-moving vehicles may be caused by a number of different factors. First, individuals who are not familiar with the managed lane facility or who are first-time users may drive more cautiously than normal. Second, some motorists naturally drive slower, especially if a managed lane has reduced geometrics. Third, buses may travel slower than automobiles under some conditions. For example, a full articulated bus going up a grade may travel slower than carpools on the same stretch.

Although there is no one specific approach that can be used to respond to these situations, the following techniques can be considered to address problems with slow vehicles. First, higher design speeds and wider cross sections may encourage faster moving traffic, as some drivers may slow down in reaction to managed lanes with tight geometrics. Second, if right-of-way is available, a passing lane can be provided in areas where it is anticipated that problems may arise due to grades or other conditions. Third, enforcement or other operation personnel can stop slow-moving vehicles and communicate speed limit information to the drivers. Finally, informational campaigns using different communication methods may be appropriate if there are continuing problems on a facility.

CHAPTER 4

MANAGED LANE FACILITY DESIGN

4.0 INTRODUCTION

This chapter discusses the design elements associated with managed lane facilities. Figure 4-1 illustrates the definition of a managed lane as presented in Chapter 1. This chapter presents information on the basic elements of the design of these facilities including appropriate design values, cross sections, ingress and egress types and locations, enforcement area design, and other special features. The chapter is intended to address the most frequently encountered design issues but does not attempt to address every possible design unique to the specific situation. For further details on any discussion provided here, the reader should reference the *HOV Systems Manual* *(4)* on which this chapter is primarily based. This chapter is separated into the following sections:

- geometric considerations for managed lane facilities (including discussion of the link between design and operations),
- cross sections for managed lane facilities,
- design considerations for terminal and access treatments,
- design considerations for managed lane enforcement,
- design considerations for bypass lanes at ramp meters,
- design considerations with priority and value pricing projects, and
- design considerations with intelligent transportation systems (ITS) and managed lane facilities.

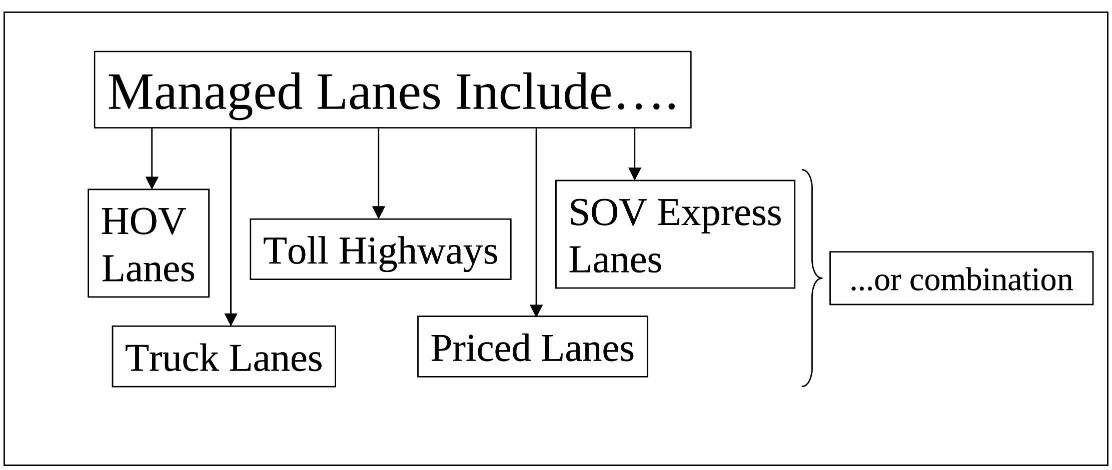


Figure 4-1. Definition of a Managed Lane.

As with the planning and operation of a managed lane, many agencies and groups are involved in designing managed lane facilities. These agencies and groups should be involved throughout the planning and design of the managed lane facility. Table 4-1 lists the potential agencies and groups involved in the design of a managed lane facility along with their likely roles and responsibilities. It is important that many of these agencies are involved in all aspects of the managed lane facility development including planning, designing, constructing, implementing, operating, and evaluating the facility to ensure interagency communication and a successful project.

4.1 GEOMETRIC CONSIDERATIONS FOR MANAGED LANE FACILITIES

Several elements, criteria, and controls should be considered in the design process for managed lane facilities. These factors are important for the safe and efficient operation of the facility. These criteria, which are similar to those applied to any type of roadway, relate to the vehicle design, driver design, design speed, and roadway alignment geometry. The desirable and reduced requirements for these design factors are based primarily on the standards recommended by the American Association of State Highway and Transportation Officials, the Institute of Transportation Engineers (ITE), and the Transportation Research Board (TRB). The desirable and reduced standards of design for managed lanes have been examined and documented by these organizations (*4,6,7*). In addition, several states have developed guidelines applicable for managed lanes including Texas, California, Washington, and New York (*8,9,10,11*).

The design of managed lane facilities on freeways is often a challenging process. In many cases, right-of-way limitations and roadway constraints may make it difficult to meet all desirable design standards. Unless a facility is being developed as part of a new project or major reconstruction of an existing facility, some compromise in design may need to be considered. Realizing that using desirable design elements may not always be realistic, this report includes information on both desirable and reduced design features. The desirable criteria include all the preferred design elements. Desirable designs generally reflect those associated with a permanent or new facility and meet AASHTO and other standards.

Designs with reduced features reflect the inability to meet the desirable criteria due to lack of available right-of-way or other significant limitations. Reduced designs do not reflect those associated with permanent facilities, and consideration of reduced designs should be given on a case-by-case basis based on sound engineering practice. The reduced values presented in this report are not intended as a standard of practice.

Table 4-1. Agencies and Groups Involved in Designing Managed Lane Facilities (Adapted from Reference *4*).

Agency or Group	Potential Roles and Responsibilities
State department of transportation	• Overall project management responsibilities with freeway projects • Supporting role if transit agency is lead on projects in separate right-of-way • Responsible for design of facilities on freeways • Staffing of multi-agency or multi-division team
Transit agency	• Overall project management on busways in separate rights-of-way • Supporting role with facilities on freeways • Design facility or assist with design • Staffing multi-agency team or participating on team
Trucking industry	• Provide information on trucking origins and destinations • Training of drivers on facility use for trucks
Toll authority	• Introduce tolling technologies • Revenue generation • Pre-operational testing
State and local police	• Assist with design, especially enforcement elements • Participate on multi-agency team
Metropolitan planning organization	• Assist in facilitating meetings and multi-agency coordination • Ensure that projects are included in necessary planning and programming documents • Assist with design of projects • May have policies relating to facility design
Rideshare agency	• Assist with design of projects • Participate on multi-agency team
Local municipalities	• Assist with design of projects • Coordinate with local managed lane facilities • Participate on multi-agency team
Federal agencies (FHWA and FTA)	• Funding support for facility design • Technical assistance • Possible approval of design or steps in design process • Participate on multi-agency team
Other groups	• EMS, fire, and other emergency personnel • Tow truck operations • Businesses • Neighborhood groups • Judicial system—state and local courts

Note: Depending on an area's institutional relationships, the roles may be different.

The design and operational components of a managed lane facility must be considered simultaneously. There is a link between the extent of operational considerations and the managed lane facility design elements. Figure 4-2 shows the link between design and operations to form an effective facility. Right-of-way constraints will normally dictate the extent of design that is possible. Therefore, the design component is shown on the bottom of each set of designs as the basis of the design. The extent of operations that is necessary to make up the difference is then shown on top. A full design requires fewer operational treatments. When full standards are used, less operational treatments are needed because the roadway provides good sight distance, the ability to handle incidents, etc. When reduced design standards are implemented, the operations component of the managed lane development becomes increasingly important. Table 4-2 lists examples of the operational treatments needed for full and reduced designs on a managed lane.

Table 4-2 indicates that when full design standards are used, surveillance and detection of incidents on the managed lane facility may be performed by visual inspection, calls from motorists using cellular telephones, and reports from roadside call boxes or commercial traffic reporters. With the use of reduced standards, there may be a need for more extensive technologies and ATMS or ITMS in addition to visual inspection or reports from motorists and commercial traffic reporters. Special or dedicated tow trucks may also be needed when a design standard (e.g., managed lane width) is reduced to ensure the ability to properly clear incidents. Further, the reduced cross sections shown throughout this chapter are footnoted with the text "operational treatments should be incorporated if the reduced design cross sections are used" to remind the designer of the importance of the design/operational connection. For illustration, Figure 4-3 presents the upstream signage for a reduced width along the US 290 barrier-separated reversible-flow managed lane in Houston, Texas.

It should be noted that reduced designs must be decided by each local area and situation. FHWA, FTA, DOT, transit agency, city, and others have to agree on what will be approved.

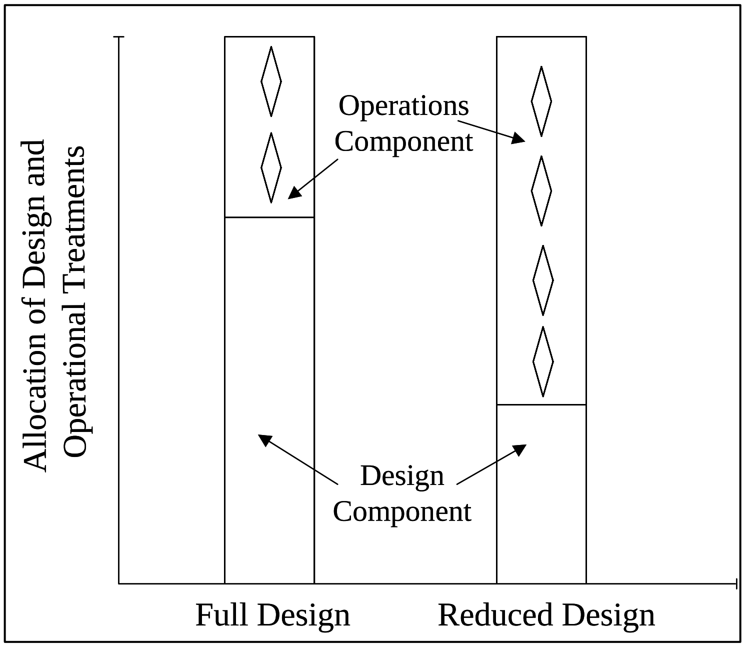


Figure 4-2. Balance Between Design and Operations Elements in Managed Lane Facility Development.

Table 4-2. Operational Treatments Needed for Full and Reduced Design Standards (Adapted from Reference 4).

Level of Design	Level of Operational Treatments	Example Operational Treatments
Full	Low	• Minimal enforcement • Visual detection by police, bus operators, motorist assistance patrols, or agency personnel • Calls from motorists using cellular telephones • Reports from roadside call boxes • Information from commercial traffic reporters • Flow metering not required • Consistent speed limit
Reduced	High	• Items noted above for full standards • AVI or inductance loop detectors for vehicle detection • Closed-circuit television cameras • Full advanced transportation management systems or integrated transportation management systems • Dedicated tow trucks with limited turning radius for narrow managed lane width • Changeable message signs (CMSs) • Entry ramp metering • Significant enforcement effort • Lower speed limits at constricted points

Figure 4-3. Reduced Width along US 290 (Northwest Freeway) Barrier-Separated Facility in Houston, Texas.

The sections that follow describe the various design and control criteria that should be considered with managed lane facilities. The design vehicle criteria are presented first, followed by a discussion of design driver criteria, design speed, and roadway alignment.

4.1.1 Design Vehicle

The physical and operating characteristics of eligible vehicles will influence the design of managed lane facilities. Standard and articulated buses, as well as carpools and vanpools, are often part of the allowed vehicle mix on these types of facilities. The dimensions for these vehicle types are illustrated in Table 4-3. The typical dimensions for a 40-foot (12.2-m), 45-foot (13.7-m), and an articulated bus are shown in Figures 4-4 through 4-6. Figures 4-7 and 4-8 illustrate the turning radii for a 40-foot (12.2-m) and an articulated bus. These dimensions, which will also accommodate vanpools and carpools, can be used by practitioners to assist with the design of managed lane projects on freeways.

These templates can be used in determining lane and shoulder widths, lateral and vertical clearances, bus stops, and other elements associated with a project. In addition, the path of the vehicle overhang beyond the outside turning radius should be considered in the design process. Double-deck buses, which may operate in some areas, have essentially the same characteristics as a standard bus except for vehicle height. Tractor-trailer buses, which do have different design characteristics, are not usually considered in the design process in most areas due to their very limited use.

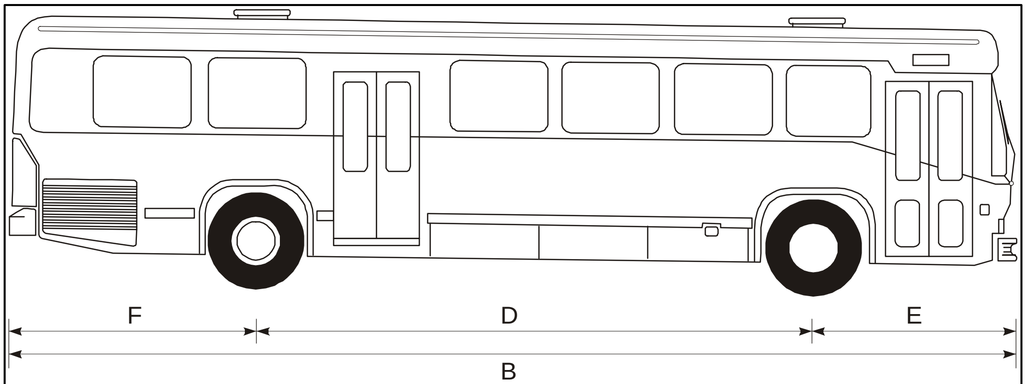
Table 4-3. Managed Lane Facility Vehicle Dimensions (Adapted from Reference 4).

Design Vehicle Type	Height	Width	Length	Overhang		Wheel Base
				Front	Rear	
Passenger Car	4.25 ft (1.3 m)	7.0 ft (2.1 m)	19.0 ft (5.8 m)	3.0 ft (0.9 m)	5.0 ft (1.5 m)	11.0 ft (3.4 m)
Van	6.5 ft (2.0 m)	7.5 ft (2.3 m)	17.0 ft (5.2 m)	2.5 ft (0.7 m)	4.0 ft (1.2 m)	10.5 ft (3.2 m)
40-foot (12.2-m) Bus[1]	9.9-11.1 ft (3.0-3.4 m)	8.2-8.5 ft (2.5-2.6 m)	40.0 ft (12.2 m)	7.2 ft (2.2 m)	9.3 ft (2.8 m)	25.0 ft (7.7 m)
45-foot (13.7-m) Bus[1]	12.2 ft (3.7 m)	8.5 ft (2.6 m)	45.0 ft (13.7 m)			22.9 ft (7.0 m)
Articulated Bus[1]	10.2 ft (3.1 m)	8.5 ft (2.6 m)	60.0 ft (18.3 m)	8.5 ft (2.6 m)	9.5 ft (2.9 m)	Front 17.5-18.6 ft (5.3-5.7 m) Rear 23.3-24.2 ft (7.1-7.4 m)
Semi-trailer Truck[2]	13.5 ft (4.1 m)	8.5 ft (2.6 m)	Varies	Varies	Varies	Varies

[1]Exact dimension may vary by bus manufacturer.
[2]Managed lane facilities may allow truck vehicles, and the proper design vehicle should be selected.

The design vehicles should be used to control the geometrics of the different managed lane facility design elements. For example, speed acceleration and deceleration lanes and corner radii should be based on a bus or other large design vehicle, while alignment geometry is typically based on the stopping sight distance of a passenger car driver. Larger design vehicles are not usually used in alignment design because the higher eye height of the driver allows them to see objects from a longer distance. Larger design vehicles, however, should be used for vertical alignment design when sight restrictions occur on long downgrades. In these situations, the speed of a bus may exceed that of a passenger car *(4)*.

If the managed lane will be used for general-purpose vehicles during off-peak periods or during incident management situations, it is recommended that consideration be given to using a semi-trailer truck as the design vehicle (e.g., WB-67). Further, for these situations and/or when the facility will be opened to truck traffic, it is important to ensure that the entire facility, including all ingress/egress locations and horizontal curvature, are designed for the semi-trailer truck design vehicle. For example, it is impractical to design long segments of the facility with the semi-trailer truck design vehicle only to have select interchange locations along the facility that are not designed to the semi-trailer truck design vehicle standard. Figure 4-9 presents the minimum turning path for the WB-67 Interstate semi-trailer along with typical dimensions.



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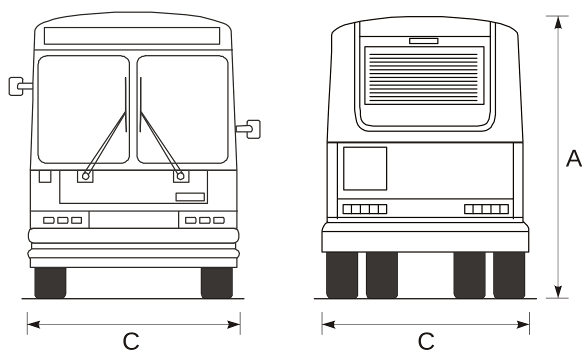
A	Overall Height	9.9 - 11.1 ft (3.0-3.4 m)*
B	Overall Length	40 ft (12.2 m)
C	Overall Width	8.2 - 8.5 ft (2.5-2.6 m)*
D	Wheel Base	23.7-24.9 ft (7.2-7.6 m)*
E	Front Axle to Bumper	7.2 ft (2.2 m)
F	Rear Axle to Bumper	9.3 ft (2.8 m)



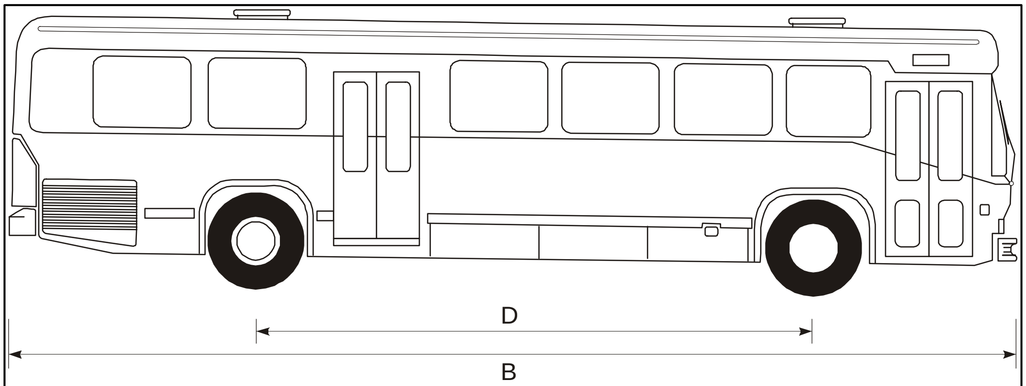
NET GROSS VEHICLE WEIGHT **

Front Axle	7,420/11,980 lbs (3,370/5,440 kg)
Rear Axle	18,060/24,660 lbs (8,200/11,200 kg)
Seating Capacity	46 - 51 *
Standing Capacity	20 - 25 *

NOTES

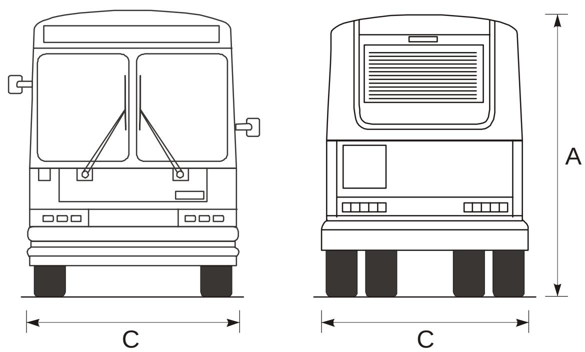
* Varies for different types of 40 ft (12.2 m) buses
** Net Weight is "Road Ready" without passengers
Gross includes passengers

Figure 4-4. Typical Dimensions for a 40-Foot (12.2-m) Bus (Adapted from Reference *4*).



ITEM

A	Overall Height	12.2 ft (3.7 m)*
B	Overall Length	45 ft (13.7 m)
C	Overall Width	8.5 ft (2.6 m)*
D	Wheel Base	22.9 ft (7.0 m)*



NET GROSS VEHICLE WEIGHT **	
All Axles	38,150/55,200 lbs (17,326/22,777 kg)

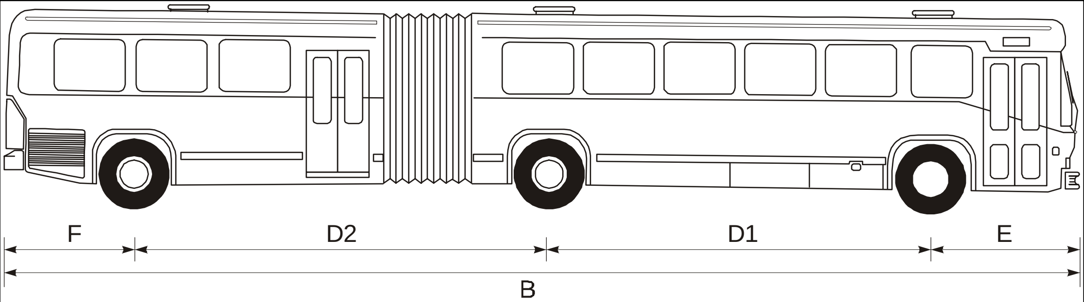
Seating Capacity	50 *
Standing Capacity	28 *

NOTES

* Varies for different types of 45 ft (13.7 m) buses

** Net Weight is "Road Ready" without passengers
Gross includes passengers

Figure 4-5. Typical Dimensions for a 45-Foot (13.7-m) Bus (Adapted from Reference *4*).



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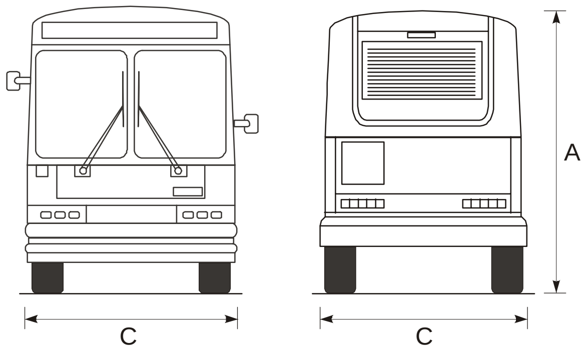
A	Overall Height	10.2 ft (3.1 m)
B	Overall Length	60 ft (18.3 m)
C	Overall Width	8.5 ft (2.6 m)
D1	Wheel Base - Front	17.5-18.6 ft (5.3-5.7 m)*
D2	Wheel Base - Rear	23.3-24.2 ft (7.1-7.4 m)*
E	Front Axle to Bumper	8.5 ft (2.6 m)
F	Rear Axle to Bumper	9.5 ft (2.9 m)



NET/GROSS VEHICLE WEIGHT **

Front Axle	11,800/16,420 lbs (5,360/7,450 kg)
Rear Axle	12,130/16,420 lbs (5,510/7,420 kg)
Center Axle	14,970/24,250 lbs (6,800/11,010 kg)

MAXIMUM BEND ANGLE

Horizontal	± 36 deg
Vertical	± 11 deg

Seating Capacity	70 - 76 *
Standing Capacity	38 *

NOTES

* Varies for different types of articulated buses
** Net Weight is “Road Ready” without passengers
Gross includes passengers

Figure 4-6. Typical Dimensions for an Articulated Bus (Adapted from Reference 4).

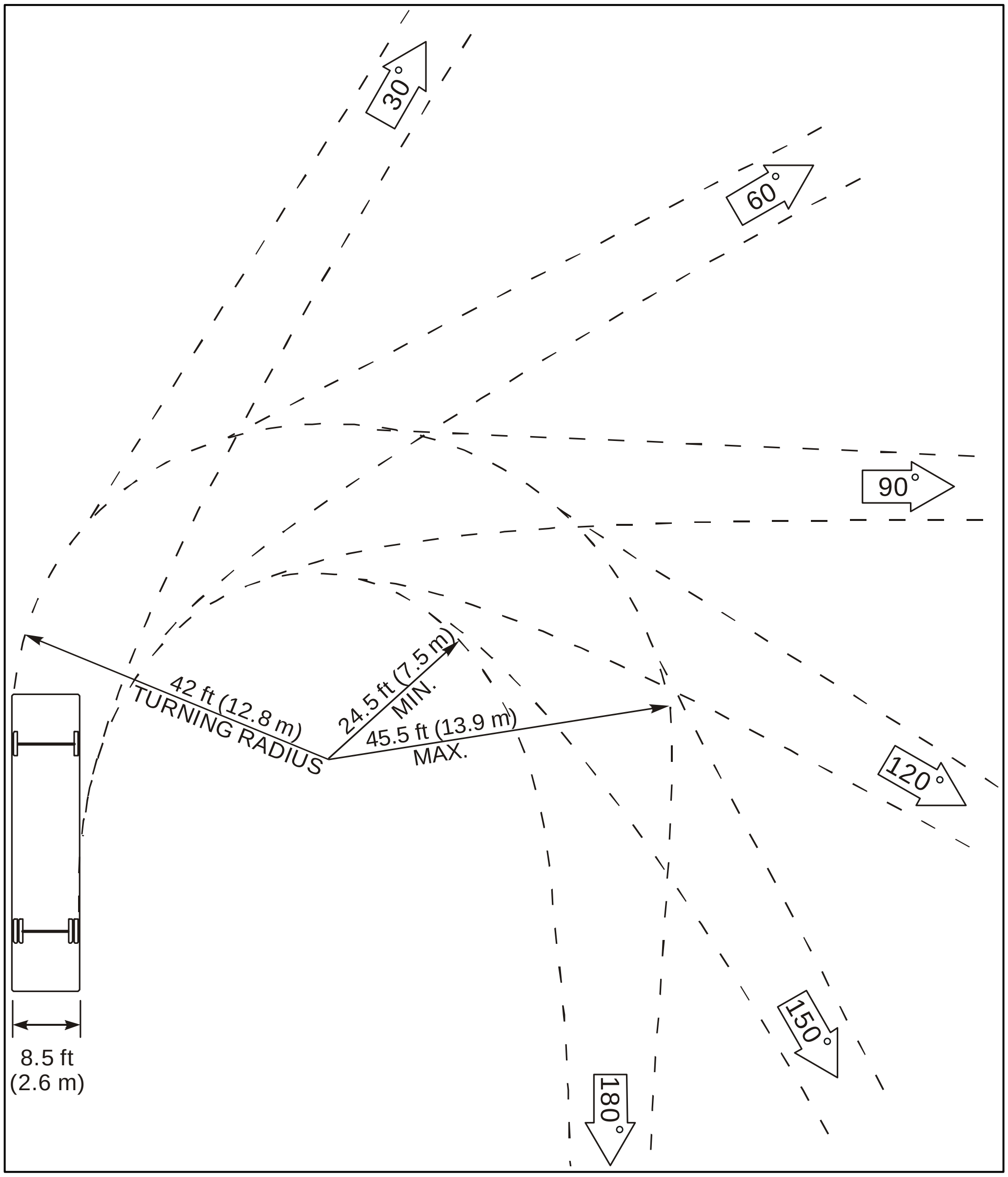


Figure 4-7. Design Template for a 40-Foot (12.2-m) Bus (Adapted from Reference *12,13*).

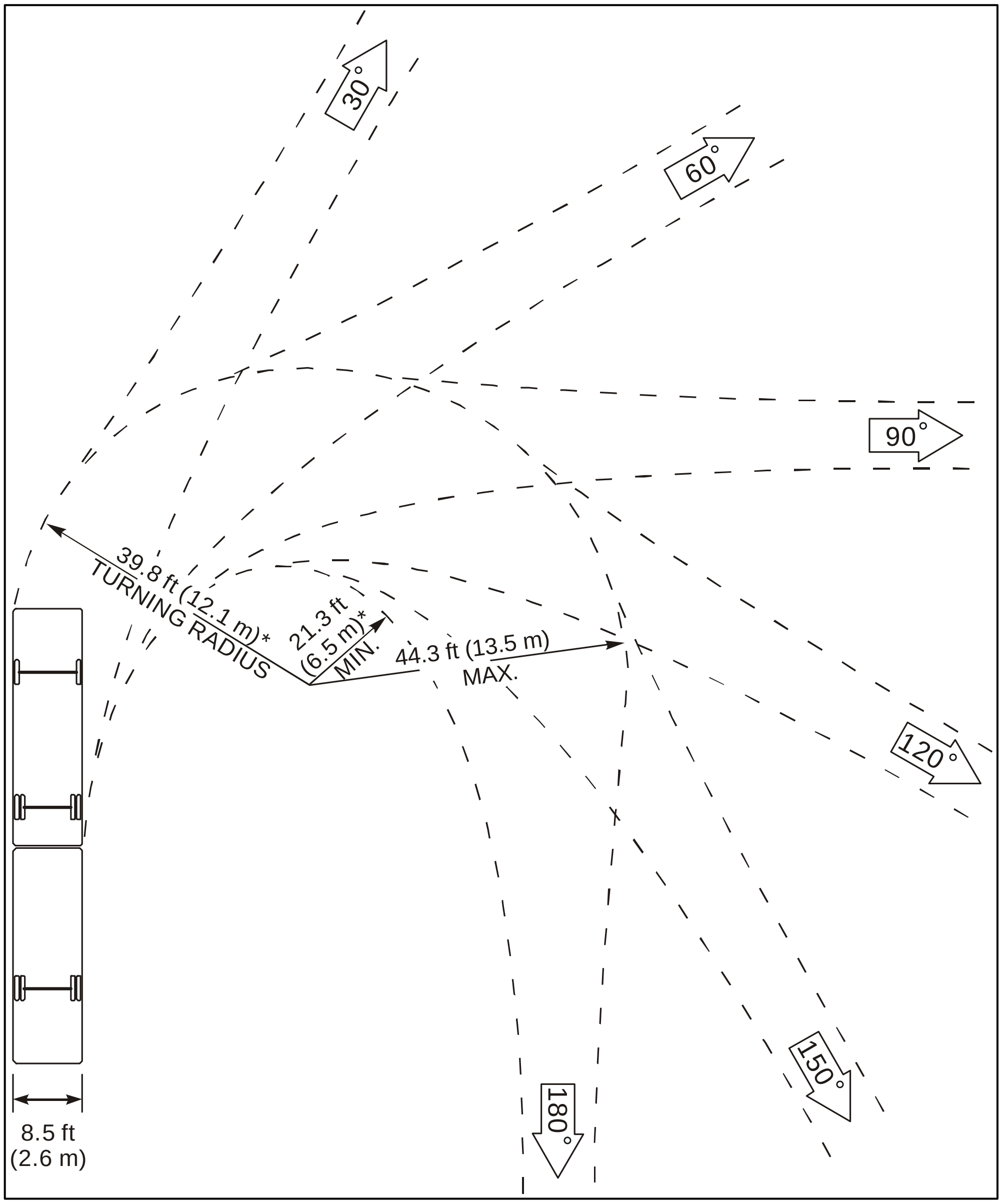


Figure 4-8. Design Template for an Articulated Bus
(Adapted from Reference *12,13*).

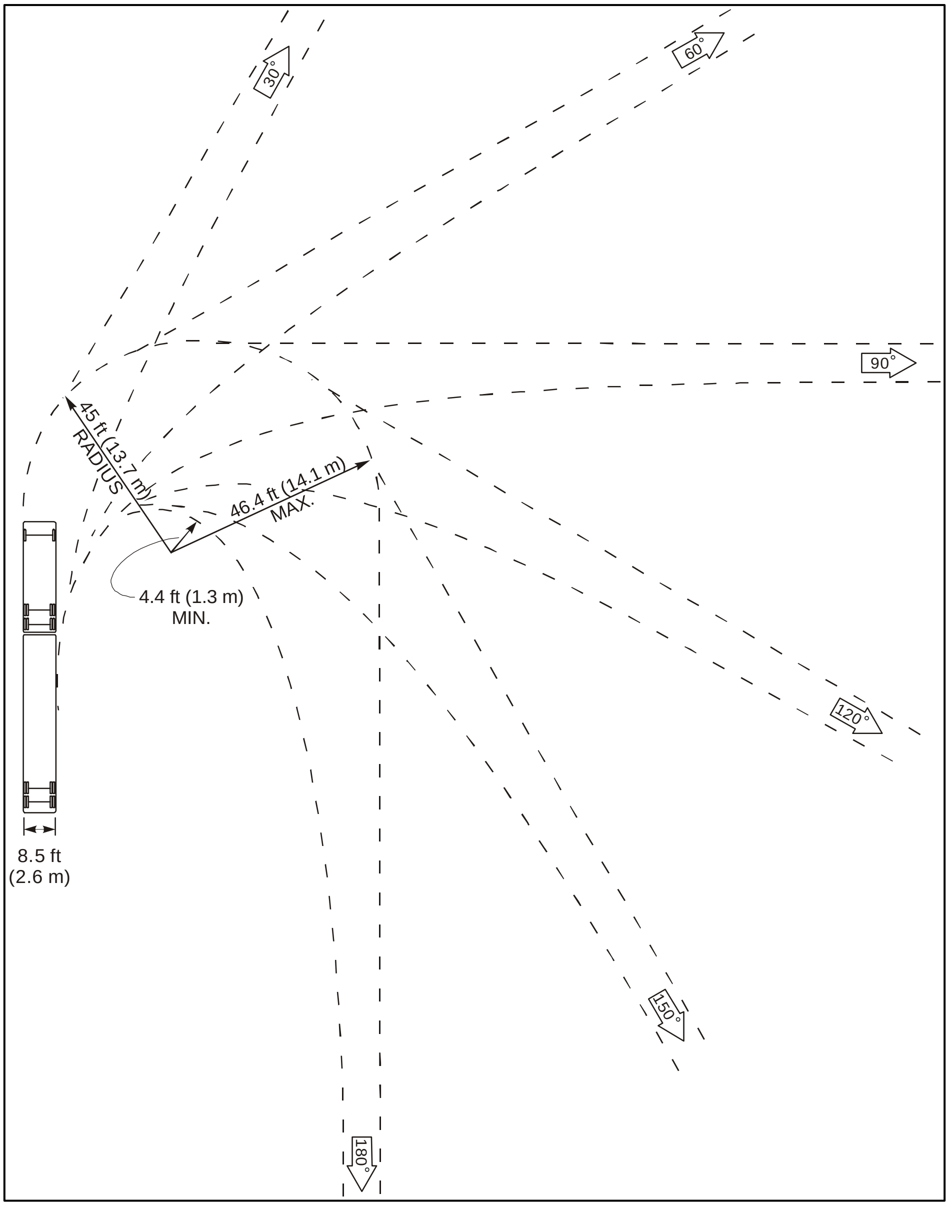


Figure 4-9. Minimum Turning Path for WB-67 (Interstate Semi-trailer) (Adapted from References *12,13*).

4.1.2 Design Speed

Roadway alignment design features are impacted by the design speed of the facility. In most cases, the design speed of managed lanes will be the same as that used on the adjacent general-purpose lanes. There may be limited instances where the design speed of the managed lanes is lower than the adjacent general-purpose lanes, however, due to the geometrics of the managed lane facility or other limitations.

The designated design speed should relate to the maximum speed the design features of the managed lane facility are expected to accommodate. Further, the design speed should accommodate the vast majority (85 percent) of users. For example, concurrent flow managed lanes should be expected to have the same design speed as the adjacent freeway lanes. A bypass lane will obviously have lower speed expectations.

AASHTO recommends design speeds of 60 mph (100 kph) to 70 mph (110 kph) on most urban freeways (*12,13*). Tables 4-4E (in English units) and 4-4M (in metric units) summarize the design speeds typically associated with various types of managed lanes. This information is provided to give a general idea of potential design speeds. The design speed for a specific facility should consider the anticipated user groups, the use of on-line and off-line stations, gradients, and local conditions. For example, in New York State the design speed for managed lanes is based on the maximum off-peak speed observed in the general-purpose lanes unless other circumstances prevent such a speed from being used.

Ramp connections for managed lanes should be designed at approximately 0.7 times mainline design speed, or nominally in the 30 mph (50 kph) to 40 mph (65 kph) speed range. This criterion is applicable to flyover ramps between managed lane facilities, elevated flyover ramps, and connecting drop ramps with local streets. At-grade slip ramps may use this criterion if dedicated weave lanes are provided, or they may be designed at a higher speed based on the specific location and operating characteristics of the freeway main lanes *(14)*.

Table 4-4E. Examples of Typical Design Speeds for Managed Lane Facilities (Adapted from Reference *4*).

Type of Managed Lanes	Typical Design Speed (mph)	
	Reduced	Desirable
Barrier-separated	50	70
Concurrent flow	50	60
Contraflow	30	50

Table 4-4M. Examples of Typical Design Speeds for Managed Lane Facilities (Adapted from Reference *4*).

Type of Managed Lanes	Typical Design Speed (kph)	
	Reduced	Desirable
Barrier-separated	80	110
Concurrent flow	80	100
Contraflow	50	80

4.1.3 Horizontal Clearance

There is a good deal of variance in the horizontal or lateral clearance in existing managed lanes. Five feet (1.5 m) is the desired clearance, but, as a minimum, at least a 2-foot (0.6-m) lateral clearance should be provided to adjacent barriers, signing columns, or other obstructions for both managed lanes and general-purpose traffic lanes. Exceptions to this minimum should be considered only in temporary situations, such as construction or reconstruction of a facility where speeds are reduced or for very short distances where other options do not exist.

4.1.4 Vertical Clearance

The height of the tallest vehicle anticipated to operate in the managed lane facility should be used to determine the vertical clearance. As discussed previously, buses are usually the tallest vehicle using a managed lane and are commonly used to determine the vertical clearance. If the managed lane will include trucks, the vertical clearance of the truck design vehicle may govern (see Table 4-3). In the case of managed lanes on freeways, the standard of 16.5 feet (5.0 m) used for the adjacent freeway lanes will also be used for the managed lane (*13*). In situations of restricted vertical clearance, a minimum of 14.5 feet (4.4 m) is acceptable, which includes an allowance of 6 inches (0.2 m) in anticipation of future resurfacing (*8*,*13*). This may also be an issue where an over crossing road is widened; a wider road means the cross slope reduces clearance.

4.1.5 Stopping Sight Distance

The design of a managed lane facility should provide adequate sight distance for all vehicle types (e.g., bus, truck, van, car) using the facility to come to a controlled stop. Due to the driver's eye height, the automobile is usually used as the design vehicle for determining stopping sight distance. AASHTO guidelines should be used in determining stopping sight distances for various travel speeds *(13)*. Tables 4-5E and 4-5M present both desirable and reduced minimum stopping sight distances for a range of 30 mph (50 kph) to 70 mph (110 kph). The deceleration associated with the desirable values in these tables will be acceptable for buses with standees. Both reduced and desirable stopping sight distance values are also applicable for calculation of horizontal curvature where the line of sight (driver to object) is 2 feet high. Finally, the stopping sight distance should be checked if barriers are used, as they may restrict the stopping sight distance *(14)*.

Table 4-5E. Managed Lane Stopping Sight Distance (Adapted from References *8,13,14*).

Managed Lane Design Speed (mph)	Stopping Sight Distance (feet)	
	Reduced	Desirable
30	200	200
40	275	305
50	350	425
60	475	570
70	600	730

Table 4-5M. Managed Lane Stopping Sight Distance (Adapted from References *8,13,14*).

Managed Lane Design Speed (kph)	Stopping Sight Distance (m)	
	Reduced	Desirable
50	60	65
70	85	105
80	110	130
100	145	185
110	185	220

4.1.6 Superelevation

Superelevation rates on managed lanes must be applicable to curvature over a range of design speeds. Consideration must be given to the higher center of gravity exhibited by buses, vans, and trucks, which will result in superelevations slightly higher than otherwise justified *(8)*. Tables 4-6E and 4-6M present recommended superelevation rates for managed lanes.

Table 4-6E. Recommended Managed Lane Superelevation Rates (Adapted from Reference *8*).

Managed Lane Design Speed (mph)	Maximum Superelevation, *e* (feet/feet)	
	Allowable	**Desirable**
40 - 50	0.06	0.04
50 - 70	0.08	0.06

Table 4-6M. Recommended Managed Lane Superelevation Rates (Adapted from Reference *8*).

Managed Lane Design Speed (kph)	Maximum Superelevation, *e* (m/m)	
	Allowable	**Desirable**
70 - 80	0.06	0.04
80 - 110	0.08	0.06

4.1.7 Cross Slope

The cross slope of a managed lane facility should generally follow the adjacent freeway, which is commonly 2.0 percent. However, managed lane facilities located in medians often straddle the crown of the roadway. It is acceptable to crown the facility with a 2.0-percent crossfall to either side if drainage requirements permit (as shown in Figure 4-10). For typical sections with five or more lanes, the uniform cross slope of 2.0 percent may not be sufficient and the outside lane(s) cross slope may require modification. For concurrent-flow facilities, the generally accepted approach is to extend the existing crossfall of the freeway main lanes. Some designs have reversed the cross slope toward the median where additional drainage can be intercepted. Reversing cross slope (i.e., creating a cross slope break of greater than 3.0 percent), except along extremely wide buffer or barrier alignments, is not recommended as it can affect driver expectations when crossing the buffer at designated access points and possibly degrade operational performance and safety *(14)*.

4.1.8 Minimum Turning Radius

Most urban transit buses are designed with a minimum turning radius (inner rear wheel path) of approximately 25 feet (7.6 m) and an outer front wheel radius of 42 feet (12.8 m) when maneuvering less than 5 mph (8 kph). This path reduces in width as the inner radius increases, but it is still a significant factor. Generally, a 50-foot (15.2 m) minimum radius (inner wheel path) is considered desirable at low speeds (10 mph [16 kph]). For a radius below this value, designers should consider the possibilities of a compound curve or of approach and departure tapers to avoid increasing the outside radius and resulting vehicle overhang. This condition is likely to be encountered at managed lane ramp intersections with local streets and possibly at ramp intersections with the main lane facility. Note that these recommended radii may differ if the managed lane facility is designed to accommodate semi-trailers *(14)*.

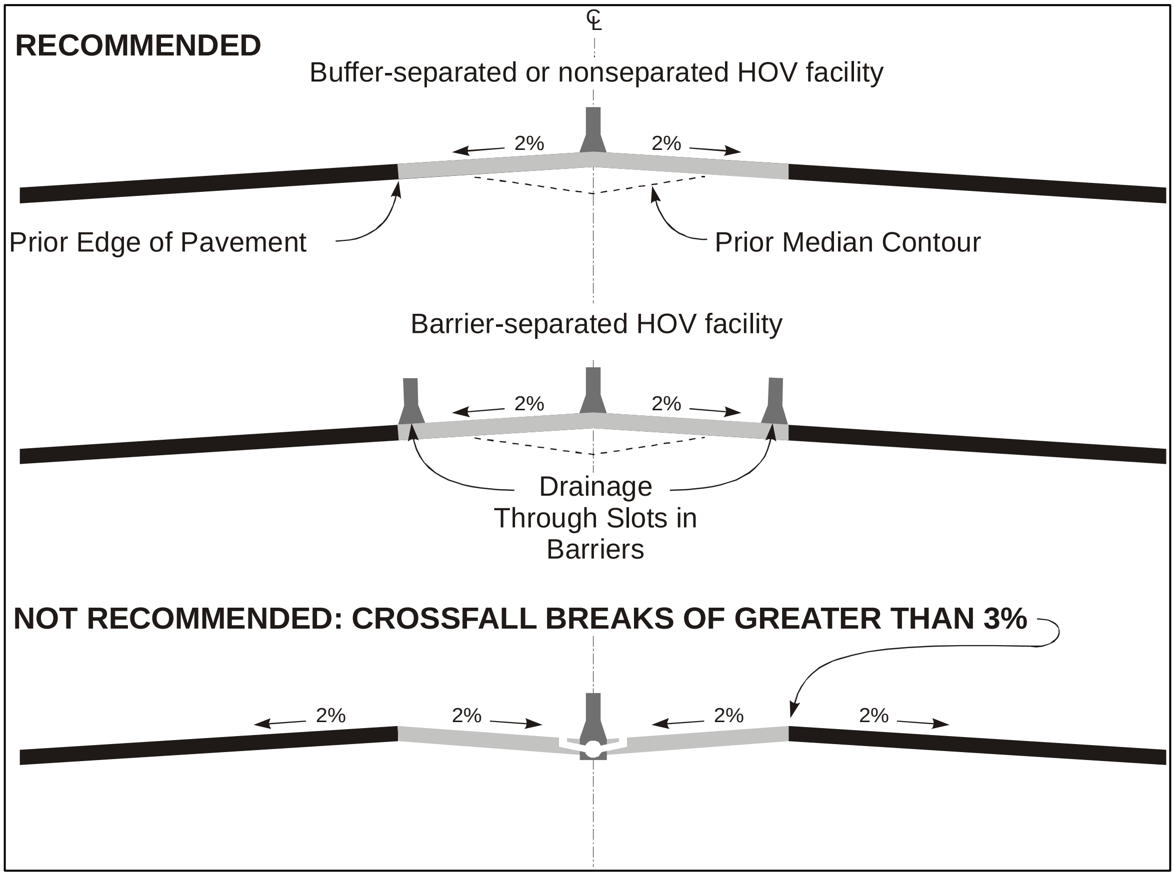


Figure 4-10. Cross-Slope Alternatives for Median Retrofit Projects (Adapted from Reference *14*).

4.1.9 Horizontal Curvature

Horizontal curvature on managed lane facilities depends on the joint relationship among design speed, pavement side friction, and superelevation to effect smooth, safe, and comfortable travel. The horizontal alignment of a managed lane should be designed to ensure that curves can be safely negotiated by all design vehicles, including buses and semi-trailers, if applicable to the managed lane facility design. Tables 4-7E and 4-7M present desirable and reduced radii for horizontal curves on managed lanes. Values for minimum radii for horizontal curvature should be used only where the cost of incorporating desirable radii is inconsistent with the benefits (*4*,*8*,*14*).

Managed lane main lane pavement on curves should provide additional lateral width for maneuvering and for the overhang of various parts of a bus. Tables 4-8E and 4-8M recommend pavement widening for managed lanes for various horizontal curve radii and design speeds. Likewise, curved ramp pavement widths must also be sufficient to accommodate the bus wheel path and allow passing of stalled vehicles. Recommended pavement widths for travel lane(s) are given for both single- and multiple-lane operation and varying ramp radii. Consideration may need to be given to providing extra lateral lane width on curves that will accommodate semi-trailers on a full- or part-time basis (*4*,*8*,*14*).

Table 4-7E. Recommended Minimum Radii for Managed Lane Horizontal Curvature (Adapted from Reference *13*).

Design Speed (mph)	Radii (feet)	
	Reduced[1]	Desirable[2]
70	2,000	2,500
60	1,400	1,400
50	800	900
40	500	600
30	250	300

[1]Reduced radii are obtained from page 161 (Reference *13*) with e_{max} = 8 percent.
[2]Desirable radii are obtained from page 159 (Reference *13*) with e_{max} = 6 percent.

Table 4-7M. Recommended Minimum Radii for Managed Lane Horizontal Curvature (Adapted from Reference *13*).

Design Speed (kph)	Radii (m)	
	Reduced	Desirable
110	500	600
100	400	500
80	250	250
70	175	200
50	80	90

[1]Reduced radii are obtained from page 161 (Reference *13*) with e_{max} = 8 percent.
[2]Desirable radii are obtained from page 159 (Reference *13*) with e_{max} = 6 percent.

Table 4-8E. Pavement Widening[1] Recommended for Horizontal Curvature (Adapted from Reference *14*).

Managed Lane Mainline				
Design Speed (mph)	**Pavement Widening (in feet) for Curve with Radius of:**			
	500 feet	750 feet	1,000 feet	2,000 feet
30	1.5	1.0	0.5	0.0
40	2.0	1.0	1.0	0.0
50	N/A	1.5	1.0	0.5
60	N/A	N/A	1.0	0.5
70	N/A	N/A	N/A	N/A
Managed Lane Ramps				
Ramp Type	**Pavement Widening for Curve with Radius of:**			
	100 feet	250 feet	500 feet	1,000 feet
Single-lane, one-way	8	6	4	2
Multiple-lane, one-way	6	4	3	2

Note: Allowances are for roadways only and do not include the need for shoulders.
[1]Based on single-lane, one-way.

Table 4-8M. Pavement Widening[1] Recommended for Horizontal Curvature (Adapted from Reference *14*).

Managed Lane Mainline				
Design Speed (kph)	**Pavement Widening (in meters) for Curve with Radius of:**			
	150 m	230 m	305 m	610 m
50	0.5	0.3	0.2	0.0
70	0.6	0.3	0.3	0.0
80	N/A	0.5	0.3	0.2
100	N/A	N/A	0.3	0.2
110	N/A	N/A	N/A	N/A
Managed Lane Ramps				
Ramp Type	**Pavement Widening for Curve with Radius of:**			
	100 m	250 m	500 m	1,000 m
Single-lane, one-way	2.4	1.8	1.2	0.6
Multiple-lane, one-way	1.8	1.2	0.9	0.6

Note: Allowances are for roadways only and do not include the need for shoulders.
[1]Based on single-lane, one-way.

4.1.10 Vertical Curvature

The length of vertical curvature depends on stopping sight distances and gradients. Managed lanes on freeways typically follow the existing vertical curvature of the facility. For busways and managed lane facilities on separate rights-of-way or new construction, K-factors are used to determine the necessary vertical curvature. K-factors are determined by applicable design speeds. For design on independent facilities outside the freeway right-of-way, K-factors (distance divided by the percentage change in algebraic difference of grades) should be used to calculate the recommended minimum length of vertical curvature. These calculations assume a driver eye height of 3.5 feet (1.1 m) (passenger cars being the most critical vehicles), object height of 2.0 feet (0.6 m), parabolic curvature, and the presence of fixed-source lighting for an urban environment. Tables 4-9E and 4-9M present recommended K-factors for length of the managed lane vertical curves over a range of design speeds and both crest and sag conditions (*13*). It is important to note that the K-factors for sag vertical curvature based on comfort are about 50 percent of that required to satisfy the headlight sight distance requirement for the normal range of design conditions (*13*). Therefore, it is important that fixed-source lighting exists along the managed lane facility to apply the sag vertical curvature values in these tables. If the fixed-source lighting does not exist or is not adequate, the headlight sight distance requirement should be used in the design of the sag vertical curvature.

Table 4-9E. Vertical Curve Criteria (K-Factors) for Managed Lane Facilities (Adapted from Reference *13*).

Design Speed (mph)	Minimum Length (feet)	Minimum K-Factors (Feet / Percent Change in Algebraic Difference of Gradients)	
		Crest Stopping	Sag Comfort
70	225	247	181
60	200	151	136
50	150	84	96
40	125	44	64
30	100	19	37

Note: Length of curve is three times the design speed (see page 280, Reference *13*).

Table 4-9M. Vertical Curve Criteria (K-Factors) for Managed Lane Facilities (Adapted from Reference *13*).

Design Speed (kph)	Minimum Length (m)	Minimum K-Factors (Meters / Percent Change in Algebraic Difference of Gradients)	
		Crest Stopping	Sag Comfort
110	70	74	55
100	60	52	45
80	50	26	30
70	45	17	23
50	30	7	13

Note: Length of curve is 0.6 times the design speed (see page 280).

4.1.11 Gradients

Recommended gradients should reflect current AASHTO practice to ensure both safety and uniformity of operation along with the capabilities of the vehicles authorized on the managed lane facility. Consideration must be given to maximum and minimum grades. Table 4-10 indicates desirable and reduced grades to be used on managed lane mainlines and connecting ramps. Values exceeding the recommended maximum may be considered in special or extreme situations only. The designer can enhance operation by providing flatter grades of adequate length at starting and stopping locations. The maximum length of grade should be such that vehicles are not slowed by more than 10 mph (16 kph) considering the length and percentage of the grade. Roadway grades can affect the performance of a managed lane facility. In particular, fully loaded buses (or semi-trailers) are severely affected on grades steeper than 3 or 4 percent. The ensuing slower bus speed can lengthen travel times for carpools under mixed mode operations.

A minimum longitudinal grade of 0.35 percent is controlled by the need to provide adequate drainage and to prevent long periods of water retention (i.e., ponding) on the roadway surface. For median facilities retrofitted at grade, the minimum grade follows the existing freeway gradient (*8*,*14*).

Table 4-10. Recommended Maximum Grades for Managed Lane Facilities (Adapted from References *8*,*14*).

Facility Type	Grade (Percent)	
	Desirable	Maximum
Mainline (70 mph [110 kph])	3	6
Ramp (40 mph [65 kph])	6	8

4.1.12 Summary of Managed Lane Mainline and Ramp Design Guidelines

Tables 4-11E and 4-11M provide a summary of alignment and other typical factors controlling design for mainline and ramp managed lane facilities is provided.

4.2 CROSS SECTIONS FOR MANAGED LANE FACILITIES

This section describes desirable and reduced cross sections for managed lane facilities. As with all components of the development of managed lane facilities, the cross section must consider the operation and enforcement of the facility.

4.2.1 Design Considerations for Exclusive Freeway Managed Lanes

Exclusive freeway managed lanes are physically separated by a barrier or wide buffer from the adjacent freeway general-purpose lanes. There are both reversible and two-way exclusive facilities. Reversible facilities may be designed as single-lane or multiple-lane facilities. As with other types of managed lane facilities, standards from AASHTO, FHWA, and local standards should be used to guide the design process.

Table 4-11E. Summary of Managed Lane Mainline and Ramp Design Criteria (Adapted from References *8*,*13*,*14*).

Design Parameter	Mainline		Ramp	
	Desirable	Reduced	Desirable	Reduced
Design Speed (mph)	**50-70**	**40**	**40**	**30**
Alignment				
Stopping distance (ft)	425-730	275	300	200
Horizontal curvature (ft/radius)	900-2,500	500	800	350
Superelevation (ft/ft)	0.06	0.08	0.04	0.06
Vertical curvature (ft)	150-225 (k=84 to 247, crest) (k=96 to 181, sag)	125 (k=44, crest) (k=64, sag)	125 (k=60, crest) (k=45, sag)	100 (k=30, crest) (k=15, sag)
Gradients				
Maximum (%)	3.0	6.0	6.0	8.0
Minimum (%)	0.3	0.3	0.3	0.3
Clearance				
Vertical (ft)	16.5	14.5	16.5	14.5
Lateral (ft)	5.0	2.0	5.0	2.0
Lane Width (ft)				
Travel lanes (ft)	12	11	13	12
Cross Slope (ft/ft)				
Maximum	0.020	0.020	0.020	0.020
Minimum	0.015	0.015	0.015	0.015
Turning Radius Minimum (ft)	N/A	N/A	50	45
Superelevation: Depends on curve radii and design speed (0.1 ft/ft maximum)				
Design Load on Structures: State DOT or AASHTO Design Load, whichever governs				

Table 4-11M. Summary of Managed Lane Mainline and Ramp Design Criteria (Adapted from References *8*,*13*,*14*).

Design Parameter	Mainline		Ramp	
	Desirable	Reduced	Desirable	Reduced
Design Speed (kph)	**80-110**	**70**	**70**	**50**
Alignment				
Stopping distance (m)	130-220	105	90	60
Horizontal curvature (m/radius)	250-600	200	245	105
Superelevation (m/m)	0.06	0.08	0.04	0.06
Vertical curvature (m)	50-70 (k=26 to 74, crest) (k=30 to 55, sag)	45 (k=17, crest) (k=23, sag)	40 (k=20, crest) (k=15, sag)	30 (k=10, crest) (k=5, sag)
Gradients				
Maximum (%)	3.0	6.0	6.0	8.0
Minimum (%)	0.3	0.3	0.3	0.3
Clearance				
Vertical (m)	5.0	4.4	5.0	4.4
Lateral (m)	1.5	0.6	1.5	0.6
Lane Width				
Travel lanes (m)	3.6	3.4	4.0	3.6
Cross Slope (m/m)				
Maximum	0.020	0.020	0.020	0.020
Minimum	0.015	0.015	0.015	0.015
Turning Radius Minimum (m)	N/A	N/A	15.2	13.7
Superelevation: Depends on curve radii and design speed (0.1 m/m maximum)				
Design Load on Structures: State DOT or AASHTO Design Load, whichever governs				

Exclusive Two-Way Managed Lane Facilities. Exclusive two-way facilities are lanes constructed within the freeway right-of-way that are physically separated from the general-purpose freeway lanes and are used exclusively as managed lanes for all, or a portion, of the day. Concrete barriers are often used to physically separate the managed lane facility from the general-purpose freeway lanes.

Exclusive facilities often have limited access points and may include direct ramps and other exclusive ingress and egress treatments. The general design approach is similar to a normal freeway design, with the addition of type of barrier or wide buffer between the managed lane facility and the general-purpose lanes. The following design components should be considered with an exclusive two-way managed lane facility. Figure 4-11 highlights these elements in a sample cross section.

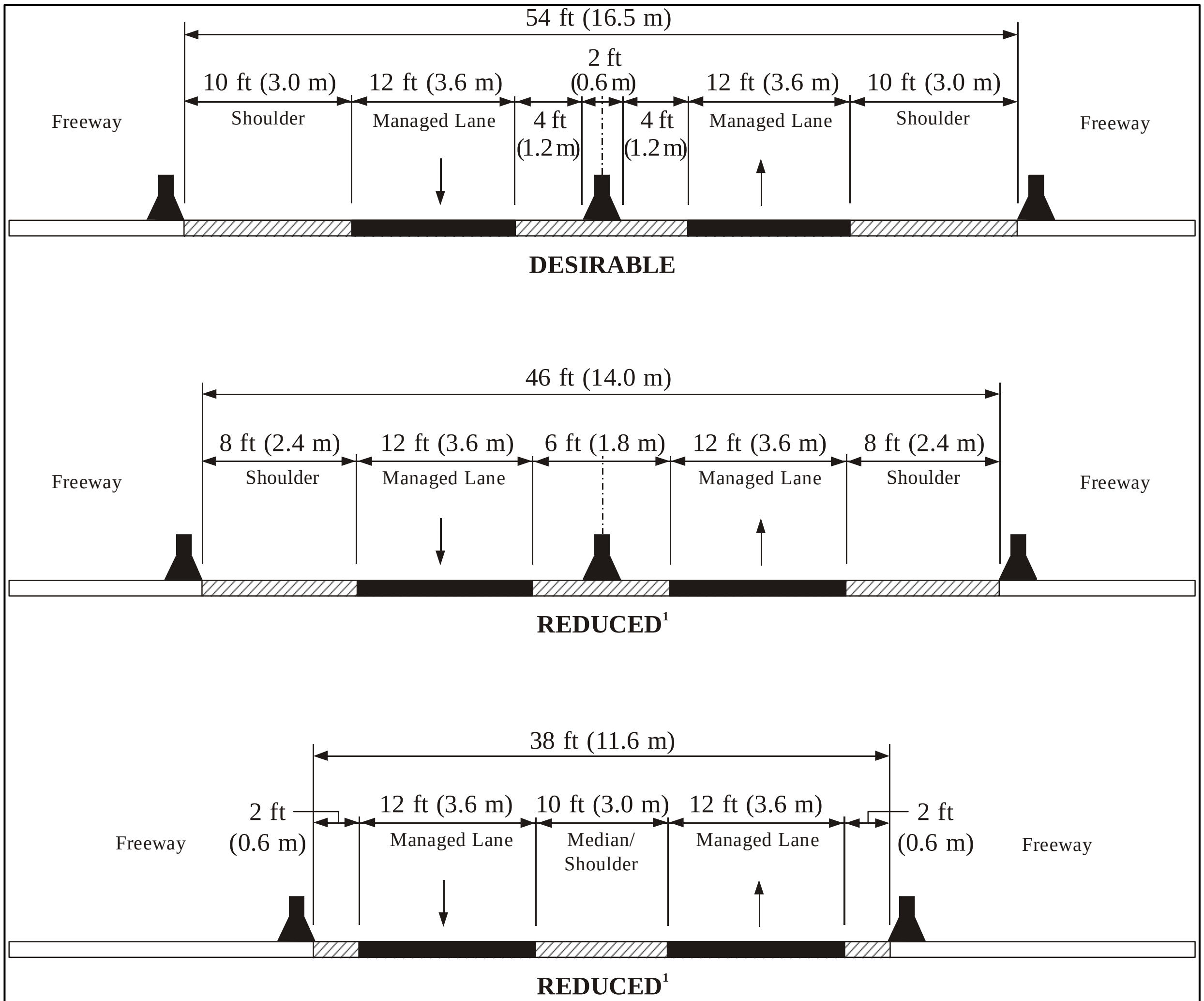
Median Component. Opposing direction managed lanes are normally separated from each other by a median barrier. AASHTO *(5)* and federal guidelines should be used to design the median barrier. A 2- to 4-foot (0.6- to 1.2-m) lateral clearance should be provided adjacent to the median barrier. If a median barrier design is not possible, a shared median shoulder of 10 feet (3.0 m) may be considered as shown in Figure 4-11. The design provides a buffer for both directions of traffic. This cross section has more application to two-way ramps, short connector sections, low volume managed lanes, or other lower speed facilities *(7)*.

Lane Component. The existing exclusive two-way managed lane facilities have 12-foot (3.6 m) travel lanes. Narrower lane widths should be considered only in special circumstances or for short distances due to limited right-of-way.

Lane Separation Component. As shown in Figure 4-11, a 2-foot (0.6 m) barrier can be provided as the separation treatment. Lateral clearance will also need to be provided adjacent to the general-purpose lanes with this approach.

Cross-Section Design Summary. A total design envelope of 38 to 54 feet (11.6 to 16.5 m) will generally be needed for a two-way exclusive managed lane facility. Reduced design standards should be considered only in special circumstances.

Design Tradeoffs. Table 4-12 shows an example ordered list of adjustments that may be made to the cross-section design of a two-way barrier-separated managed lane when there is limited right-of-way. As noted in the cross-section figures, the operational allowances described in section 4.1 and described in detail in Chapter 3 should be considered prior to using reduced design cross sections. Table 4-12 is only an example; each area should consider these and decide what will be approved. FHWA, FTA, DOT, transit agency, city, and others have to agree on what will be approved.



[1] Operational treatments should be incorporated if the reduced design cross sections are used (see section 4.1)

Figure 4-11. Examples of Cross Sections for Exclusive Two-way Managed Lane Facilities (Adapted from Reference *4*).

Table 4-12. Example Design Tradeoffs for Two-way Barrier-Separated Managed Lanes Facilities (Adapted from Reference *14*).

Ordered Sequence	Cross-Section Design Change
First	Reduce left managed lane lateral clearance to no less than 2 feet (0.6 m).
Second	Reduce right managed lane lateral clearance to no less than 8 feet (24 m) .
Third	Reduce freeway left lateral clearance to no less than 2 feet (0.6 m).
Fourth	Reduce freeway right lateral clearance (shoulder) from 10 feet (30 m) to no less than 8 ft (24 m) .
Fifth	Reduce managed lane width to no less than 11 feet (34 m) (some agencies prefer reversing the fifth and sixth steps when buses or trucks are projected to use the managed lane facility).
Sixth	Reduce selected mixed-flow lane widths to no less than 11 feet (34 m). (Leave at least one 12-foot (36 m) outside lane for trucks).
Seventh	Reduce freeway right lateral clearance shoulder from 8 feet (24 m) to no less than 4 feet (12 m).
Eighth	Convert barrier shape at columns to a vertical face.

Exclusive Reversible Managed Lane Facility. The second type of exclusive managed lane treatment is a reversible lane or lanes. Like a two-way facility, this approach involves a lane or lanes within the freeway right-of-way that are physically separated from the general-purpose freeway lanes and are used exclusively by eligible vehicles for all or a portion of the day. Trucks may also be eligible users of the facility.

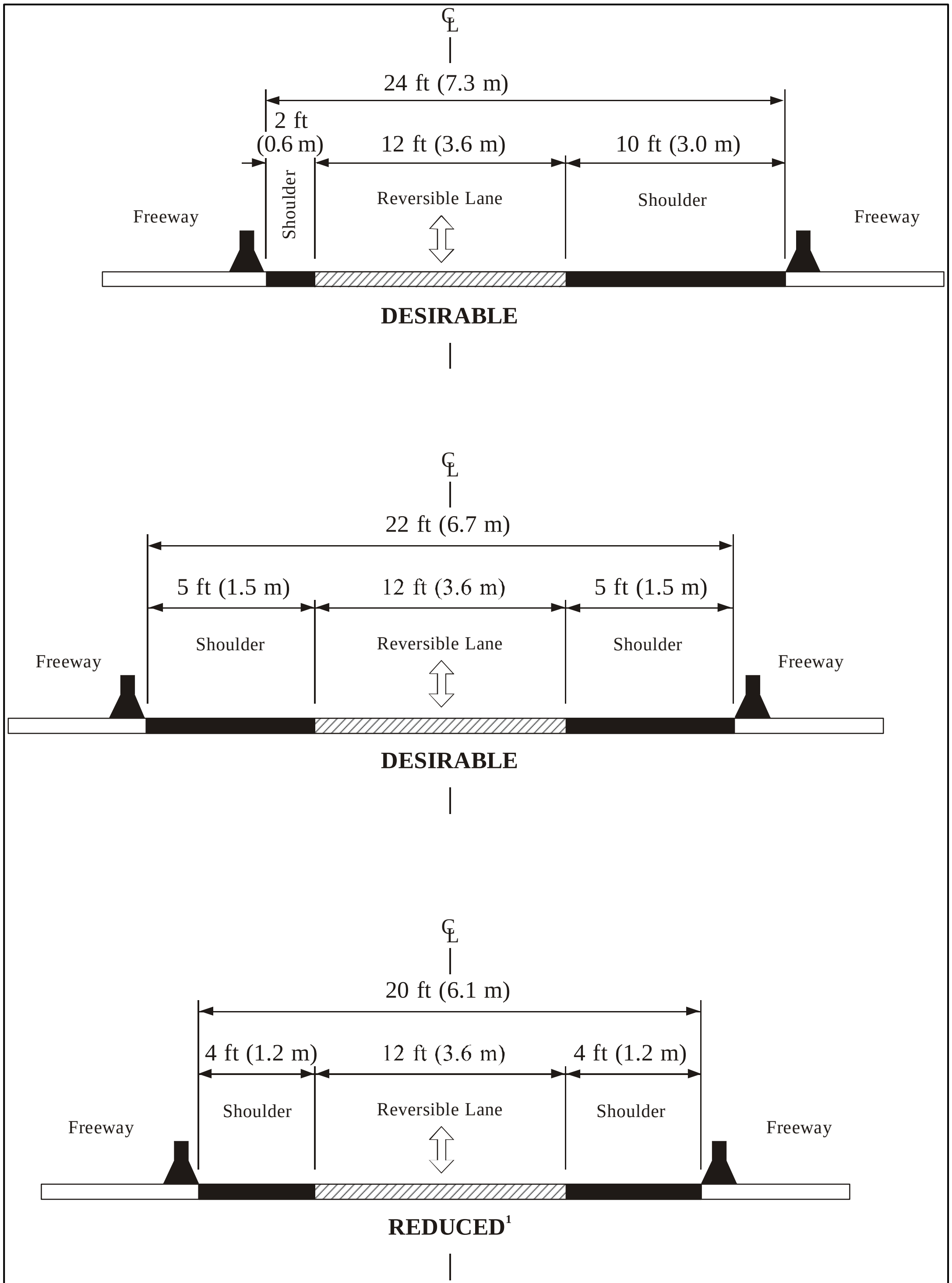
Exclusive reversible managed lane facilities usually operate inbound toward the CBD or other major activity center in the morning and outbound in the afternoon. Some type of daily setup is required with reversible facilities. This often includes opening gates to the lanes in the morning, closing the lanes to inbound traffic, reopening the lanes in the reverse direction of travel in the afternoon, and closing the lanes in the evening. Both manual and automated techniques are used to open and close reversible managed lane facilities.

These types of facilities are in operation in Houston, Texas, on the North (I-45), Northwest (US 290), Katy (I-10), Southwest (US 59), Gulf (I-45), and Eastex (US 59) freeways. Table 4-13 shows examples of design elements for existing exclusive reversible managed lane facilities including those in Texas. Figure 4-12 illustrates cross-section examples of the design components for a single-lane barrier-separated reversible facility, and Figure 4-13 illustrates a two-lane facility. The following items highlight the design elements associated with these types of projects.

Table 4-13. Examples of Design Elements for Existing Exclusive Reversible Managed Lane Facilities (Adapted from Reference *4*).

Location and Managed Lane Facility	Number of Managed Lanes	Width of Managed Lanes	Lateral Clearances Width[1]		General-Purpose Lanes		
			Left	Right	Left Shoulder	Freeway Lane	Right Shoulder
Denver, CO, I-25	2	12 ft (3.6 m)	6 ft (1.8 m)	10 ft (3 m)	N/A	N/A	N/A
Houston, TX:							
Katy, I-10	1	12 ft (3.6 m)	3.75 ft (1.1 m)	3.75 ft (1.1 m)	1 ft (0.3 m)	11 ft (3.3 m)	10 ft (3.0 m)
North, I-45	1	12 ft (3.6 m)	3.75 ft (1.1 m)	3.75 ft (1.1 m)	1 ft (0.3 m)	12 ft (3.6 m)	10 ft (3.0 m)
Gulf, I-45	1	12 ft (3.6 m)	4 ft (1.2 m)	4 ft (1.2 m)	1 ft (0.3 m)	12 ft (3.6 m)	10 ft (3.0 m)
Northwest, US 290	1	12 ft (3.6 m)	4 ft (1.2 m)	4 ft (1.2 m)	1 ft (0.3 m)	12 ft (3.6 m)	10 ft (3.0 m)
Southwest, US 59	1	12 ft (3.6 m)	4 ft (1.2 m)	4 ft (1.2 m)	1 ft (0.3 m)	12 ft (3.6 m)	10 ft (3.0 m)
Eastex, US 59	1	12 ft (3.6 m)	6 ft (1.8 m)	6 ft (1.8 m)	10 ft (3.0 m)	12 ft (3.6 m)	10 ft (3.0 m)
Minneapolis, MN, I-394	2	12 ft (3.6 m)	5 ft (1.5 m)	10 ft (3.0 m)	10 ft (3.0 m)	12 ft (3.6 m)	12 ft (3.6 m)
Pittsburgh, PA, I-279/579	2	12 ft (3.6 m)	2 ft (0.6 m)	10 ft (3.0 m)	4-10 ft (1.2-3.0 m)	12 ft (3.6 m)	12 ft (3.6 m)
San Diego, CA, I-15	2	12 ft (3.6 m)	10.5 ft (3.2 m)	10.5 ft (3.2 m)	10 ft (3.0 m)	12 ft (3.6 m)	10 ft (3.0 m)
Seattle, WA, I-90	2	12 ft (3.6 m)	8 ft (2.4 m)	8 ft (2.4 m)	6-8 ft (1.3-2.4 m)	12 ft (3.6 m)	8-10 ft (2.4-3.0 m)
Northern Virginia/Washington, DC, Shirley, I-395	2	12 ft (3.6 m)	10 ft (3.0 m)	10 ft (3.0 m)	10 ft (3.0 m)	12 ft (3.6 m)	10 ft (3.0 m)

N/A—not available.
[1] Lateral clearance widths on reversible managed lane refers to one direction of travel; shoulder widths are reversed for travel in other direction.



[1] Operational treatments should be incorporated if the reduced design cross sections are used (see section 4.1)

Figure 4-12. Examples of Cross Sections for Single-Lane, Exclusive Reversible Managed Lane Facilities (Adapted from Reference *4*).

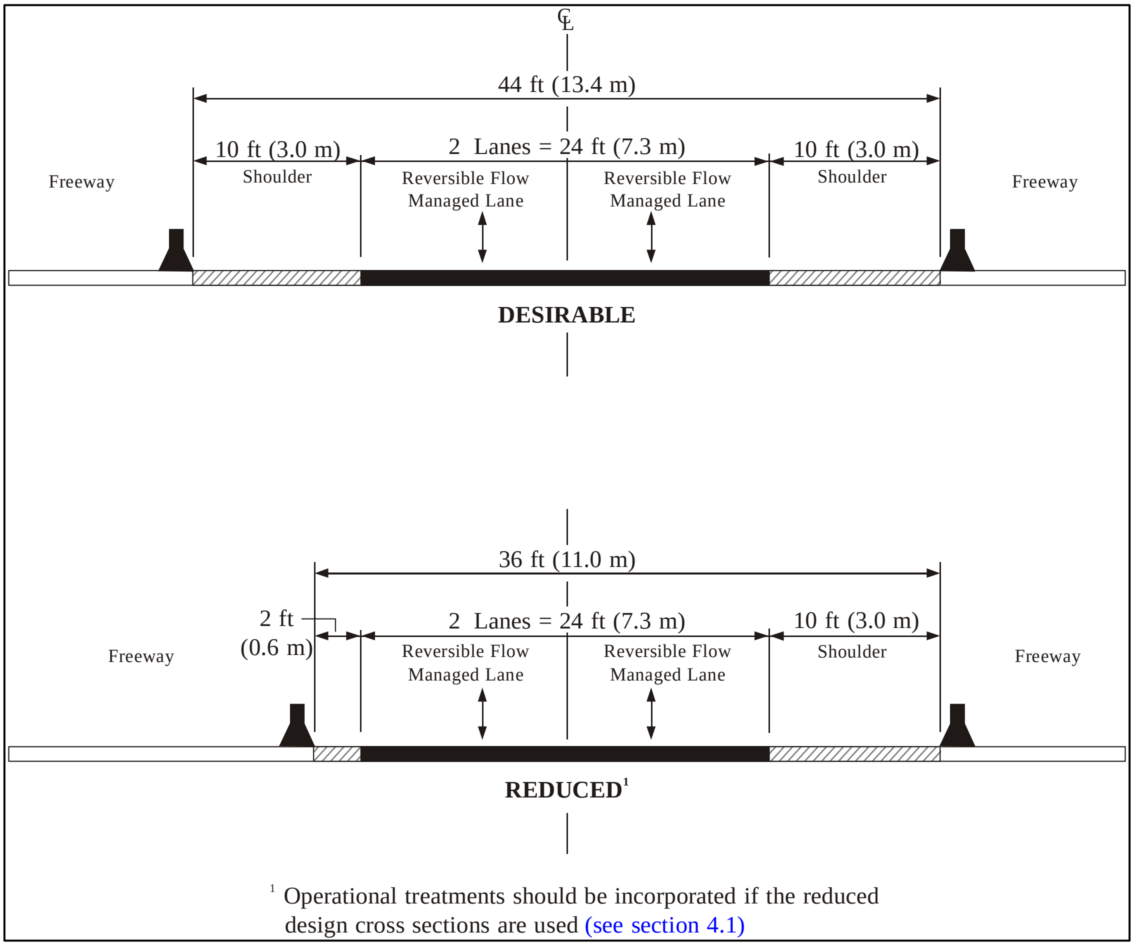


Figure 4-13. Examples of Cross Sections for Two-Lane Exclusive Reversible Managed Lane Facilities (Adapted from Reference *4*).

Lane Component. AASHTO (*6*,*13*) and other sources (*7*,*14*) recommend 12-foot-wide (3.6-m) managed lanes for either a single- or two-lane facility. All of the currently operating exclusive reversible managed lane facilities meet these guidelines.

Cross-Section Design Summary. A design envelope of 22 feet to 24 feet (6.7 m to 7.3 m) is recommended for a single exclusive reversible managed lane (*6*,*13*,*14*). A reduced envelope of 20 feet (6.1 m) may also be considered. A design envelope of 44 feet (13.4 m) is recommended for a two-lane facility, with a reduced design envelope of 36 feet (11 m). The main difference in the design envelope is the width of the shoulders and lateral clearance provided. The key design elements with reversible facilities include ensuring that vehicles can pass a disabled bus, van, automobile, or truck (if allowed) and providing for the safe and efficient operation of both the managed lane and the freeway lanes.

Shoulder, Lateral Clearance, and Separation Component. The major differences among existing reversible managed lane facilities relate to the width of the shoulder or lateral clearance provided on both sides of the managed lane. The single-lane reversible facilities in Houston include 4-foot (1.2 m) shoulders on each side of the HOV lane facility and a 2-foot (0.6 m) barrier. Most two-lane facilities provide a 10-foot (3 m) shoulder on one side and a 2- to 10-foot (0.6 to 3 m) lateral clearance or shoulder on the other side. AASHTO (*6*,*13*) recommends at least one 10-foot (3 m) shoulder. Shoulder widths between 4 feet (1.2 m) and 8 feet (2.4 m) should be avoided on freeways between curbs or barriers and a travel lane as they may encourage the unsafe use of the shoulder as a breakdown or emergency stopping area. It should be noted that in cold climate areas, adequate shoulder space is also needed for snow removal.

Design Tradeoffs. Table 4-14 shows an example of an ordered list of adjustments that may be made to the cross-section design of a reversible barrier-separated managed lane when there is limited right-of-way. As noted in the cross-section figures, the operational allowances described in section 4.1 and described in detail in Chapter 3 should be considered prior to using reduced design cross sections. Table 4-14 is only an example as each area should consider these and decide what will be approved. FHWA, FTA, DOT, transit agency, city, and others have to agree on what will be approved.

Table 4-14. Example Design Tradeoffs for Reversible-Flow Managed Lane Facilities (Adapted from Reference *14*).

Ordered Sequence	Cross-Section Design Change
First	Reduce single-lane managed lane envelope to no less than 20 feet (61 m), or two-lane envelope to no less than 28 feet (85 m).
Second	Reduce freeway left lateral clearance to no less than 2 feet (0.6 m).
Third	Reduce freeway right lateral clearance (shoulder) from 10 feet (3 m) to no less than 8 feet (24 m).
Fourth	Reduce managed lane width to no less than 11 feet (33 m) (some agencies prefer reversing fourth and fifth steps when buses are projected to use the managed lane facility).
Fifth	Reduce selected general-purpose lane widths to no less than 11 feet (33 m). (Leave at least one 12-foot (36 m) outside lane for trucks).
Sixth	Reduce freeway right lateral clearance shoulder from 8 feet (24 m) to no less than 4 feet (12 m).
Seventh	Convert barrier shape at columns to a vertical face.

4.2.2 Design Considerations for Concurrent Flow Managed Lane Facilities

Concurrent flow managed lanes are defined as freeway lanes in the same direction of travel, not physically separated from the general-purpose traffic lanes, and designated for exclusive use by eligible vehicles for all or a portion of the day. A few facilities are open only to buses, allowing transit vehicles to bypass specific bottlenecks.

Concurrent flow lanes are usually, although not always, located on the inside lane or shoulder. Pavement markings are a common means used to separate these lanes. Unlimited ingress and egress may be allowed with a concurrent flow managed lane, or only specific access points may be provided.

Concurrent flow managed lane facilities are the most common managed lane application in North America. Concurrent flow HOV lanes are used extensively in Seattle and metropolitan areas in California, as well as other cities throughout the country. Examples of concurrent flow lanes are SR 520, I-405, I-5, SR 167, and I-90 in Seattle, Washington; SR 55, I-405, SR 91, SR 57, I-5, I-605, I-105, I-210, SR 134, and SR 118 in Los Angeles/Orange County, California; SR 101 in San Jose, California; I-280, I-80, SR 237, and US 101 in the San Francisco Bay area, California; US 36 in Denver, Colorado; I-10 and I-17 in Phoenix, Arizona; I-394 in Minneapolis, Minnesota; I-65 in Nashville, Tennessee; I-95 and SR 112 in Miami, Florida; SR 44 and I-564 in Norfolk/Virginia Beach, Virginia; I-270 in Maryland; I-20, I-75, and I-85 in Atlanta, Georgia; and I-35E and I-635 in Dallas, Texas.

Concurrent flow managed lane facilities are often developed by retrofitting an existing freeway cross section. For example, the inside shoulder or center median may be converted to an additional lane, or the freeway right-of-way may be expanded and a managed lane added. As a result, a wide range of design treatments are found with these types of projects. The various approaches that are currently used and the design elements that should be considered with concurrent flow managed lane facilities are described next and highlighted in Table 4-15 and Figure 4-14.

Median and Shoulder Component. As illustrated in Figure 4-14, the desirable cross section for a concurrent flow lane located on the inside includes a breakdown shoulder. AASHTO (*6*,*13*) and other sources (*7*,*14*) identify a shoulder width of 10 to 14 feet (3.0 to 4.2 m) as desirable next to the median barrier. Many of the current projects have shoulders, although as noted in Table 4-15, a number use reduced designs. Operational allowances should be considered prior to using reduced design cross sections (see section 4.2.1). The application of reduced shoulders or limited lateral clearances should be examined carefully on a project-by-project basis. Figure 4-14 also shows how an enforcement shoulder can be accommodated along the inside shoulder. Enforcement of all managed lane facilities should be considered throughout the design of the facility. Enforcement area design is discussed in section 4.5.

Lane Component. A concurrent flow managed lane should be designed to the same standards as the freeway general-purpose lanes. A 12-foot (3.6-m) travel lane is desired. Narrower lanes should be used only in special circumstances.

Separation from General-Purpose Lane. A variety of treatments are currently used to separate the managed lane from the general-purpose lanes. As illustrated in Figure 4-14, these range from no separation other than additional paint striping to a narrow buffer of 2 to 4 feet (0.6 to 1.2 m). An advantage of a narrow buffer is the additional separation provided between the managed lane and the general-purpose lane. A potential disadvantage of this approach is that drivers may perceive and use the space as a breakdown lane, causing a safety hazard. Further, if limited access points are used with this treatment, weaving movements may be concentrated in these areas. This makes the effects of weaving worse than with other approaches.

Cross-Section Design Summary. The desirable cross section for a concurrent flow managed lane on the inside of a freeway includes the center median, a shoulder or lateral clearance, the managed lane, and a paint stripe or buffer separating the managed lane from the general-purpose lane. The desirable general design envelope for all these elements is 54 to 62 feet (16.3 to 18.8 m). Consideration may be given to reducing some of these elements under special circumstances. A reduced design envelope as narrow as 34 feet (10.3 m) may be considered in these cases. However, reductions should not be made if they will adversely affect the safe and efficient operation of a facility. Figure 4-15 provides an example of a cross section for a managed lane on the outside of a freeway. Outside shoulder lanes are currently operating along SR 520 in Seattle. These facilities work well because of freeway flyer transit stops on the outside shoulder of these facilities. A paint stripe is the normal method of separation from the general-purpose traffic lanes, and, since the outside shoulder may be used for the managed lane, there may be either no shoulder or only a very narrow one. The outer areas of these managed lanes need to be monitored so there are not any breakdowns.

Design Tradeoffs. Table 4-16 shows an example ordered list of adjustments that may be made to the cross-section design of a concurrent flow managed lane facility when there is limited right-of-way. As noted in the cross-section figures, the operational allowances described in section 4.1 and described in detail in Chapter 3 should be considered prior to using reduced design cross sections. Table 4-16 is only an example as each area should consider these and decide what will be approved. FHWA, FTA, DOT, transit agency, city, and others have to agree on what will be approved.

Table 4-15. Examples of Design Elements for Operating Freeway Concurrent Flow Managed Lane Facilities (Adapted from Reference *4*).

Location and Managed Lane Facility	Left Shoulder or Lateral Clearance	Managed Lane Width	Separation	Mixed-Flow Freeway Lanes	Right Shoulder
Dallas					
I-35E	2 ft (0.6 m)	11.5 ft (3.5 m)	3 ft (0.9 m)	11 ft (3.3 m)	10 ft (3.0 m)
I-635	3 ft (0.9 m)	11 ft (3.3 m)	3 ft (0.9 m)	11 ft (3.3 m)	10 ft (3.0 m)
Honolulu, Moanalua Expwy	7 ft (2.1 m)	12 ft (3.6 m)	0	12 ft (3.6 m)	7 ft (2.1 m)
Los Angeles					
Century, I-105	Varies	12 ft (3.6 m)	4 ft (1.2 m)	12 ft (3.6 m)	10 ft (3.0 m)
Harbor, I-110	12 ft (3.6 m)	12 ft (3.6 m)	4 ft (1.2 m)	12 ft (3.6 m)	10 ft (3.0 m)
SR 91	3 ft (0.9 m)	11 ft (3.3 m)	2 ft (0.6 m)	11.75 ft (3.6 m)	10 ft (3.0 m)
Miami and Ft. Lauderdale, I-95	10-12 ft (3.0-3.6 m)	12 ft (3.6 m)	2 ft (0.6 m)	12 ft (3.6 m)	12 ft (3.6 m)
Minneapolis, I-394	10 ft (3.0 m)	12 ft (3.6 m)	0[3]	12 ft (3.6 m)	12 ft (3.6 m)
Orlando, I-4	10 ft (3.0 m)	12 ft (3.6 m)	0	12 ft (3.6 m)	10 ft (3.0 m)
Orange County					
SR-55	2 ft (0.6 m)	11 ft (3.3 m)	1 ft (0.3 m)	12 ft (3.6 m)	8 ft (2.4 m)
I-405	4 ft (1.2 m)	12 ft (3.6 m)	4 ft (1.2 m)	12 ft (3.6 m)	10 ft (3.0 m)
Phoenix, I-10	12 ft (3.6 m)	12 ft (3.6 m)	4 ft (1.2 m)	12 ft (3.6 m)	12 ft (3.6 m)
Marin County, US 101	3-6 ft (0.9 to 1.8 m)	11-12 ft (3.3-3.6 m)	0[3]	11 and 12 ft (3.3 & 3.6 m)	8-11 ft (2.4-3.3 m)
Santa Clara County					
San Tomas Expwy	0	13 ft (3.9 m)[1,2]	0[3]	11 and 13 ft (3.3 & 3.9 m)	0-10 ft (0-3.0 m)
Montague Expwy	0	13 ft (3.9 m)[1,2]	0[3]	11 and 13 ft (3.3 & 3.9 m)	0
Rte. 237	0	13 ft (3.9 m)[1,2]	0[3]	11 and 13 ft (3.3 & 3.9 m)	0
Seattle					
I-5	10 ft (3.0 m)	12 ft (3.6 m)	0	11 and 12 ft (3.3 & 3.6 m)	10 ft (3.0 m)
I-405	4 ft (1.2 m)	12 ft (3.6 m)	0	11 ft (3.3 m)	6 ft (1.8 m)
SR 520 (outside shoulder)	1 ft (0.3 m)	12 ft (3.6 m)[2]	0	11 ft (3.3 m)	4-10 ft (1.2-3.0 m)

[1]Limited access facilities with some signalized intersections.
[2]Managed lane on outside shoulder.
[3]Peak-period-only operation, managed lane reverts to another mixed-flow lane outside operation period.

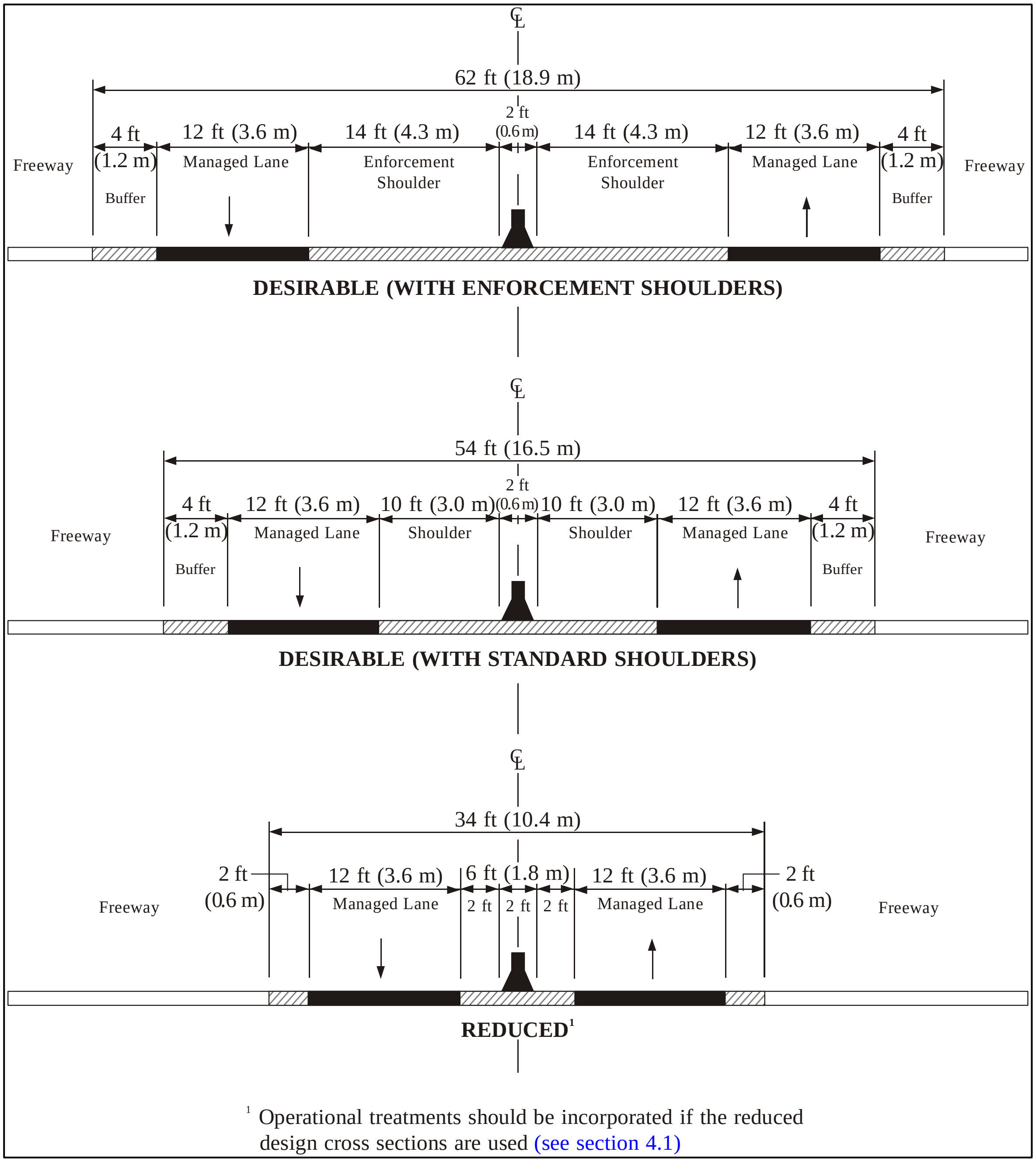


Figure 4-14. Examples of Cross Sections for Concurrent Flow Managed Lane Facilities Located on the Inside of a Freeway (Adapted from Reference *4*).

Table 4-16. Example Design Tradeoffs for Concurrent Flow Managed Lane Facilities (Adapted from Reference *14*).

Ordered Sequence	Cross-Section Design Change
First	Reduce left managed lane lateral clearance to no less than 2 feet (0.6 m).
Second	Reduce freeway right lateral clearance (shoulder) from 10 feet (3 m) to no less than 8 feet (24 m).
Third	Reduce buffer separation to no less than 1 foot (0.3 m).
Fourth	Reduce managed lane width to no less than 11 feet (33 m). (Some agencies prefer reversing fourth and fifth steps when buses are projected to use the managed lane facility).
Fifth	Reduce selected mixed-flow lane widths to no less than 11 feet (33 m). (Leave at least one 12-foot (36 m) outside lane for trucks).
Sixth	Reduce freeway right lateral clearance shoulder from 8 feet (24 m) to no less than 4 feet (12 m).
Seventh	Transition barrier shape at columns to vertical face, or remove buffer separation between the managed lane and mixed-flow lanes.

4.2.3 Design Considerations for Freeway Contraflow Managed Lanes

Contraflow managed lanes borrow a lane from the off-peak direction of travel for use by eligible vehicles in the peak direction. Contraflow managed lanes should be considered only in cases where there is a high directional split, where capacity exists in the off-peak direction of travel, and where the facility can be designed and operated safely. Since contraflow facilities involve traffic operating in opposing directions on the same side of a freeway, safety for both managed lanes and general-purpose traffic should be a critical element in the design process.

Contraflow managed lanes have two somewhat unique design elements. The first is the treatment used to separate the lane from the general-purpose traffic operating in the opposite direction of travel. The other is the access to and from the lane. The separation treatments and other lane design elements are highlighted in this section. Access treatments are discussed in section 4.3 of this chapter.

Contraflow HOV lanes are in operation on only a few freeways in the United States. Two of these facilities—Route 495 and the Long Island Expressway in the New York City/New Jersey area—use plastic pylons inserted into holes in the pavement to separate the traffic lanes. Two other facilities use a moveable barrier to create the contraflow managed lane. This technique is used on I-30 (East R. L. Thornton Freeway) in Dallas and the Southeast Expressway in Boston.

Table 4-17 highlights the design elements of operating contraflow facilities. Figures 4-15 and 4-16 provide examples of cross sections for contraflow managed lane facilities using both types of treatments. These elements are described next.

Table 4-17. Examples of Design Elements for Operating Contraflow Managed Lanes (Adapted from Reference *4*).

Location and Managed Lane Facility	Left Lateral Clearance	Managed Lane Width	General-Purpose Lane Width
New York City/New Jersey Route-495	0	10-10.7 ft (3.0-3.3 m)	10-10.7 ft (3.0-3.3 m)
Long Island Expressway	0-6 ft (0-1.8 m)	12 ft (3.6 m)	12 ft (3.6 m)
Dallas East R. L. Thornton	10 ft (3.0 m)	12 ft (3.6 m)	12 ft (3.6 m)
Boston Southeast Expressway	0[1]	12 ft (3.6 m)	12 ft (3.6 m)

[1]Incident management areas are periodically provided along the northbound and southbound contraflow HOV lanes.

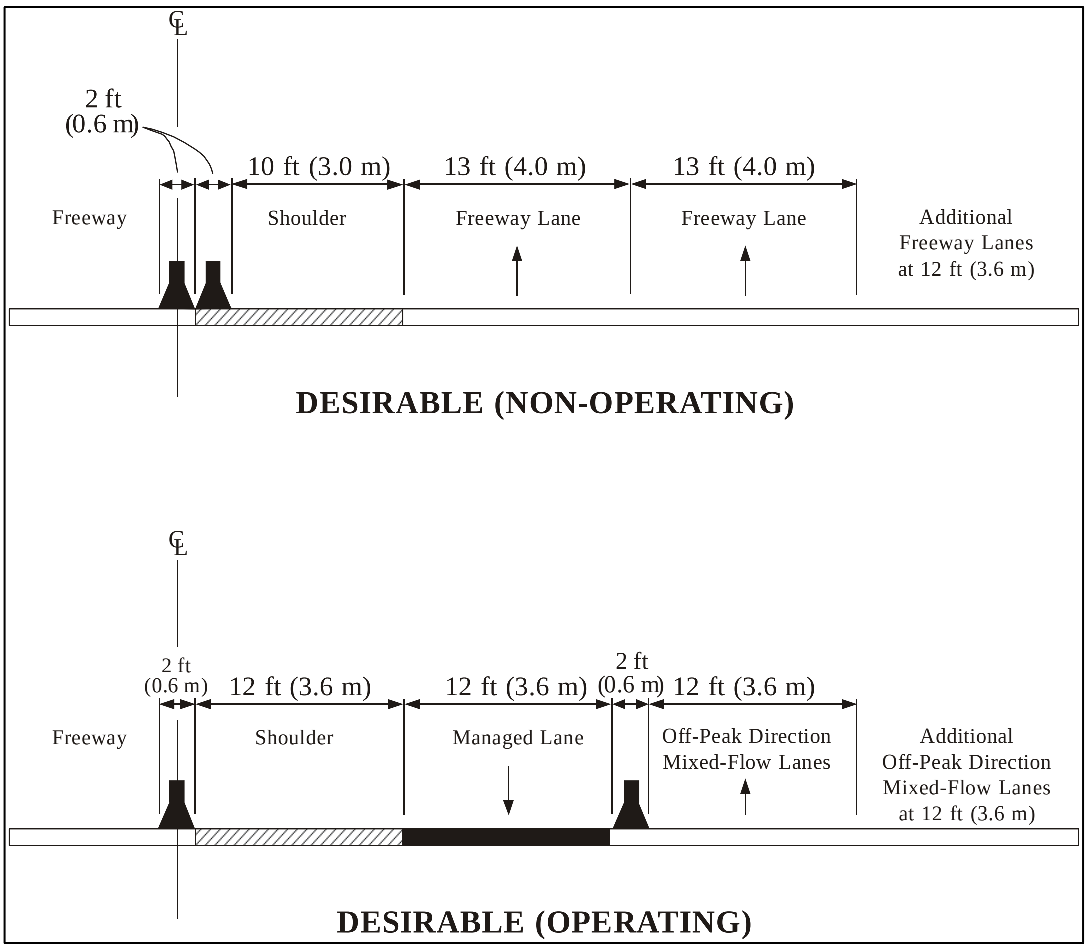
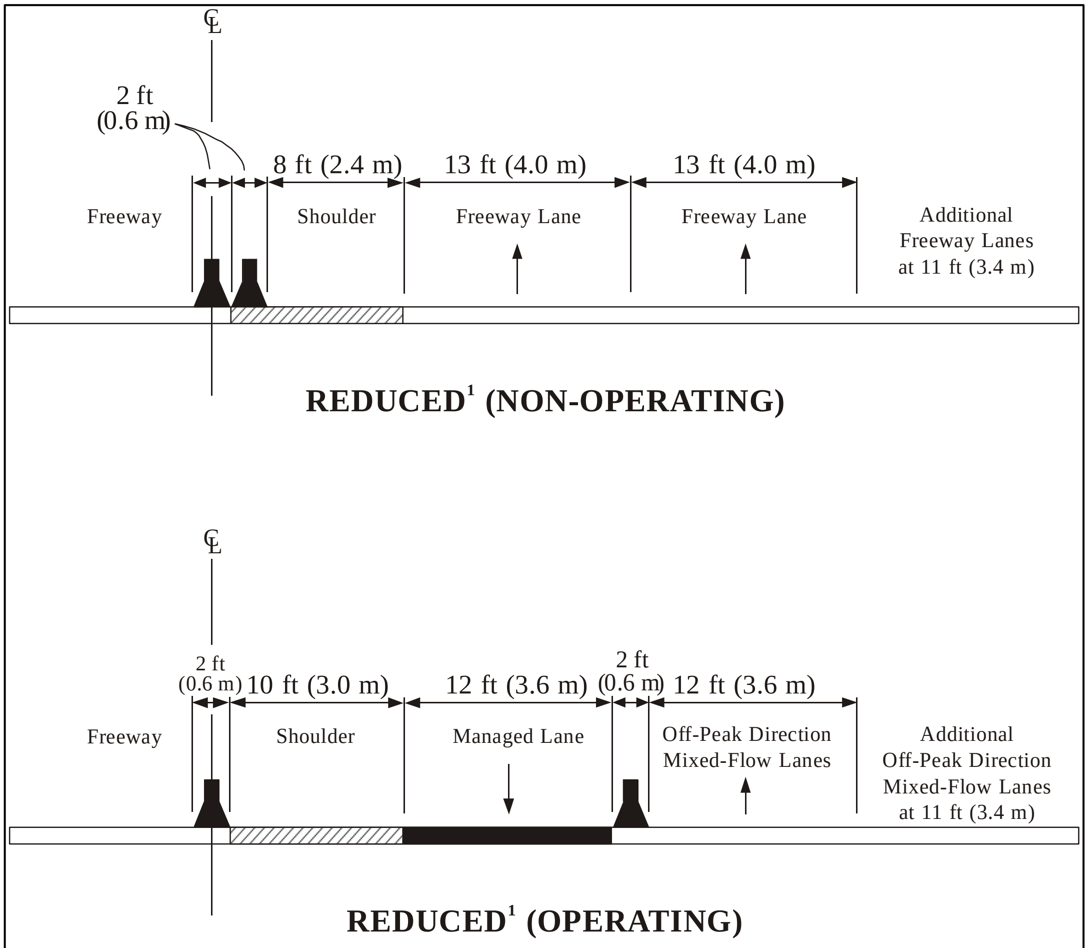


Figure 4-15. Desirable Cross Sections for Contraflow Managed Lanes.



[1] Operational treatments should be incorporated if the reduced design cross sections are used (see section 4.1)

Figure 4-16. Reduced Cross Sections for Contraflow Managed Lanes.

Median and Shoulder Component. As illustrated in Figures 4-15 and 4-16, the existing freeway median and inside shoulder are on the right of vehicles using a contraflow lane. Since most contraflow lanes are retrofitted into an existing freeway, there may be little flexibility with the provision of an inside shoulder if one does not exist. A 10.0-foot (3.0 m) shoulder is desirable. If a continuous shoulder cannot be provided, periodic breakdown areas should be considered for disabled vehicles.

Roadway Lane Component. Contraflow lanes typically use the inside general-purpose lane in the opposite direction of travel. As shown in Table 4-17, the width of these lanes is commonly the normal freeway lane width of 12 feet (3.6 m), although examples of narrower lanes exist. Similarly, the width of the general-purpose lanes on most projects is 12 feet (3.6 m). One exception is the Route 495 Exclusive Bus Lane (XBL) on the approach to the Lincoln Tunnel, which has narrower lanes. Figure 4-15 shows desirable cross sections for contraflow facilities that provide for a 12-foot (3.6-m) shoulder during operation of the lane. Figure 4-16 shows the reduced cross section during non-operating and operating conditions. It operates with a 10-foot (3-0 m) shoulder. This is the design currently in operation along I-30 (East R. L. Thornton Freeway) in Dallas, Texas.

Lateral Clearance Component. A lateral clearance of 2 feet (0.6 m) is recommended next to the pylons or moveable barrier. A similar lateral clearance should be considered for the general-purpose lane adjacent to the plastic pylons or the moveable barrier. Providing this lateral clearance may not always be possible due to limited right-of-way, however. None of the existing contraflow projects has been able to provide the recommended lateral clearance due to limited pavement widths.

Cross-Section Design Summary. The design of a contraflow managed lane should incorporate all the appropriate AASHTO, ITE, FHWA, state, and local guidelines. Careful consideration should be given to the design of a contraflow lane to ensure the safe operation for both managed lane traffic and general-purpose traffic. As illustrated in Figure 4-15, a 22- to 24-foot (6.6- to 7.2-m) envelope should be considered for the travel lane, breakdown shoulder, and pylons or moveable barrier. The available width will have a direct effect on the operating speeds of vehicles in the contraflow lane. Restricted widths may require lower operating speeds as evidenced on the facilities in the New York City area.

4.3 DESIGN CONSIDERATIONS FOR TERMINAL AND ACCESS TREATMENTS

Vehicles may enter a managed lane facility at the beginning or, in most cases, at some point along the lane. Correspondingly, vehicles traveling the facility may exit a facility at the end or at other egress locations. The type of access provided will depend on the nature of the managed lane facility, the objectives of the project, land uses in the corridor, available right-of-way, and funding. Experiences from the design of ingress/egress locations for managed lanes suggest the following lessons learned (adapted from References *14,15*).

- Where possible, the same geometric criteria should be applied as would be used for a freeway ramp, including locally recognized entrance and exit standards.

- Sight distance is particularly critical due to the proximity of barriers to ramp lane alignments. Lateral clearances are often no greater than 2 feet (0.6 m) from the edge of the travel lane to barrier. Where practical, removal of barrier-mounted glare screens or slight adjustments in striping alignment may be necessary within the ramp envelope to accommodate the proper design speed.

- The location of ingress/egress facilities is influenced by a number of factors. For example, direct access ramps to/from local streets should be made with candidate streets that currently do not have freeway access to better distribute demand and prevent overloading existing intersections. For at-grade access with the adjacent freeway lanes, designated outlets should be strategically positioned so as to minimize erratic weaving to reach nearby freeway exits.

- Locate access/egress points associated with street access away from intersections that are operating at or near the traffic capacity.

- Vehicles entering the managed lane facility should be required to make an overt maneuver to enter the lane. A freeway lane should not end at a managed lane entrance; the freeway lane should be moved laterally and the managed lane entrance located out of the normal path of travel.

- Managed lane ramps should provide adequate space for possible metering and storage.

- Left- or right-hand exits from a single-lane managed lane facility are equally valid and equally safe. The standard "right hand only" rule for entrance and exit ramps should not apply for managed lane facilities.

- During the early operations of a managed lane facility, demand may not warrant exclusive or elevated ramps. If demand increases subsequent to implementation of the managed lane, a retrofit design could be difficult and expensive; consequently, if exclusive ramps are not included in an initial project design, provisions should be made so that the ramps can be added later.

- Adequate advance signing should be provided, and pavement markings should emphasize the mainline (possibly through use of skip stripe markings across the diverging exit ramp).

- ♦ Safety lighting should be applied for all ingress/egress locations using the same warrants applied for urban freeway entrance and exit ramps.
- ♦ Where possible, provision for entrance ramp metering and/or enforcement should be considered (these are project-specific considerations based on a number of local issues and input from enforcement agents).

As previously mentioned, all aspects of managed lane design must be considered in light of the operation and enforcement of the facility. This section examines the design elements associated with different types of terminal and access treatments associated with managed lane facilities. Full standards for access include direct ramps to park-and-ride facilities or local streets with barrier-separated facilities. These design elements are discussed first in the discussion that follows. When general-purpose exit and entrance ramps are spaced relatively far apart (2 to 3 miles), concurrent flow facilities with at-grade entrance and exit ramps may be acceptable. Difficult weaving patterns may be created at the weaving sections of concurrent flow facilities when traffic volumes entering and/or exiting the managed lane facility are high at an at-grade access point. Historically, transit agencies in Texas have offered significant portions of funding for the development of managed lane facilities in Houston and Dallas, allowing the design of barrier-separated facilities to avoid weaving difficulties.

To handle large eligible-vehicle demand estimates, multi-lane managed lane facilities may be necessary. The fundamental design of these facilities should follow the same geometric criteria for freeway ramps with locally recognized entrance and exit standards. Ultimately, one critical volume and/or mode of travel will guide the design for the number of mainline lanes and ingress/egress locations. For maximum travel time savings and trip reliability benefits, the facility should be located where the primary critical volume and/or mode is most congested. Direct access and direct connections of managed lane facilities provide the opportunity to handle multi-lane geometrics.

Table 4-18 summarizes the objectives, advantages, and limitations of various access treatments for managed lane facilities. Further, Table 4-19 provides guidelines for applying ingress/egress treatments. Each type of access treatment will be described in the following discussion.

4.3.1 Direct Access Ramps

Grade separated or direct access ramps are the desirable access treatments. Grade separated or direct access ramps can provide ingress and egress for eligible vehicles where high vehicle volumes are anticipated or where additional time savings and operational efficiencies can be gained. A variety of treatments may be used to provide direct access from adjacent roadways, park-and-ride lots, and transit stations. Direct access ramps are usually found with exclusive managed lanes, but they may be used with any type of lane. Further, direct access ramps may be used at the start, end, or intermediate locations along a managed facility.

Table 4-18. Objectives, Advantages, and Limitations of Access Treatments (Adapted from Reference *4*).

T-ramp or Drop Ramp with a Street
- Effective way of collecting and distributing all mixes of eligible vehicles, as well as serving off-line support facilities
- Provides opportunities to control or enforce entering volumes
- Works for reversible-flow or two-way configurations
- Best if not considered at an existing intersection with freeway access

T-ramp or Drop Ramp with a Park-and-Ride Lot or Off-Line Bus Transit Station
- A very effective way of extending preferential treatment into an off-line support facility, thereby increasing travel time savings
- Not recommended for serving other eligible users that have no affinity for the support facility; poses circulation conflicts within the support facility
- Generally requires high transit and/or rideshare volumes to be cost effective
- Works best for two-way operations, although can be workable for reversible flow if T-ramps are reversed as well

Flyover Ramp
- Highest-speed design intended for high interfacing volumes; most closely approximates any other freeway ramp in design speed
- Serves all managed lane users well
- Can be applicable as an intermediate access or termination treatment
- Can be cost-prohibitive as a means of accessing support facilities
- Least flexible treatment; sometimes overlooked on an interim managed lane operation and added later as demand warrants
- Equally appropriate for two-way or reversible-flow operations

Direct Merge or At-Grade Access
- Lower cost
- Easy to implement
- Easy to modify
- Possible safety concerns

At-Grade Slip Ramp at Project Termination
- An effective way of feeding and distributing high lane volumes with the adjacent freeway
- Requires left-hand entry/exit with the freeway
- Can be designed as a safe and enforceable treatment
- Low cost; easily modified if managed lane facility is extended
- Used as a "standard" termination treatment on most projects

At-Grade Slip Ramp as an Intermediate Access
- Lowest-cost intermediate access approach; can be easily modified (relocated or removed)
- Most compatible with restricted envelopes; requires little widening
- Not safe for high accessing volumes without inclusion of a parallel weave lane
- Not the best traffic operation under high-volume conditions; can disrupt the adjacent freeway or managed lane level of service
- Cannot be safely enforced
- Location is critical; if too close to nearby freeway intersections, weaving problems across the freeway increase

Table 4-19. Guidelines for Applying Ingress/Egress Treatments (Adapted from Reference *13*).

Objective	Type of Treatment[1]			
	T-ramp or Drop Ramp with Park-and-Ride Lot or Transit Station	T-ramp or Drop Ramp with Street	Flyover Ramp	At-Grade Slip Ramp with Freeway
Frequent spacing [< 3 miles (4.8 km)]	+	0	-	0
Maximize bus travel time savings	+	0	0	0
User mix requirements				
Buses only	+	+	+	+
Buses and other eligible vehicles	+	+	+	+
Primarily carpools and vanpools	+	+	+	+
Potential conflict with general-purpose traffic	+	+	+	0
Enforceability	+	+	0	-
Traffic regulation capability[2]	+	+	+	-
Capital cost	0	0	-	+
High vehicle volumes (> 400 vph)	-	+	+	Terminations + Intermediate sites -
Low vehicle volumes (< 400 vph)	+	+	-	+
High design speed [> 35 mph (60 kph)]	-	-	+	+
Low design speed [< 35 mph (60 kph)]	+	+	N/A	-
Retrofit compatibility with exiting freeway	0	+	0	+
Flexibility to modify later	-	-	-	+

Legend: + = favorable, 0 = neutral, often depends on the design or site specifics, - = not favorable, N/A = not applicable.

[1]Not included are busway street intersections used for low-volume, bus-only operation in separate right-of-way.

[2]Assumes use of meters to regulate entering flow of vehicles.

Advantages of direct connections include the ability to move high volumes of eligible vehicles into and out of a managed lane facility without disrupting flow in the freeway general-purpose lanes, additional travel time savings, improved travel time reliability, ease of enforcement, and enhanced safety. Potential disadvantages include the need for additional right-of-way and the capital costs associated with different design treatments. Direct connections can be the most efficient means of managing these conflicting movements at locations where there is substantial congestion in the general-purpose lanes and a large volume of vehicles accessing the managed lane. Enforcement is also facilitated through the use of direct access ramps.

A variety of managed lane ramp alignments including drop ramps, T-ramps, Y-ramps, and flyover ramps are all examples of direct access connections. The exact design of these types of facilities will depend on the nature and design of the managed lane and the adjacent roadway or facility, available right-of-way, and national and state design practices. The following information provides design examples for these types of access treatments.

T-ramps and Drop Ramps. The names of these facilities reflect the fact that this type of direct access ramp looks like the letter "T" and drops from the managed lane to the freeway, local roadway, park-and-ride lot, or other facility. These access treatments are usually used with barrier-separated exclusive managed lanes, but they may also be considered with other types of managed lane facilities. Figure 4-17 shows an example T-ramp design from a reversible-flow managed lane to a park-and-ride lot or arterial street. Figure 4-18 presents a schematic of the managed lane acceleration lane, deceleration lane, and taper lengths for a T-ramp. Tables 4-20E and 4-20M show the recommended acceleration/deceleration lane lengths for managed lanes for providing access with a T-ramp to a reversible managed lane facility. The lengths shown are based upon acceleration and deceleration rates for single-unit buses of 2.0 mph/second (3.2 kph/second) and 2.5 mph/second (4.0 kph/second), respectively, on a level grade. Further, the effective reduction for the length of a deceleration lane on an upgrade is approximately 5 percent for every 1 percent positive grade (*15*). The effective reduction for the length of acceleration lane on a downgrade is approximately 10 percent for every 1 percent negative grade. These guidelines are restricted to gradients of 6 percent or less and lengths of grade of 1,000 feet (300 m) or less (*8*).

Figure 4-19 presents a photograph of a typical T-ramp at the Eastwood Transit Center on I-45 (Gulf Freeway) in Houston, Texas. Figure 4-20 shows a photograph of the connections that allow for the reverse direction of the T-ramp at the Kuykendahl Park-and-Ride Lot on I-45 (North Freeway) in Houston, Texas. Figure 4-21 shows the crossover of traffic to the T-ramp on I-45 (North Freeway) that allows access to an arterial street (Airline Drive). Figure 4-22 shows a schematic of the morning and afternoon operation, and Figure 4-23 shows a close-up photograph of the ramp afternoon operation. Figure 4-24 shows an alternate T-ramp access treatment to the Tidwell Transit Center along US 59 (Eastex Freeway) at the Tidwell Transit Center in Houston, Texas. In contrast to Figure 4-17, this design allows for through vehicles to remain at-grade and bypass the intersection below the elevated section. Figure 4-25 shows a close-up photograph. Figure 4-26 shows a schematic of this operation. Entering traffic from the T-ramp merges downstream of the elevated section. Figure 4-27 shows ramps to both the Fuqua and South Point Park-and-Ride lots along I-45 (Gulf Freeway) in Houston, Texas.

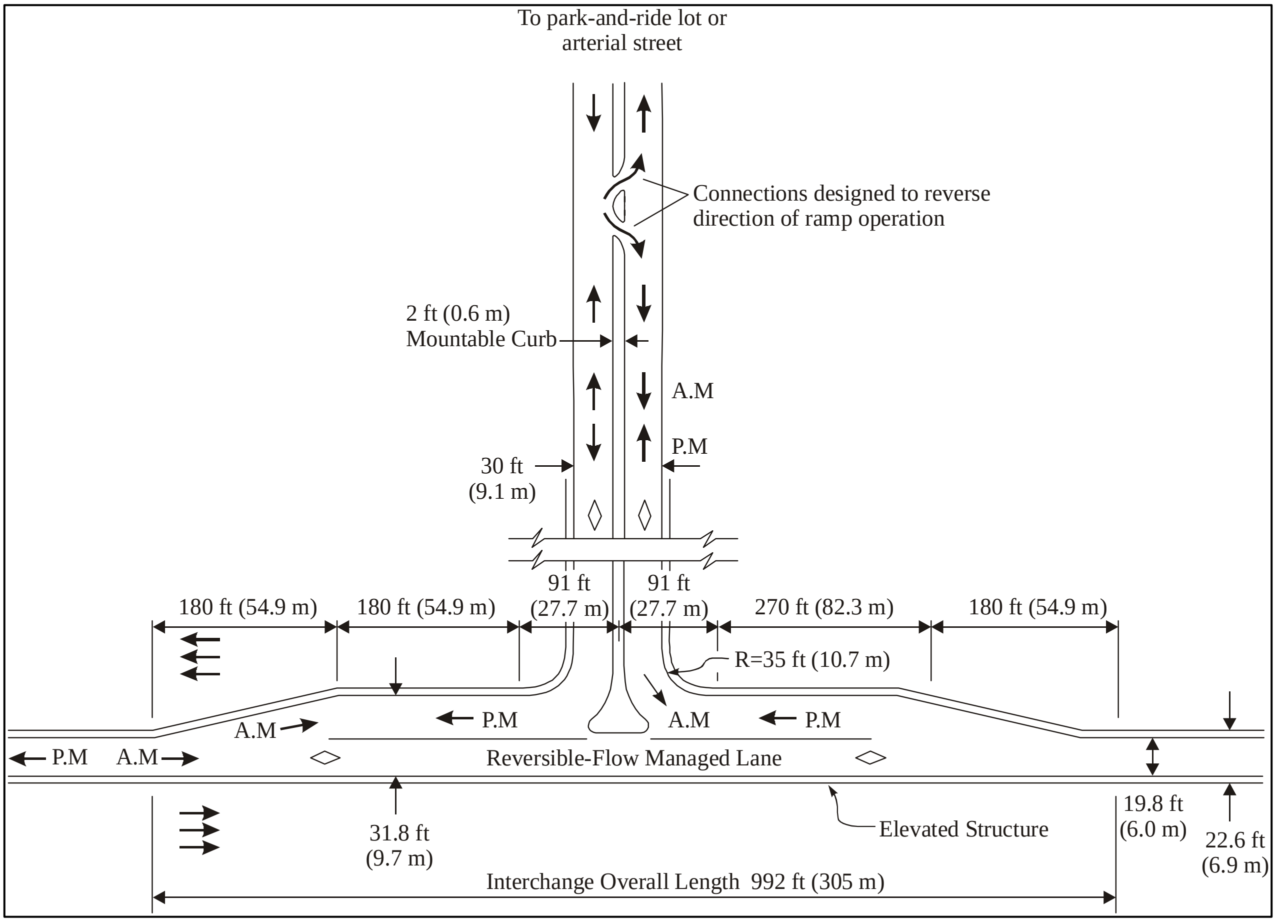


Figure 4-17. Typical T-ramp for Reversible Managed Lane Facility (Adapted from Reference *4*).

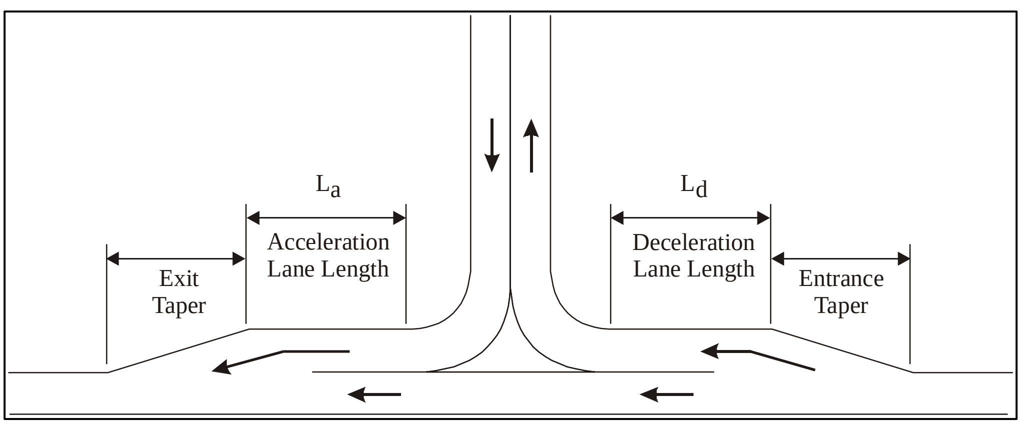


Figure 4-18. Managed Lane Acceleration Lane, Deceleration Lane, and Taper Lengths (Adapted from Reference *15*).

Table 4-20E. Recommended Acceleration/Deceleration Lane Lengths for T-ramps (Adapted from Reference *15*).

Main lane Managed Lane Speed (mph)	Managed Lane Entering Speed[1] (mph)	Length of Acceleration/ Deceleration Lane (feet)	Length of Taper[2] (feet)	Recommended Total Length (feet)
35	25	250	170	420
40	30	400	190	590
45	35	700	210	910
50	40	975	230	1,205
55	45	1,400	250	1,650
60	50	1,900	270	2,170
65	55	2,400	280	2,680
70	60	3,000	290	3,290

[1]Bus speed at end of taper.
[2]Usual desirable taper - 50:1; minimum taper - 20:1.

Table 4-20M. Recommended Acceleration/Deceleration Lane Lengths for T-ramps (Adapted from Reference *15*).

Main lane Managed Lane Speed (kph)	Managed Lane Entering Speed[1] (kph)	Length of Acceleration/ Deceleration Lane (m)	Length of Taper[2] (m)	Recommended Total Length (m)
60	40	75	50	130
65	50	120	60	180
70	55	210	65	275
80	65	300	70	365
90	70	425	75	505
100	80	580	80	660
105	90	730	85	815
110	100	915	90	1000

[1]Bus speed at end of taper.
[2]Usual desirable taper - 50:1; minimum taper - 20:1.

Figure 4-19. T-ramp at Eastwood Transit Center I-45 (Gulf Freeway) in Houston, Texas.

Figure 4-20. Kuykendahl Park-and-Ride Lot Showing Crossover Traffic at Bottom of T-ramp on I-45 (North Freeway) in Houston, Texas.

Figure 4-21. Crossover Traffic Operation for T-ramp at an Arterial Street along I-45 (North Freeway) in Houston, Texas.

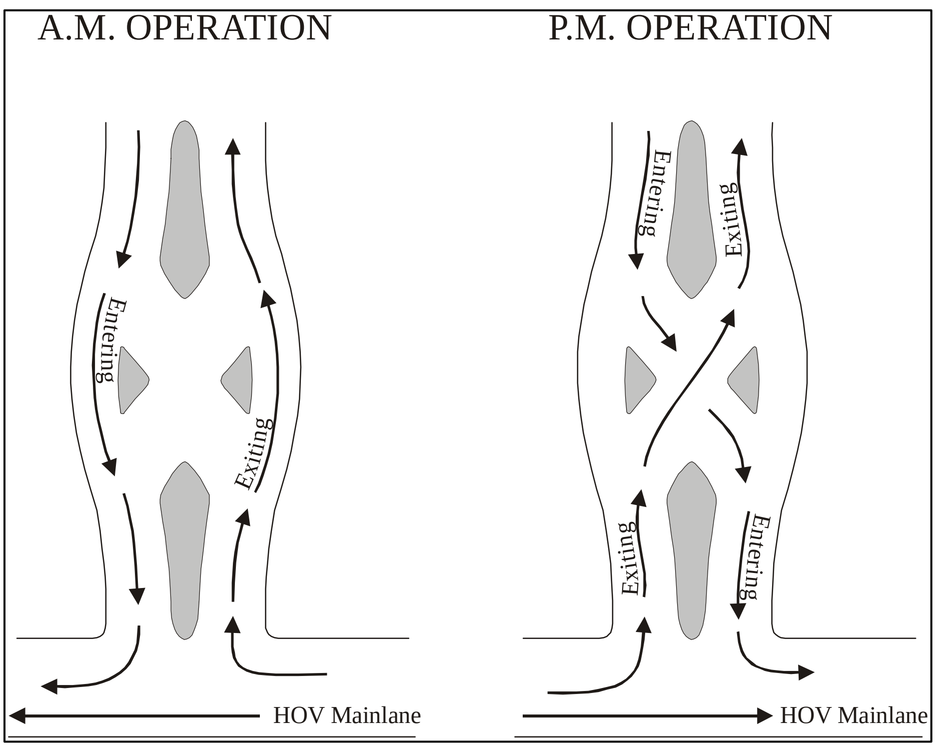


Figure 4-22. Schematic of Morning and Afternoon Operation on Ramp Crossover.

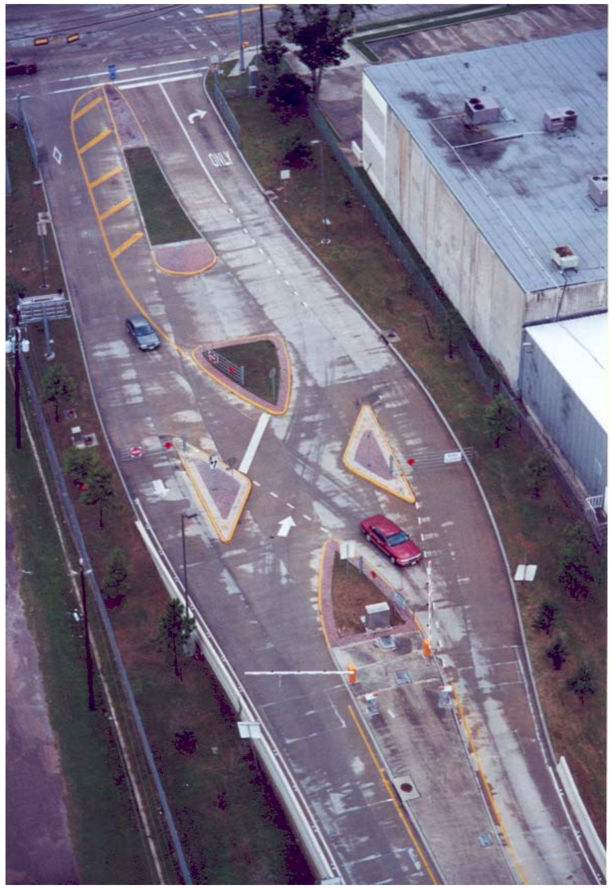


Figure 4-23. Close-up of Ramp Crossover at an Arterial Street along I-45 (North Freeway) in Houston, Texas.

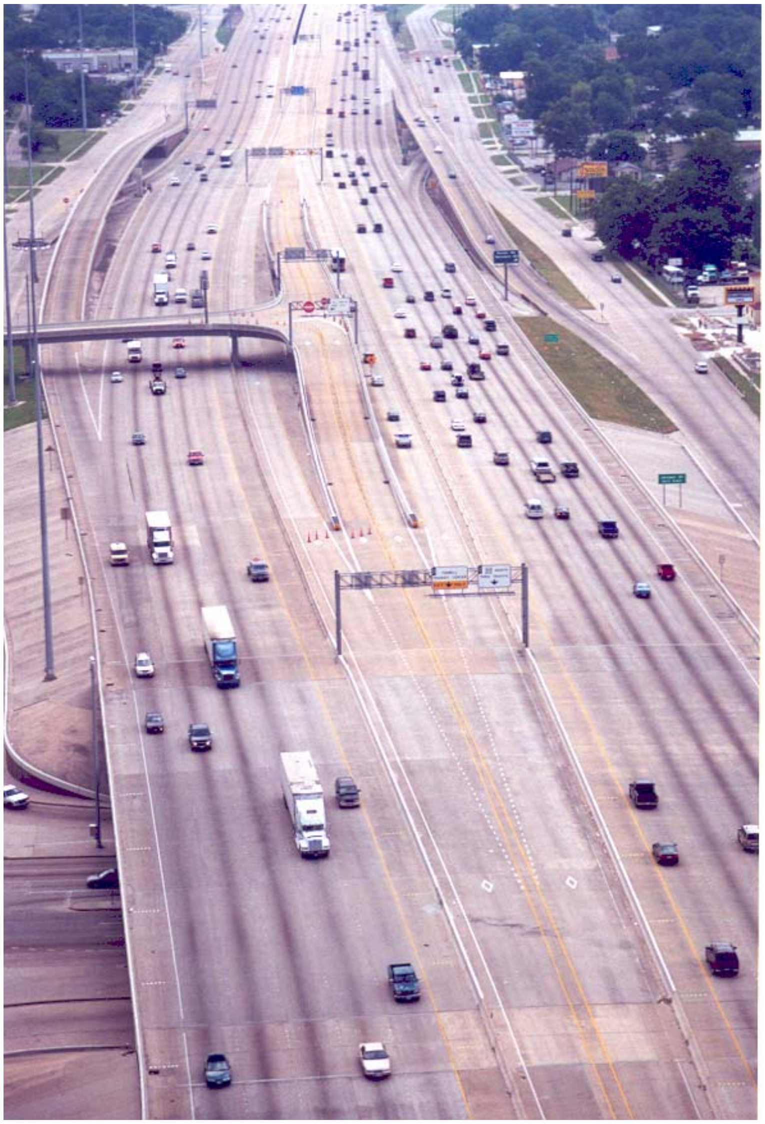


Figure 4-24. T-ramp Transit Center Access with At-Grade Bypass Lanes along US 59 (Eastex Freeway) in Houston, Texas.
(Through traffic handled at ground level)

Figure 4-25. Design Features of T-ramp with Entrance/Exit Features along US 59 (Eastex Freeway) in Houston, Texas.
(Through traffic handled at ground level)

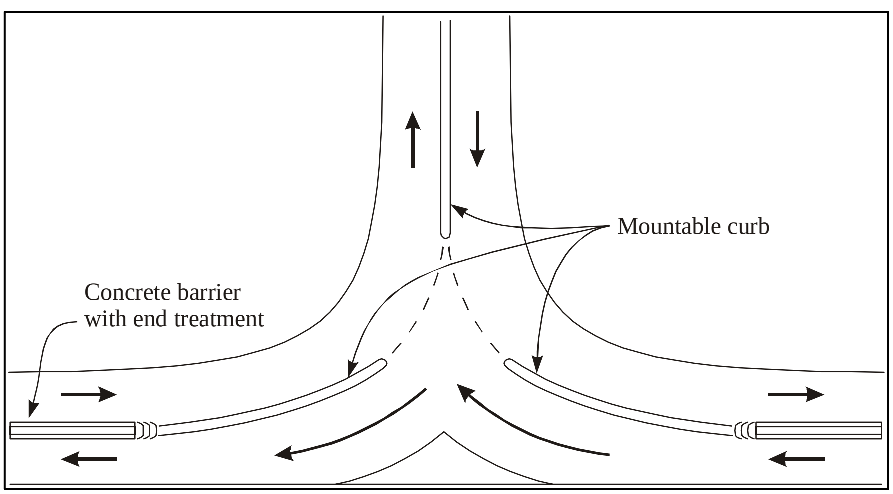


Figure 4-26. T-ramp Design for Entrance/Exit Only (Adapted from Reference *10*).
(Through traffic handled at ground level)

Figure 4-27. Access to Two Park-and-Ride Facilities along I-45 (Gulf Freeway) in Houston, Texas.

Figure 4-28 shows a drop lane that provides access to a two-lane reversible-flow HOV lane facility along I-395 (Shirley Freeway) in Northern Virginia (Washington, D.C.). Figure 4-29 shows a two-way drop ramp. The upper schematic is for a barrier separation on the ramp and provides for an enforcement area for entering vehicles. The lower schematic provides for an enforcement area on the ramp in a buffered area. Figure 4-30 shows a photograph of a drop ramp along US 59 (Southwest Freeway) at Edloe in Greenway Plaza in Houston, Texas. Figure 4-31 shows a close-up photograph of the design features at the intersection. The following elements should be considered in the design of drop or T-ramps.

Design Speed. The design speed for the drop or T-ramp should be based on the characteristics of the individual project. However, the managed lane main lane should not be adversely affected by the ramp design speed. Providing acceleration and deceleration lanes along the managed lane main lane is required to help ensure the safe and efficient operation of the managed lane facility.

Shoulder. A shoulder should be provided for each direction of travel. If a full shoulder cannot be provided, other approaches may be used. A center barrier should be considered with two-way ramps, especially if high volumes of carpools and vanpools are projected to use the facility.

Cross Section. A cross section of 22 to 25 feet (6.7 to 7.6 m) is desirable for a single direction or reversible-flow drop or T-ramp. The desirable cross section for a two-way ramp is 45 feet (13.7 m) for two 12-foot (3.6-m) lanes, two 4-foot (1.2-m) shoulders, and a 10-foot (3.0-m) buffer between the opposing lanes. A reduced cross-section width of 38 feet (11.6 m) for a two-way ramp may be considered in certain instances where low speeds are anticipated.

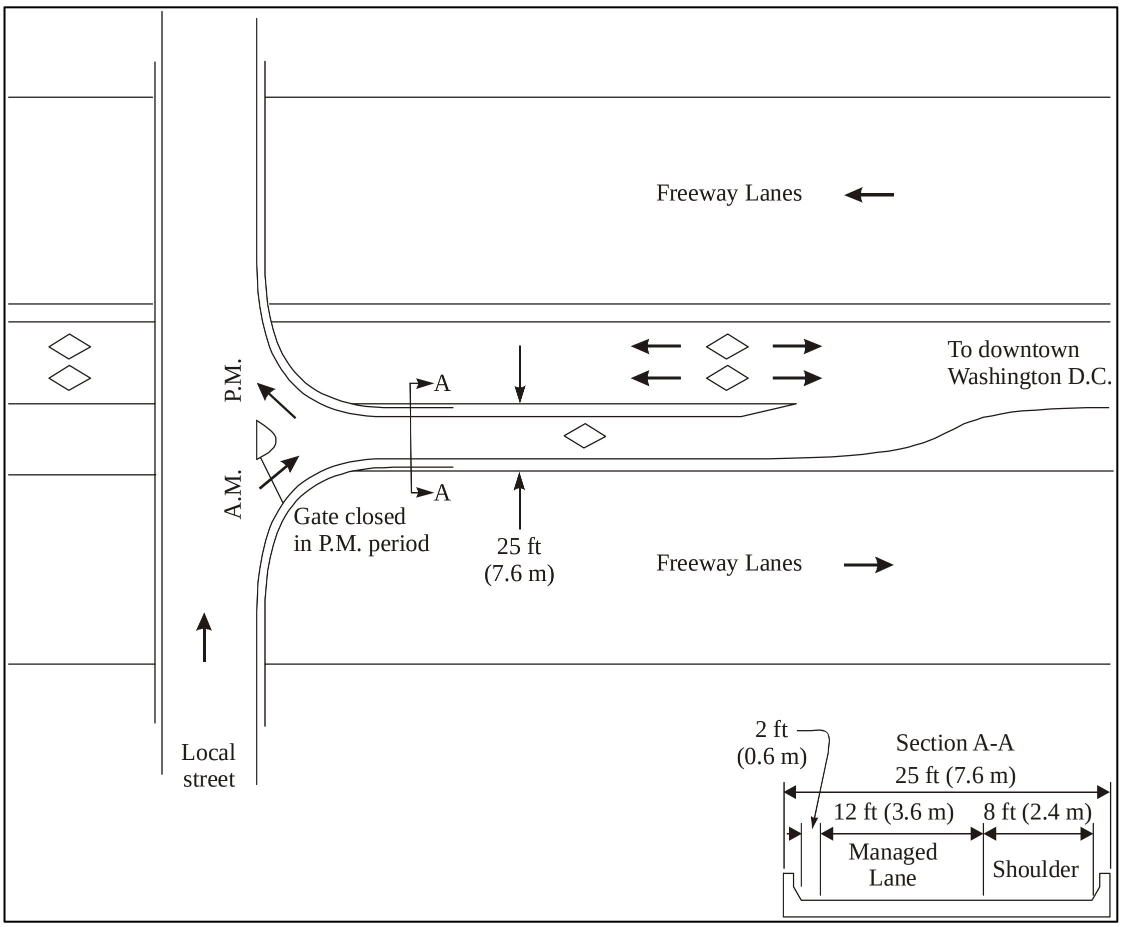


Figure 4-28. Drop Ramp Providing Access to a Two-Lane Reversible-Flow Managed Lane Facility (Adapted from Reference *14*).

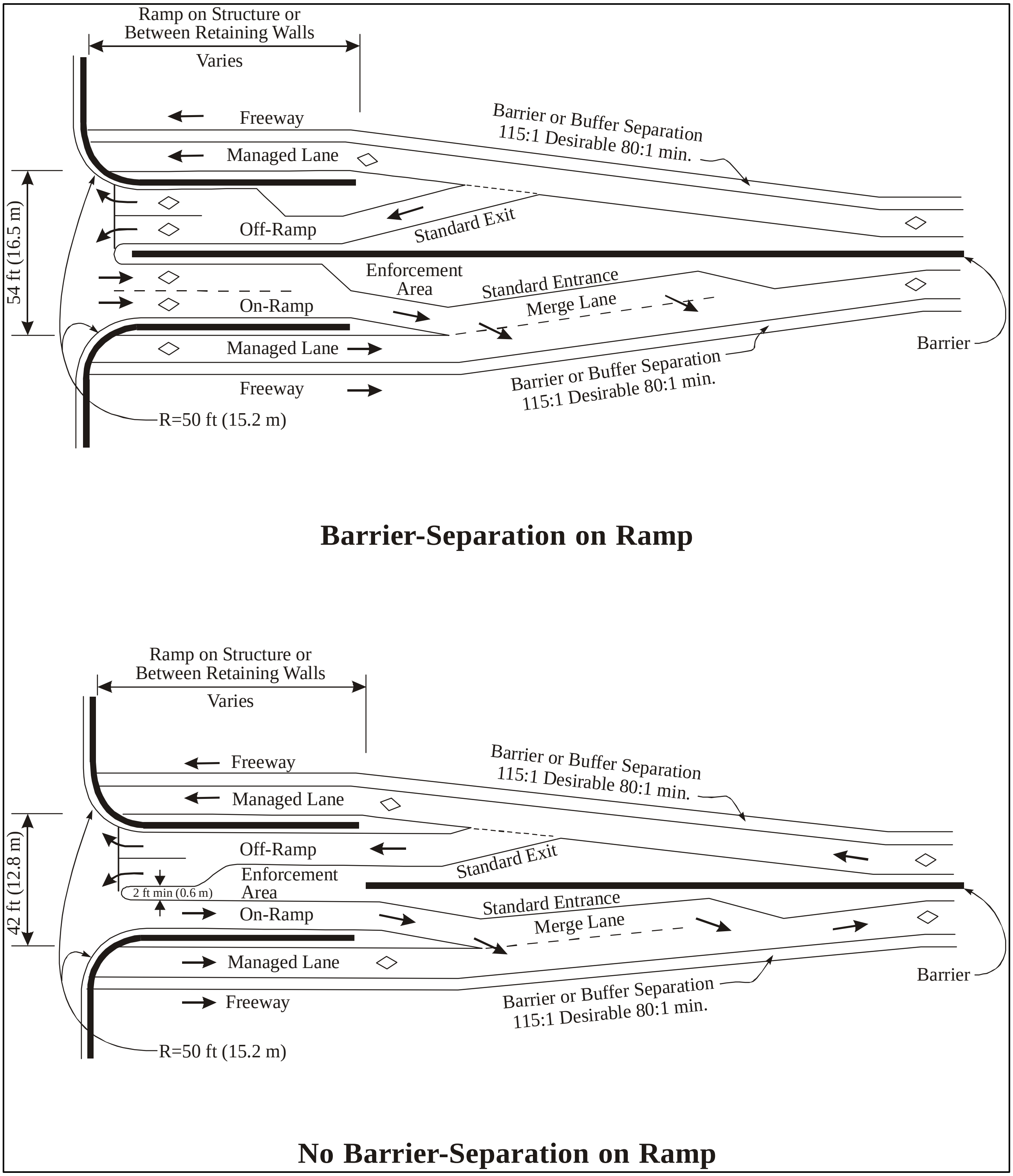


Figure 4-29. Two-way Drop Ramp (Adapted from Reference *14*).

Figure 4-30. Drop Ramp at Edloe on US 59 (Southwest Freeway) in Houston, Texas.

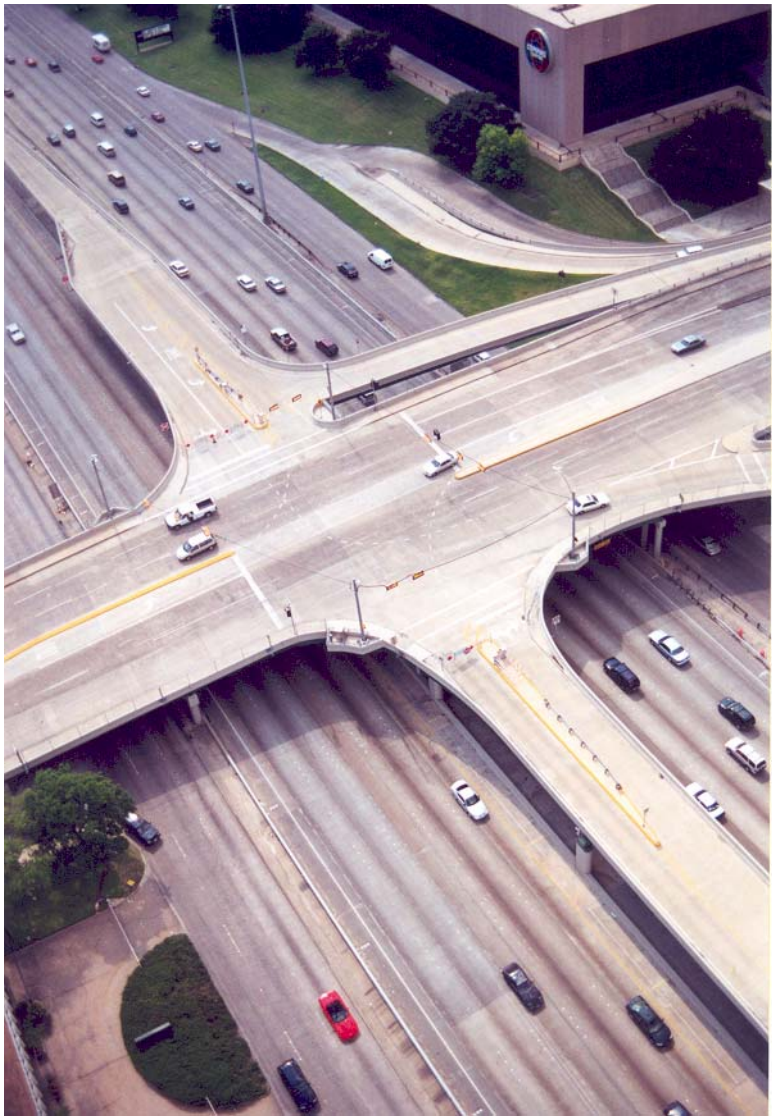


Figure 4-31. Close-up of Drop Ramp Design Features on US 59 (Southwest Freeway) at Edloe in Houston, Texas.

Flyover and Y-Ramps. This ramp design accommodates high-speed, high-volume access to and from a managed lane facility. The names reflect the design, which looks like the letter "Y" and flies over other facilities. The function of a flyover ramp is to provide direct, high-speed connections between the general-purpose freeway lanes, park-and-ride lot, or other roadway and the managed lane facility. A variety of design treatments can be used with flyover ramps. Figure 4-32 shows a schematic of a flyover ramp that provides access to a single-lane reversible-flow managed lane at FM 1960 along the I-45 (North Freeway) HOV lane in Houston, Texas. Figure 4-33 shows a photograph of this facility, and Figure 4-34 also shows a similar flyover ramp at the southern end of I-45 (Gulf Freeway) in Houston, Texas. Figure 4-35 shows a flyover ramp to a single-lane reversible-flow HOV lane facility along I-45 (Gulf Freeway) at the downtown terminus in Houston, Texas. A photograph of this facility is shown in Figure 4-36. Figure 4-37 shows a flyover ramp (Y-ramp) from a two-lane reversible facility on I-15 in San Diego, California. Figure 4-38 illustrates flyover ramps to Del Mar Avenue from I-10 (El Monte) in Los Angeles, California, and Figure 4-39 shows a photograph of the design. Finally, Figure 4-40 illustrates a flyover ramp terminus for a buffer-separated HOV lane on I-91 in Hartford, Connecticut.

If possible, the cross section for a flyover ramp should be similar to the managed lane main lane design. Based on this objective, the cross section for a flyover ramp would be in the range of 22 to 28 feet (6.7 to 8.5 m) per direction, or 44 to 56 feet (13.4 to 17.1 m) total, with a reduced cross section of 20 to 22 feet (6.1 to 6.7 m).

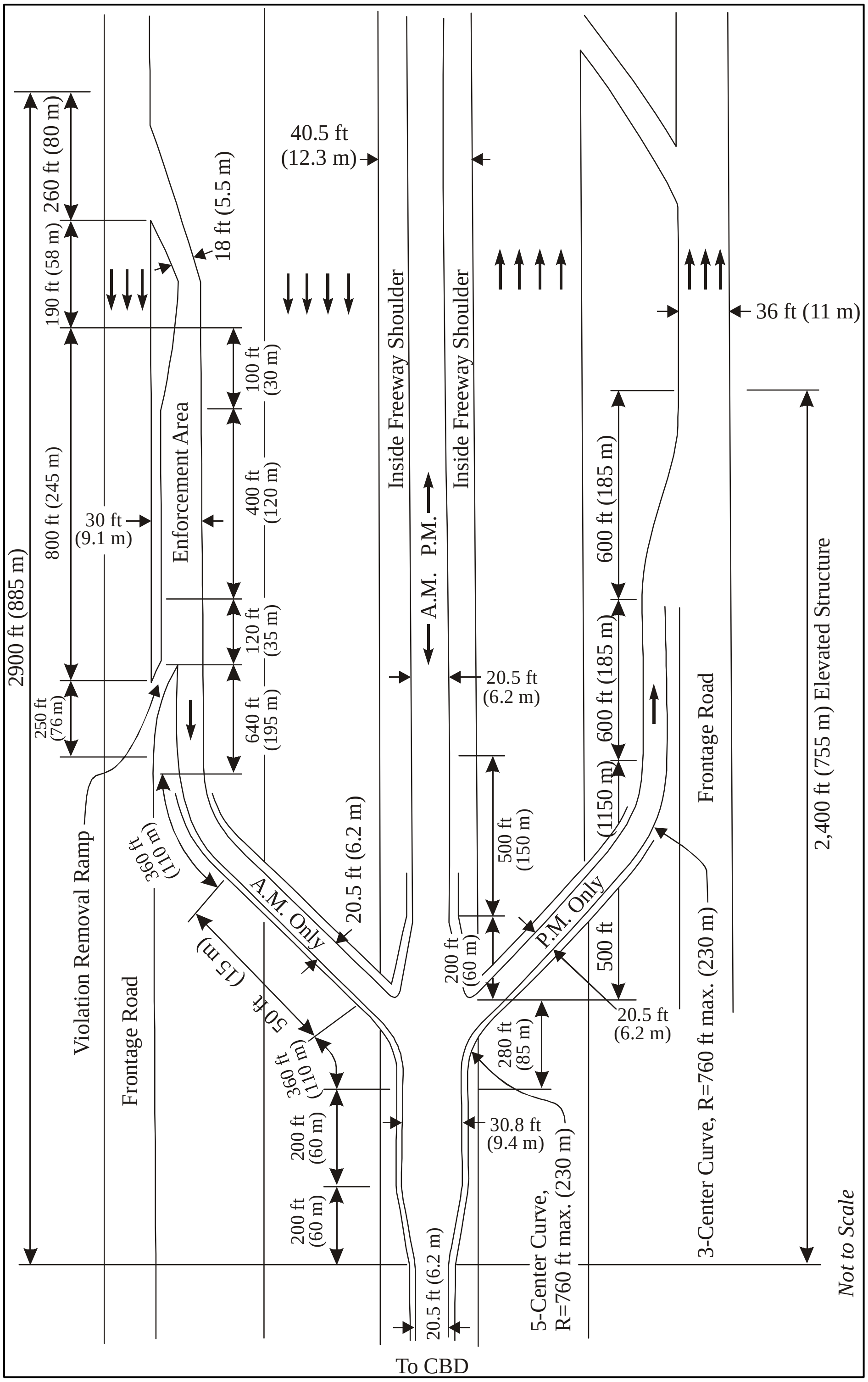


Figure 4-32. Flyover Ramp Used at FM 1960 along I-45 (North Freeway) in Houston, Texas (Adapted from Reference *14*).

Figure 4-33. Photograph of Flyover Ramp at FM 1960 along I-45 (North Freeway) in Houston, Texas.

Figure 4-34. Wishbone Flyover Ramp at Dixie Farm Road at Southern End of I-45 (Gulf Freeway) Managed Lane in Houston, Texas.

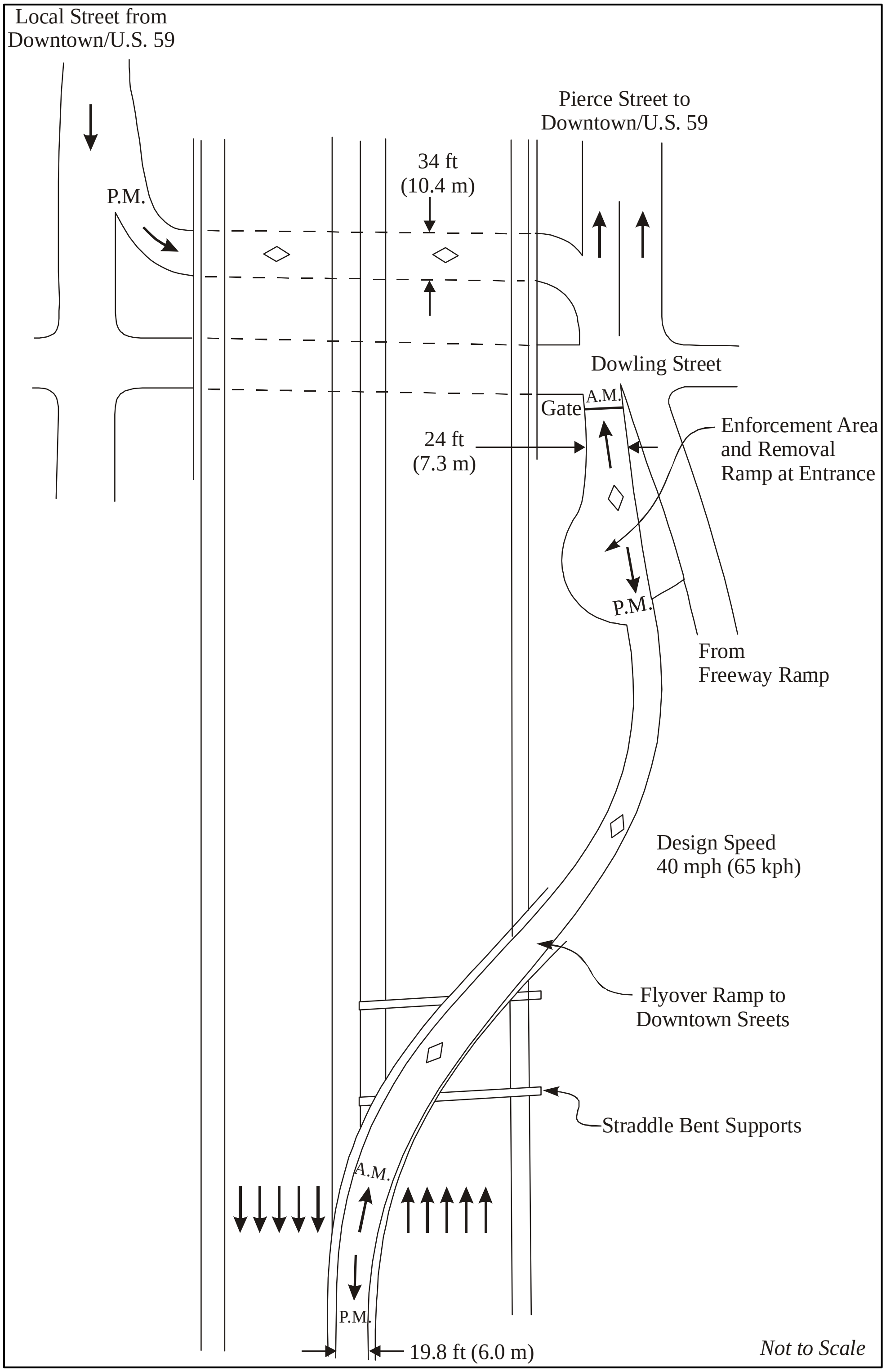


Figure 4-35. Flyover Ramp Used at Downtown Terminus of I-45 (Gulf Freeway) Managed Lane in Houston, Texas (Adapted from Reference *14*).

Figure 4-36. Photograph of Flyover Ramp at Downtown Terminus of I-45 (Gulf Freeway) in Houston, Texas.

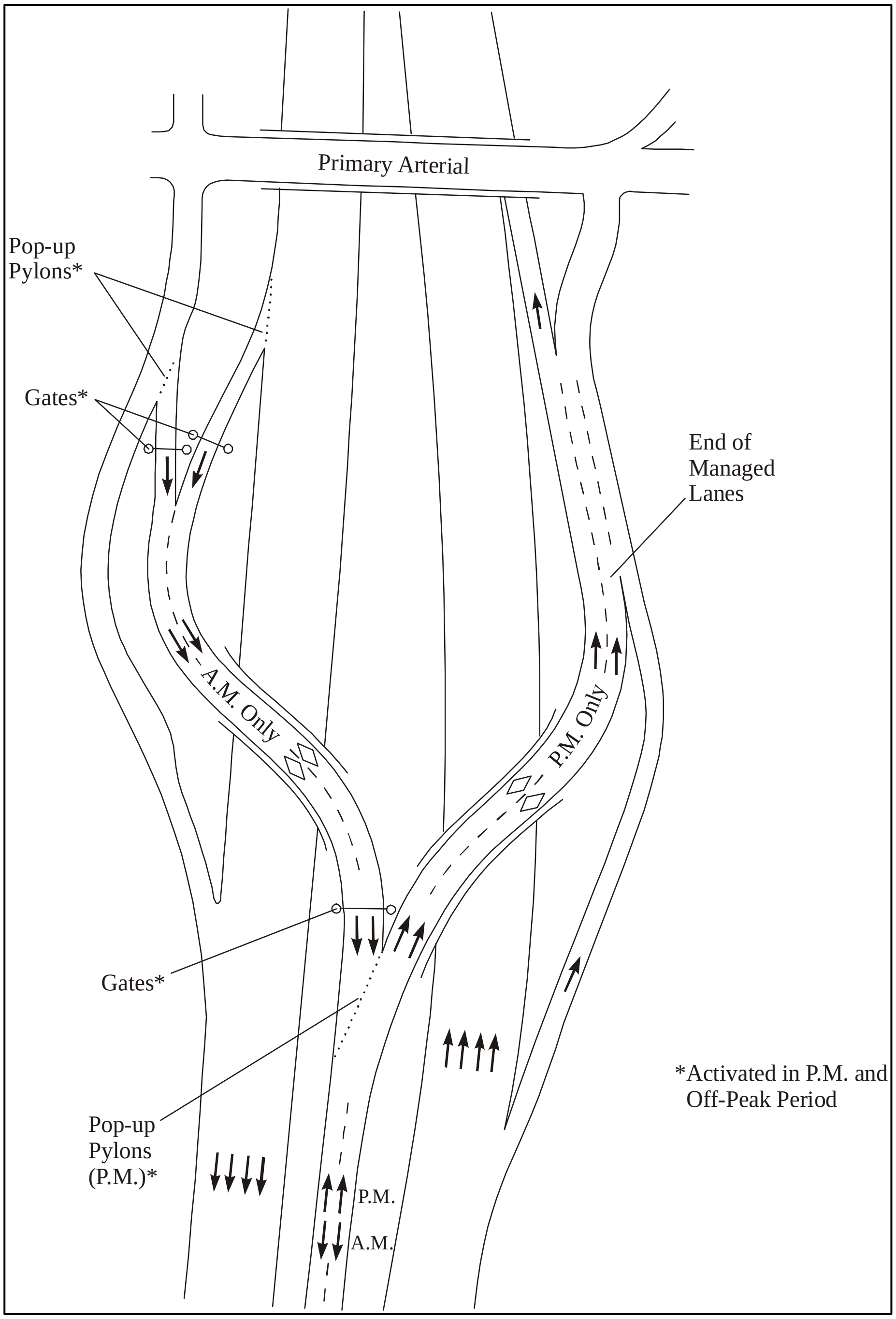


Figure 4-37. Flyover Ramp (Y-ramp) for a Two-Lane Reversible Managed Lane along I-15 in San Diego, California (Adapted from Reference *14*).

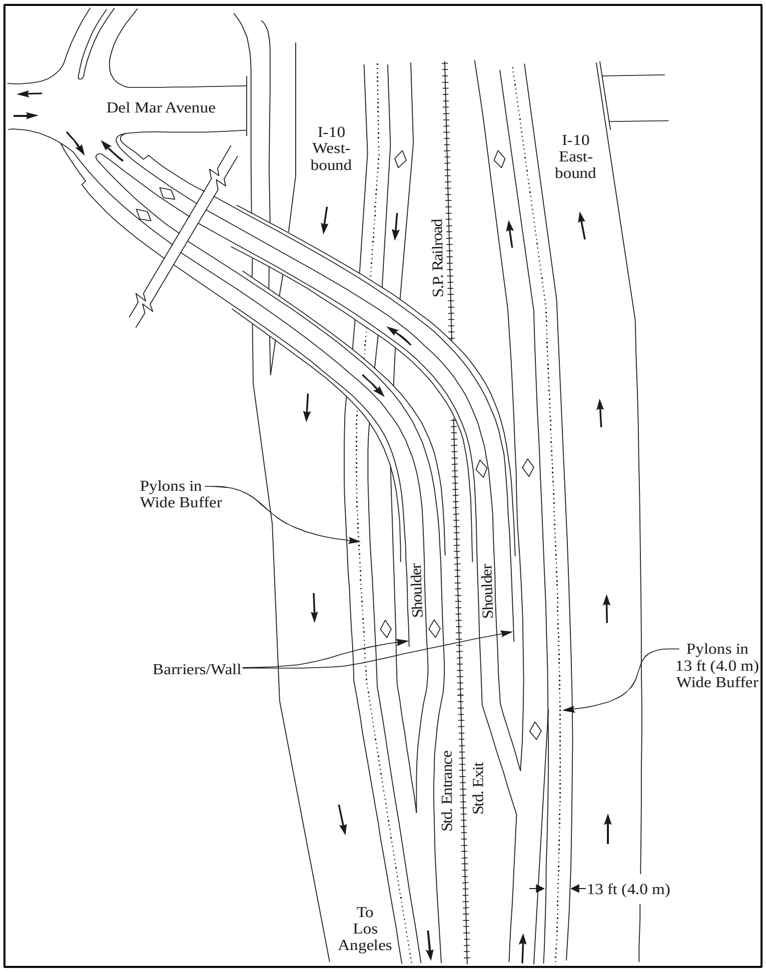


Figure 4-38. Two-way Flyover Ramp to Del Mar Avenue from Managed Lane on I-10 (El Monte) in Los Angeles, California (Adapted from Reference *14*).

Figure 4-39. Flyover Ramps at Del Mar Avenue on I-10 (El Monte) in Los Angeles, California.

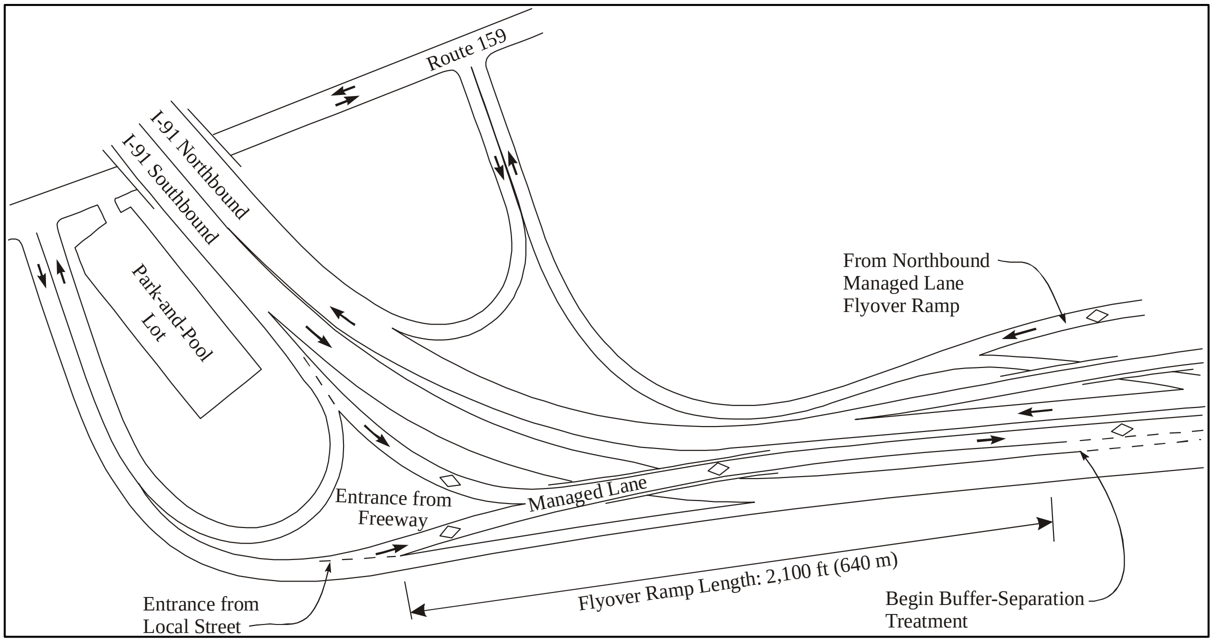


Figure 4-40. Flyover Ramp Terminus for a Buffer-Separated Managed Lane (Adapted from Reference *14*).

Buffer-separated, two-way elevated HOV facilities are in operation in Houston. Although these facilities are not ramps, per se, they are provided at the terminus of the facility and operate as two-way. Figure 4-41 shows a portion of the 1.4-mile (2.4-km) segment of I-610/US 290 that links the Northwest Transit Center with the single-lane barrier-separated HOV lane along US 290. Figure 4-42 shows a similar design for a connection between I-10 (Katy Freeway) and the downtown terminus into Houston.

4.3.2 Freeway-Managed-Lane-to-Freeway-Managed-Lane Connection

The development of a coordinated managed lane system may include linking managed lanes on multiple freeways. As highlighted in Table 4-21, freeway-to-freeway managed-lane connections are currently in operation in Los Angeles and Orange County, California; Phoenix, Arizona; Miami, Florida; Rockville, Maryland; Northern Virginia; and Dallas, Texas. Additional projects are also being planned, designed, and constructed in Seattle and Tacoma, Washington; Oakland, Los Angeles, and Orange County, California; and Dallas, Texas.

Although freeway-to-freeway managed-lane connections can have major benefits in terms of travel time savings and improved operating efficiencies, they represent a significant capital cost. The need for this type of facility should be considered during the planning process. Elements that may be considered in this analysis include high levels of eligible vehicle demand, usually in the range of 800 to 1,000 vehicles per hour, safety and operational enhancements, and cost.

The design of managed-lane-to-managed-lane connections is similar to a general-purpose freeway-to-freeway ramp. The same design speeds, geometrics, cross sections, and other design elements used with a normal freeway-to-freeway ramp should be applied with a freeway-managed-lane-to-freeway-managed-lane connection. Figure 4-43 provides an example of a layout for this type of facility. Figure 4-44 shows a photograph of the I-105 to I-110 HOV lane ramp at the top level of an all-directional interchange in Los Angeles, California.

Figure 4-41. Two-way Elevated Flyover along I-610/ US 290 in Houston, Texas.

Figure 4-42. Two-way Elevated Flyover along I-10 (Katy Freeway) in Houston, Texas.

Table 4-21. Examples of Managed-Lane-to-Managed-Lane Connections (Adapted from Reference *4*).

Location	Type of Design	Status
I-105/I-110, Los Angeles, CA	Directional ramps from I-105 east and west to I-110 north	Open
I-5/I-405, Orange County, CA	Two-way common ramp between I-5 south and I-405	Open
I-5/SR 55, Orange County, CA	Two-way common ramp between SR 55 south and I-5 north	Open
I-5/SR 57, Orange County, CA	Two-way common ramp between I-5 south and SR 57	Open
I-10/SR 202, Phoenix	Directional ramps between SR 202 east to I-10 west	Open
SR 55/91, Orange County, CA	Directional ramps between SR 55 south and SR 91 east	Open
I-95, Miami, FL	Two-way common viaduct through Golden Glades interchange	Open
I-270/I-270, eastern connector, Rockville, MD	Two-way common ramp between I-270 eastern connector and I-270 north	Open
I-5/SR 57, Los Angeles County, CA	Two-way common ramp	Open
I-80/I-880, Oakland, CA	Two-way common ramp	Open
I-5/SR 91, Orange County, CA	Two-way common ramp between I-5 south and SR 91 west and SR 91 east and I-5 north	Open
SR 57/91, Orange County, CA	Two-way common ramp between SR 57 south and SR 91 east	Open
SR 55/I-405, Orange County, CA	Common and directional ramps between SR 55 north and I-405 north and south	Construction
I-5/I-405, I-90/I-405, SR 167/I-405, Seattle, WA	Various design concepts	Planning
I-5/SR 16, Tacoma, WA	Two-way common ramp between SR 16 west and I-5 north	Planning
I-95/I-395, Northern VA	Directional ramp	Open
Loop 1/US 183, Austin, TX	Directional or two-way common ramp	Planning
I-35E/Loop 12/I-635, Dallas, TX	Directional ramp	Planning
I-635/US 75N, Dallas, TX	Two-way ramp(s)	Construction
I-35E/US 67, Dallas, TX	Directional reversible ramp	Open
SH 183, I-35E, others, Dallas, TX	Directional ramps	Planning
I-75/Outer Beltway, other locations, Atlanta, GA	Two-way ramps	Design

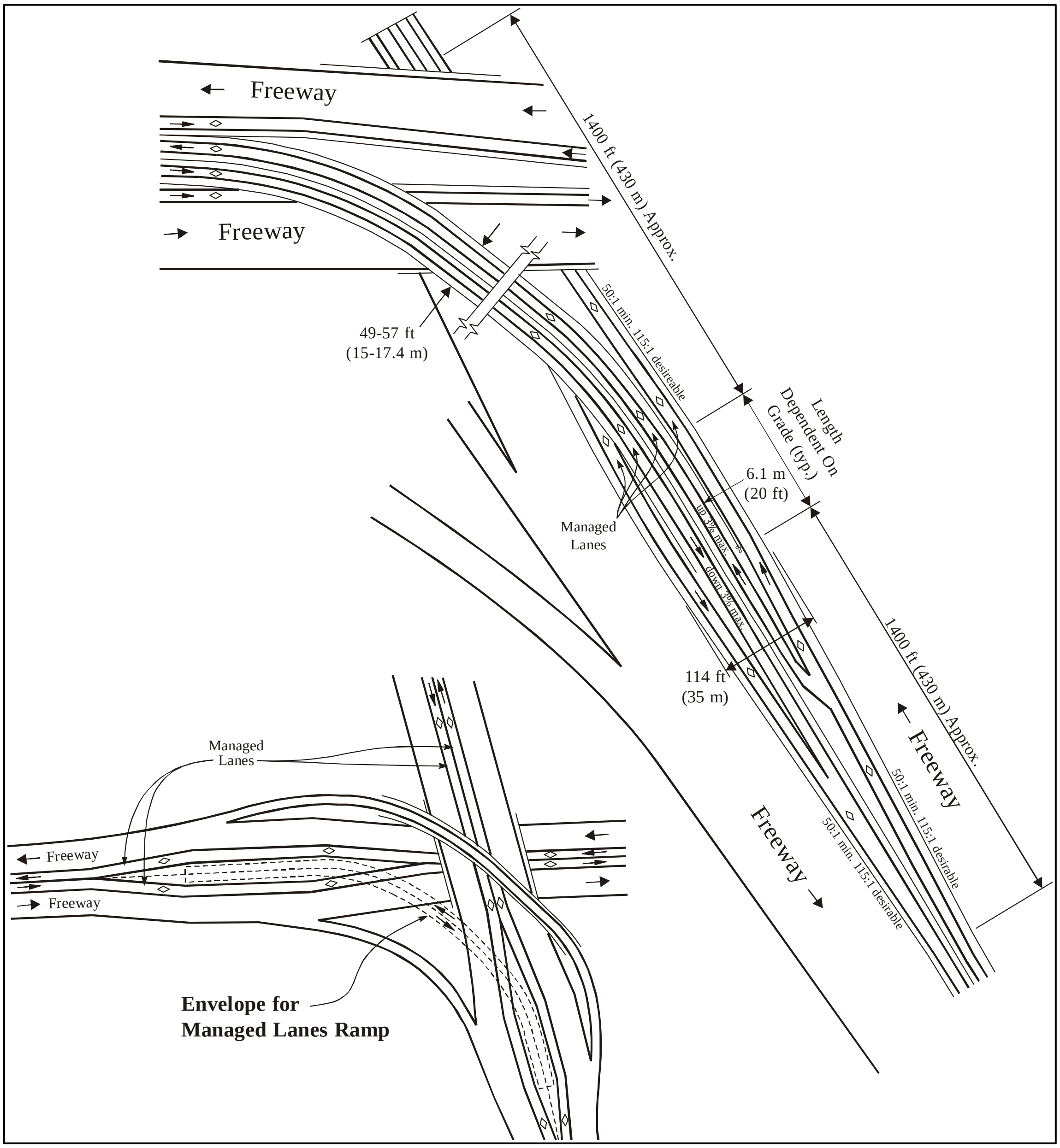


Figure 4-43. Illustration of Managed-Lane-to-Managed-Lane Ramp (Adapted from Reference *4*).

Figure 4-44. I-105 to I-110 Managed Lane Ramp in Los Angeles, California.

4.3.3 Direct Merge or At-Grade Access

Direct merge or at-grade access represents the most commonly used treatment with concurrent flow managed lanes. Two types of approaches—unrestricted or unlimited (continuous) access, and restricted or limited access—are currently in use with concurrent flow managed lanes in North America. The decision to use unrestricted or restricted access for concurrent flow lanes depends upon the operation of the facility. Metropolitan areas that experience short definable peak commute periods (two to four hours during the mornings and evenings) separated by a long midday off-peak traffic period are conducive to part-time operation with unrestricted access. For peak-only operations with no buffer treatment, continuous access is generally provided. This approach allows the managed lane to easily revert to a general-purpose lane at other times. Conversely, metropolitan areas that experience lengthy commute periods (typically between six to eleven hours of congestion) and short off-peak traffic hours are conducive to full-time operation and restricted access. This restricted access configuration with designated ingress and egress provides eligible vehicles consistently greater overall travel speeds which translates to greater time savings per trip as well as making enforcement easier. For 24-hour operation with a buffer treatment, limited access locations are generally provided. For 24-hour operation of the managed lane with no buffer, restricted or unrestricted access may be provided.

Continuous access allows eligible vehicles to enter and leave the lane at any point. No weave, acceleration or deceleration lane is provided. Rather, vehicles simply merge into and out of the managed lane in the same way they would change lanes in the general-purpose lanes. The paint striping used to separate the general-purpose and the managed lanes, along with signing and pavement markings, should all indicate that access can occur at any point. The unlimited access concept is frequently used in projects where no buffer separates the managed lane and the general-purpose lanes. It can be used for buffer-separated projects, but the striping and signing plans may be more complicated. It is difficult to communicate the proper operation of the buffer area during off-peak times when the managed lane designation is not in effect.

Restricted or limited access regulates the locations that vehicles can enter and leave a managed lane. In most cases, the same section accommodates both movements. In some situations, however, only ingress or egress may be allowed. No special weave or acceleration or deceleration lane is typically provided. Vehicles merge directly from the general-purpose lane into the managed lane or from the managed lane into the general-purpose lane. An opening or merge area of 1,300 to 1,500 feet (400 to 460 m) is desirable. Weave lanes are used on a few managed lane projects in California and New York. Restricted access is more common in buffer-separated projects. Figure 4-45 illustrates a schematic for a buffer-separated option with and without a weave lane. Figure 4-46 shows a photograph of I-35E (Stemmons Freeway) in Dallas, Texas, illustrating a narrow buffer treatment and ingress/egress to the HOV lane facility at the same access location.

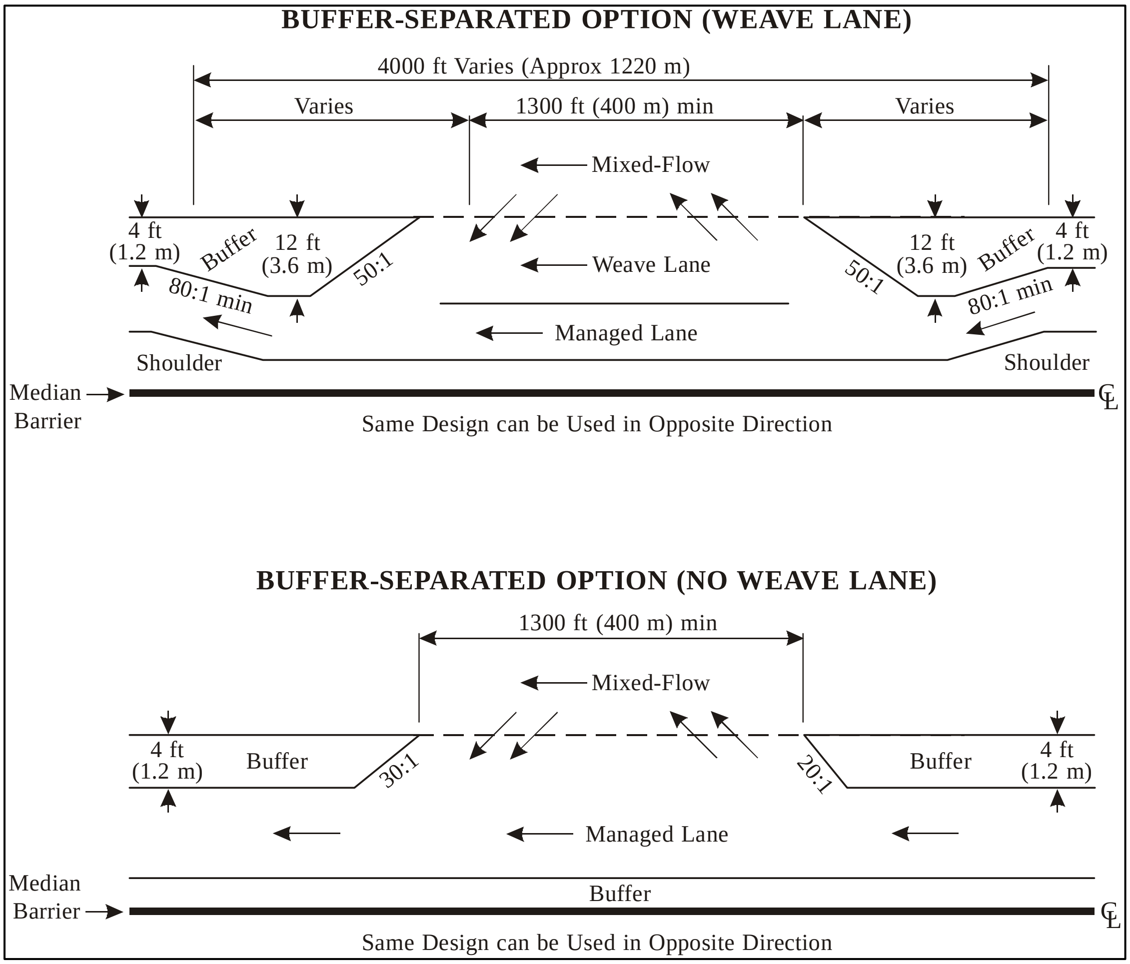


Figure 4-45. Buffer-Separated Intermediate Access With and Without Weave Lane (Adapted from Reference *4*).

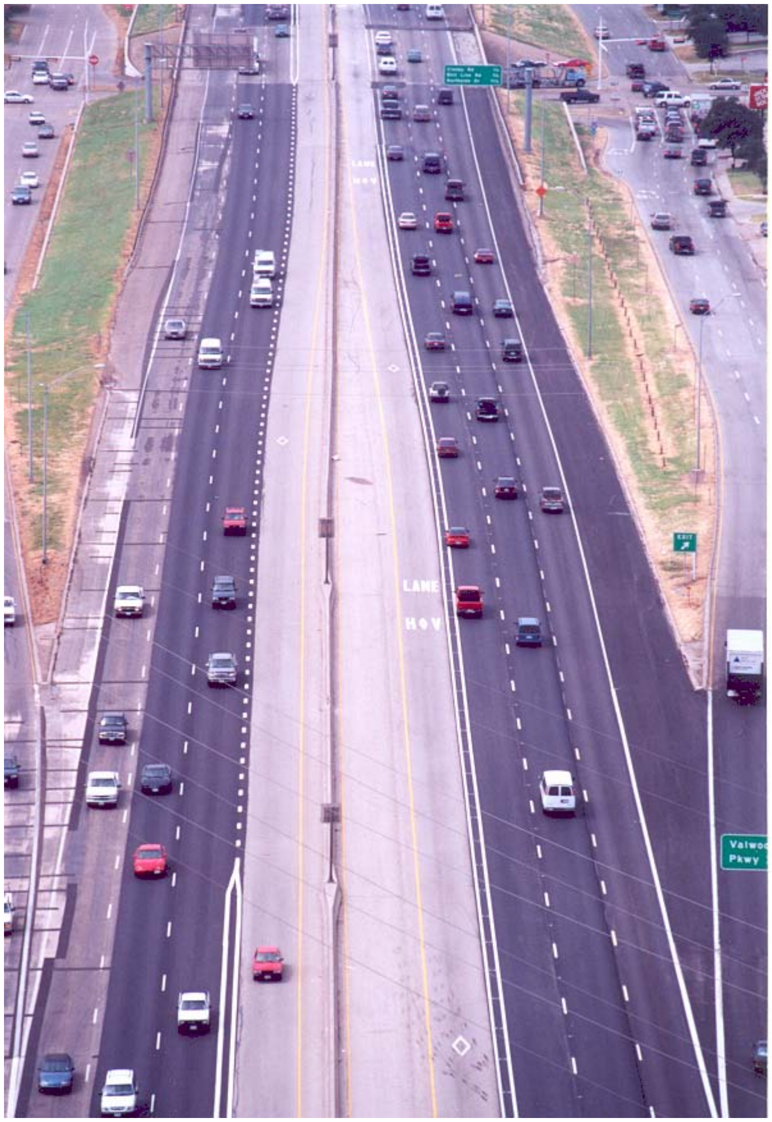


Figure 4-46. I-35E (Stemmons Freeway) Showing Ingress/Egress at the Same Location in Dallas, Texas.
(HOV lane access is shown for the downward direction of the HOV lane)

Both types of at-grade access treatments are relatively easy to implement. They are also the lowest cost access alternatives and provide a great deal of flexibility. Disadvantages of these techniques include the lack of control over vehicles entering and exiting the lane, which makes enforcement more difficult, and potentially increases the number of conflict points between general-purpose motorists and motorists using the managed lane. Allowing drivers to judge the distance required to merge across freeway lanes to exit ramps may create weaving difficulty. Difficulty may also emerge with limited access points by concentrating weaving movements in a few areas. The use of at-grade access must consider the volumes in the general-purpose lanes that will be merging with the managed lane facility vehicles. Relatively long 2- to 3-mile (3.2- to 4.8-km) spacings between access points for the general-purpose lanes may allow for successful weaving maneuvers for at-grade access treatments; however, the use of at-grade access treatments are less preferred than direct access treatments unless the operational integrity of the managed lane facility and general-purpose lanes will not diminish. Adequate enforcement for the concurrent managed lane facility must also be provided.

Figure 4-47 shows the termination of a managed lane as a "free" lane to the inside. California planning criteria suggest 1,000 feet (305 m) per lane change is desirable to allow weaving from the managed lane to the downstream exit ramp. Similar criteria are used for the entrance to the facility although specific distances are based upon a weaving evaluation. Figure 4-48 shows the start/end of the concurrent flow lanes along I-10 (Katy Freeway) in Houston, Texas. Figure 4-49 shows the start/end of the US 67 buffer-separated lanes in Dallas, Texas.

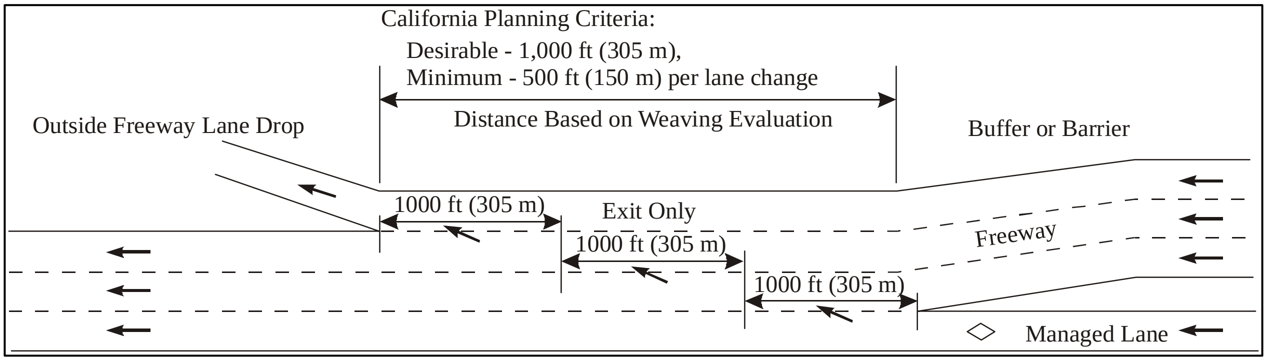


Figure 4-47. Termination of Managed Lane as a "Free" Lane to Inside (Adapted from Reference *14*).

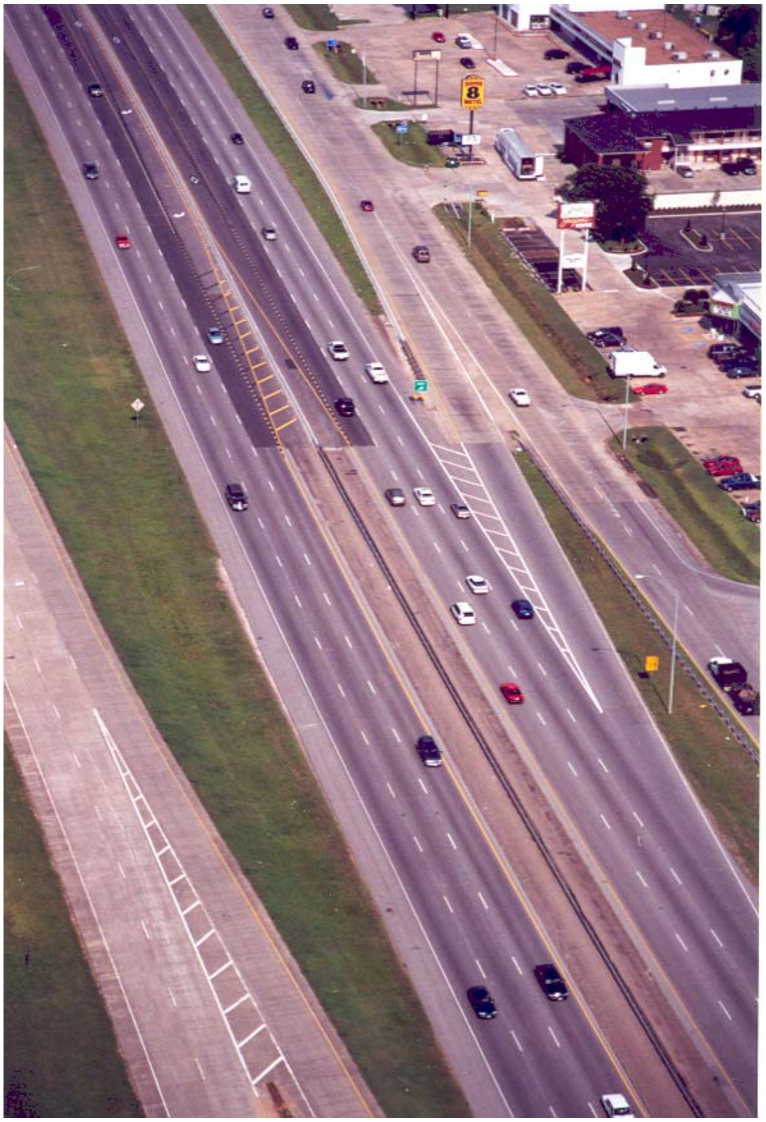


Figure 4-48. Start/End of Concurrent Flow Lanes along I-10 (Katy Freeway) in Houston, Texas.

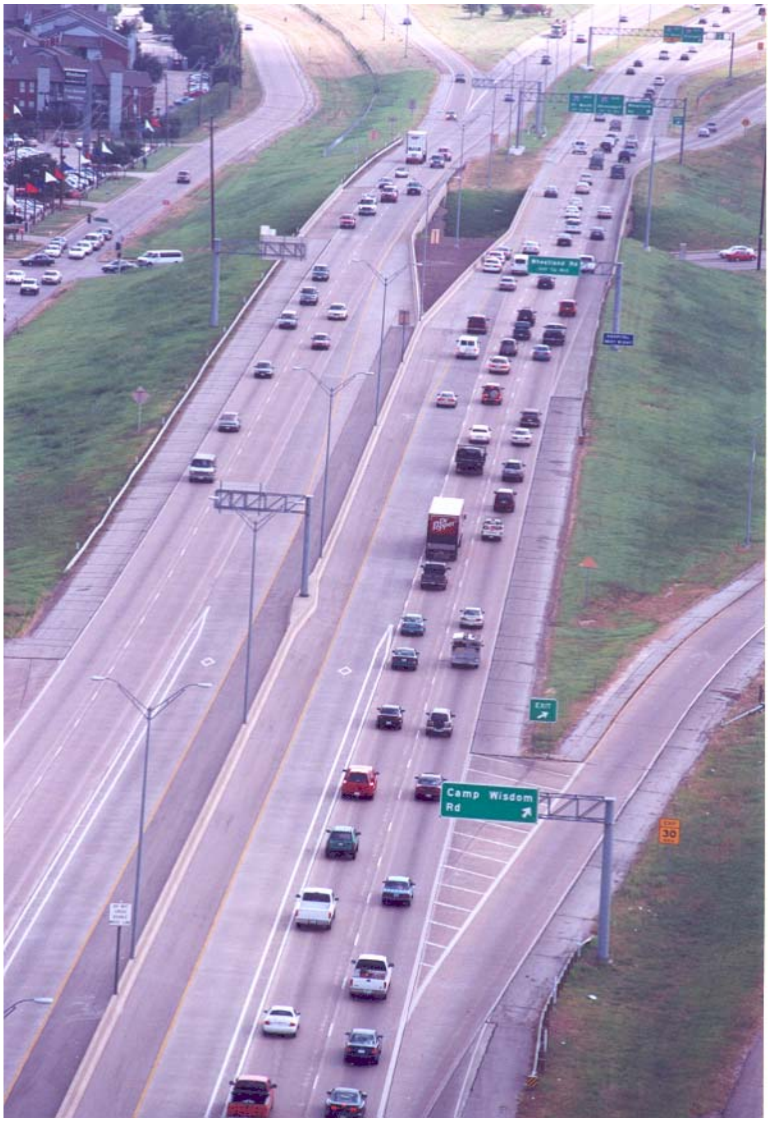


Figure 4-49. Start/End of Concurrent Flow Lanes along US 67 in Dallas, Texas.

4.3.4 Slip Ramps

Slip ramps are used with barrier-separated facilities. The first step when determining access locations on barrier-separated facilities is to determine whether grade-separated (direct access) or slip ramps are best. If the location of the proposed access is a terminal point at the outer end of the lane, it may be appropriate to use a slip ramp. If the access location is intermediate, a high-volume or high-bus activity area, it may not be appropriate to use a slip ramp. One benefit of slip ramps is that they provide for ingress or egress but not for both movements at the same location, eliminating the need to weave traffic both directions. Figure 4-50 illustrates an at-grade intermediate-access (exit as shown) for a single-lane reversible-flow HOV lane facility along the I-10 (Katy Freeway) just east of Gessner in Houston, Texas. Figure 4-51 shows a photograph of this location. If an entrance ramp is also necessary at a location where an exit is provided, it may be better to provide the exit first and then the entrance to avoid the creation of a bottleneck on the general-purpose lanes where there is no location for vehicles to pass.

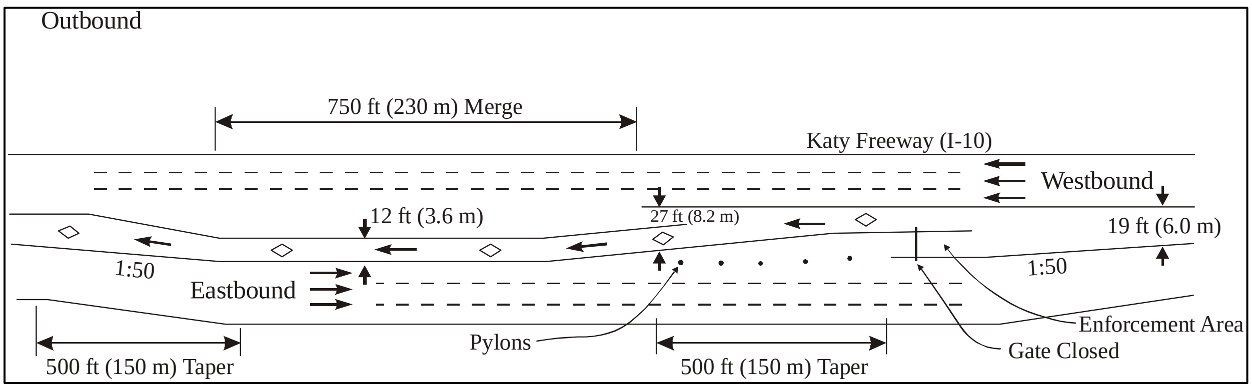


Figure 4-50. Intermediate Slip Ramp for Barrier-Separated Single-Lane Reversible-Flow Managed Lane Facility (Adapted from Reference *14*).

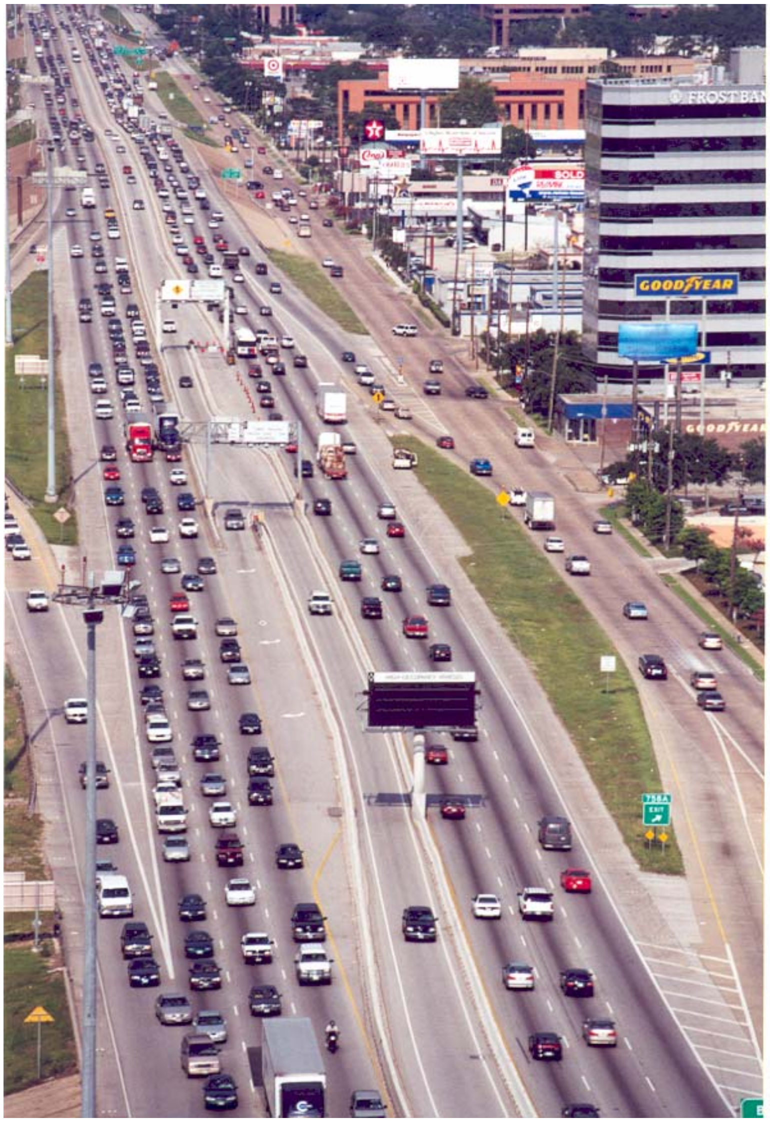


Figure 4-51. Outbound Exit Only along I-10 (Katy Freeway) in Houston, Texas.

Figures 4-52 and 4-53 provide examples of entrance and exit terminal locations with slip ramps, respectively. At the termination of a managed lane, continuing the lane as a general-purpose lane is suggested. If the managed lane volumes do not exceed 1,000 vehicles per hour, a merge area of approximately 1,500 feet (460 m) downstream of the slip ramp may be acceptable but effects on the general-purpose lanes should be checked. Signing at the entrance to a managed lane facility is essential. In all cases, signing should be located at least 1.0 mile (1.6 km) in advance of the entry point. It should also be noted that the merge tapers in design are desirably 115:1 with a minimum of 50:1, and diverge tapers are desirably 50:1 with a minimum of 20:1. The entrance to the managed lane facility should be a lane change not simply a re-designation of the lane to prevent unaware motorists from entering the facility.

Figure 4-54 illustrates an at-grade slip ramp to a two-lane reversible-flow HOV lane on I-395 (Shirley Highway) in Northern Virginia/Washington, D.C. with the use of gates for traffic control. Figure 4-55 shows the origin of a contraflow lane within a freeway interchange with an enforcement area that is present at the I-95/SR 495 Interchange in New Jersey. The schematic in Figure 4-56 shows the north terminus morning and afternoon termination of the contraflow facility that operated along I-45 (North Freeway) in Houston, Texas, from 1979 to 1984. Figure 4-57 illustrates the western terminus of the I-30 (East R. L. Thornton Freeway) contraflow facility in Dallas, Texas. Figure 4-58 shows a photograph of the western (downtown) terminus of I-30 (East R. L. Thornton Freeway) contraflow facility. The photograph shows the afternoon (outbound) operation. Figure 4-59 also shows the X-ramps at the middle of the corridor illustrating an exit-only egress location. Finally, Figure 4-60 shows a slip ramp on I-10 (Katy Freeway) in Houston, Texas, that transitions the HOV lane from barrier-separated to concurrent flow lanes during the afternoon (outbound operation).

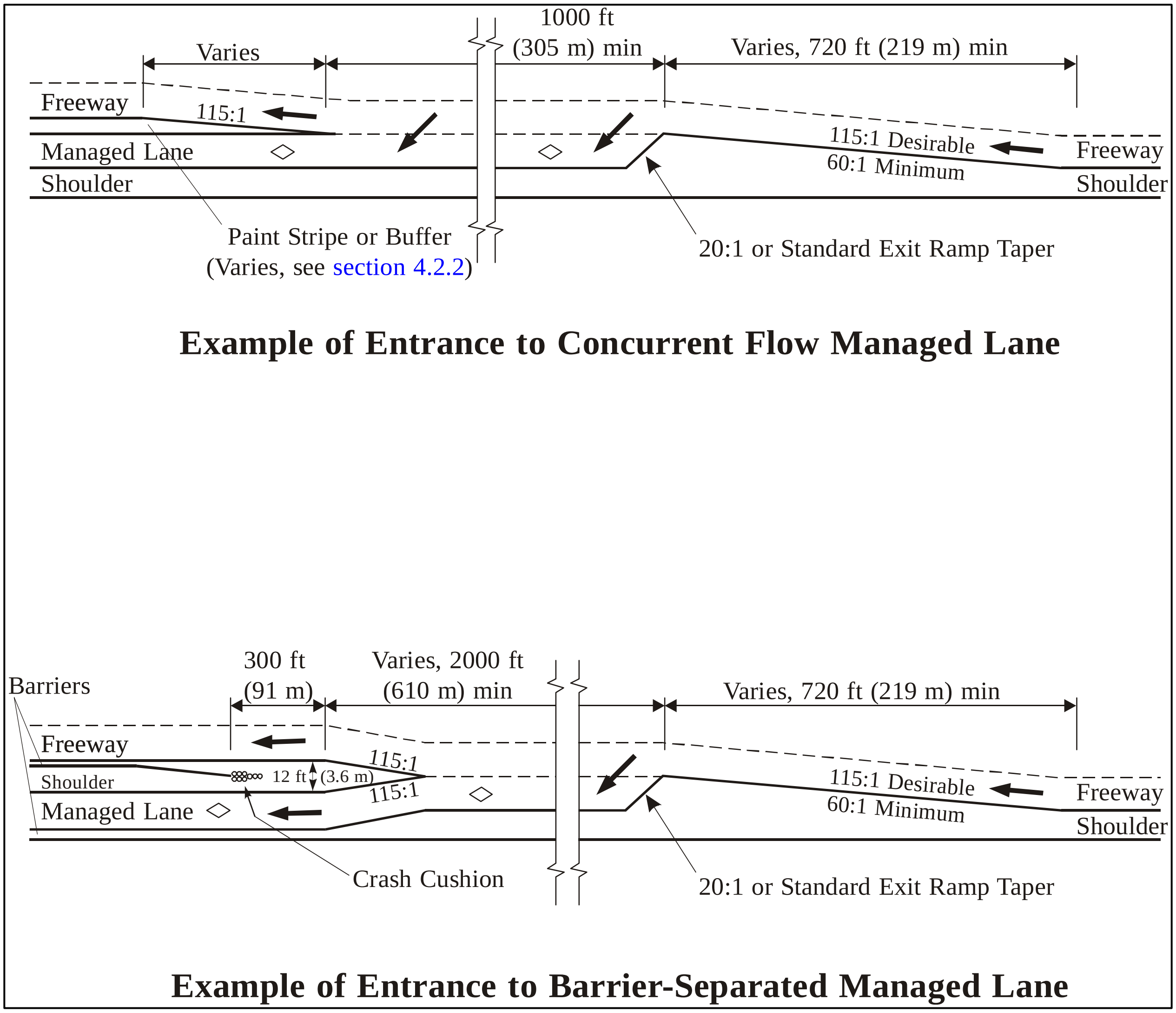


Figure 4-52. Example of Layouts for Managed Lane Entry Terminal with Slip Ramps (Adapted from Reference 4).

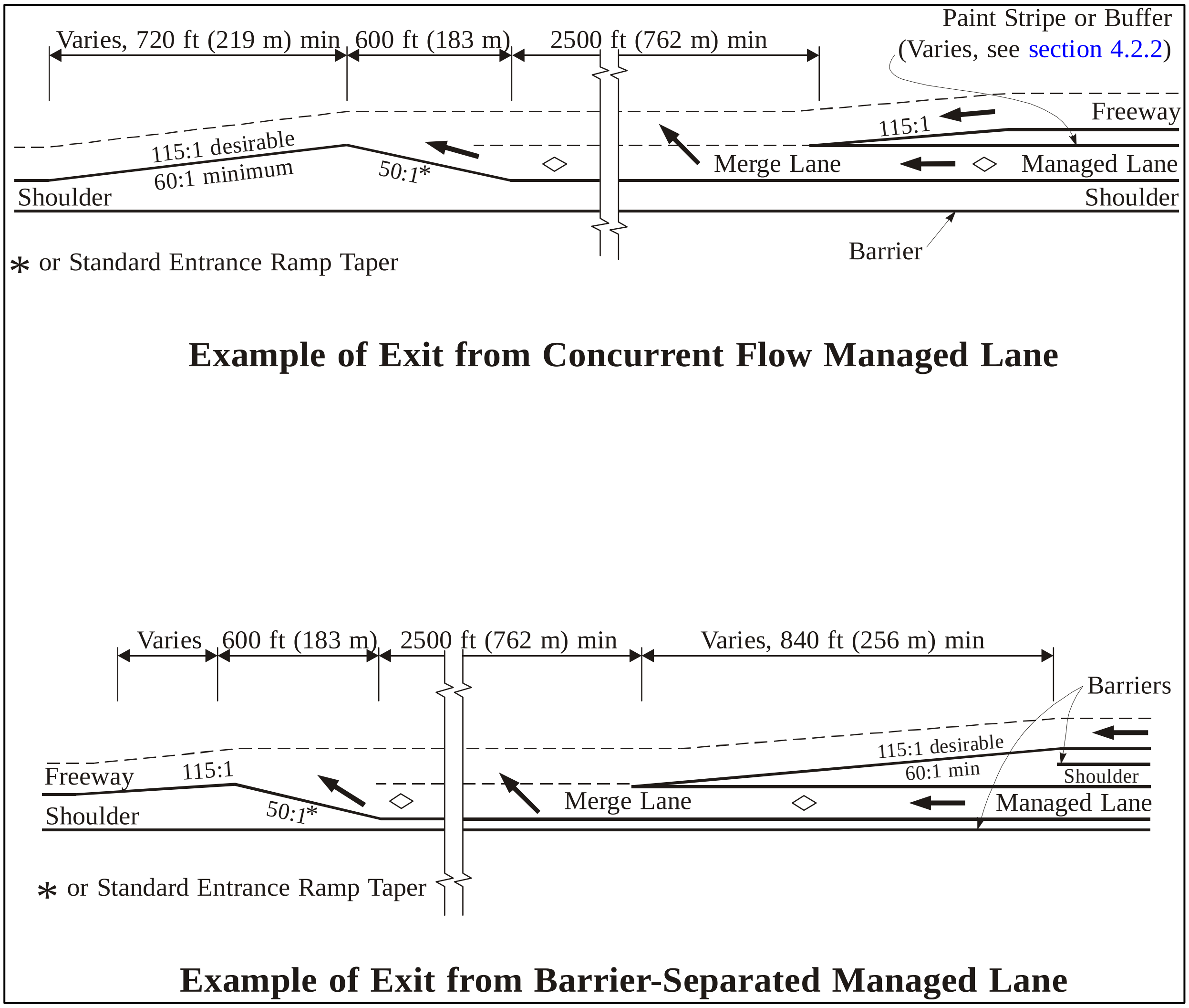


Figure 4-53. Example of Layouts for Managed Lane Exit Terminal with Slip Ramps (Adapted from Reference *4*).

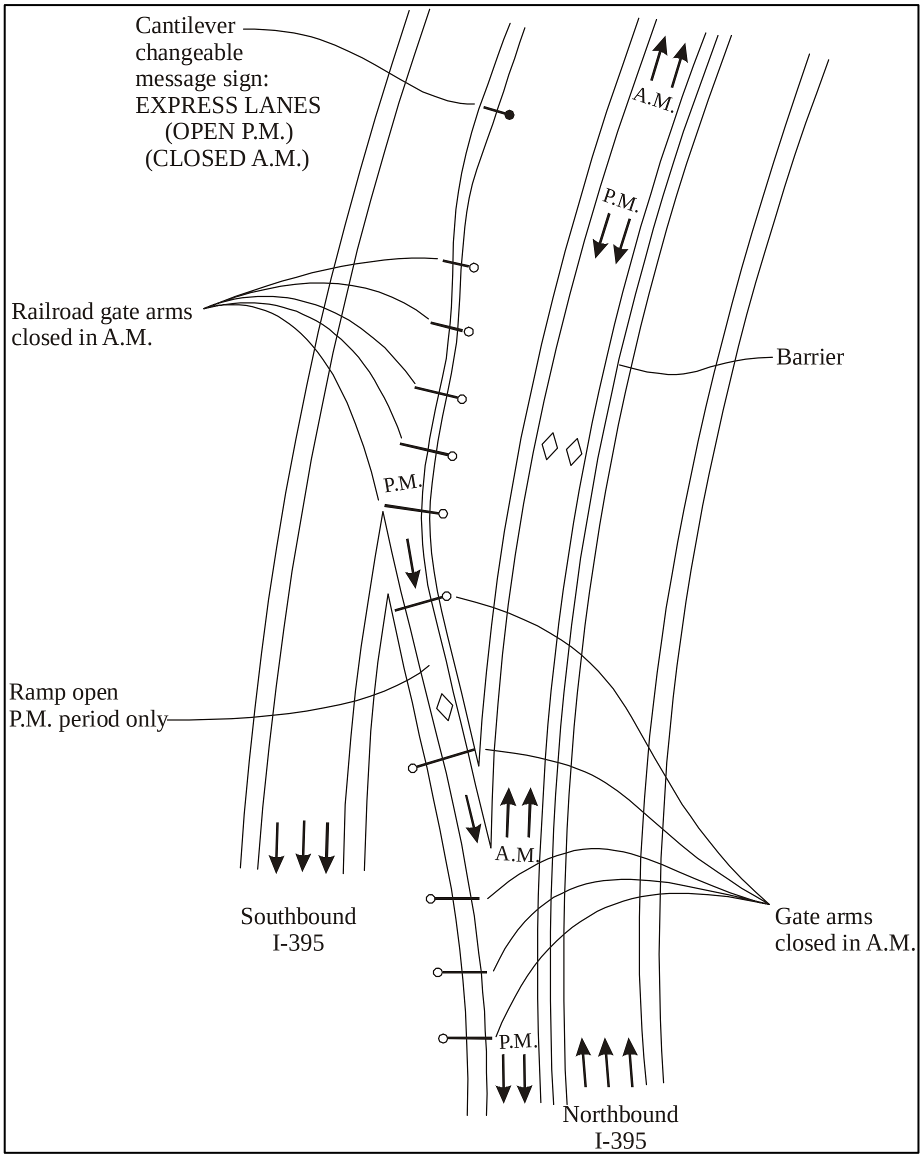


Figure 4-54. At-Grade Slip Ramp to Two-Lane Reversible-Flow Managed Lane along I-395 (Shirley Highway) (Adapted from Reference *14*).

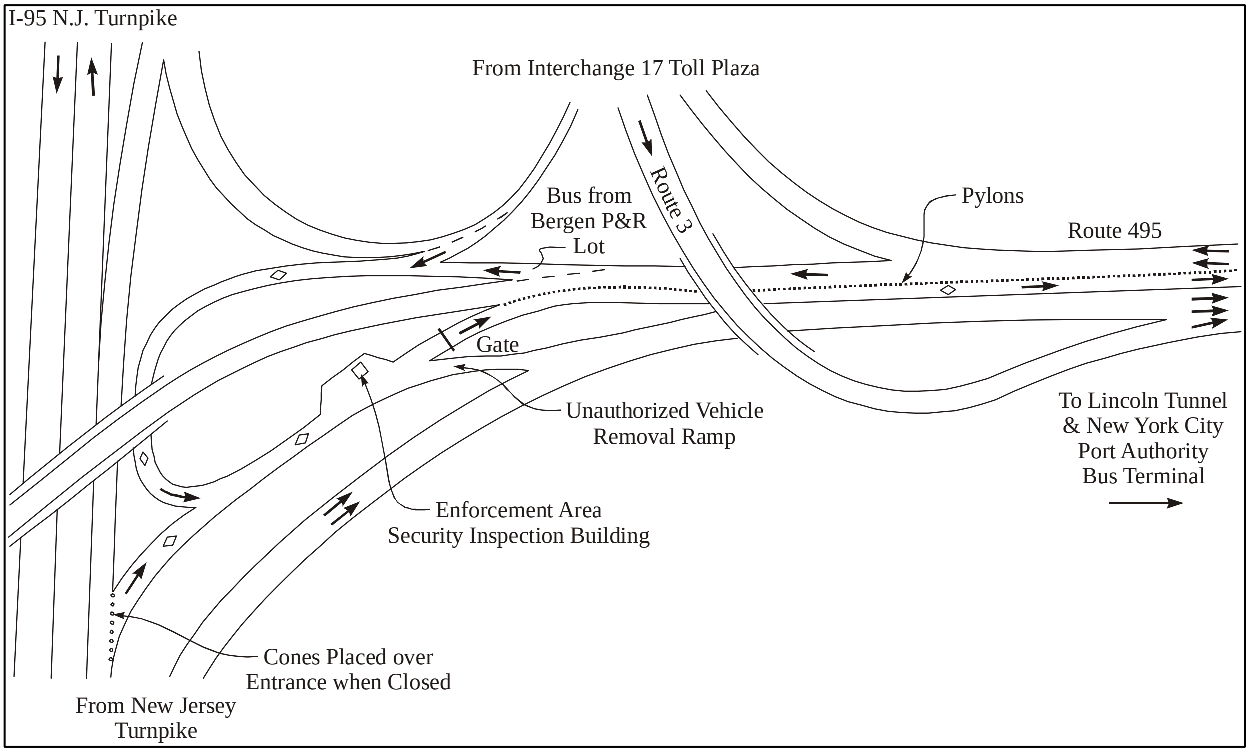


Figure 4-55. Origin of Route 495 Contraflow Within a Freeway Interchange (Adapted from Reference *14*).

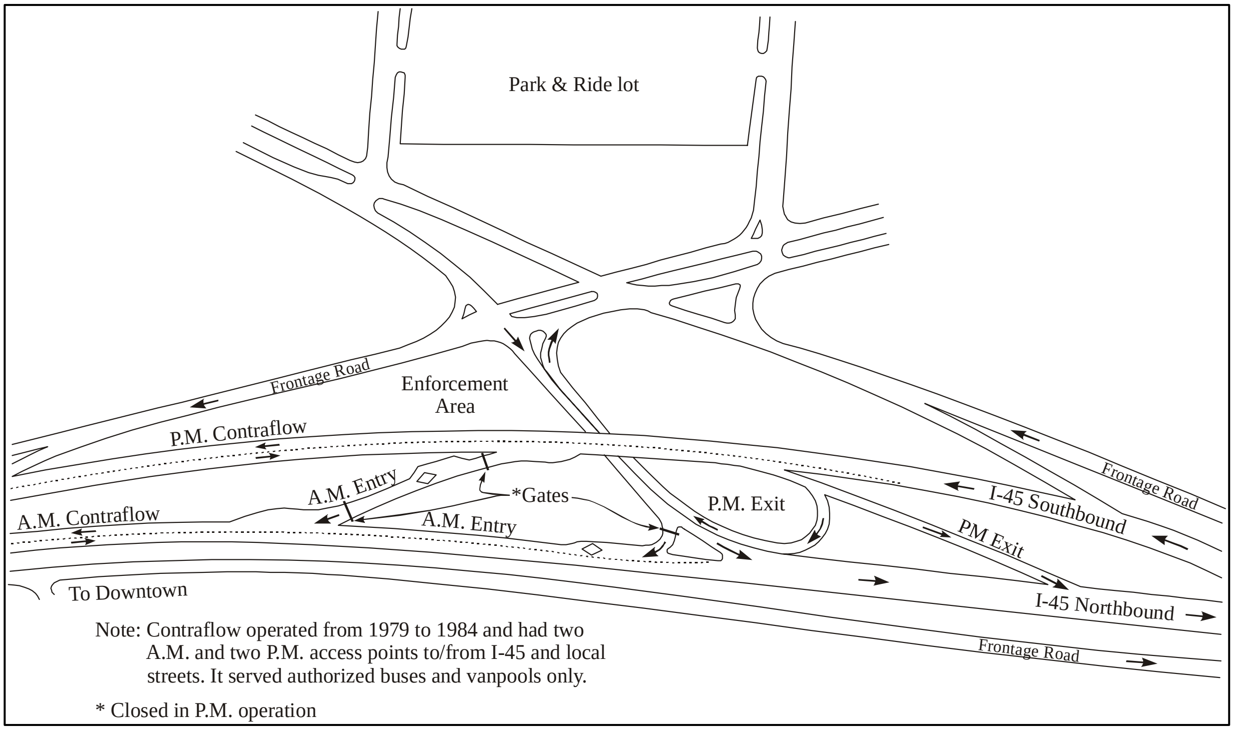


Figure 4-56. Morning Origin and Afternoon Termination of a Contraflow Facility (Adapted from Reference *14*).

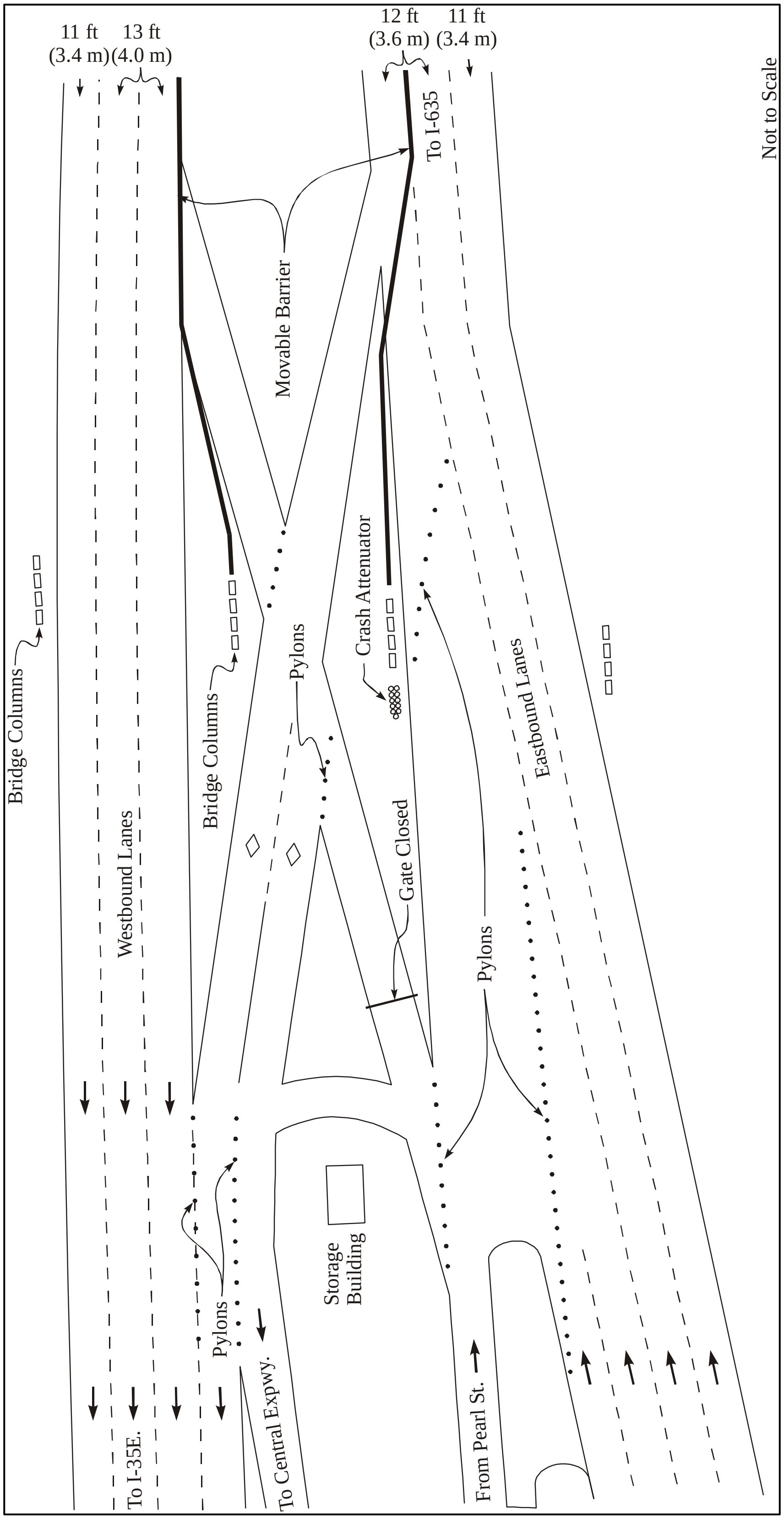


Figure 4-57. Western Downtown Terminus of the I-30 (East R. L. Thornton Freeway) Contraflow Facility in Dallas, Texas (Adapted from Reference *16*).

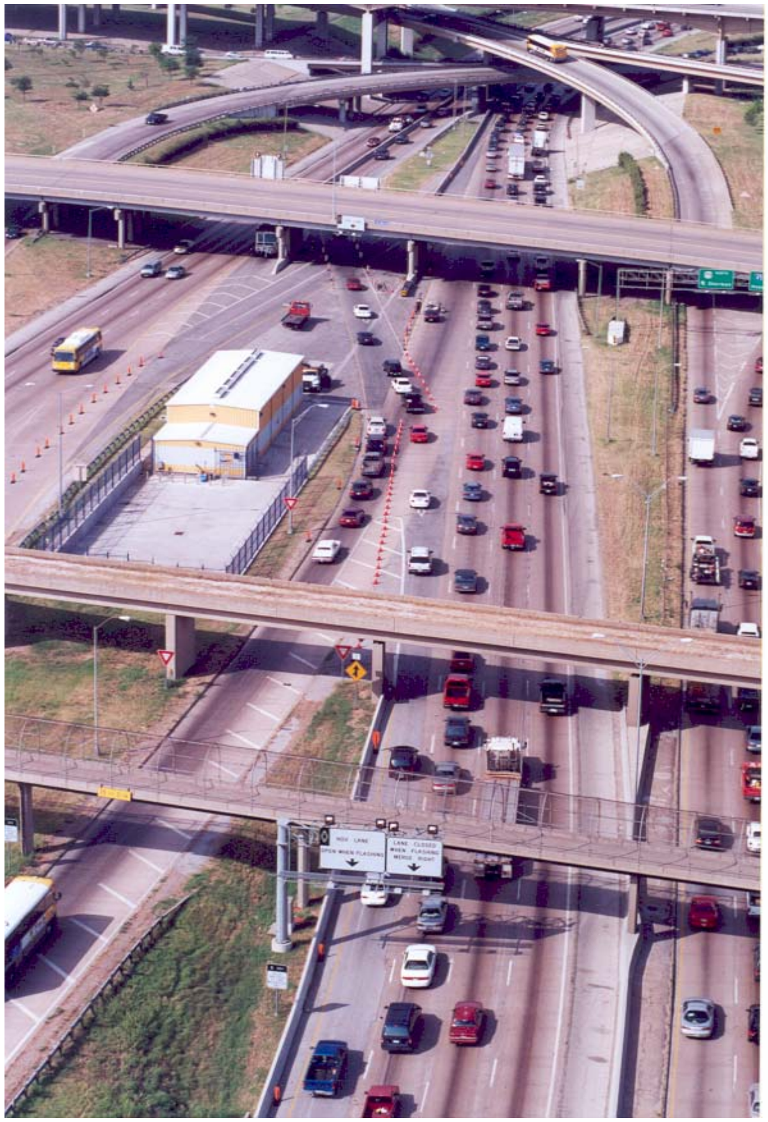


Figure 4-58. X-ramp of Afternoon Operation at Downtown Origin of I-30 (East R. L. Thornton Freeway) in Dallas, Texas.

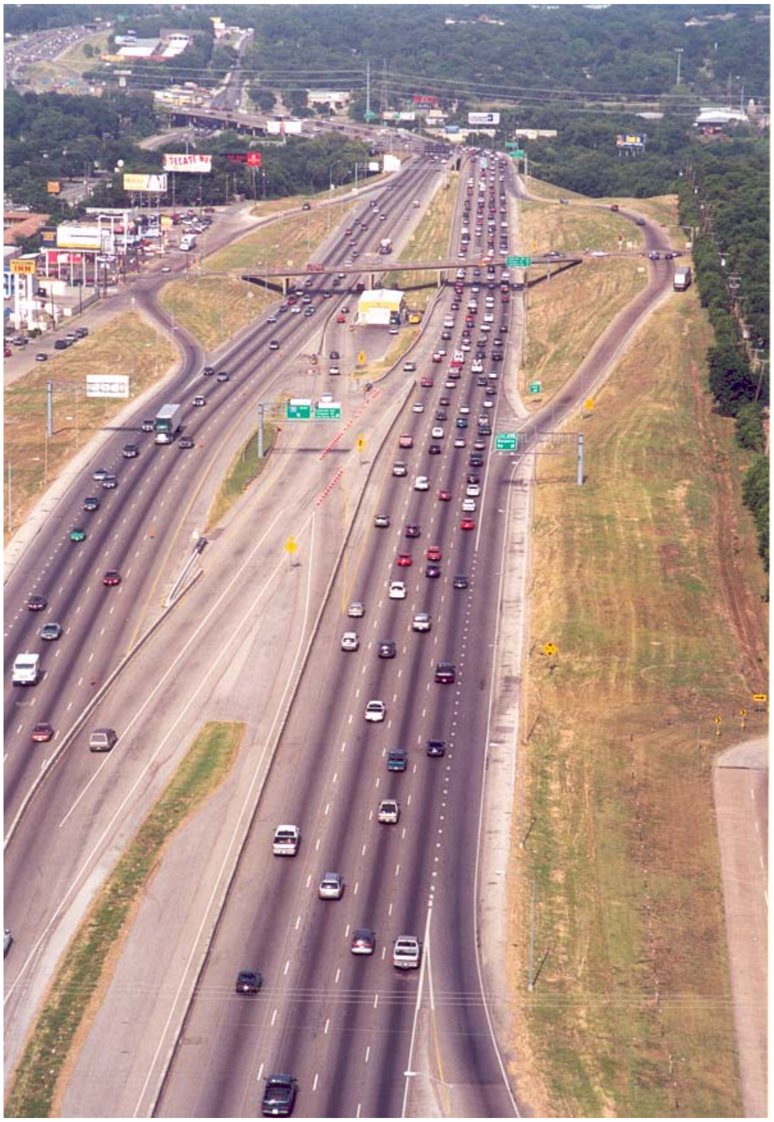


Figure 4-59. X-ramp of Afternoon Operation Showing Exit Ramp to Upward Direction General-Purpose Near Dolphin Road on I-30 (East R. L. Thornton Freeway) in Dallas, Texas.
(HOV lane makes an "S" curve through the middle of the X-ramp)

Figure 4-60. Slip Ramp from Barrier-Separated to Concurrent Flow Facility on I-10 (Katy Freeway) in Houston, Texas.

4.4 DESIGN CONSIDERATIONS FOR BYPASS LANES AT RAMP METERS

Metering freeway entrance ramps is a technique being used by some state departments of transportation to better manage traffic on freeways in some metropolitan areas. Metering vehicles entering a freeway can improve the overall level of service by regulating the flow of traffic and by dispersing the platoons of vehicles that typically enter a freeway during the peak periods. Ramp metering may also discourage drivers from using a freeway for a short-distance trip that can be more effectively served on the local street system.

Providing vehicles that are eligible to use a managed lane with a way to bypass the queues that frequently form at ramp meters, especially during the peak hours, can help encourage greater use of carpools, vanpools, and buses. Bypass ramps for eligible vehicles may be used in conjunction with a freeway managed lane, or they may be provided as stand-alone treatments on freeways that do not have managed lanes.

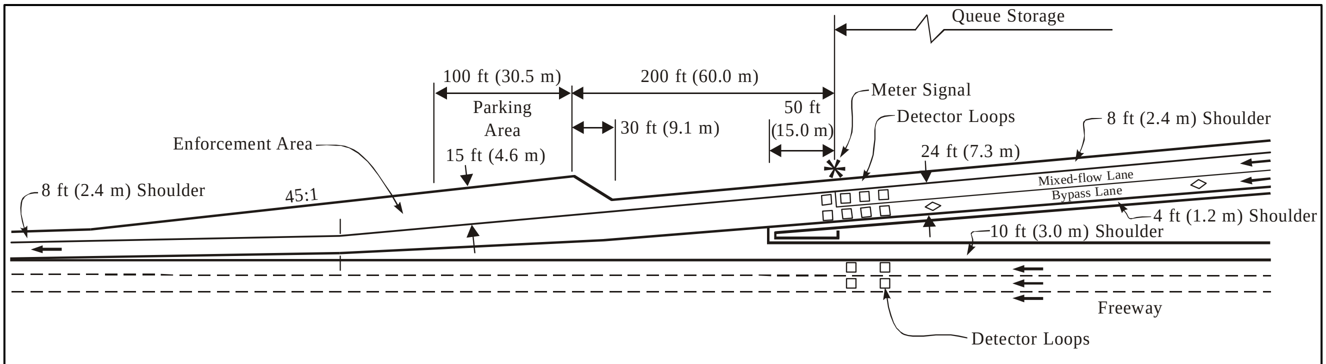
Two general types of treatments are usually used with bypass lanes at metered freeway entrance ramps. These are 1) providing an additional lane as part of the existing ramp and 2) the more common provision of a separate lane for eligible vehicles around the meter. Figure 4-61 shows layouts of each type of bypass lane. The design elements associated with these treatments are highlighted in the text that follows.

As shown in the upper schematic of Figure 4-61, a commonly used approach is to provide a lane for eligible vehicles directly adjacent to the general traffic lane upstream from the meter. A lane width of 12 feet (3.6 m) with ramp shoulders is recommended by AASHTO (*5*). However, adequate space within the existing freeway alignment or additional right-of-way may not be available to meet these criteria. As a result, narrowing the lane to 10 to 11 feet (3.0 to 3.4 m) and dropping the shoulder may be considered in some cases. A distance of 300 feet (91 m) from the meter to the freeway is also recommended by AASHTO to allow the eligible vehicles to merge with the ramp traffic (*5*).

The use of a solid line to separate the eligible vehicle lane from the general traffic lane appears to be the most common approach (*13*). A painted buffer or mountable curb may also be considered to provide further separation. The length of the bypass lane will depend on the length of the ramp and the location of the meter. As a general guide, the bypass lane should be long enough to allow eligible vehicles to avoid the queue in the general-purpose lane. Figure 4-62 shows a bypass lane for eligible vehicles in Los Angeles, California, where bypass lanes are common.

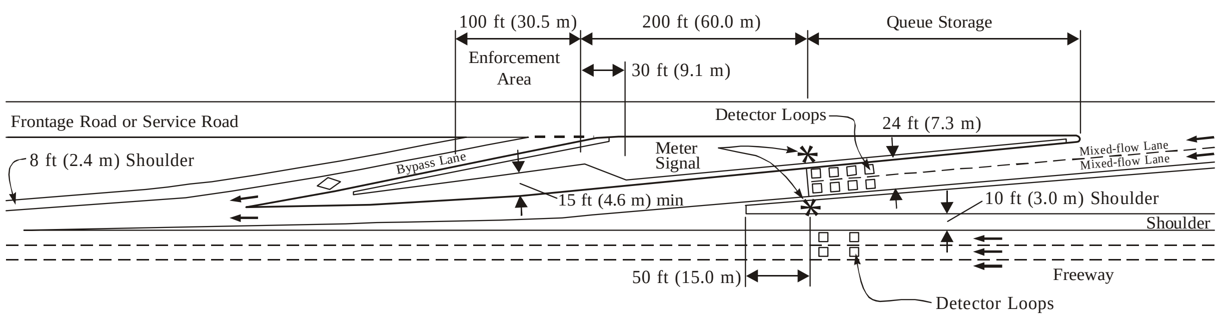
A bypass lane can be located on either the left or right side of the existing general-purpose ramp lane. Advantages of a left-side bypass lane include reinforcing the normal "pass on the left" orientation. A left lane location may be less likely to be blocked at the street or feeder route entrance. A possible disadvantage with the left orientation is that buses must merge to the right after the meter. Bus operators cannot easily see to the right, so right merges are more difficult. Enforcement of a right-side bypass lane may be easier if an enforcement area is provided, as more space is usually available on the right of an entrance ramp. A bypass lane located on the right side may be more susceptible to being blocked by vehicles backed up from the meter onto the access roadway.

In a few cases, the freeway entry ramp may have two general-purpose lanes, with a third lane for eligible vehicles only. The same preferred lane width of 12 feet (3.6 m) should be used in these cases, although modifications may be needed based on local conditions.



Note: Depending on traffic patterns the bypass and mixed-flow lane designations may be reversed.

Bypass Lane Layout at Metered Entrance Ramp



Bypass Lane Layout for Separate Ramp on Metered Freeway

Figure 4-61. Example of Layouts for Bypass Lane at Metered Freeway Entrance Ramp (Adapted from Reference *4*).

Figure 4-62. Bypass Lane in Los Angeles, California.

A second approach to providing eligible vehicles with preferential treatment at metered ramps is to provide a separate entrance ramp. The design of these ramps should follow national and state guidelines on freeway entrance ramps. As in the previous case, the eligible vehicle ramp and the general-purpose ramp should merge into a common acceleration lane prior to entering the freeway. It is also suggested that separate bypass lanes be located downstream of the general-purpose ramp. In some cases, the eligible vehicle lane may also be metered, although at a faster rate, to ensure a smooth flow of traffic.

Enforcement areas should be provided with either type of bypass treatment. The location and general design of enforcement areas are shown in Figure 4-61. Due to limited right-of-way and lack of available personnel, enforcement areas are not commonly found with bypass lanes. Enforcement tends to be provided by roving patrols or motorcycle police.

The exact location and design of bypass lanes at a metered freeway ramp will depend on location conditions and site specific elements. Bypass lanes should be considered only at ramps with high volumes of current or projected eligible vehicle levels. Further, the design of the existing ramp, the location of the ramp meter, the availability of needed right-of-way, ramp volumes, and the local street system should all be considered in the design of a bypass lane. Additional signing and markings should be provided with bypass lanes.

4.5 DESIGN CONSIDERATIONS FOR MANAGED LANE ENFORCEMENT

The importance of enforcement in the success of a managed lane project has been stressed throughout this report. Many of the figures previously shown in this report have demonstrated enforcement zones. This section highlights the elements that should be considered in designing enforcement areas associated with the various types of managed lanes on freeways.

Managed lane projects should be designed so that they can be safely and efficiently enforced. The safety of police personnel, as well as travelers in the managed lane and the general-purpose lanes, should be key considerations in the design process. Experience indicates that poorly designed and unsafe enforcement areas will not be used, which jeopardizes managed lane project success.

Table 4-22 highlights some of the attributes associated with enforcing different types of managed lane facilities. Busways on separate rights-of-way and barrier-separated managed lanes are generally considered to be easier to enforce than other facilities because of the limited and controlled access they provide. Contraflow facilities and queue bypasses may be enforced through a single strategically located monitoring area. Concurrent flow managed lanes, especially those allowing continuous access, are the most difficult to enforce.

4.5.1 General Enforcement Design Considerations

The term enforcement area is used to refer to a number of potential design treatments that provide space for police personnel to monitor a managed lane facility, to pursue a violator, and to apprehend a violator and issue a ticket or a citation. Space adjacent to a managed lane is required for these functions. The primary type of infraction that enforcement officers confront is occupancy violations, which requires the ability to see inside a vehicle. Good lighting and good visibility from a safe vantage point are needed to perform these enforcement functions.

A variety of enforcement practices may be used on a facility. The design of enforcement areas should be flexible to account for a variety of enforcement strategies. On barrier-separated facilities, enforcement actions are usually performed near the entrance or exit ramps where traffic is often moving more slowly. The enforcement area serves as both a monitoring and an apprehension site. For non-barrier facilities, enforcement areas may allow officers to monitor traffic with the apprehension of violators occurring at a downstream location. This location may be another enforcement area or a wide left or right shoulder.

Table 4-22. Enforcement Attributes Associated with Different Types of Managed Lane Facilities (Adapted from Reference *4*).

Type of Managed Lane Facility	Preferred Enforcement Attributes	Minimum Enforcement Attributes
Exclusive Barrier Separated		
• Reversible	• Enforcement areas at entrances and exits	• Enforcement areas at entrances or exits
• Two-way	• Enforcement areas at entrances and exits	• Enforcement areas at entrances or exits
Concurrent Flow	• Continuous enforcement shoulders with periodic barrier offsets • Continuous right-side shoulders	• Periodic mainline enforcement areas • Monitoring areas • Continuous right-side shoulders
Contraflow	• Enforcement area at entrance • Continuous shoulder for enforcement	• Enforcement area at entrance
Queue Bypass Treatments	• Enforcement area on right-side shoulder • Continuous right-side shoulder • Duplicate signal head facing enforcement area	• Enforcement monitoring pad with continuous right-side shoulder downstream

Two general classifications for enforcement areas are often used. These categories relate to the exclusive or barrier-separated and non-barrier-separated managed lane treatments. The two approaches are low-speed enforcement areas at entrance and exit ramps, and high-speed settings along the managed lane mainline. The general characteristics associated with these two approaches are described next, followed by specific examples of enforcement area designs with different types of managed lanes.

Low-Speed Enforcement Area. 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). Low-speed enforcement areas are often designed to provide for monitoring, apprehension, and citing of violators, and where practicable, violator removal from the managed lane facility. The following design features may be considered with slow-speed enforcement areas.

♦ The enforcement area should be at least 100 feet (30 m) in length and preferably up to 200 feet (60 m) on high-volume facilities, not including approach and departure tapers.

♦ The enforcement area should be at least 14 to 15 feet (4.3 to 4.6 m) wide.

- The enforcement area should have an approach taper of 2:1 or 30 feet (9.1 m).

- The enforcement area should have a departure taper of 10:1 or 150 feet (45.7 m) to allow for acceleration into the lane.

High-Speed Enforcement Area. If a managed lane includes a number of high-speed (45 mph [75 kph or higher]) at-grade access locations or lacks continuous shoulders wide enough for enforcement, consideration should be given to periodically spaced enforcement areas. These areas are usually designed for monitoring traffic or for monitoring and apprehending violators. For either application, police personnel often prefer that periodic enforcement areas for concurrent flow be designed in conjunction with full outside shoulders. Most apprehension activities are performed in the right shoulder, and some state vehicle codes require that motorists being pursued by police move to the right. The following elements should be considered in the design of high-speed enforcement areas.

- The length of a high-speed monitoring area should be at least 100 feet (30 m), not including the approach and departure tapers. For monitoring and apprehension, the preferable length is 1,300 feet (396 m).

- The enforcement area should be at least 14 to 15 feet (4.3 to 4.6 m) wide.

- 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.

4.5.2 Enforcement Design Considerations for Exclusive Freeway Managed Lane Facilities

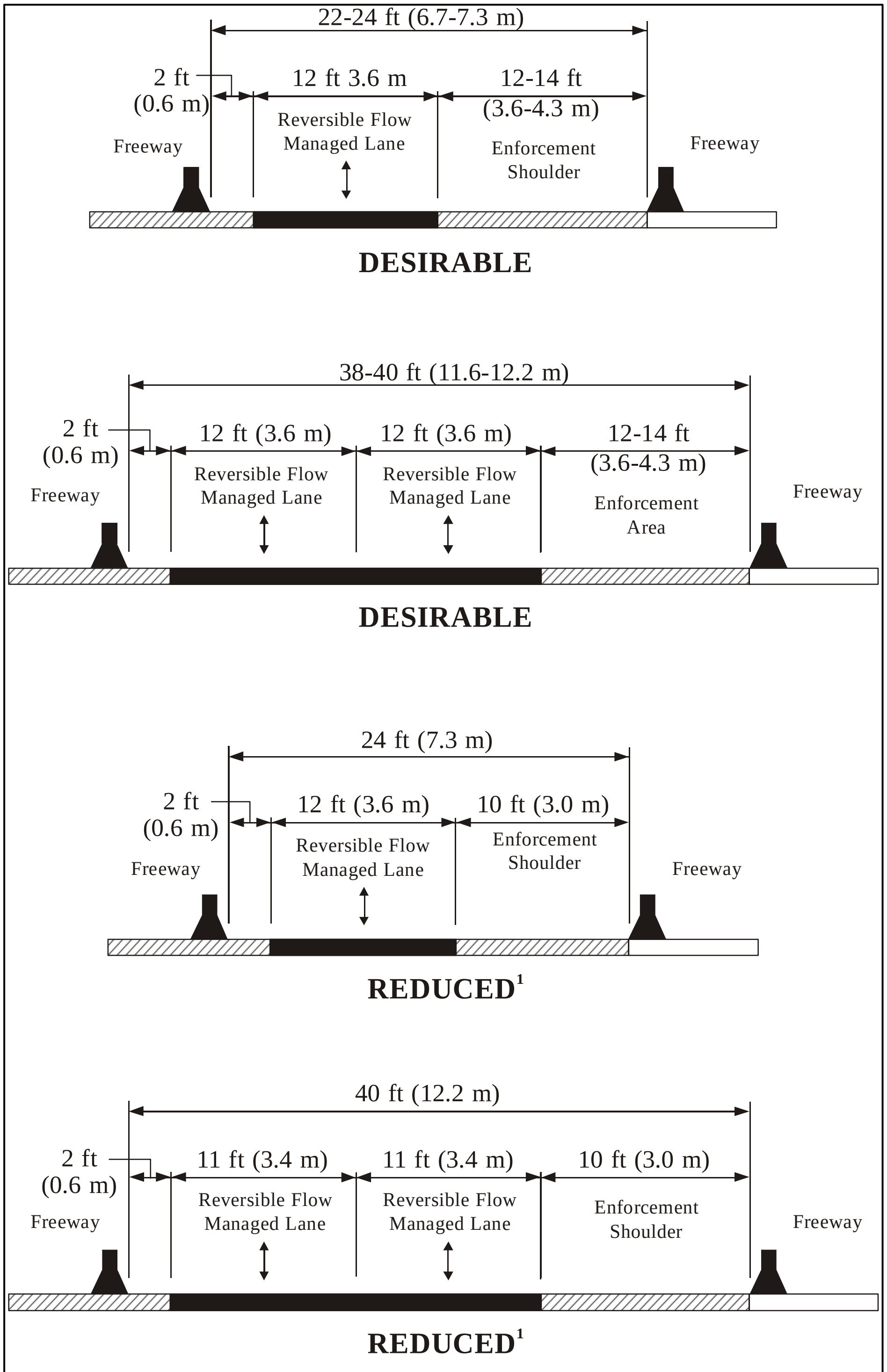
Enforcement of two-way and reversible exclusive barrier-separated managed lane facilities is easier than with concurrent flow lanes due to limited access points. Violators may be stopped at entry and exit points where travel speeds are usually lower. The enforcement designs used with reversible lanes are discussed first, followed by the design approaches used with two-way facilities.

Reversible Exclusive Managed Lane Facilities. Reversible exclusive managed lanes may be the easiest to enforce other than busways. The design of these facilities significantly reduces the number of access points and prohibits random ingress and egress. Most managed lanes of this type contain from one to no more than five access locations, making surveillance and apprehension at entrances or exits efficient and effective. Barrier-separated lanes also act as a deterrent to potential misuse, as violators are trapped in the lanes. Enforcement officers may work in tandem, reporting violators at one entrance and allowing a second officer downstream to apprehend and cite violators. Figure 4-63 shows enforcement along US 290 in Houston, Texas, approaching the Northwest Transit Center. In addition, the geometric requirements for a reversible facility provide enforcement pockets within the ramps that can serve as enforcement areas for the opposing direction. In some cases, these pockets are large enough to provide a means of removing violators by sending them out in the off-peak direction, thus penalizing the offending commuter with a travel delay as well.

Designated shoulders or other enforcement pockets located along the lane can serve to facilitate enforcement activities. Figure 4-64 provides examples of cross sections illustrating this approach.

Two-Way Exclusive Managed Lane Facilities. Two-way barrier-separated facilities offer the same advantage of limited ingress and egress as reversible managed lane facilities. There are two differences, however, which make enforcement more difficult. First, there are no unused elements of the managed lane roadway. Second, there may be more options for accessing the lanes. As a result, there is less likelihood that enforcement can be performed exclusively at entrances or exits. Additional design features such as barrier offsets or wider than standard shoulders may need to be considered to help ensure safe places where enforcement can be performed. Enforcement areas at low-speed ramps should be considered as prime locations.

Figure 4-63. I-610/US 290 Enforcement Near Northwest Transit Center in Houston, Texas.



[1] Operational treatments should be incorporated if the reduced design cross sections are used (see section 4.1)

Figure 4-64. Examples of Cross Sections of Enforcement Areas along a Reversible Barrier-Separated Managed Lane (Adapted from Reference 4).

4.5.3 Enforcement Design Considerations for Freeway Concurrent Flow Managed Lanes

Concurrent flow managed lane facilities provide no physical separation from the adjacent freeway lanes. As a result, concurrent flow lanes are the most difficult type of managed lane facility to enforce, as single-occupant vehicles may merge in and out at will. The perception of enforcement, as much as an actual enforcement presence, is an important attribute to managing lane violations on these facilities, and the more effective the design is at meeting this objective, the better the design is at addressing enforcement needs.

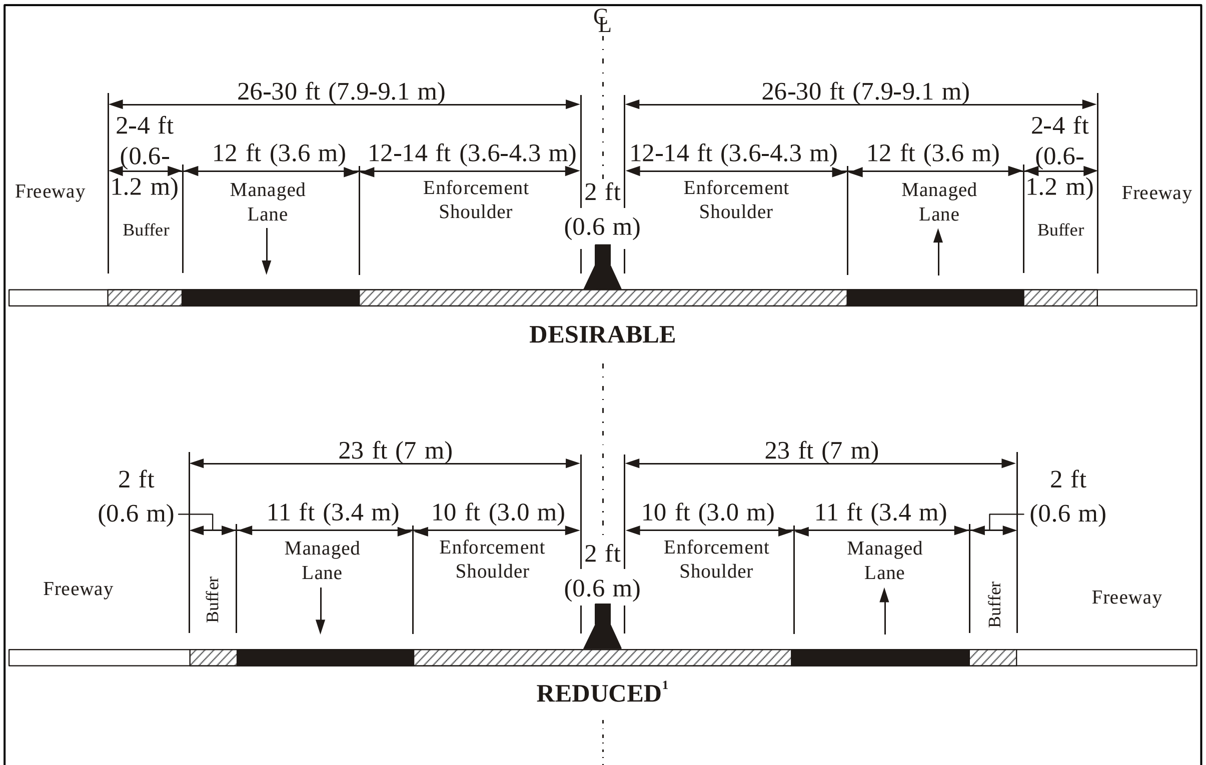
Figures 4-65 and 4-66 provide examples of cross sections and layouts for different types of enforcement techniques with concurrent flow managed lanes. Wide, continuous shoulders are used for enforcement in many areas. Where full shoulders are not available, mainline enforcement areas should be considered at regular intervals, and spacing is typically 2 to 3 miles (3.2 to 4.8 km). Enforcement areas should meet the guidelines defined previously for high-speed conditions. Augmenting the entrance areas with continuous outside shoulders along the freeway is also beneficial. A sufficient length should be provided to pull over a violator and, once cited, allow the violator to safely reenter the traffic stream. The minimum length required for this operation is approximately 1,300 feet (396 m), excluding tapers. It should be noted that officers in many areas prefer to direct violators to the right shoulder, and, not surprisingly, general-purpose drivers are very cooperative when they see a violator being apprehended. Prior to providing full inside shoulders for enforcement, officers and enforcement agency representatives should be contacted to discuss how enforcement will likely be performed.

Additional features, including a protective barrier for the officers monitoring traffic, a median opening that allows the officer to observe both directions of managed lane operation, lighting, and removal of any barrier-top glare screen on the barrier in the affected area should be considered. The opening is a particularly beneficial consideration for motorcycle officers who can maneuver within the median opening. The enforcement area should not be signed or otherwise draw attention to its function, but it may require extra lighting.

4.5.4 Enforcement Design Considerations for Freeway Contraflow Managed Lanes

Contraflow operations typically include a single entrance area and a single exit, although multiple access points may be provided. Setting pylons or moving barriers to define the borrowed lane requires a deployment crew at the beginning and the end of each operating period. During the operating period, safe and efficient operation is ensured by allowing the deployment crew to monitor the lane, operate tow truck services, and perform other functions. A tow truck is usually stationed on the downstream end, and enforcement personnel are positioned at the upstream end.

To maintain safety for this type of operation, it is very important to stop and remove any errant motorists who accidentally enter the facility. This necessitates continuous monitoring at the entrance and some means of shunting ineligible users back into the mixed-flow traffic stream. Enforcement is typically handled at the entrance to a contraflow lane. Figure 4-67 illustrates the enforcement of the I-45 (North Freeway) contraflow operation in Houston, Texas, on the interim project that operated from 1979 to 1984.



[1] Operational treatments should be incorporated if the reduced design cross sections are used (see section 4.1)

Figure 4-65. Examples of Cross Sections for Enforcement Areas along Concurrent Flow and Exclusive Buffer-Separated Managed Lanes (Adapted from Reference *4*).

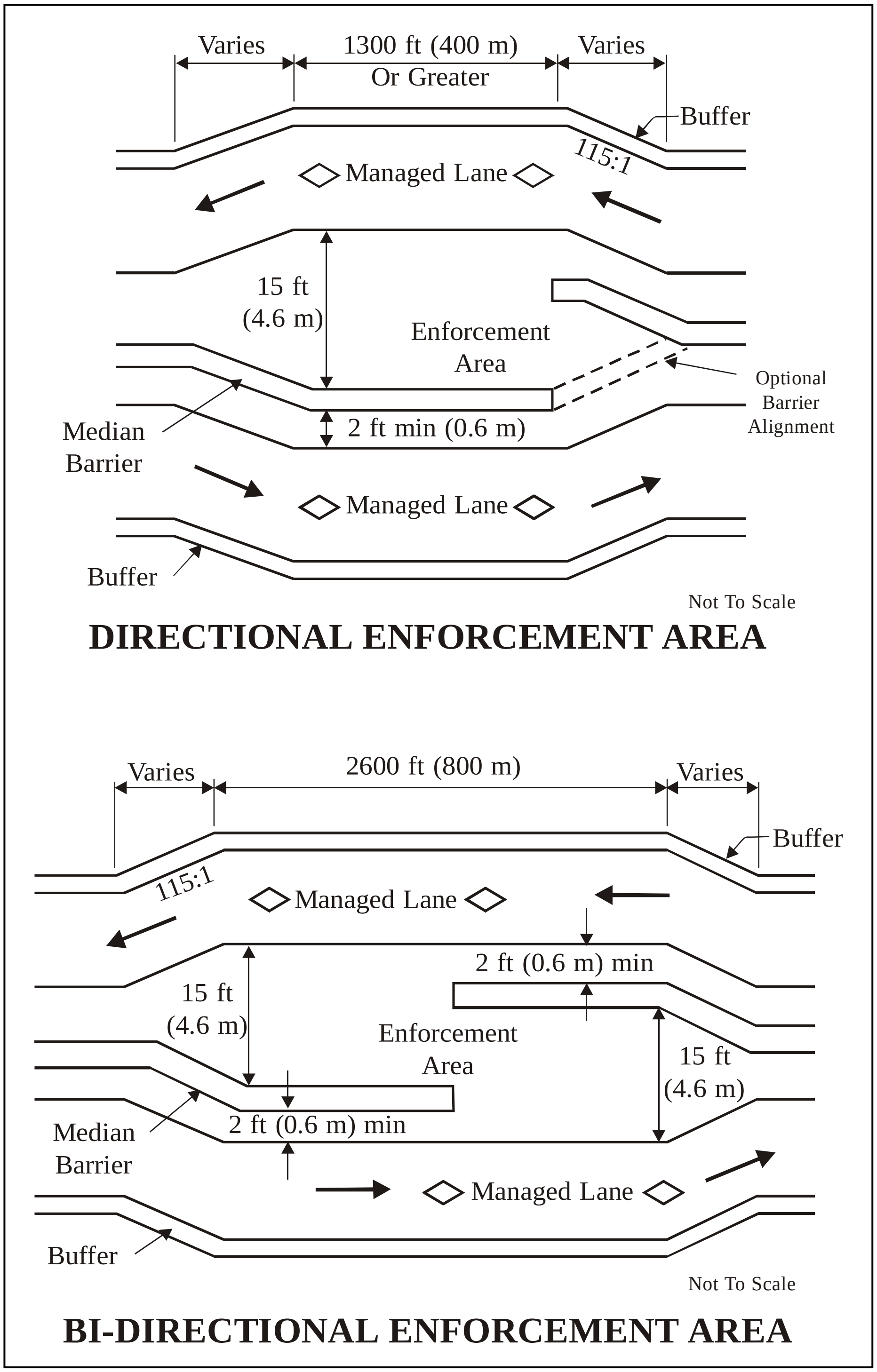


Figure 4-66. Examples of Directional and Bi-Directional Enforcement Area Layouts (Adapted from Reference *4*).

Figure 4-67. Enforcement of Interim I-45 (North Freeway) Contraflow Lane.

4.6 DESIGN CONSIDERATIONS WITH PRIORITY AND VALUE PRICING PROJECTS

The major design elements that will need to be considered with priority pricing projects for eligible vehicles relate to the toll collection technology, enforcement, and signing. Access issues may be more critical with these types of projects than with general managed lanes. The type of payment method used will influence the extent of design modifications or changes. The use of a simple prepaid hang tag, like those used during the initial phase of the I-15 project in San Diego, California, may not require any design changes. On the other hand, the use of an automated payment system will require additional design considerations. The location and design of electronic toll tag readers, the possible use of toll booths, and other related elements will need to be addressed. The design features of the SR 91 express lanes in Orange County, California, the I-15 project in San Diego, California, the I-10 (Katy Freeway) *QuickRide* demonstration in Houston, Texas, and existing toll facilities can all be used as models for a new project. See section 3.9.3 for further discussion of these projects.

4.7 DESIGN CONSIDERATIONS WITH ITS AND MANAGED LANE FACILITIES

A wide range of ITS technologies may be appropriate for use with managed lane facilities. ITS may enhance the operation and enforcement of managed lane facilities and support services, improve the convenience and ease of use of transit and ridesharing, and provide real-time information to commuters. Further, managed lane facilities are being used to test various elements of the Automated Highway System (AHS) and may be the locations for the first deployment of an AHS. Priority treatments for eligible vehicles are provided on some toll facilities in the United States. Techniques currently utilized include reduced pricing strategies, managed lanes approaching a toll plaza, and toll booths reserved for eligible vehicles only. At least 23 toll facilities provide special pricing for eligible vehicles, and at least 12 provide some type of priority treatment for eligible vehicles on the roadway or at the toll plazas (*17*).

CHAPTER 5

SIGNS AND PAVEMENT MARKINGS

5.0 INTRODUCTION AND GENERAL RECOMMENDATIONS

Standard symbols, signs, and pavement markings for managed lane facilities are important in building public awareness, understanding, and acceptance. Adequate regulatory and guide signs are critical for users and non-users of these facilities, and signing plays a key role in public education and enforcement strategies. Ideally, uniform symbol, signs, and pavement markings should be used with all managed lane facilities. However, although freeways and managed lane facilities share many common signing and pavement markings, there are many unique elements associated with managed lane facilities *(4)*.

The wide variety of managed lane designs necessitates some innovation in signing and pavement markings. Signing and pavement markings for two-way facilities are generally simpler than for reversible-flow facilities. Contraflow and reversible facilities require special attention to communicate the direction of travel in addition to ingress/egress locations. Overhead lane arrows, gates, changeable message signs, and other devices have been applied for this purpose *(14)*.

Previous problems with managed lane signing include:

- lack of adherence to *Manual on Uniform Traffic Control Devices (MUTCD)* color standards,
- lack of diamond symbol exhibited on signs,
- confusing regulatory sign information,
- sign lettering too small to read at the posted speed level,
- managed lane signs placed so that they can be read by mixed-flow drivers, and
- signs that have not been upgraded to reflect the most current operating rules *(14)*.

The *MUTCD 2000* *(18)* provides additional guidance on signing and pavement markings for managed lane facilities. Use of the *MUTCD 2000* guidelines will aid in providing consistency for users of managed lane facilities. The *MUTCD 2000* guidelines are summarized in this chapter. However, there are several *MUTCD* subject areas open for use of local terms and practice. TxDOT is still operating under the *1980 Texas Manual on Uniform Traffic Control Devices* while developing an updated version in response to the *MUTCD 2000*. The *Texas Manual* may provide additional guidance on signing and pavement markings for managed lanes in Texas.

The following recommendations are suggested to improve signing on managed lane facilities.

- The standard sign for managed lane regulatory signing is black on white with a white diamond symbol on a black background in the upper left corner.
- The size of the sign should be based upon the design speed, using the same relationship in letter size as required for any other highway signing.

- Signs should be considered on the approaches to all managed lane ingress and egress locations. It may be necessary to mount such signs over the lane to provide proper sizing.
- Regulatory signs related to lane restrictions should be mounted over the lane at regular intervals.
- Regulatory signs located in advance of a preferential lane should be mounted on the appropriate side of the approach roadway.
- If dynamic signing is used, the diamond symbol should be applied in the upper left corner or above the changeable sign.
- Regulatory signing should periodically clarify user eligibility, hours of operation, direction (if appropriate), and other operational restrictions.
- Regulatory information should be repeated at 0.5- to 1.0-mile (0.8- to 1.6-km) intervals along non-barrier-separated facilities. Regulatory information for barrier-separated facilities can be displayed at entrances and exits only.
- Carpools and vanpools should be defined in terms of 'Person.' (For example: Buses and 2+ Person HOVs only.)
- Where lateral distance is limited, the sign panel may have to be skewed as much as 30 degrees to allow for an increase in panel length.
- All signing should be reevaluated whenever operation policies change. Signs should be changed in accordance with the revised policies. Signs should not be cluttered with amended information that confuses or contradicts the primary message or information being communicated.
- Where guide signing to similar destinations can potentially be seen by both HOV users and nonusers, the HOV message should be reinforced with the diamond symbol. All guide signs in the area of confusion should be mounted over the appropriate roadways *(14)*.

5.1 MUTCD SPECIFICATIONS

The material in the remainder of this chapter is excerpted from the *MUTCD 2000* *(18)*. Therefore, the terminology is left as "HOV lanes" as it appears in the *MUTCD*.

5.1.1 Occupancy and Hours of Operation

The agencies that own and operate HOV lanes shall have the authority and responsibility to determine how they are operated and the occupancy requirements for vehicles operating in HOV lanes. The minimum occupancy requirement shall be two occupants per vehicle.

HOV lanes may be operated on a 24-hour basis, for extended periods of the day, during peak travel periods only, during special events, or during other activities. An engineering study should be the basis for determining when, during a typical day, there should be a minimum occupancy requirement for a vehicle to use an HOV lane. The study should be based on current and estimated future travel demand for a corridor and facility. HOV lanes may take many forms depending on the level of usage and the design of the facility. They may be physically separated from the other travel lanes by a barrier or median, or they may be concurrent with other travel lanes and be separated only by longitudinal pavement markings. Physically separated HOV lanes may be operated in a constant direction or may be operated as reversible lanes.

5.2 SIGNS

Preferential lane signs and pavement markings shall be used to advise road users when a preferential lane is established. Agencies may select from either the HOV abbreviation or the diamond symbol to reference the HOV lane designation. The diamond symbol on the HOV preferential lane signs (R3-11, R3-13, and R3-14) should appear in the top-left quadrant. The diamond symbol *should not* be used on the bus, taxi, or bicycle preferential lane signs.

HOV signs shall display the minimum allowable vehicle-occupancy requirement established for each HOV lane. The vehicle-occupancy requirement established for an HOV lane shall be referenced immediately after the word message HOV or the diamond symbol. The diamond symbol shall be restricted for use with HOV lanes only. Motorcycles shall be eligible to use HOV lanes that received federal-aid highway program funding.

5.2.1 Advance Signing

The Lane Ahead signs R3-10, R3-10a, R3-12, R3-13, R3-15, and R3-16 should be used for advance notification of preferential lanes. The R3-10 and R3-13 signs should be used in situations where agencies determine it is appropriate to provide a sign that defines the minimum occupancy requirement for a vehicle to use an HOV lane. The legend and format of the R3-10 and R3-13 signs should have this sequence, as shown in Figure 5-1:

- Top Line: HOV 2+; and
- Bottom Lines: 2 OR MORE PERSONS PER VEHICLE.

R3-10 R3-13

Figure 5-1. Examples of Regulatory Signing (Adapted from Reference *18*).

Photographs of advance signing are shown in Figures 5-2 through 5-4.

Figure 5-2. Advance Signing on I-35E (Stemmons Freeway) in Dallas, Texas.

Figure 5-3. Advance Signing for Exits on I-635 (LBJ Freeway) in Dallas, Texas.

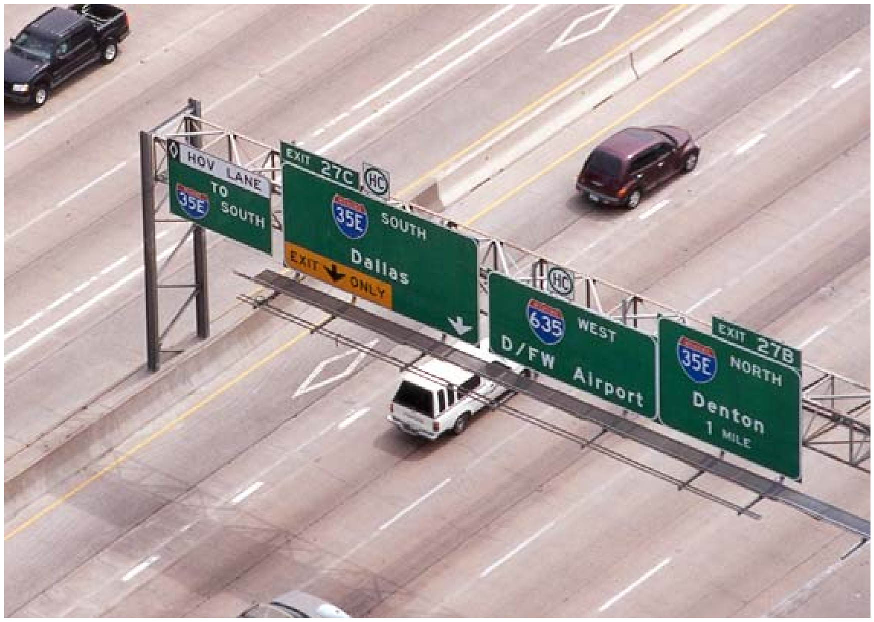
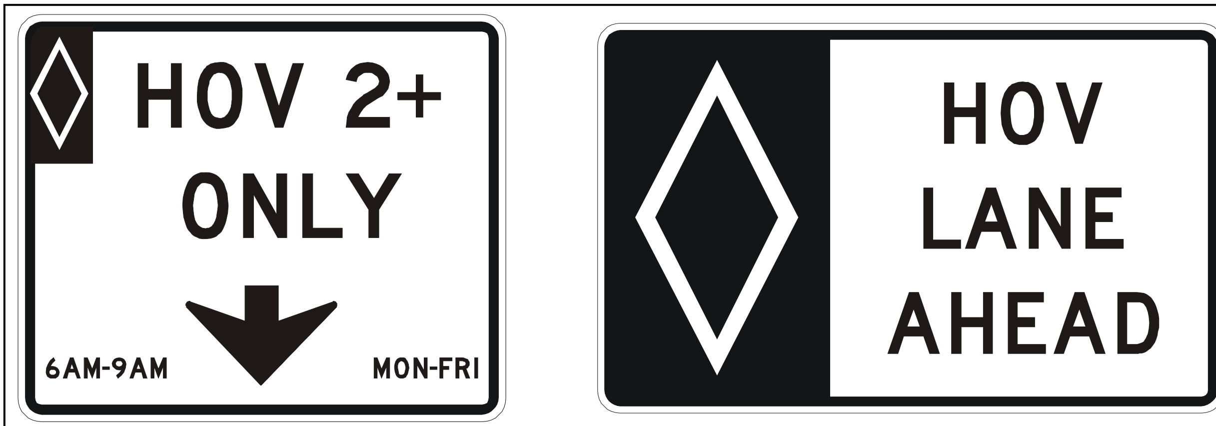


Figure 5-4. Advance Signing for HOV Lane on I-635 (LBJ Freeway) in Dallas, Texas.

5.2.2 Overhead Signs

Overhead HOV signs shall be located in advance of and at all entry points to barrier-separated HOV lanes. The overhead advance regulatory sign (R3-13 or R3-15) shall be used in advance of all barrier-separated HOV lanes. The overhead HOV sign (R3-14) shall be used at the beginning or entry point to all barrier-separated HOV lanes. The R3-14 (overhead) signs should be used exclusively with preferential lanes for high-occupancy vehicles to indicate the particular vehicle-occupancy requirement and time restrictions applying to that lane. The R3-14 and R3-14a signs should be mounted directly over the lane. Figure 5-5 illustrates the R3-14 and R3-15 signs.



R3-14 **R3-15**

Figure 5-5. Overhead Regulatory Signs (Adapted from Reference *18*).

Legend formats for the overhead High-occupancy Vehicle Only (R3-14) sign should have the following sequence:

- ♦ Top Line: HOV 2+ (lane occupancy requirement such as 2+, 3+, or 4+, or other applicable turning movement). [Also, the diamond symbol may be used instead of the word message HOV. The diamond symbol on the HOV preferential lane signs (R3-11, R3-13, and R3-14) should appear in the top-left quadrant. The diamond symbol *should not* be used on the bus, taxi, or bicycle preferential lane signs.]

- ♦ Middle Line (to be used with permitted movements): Where additional movements are permitted from an HOV lane on an approach to an intersection, the middle line legend format may be modified to accommodate the permitted movements (for example, RIGHT TURNS ONLY) on the R3-11 and R3-14 signs.

- ♦ Bottom Lines: Applicable time and day, with the time and day separated by a down arrow (for example, 7-9 AM, 4-6 PM, MON-FRI).

Figures 5-6 and 5-7 show examples of overhead signs.

Figure 5-6. Overhead Signing on Reversible HOV Facility at Park-and-Ride Lot on US 290 (Northwest Freeway) in Houston, Texas.

Figure 5-7. Overhead Exit Signing on I-30
(East R. L. Thornton Freeway) in Dallas, Texas.

5.2.3 Ground-mounted Signs

Ground-mounted HOV regulatory signs (R3-10, R3-11, and R3-12) shall be used only as a supplement to overhead HOV signs (R3-13 and R3-14) in advance of and at the entry to barrier-separated HOV lanes. The R3-11 and R3-11a (ground-mounted) signs should be used exclusively with preferential lanes for high-occupancy vehicles to indicate the particular vehicle-occupancy requirement and time restrictions applying to that lane. (The R3-11b [ground-mounted] or R3-14a [overhead] word message signs should be used in situations where a preferential lane is not an HOV lane but is designated exclusively for bus and/or taxi use. Figure 5-8 illustrates these signs.) The R3-11, R3-11a, and R3-11b signs should be located adjacent to the preferential lanes.

Legend formats for the ground-mounted High-occupancy Vehicle Only (R3-11 series) signs should have the following sequence:

- Top Lines: Lanes Applicable (for example, CENTER LANE, CURB LANE, RIGHT 2 LANES, THIS LANE).
- Middle Lines: HOV 2+ ONLY (lane occupancy requirement such as 2+, 3+, or 4+, or other applicable turning movement) [The diamond symbol may be used instead of the word message HOV. The diamond symbol on the HOV preferential lane signs (R3-11, R3-13, and R3-14) should appear in the top-left quadrant. The diamond symbol *should not* be used on the bus, taxi, or bicycle preferential lane signs.] Also, where additional movements are permitted from an HOV lane on an approach to an intersection, the middle line legend format may be modified to accommodate the permitted movements (for example, RIGHT TURNS ONLY) on the R3-11 and R3-14 signs.
- Bottom Lines: Applicable time and day (for example, 7-9 AM, 4-6 PM, MON-FRI).

Signs R3-11, R3-11a, R3-14, and R3-14a may be used to supplement overhead lane control signals or changeable message signs that are used to convey preferential lane restrictions.

Figure 5-8 shows legend formats, and Figures 5-9 and 5-10 illustrate examples of ground-mounted signs. Figure 5-11 illustrates the use of a changeable message sign with HOV lanes.

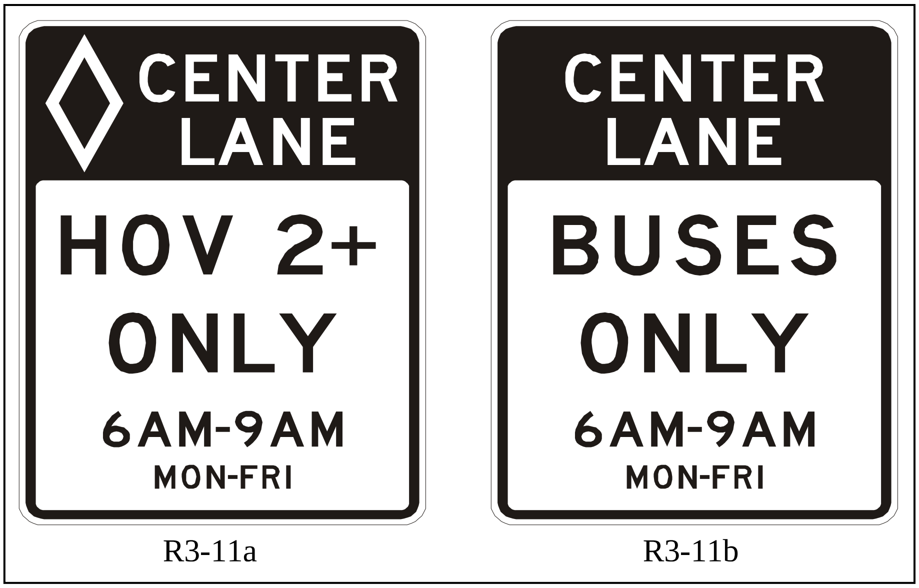


Figure 5-8. Examples of Ground-mounted Signs (Adapted from Reference *18*).

Figure 5-9. Ground-mounted Sign on US 290 (Northwest Freeway) in Houston, Texas.

Figure 5-10. Ground-mounted Sign for Park-and-Ride Lot on US 290 (Northwest Freeway) in Houston, Texas.

Figure 5-11. Changeable Message Sign on I-30 (East R. L. Thornton Freeway) in Dallas, Texas.

5.3 PAVEMENT MARKINGS

Where a preferential lane use is established, the preferential lane shall be marked with symbol or word markings for the lane use specified. Signs or signals shall be used with the preferential lane word or symbol markings. All preferential lane word and symbol markings shall be *white*. Also, all preferential lane word and symbol markings shall be positioned laterally in the *center* of the preferred-use lane. Preferential lane longitudinal markings for motorized vehicles shall be marked with the appropriate word or symbol pavement markings.

5.3.1 Word or Symbol Markings

The preferential lane use marking for high-occupancy vehicle lanes shall consist of white lines formed in a diamond shape. The diamond shape shall be at least 2.5 feet (0.75 m) wide and 12 feet (3.7 m) in length. The lines shall be at least 6 inches (150 mm) in width. The vehicle-occupancy requirements for an HOV lane may be included in sequence after the diamond symbol. The word message HOV may be used instead of the diamond symbol.

The spacing of the markings is an engineering judgment that is based on the prevailing speed, block lengths, distance from intersections, and other factors that affect clear communication to the road user. Markings spaced as close as 80 feet (24 m) apart might be appropriate on city streets, while markings spaced 1000 feet (300 m) might be appropriate for freeways.

Figures 5-12 and 5-13 show examples of symbol and word pavement markings.

Figure 5-12. Diamond Pavement Marking on US 290 (Northwest Freeway) Terminus to Northwest Transit Center.

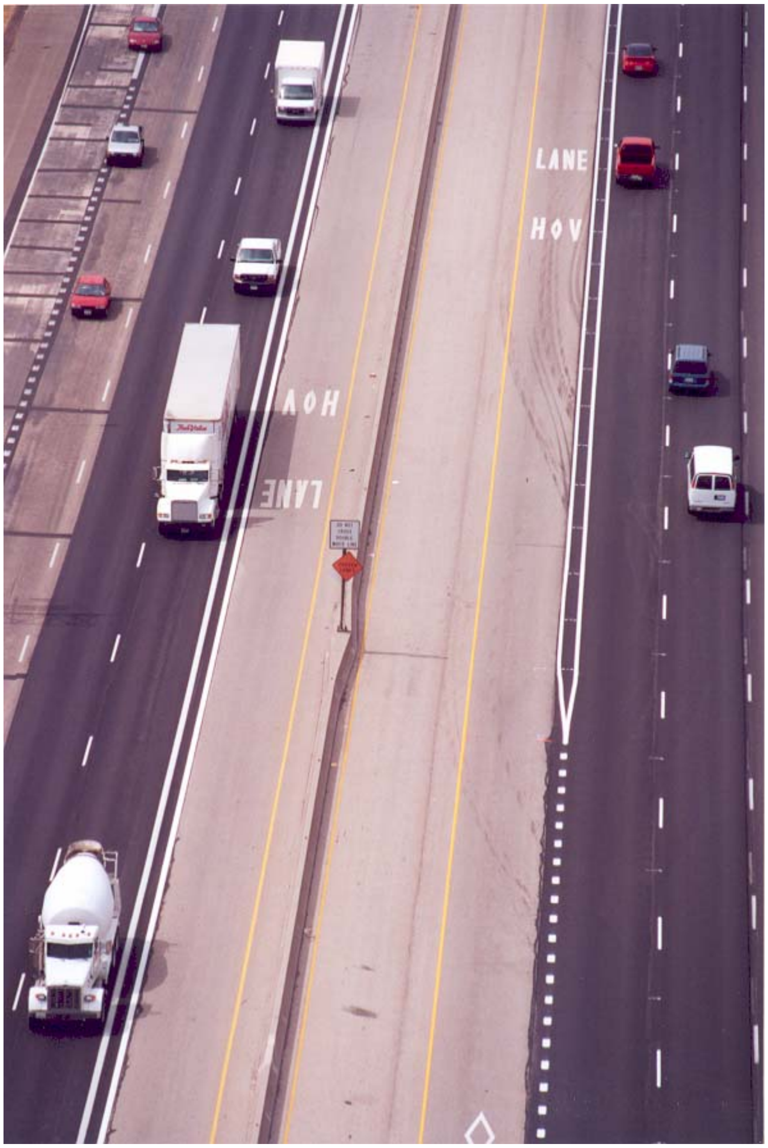


Figure 5-13. Word and Diamond Pavement Markings on I-35E (Stemmons Freeway) in Dallas, Texas.

5.3.2 Longitudinal Markings

HOV lanes may be physically separated from the other travel lanes by a barrier, median, or painted neutral area, or they may be concurrent with other travel lanes and separated only by longitudinal pavement markings. Table 5-1 includes markings for these conditions.

Figures 5-14 and 5-15 show examples of longitudinal pavement markings in Texas. Additionally, typical markings for preferential lanes are illustrated in Figure 5-16.

5.3.3 Other Notes

Engineering judgment should determine the need for supplemental devices such as tubular markers, traffic cones, or flashing lights.

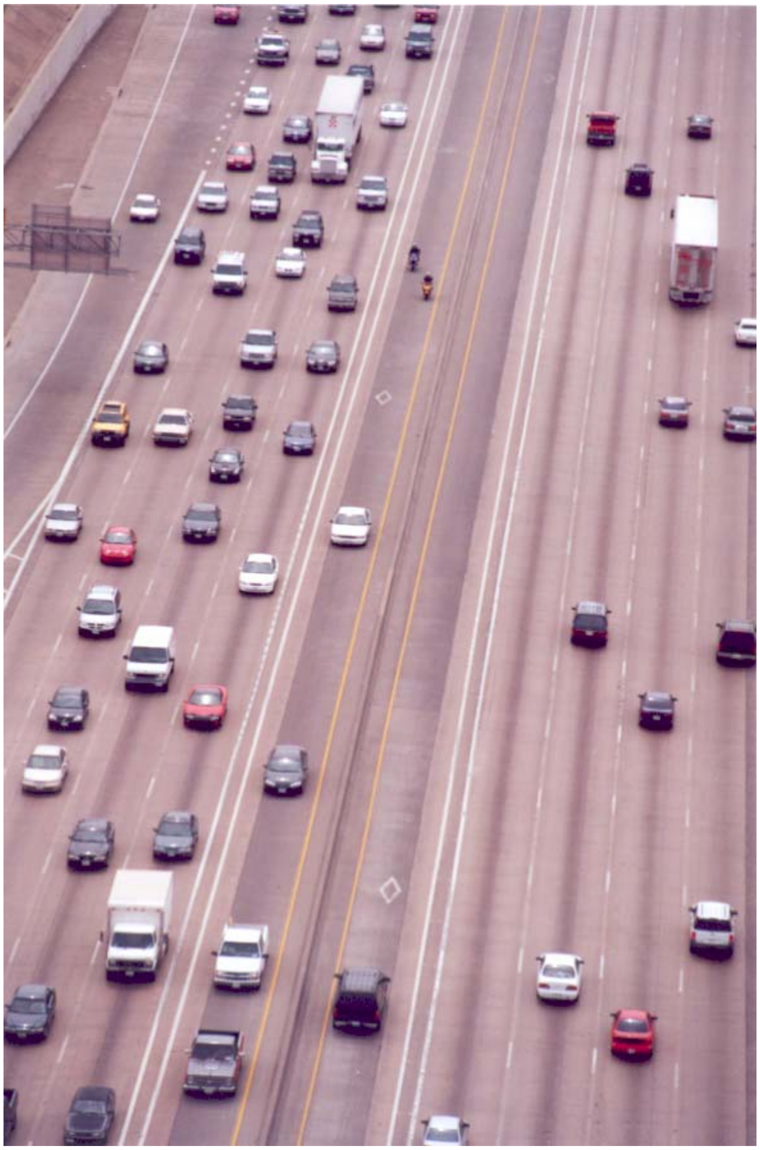


Figure 5-14. Pavement Markings on I-635 (LBJ Freeway) in Dallas, Texas.

(Buffer-separated lanes, separated by double solid white lines)

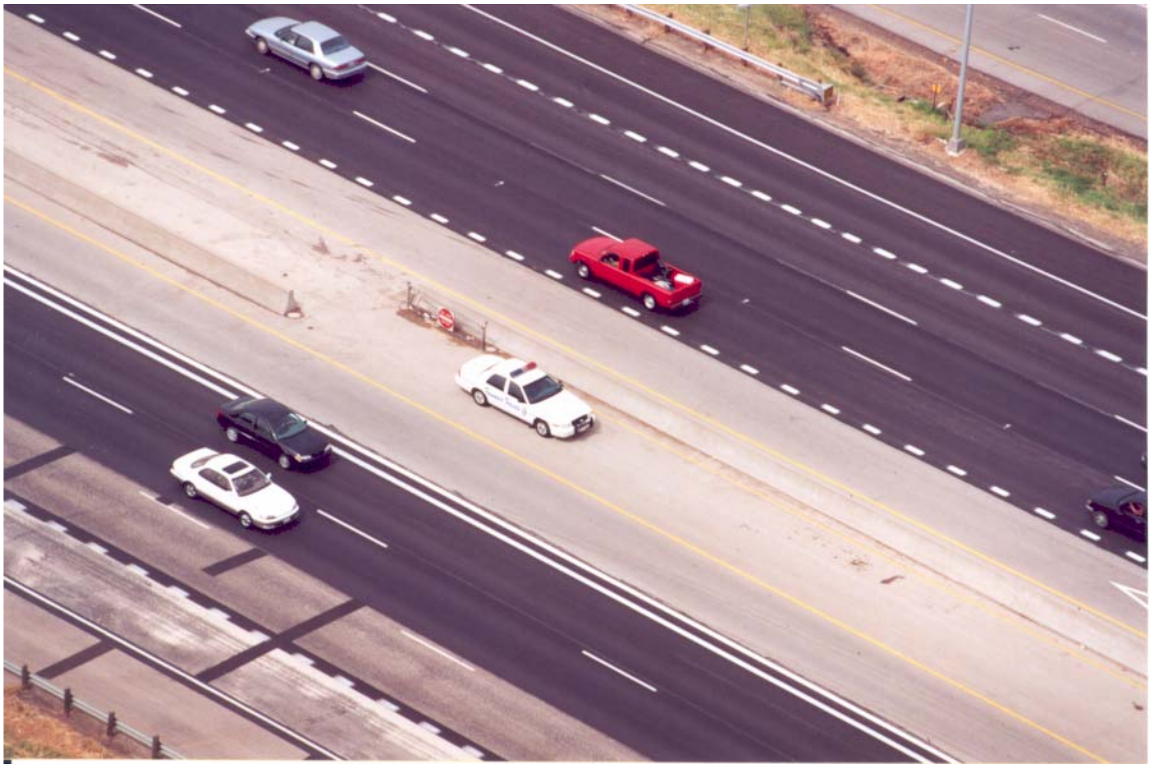


Figure 5-15. Pavement Markings on I-35 (Stemmons Freeway) in Dallas, Texas.
(Limited access point indicated by dashed white line)

Table 5-1. Standard Edge Line Lane Markings for Preferential Lanes (Adapted from Reference *18*).

Type of Preferential Lane	Left Edge Line	Right Edge Line
Physically separated, non-reversible	A single normal solid yellow line	A single normal solid white line (see Figure 5-16a)
Physically separated, reversible	A single normal solid white line	A single normal solid white line (see Figure 5-16a)
Concurrent flow - left side	A single normal solid yellow line	A double solid white line where crossing is prohibited (see Figure 5-16b) A single solid wide white line where crossing is discouraged (see Figure 5-16c) A single broken wide white line where crossing is permitted (see Figure 5-16d)
Concurrent flow - right side	A double solid wide white line where crossing is prohibited (see Figure 5-16b) A single solid wide white line where crossing is discouraged (see Figure 5-16c) A single broken wide white line where crossing is permitted (see Figure 5-16d) A single dotted normal white line where crossing is permitted for any vehicle to perform a right-turn maneuver (see Figure 5-16e)	A single normal solid white line
Notes: If there are two or more preferential lanes, they shall be separated with a normal broken white line. When concurrent flow preferential lanes and other travel lanes are separated by more than 4 ft (1.2 m), chevron markings should be placed in the neutral area. The chevron spacing should be 100 ft (30 m) or greater. For full-time or part-time concurrent flow preferential lanes, the spacing or skip pattern of the single broken wide white line may be reduced. The width of the single broken wide white line may be increased.		

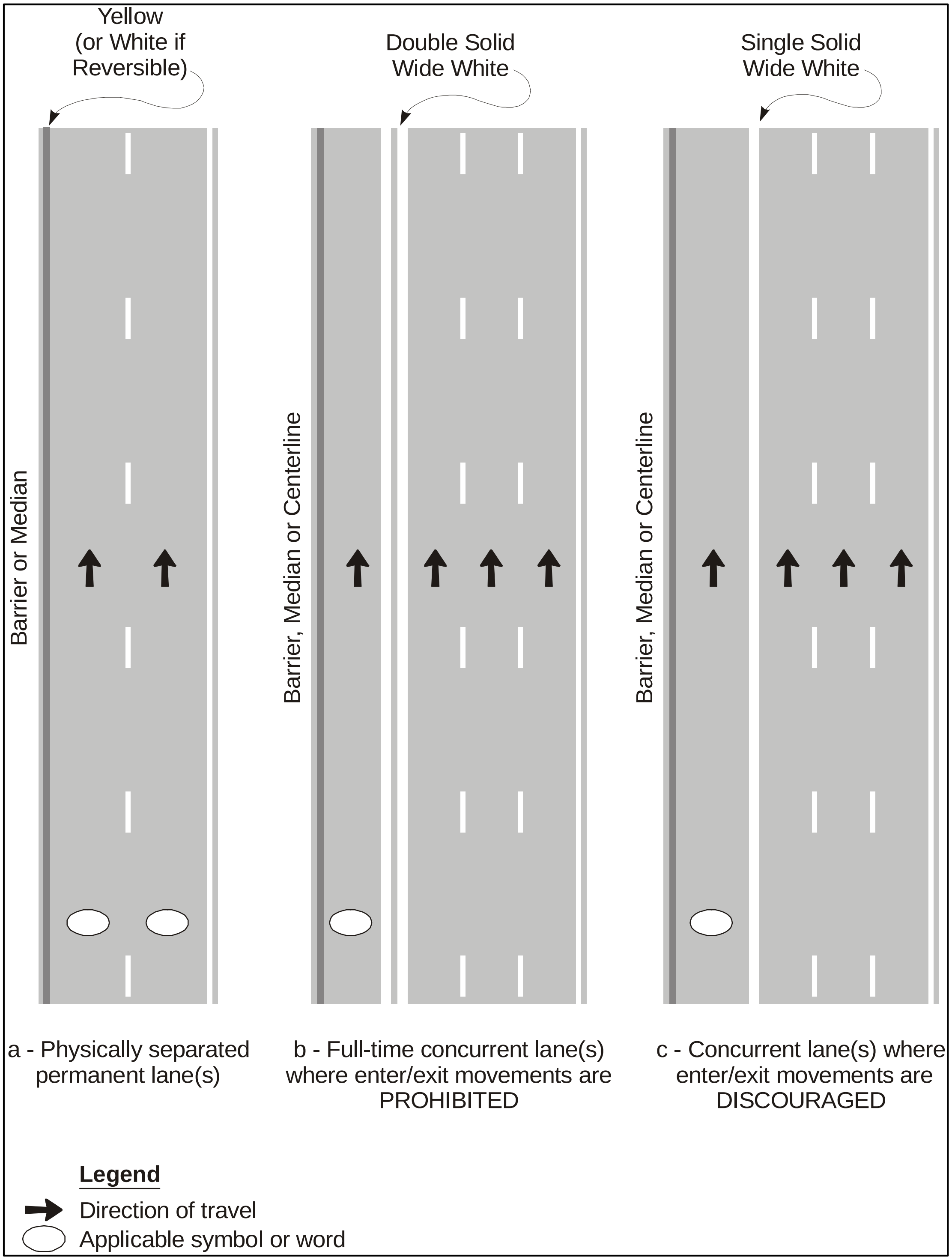


Figure 5-16. Pavement Markings for Concurrent Lanes (Adapted from Reference *18*).

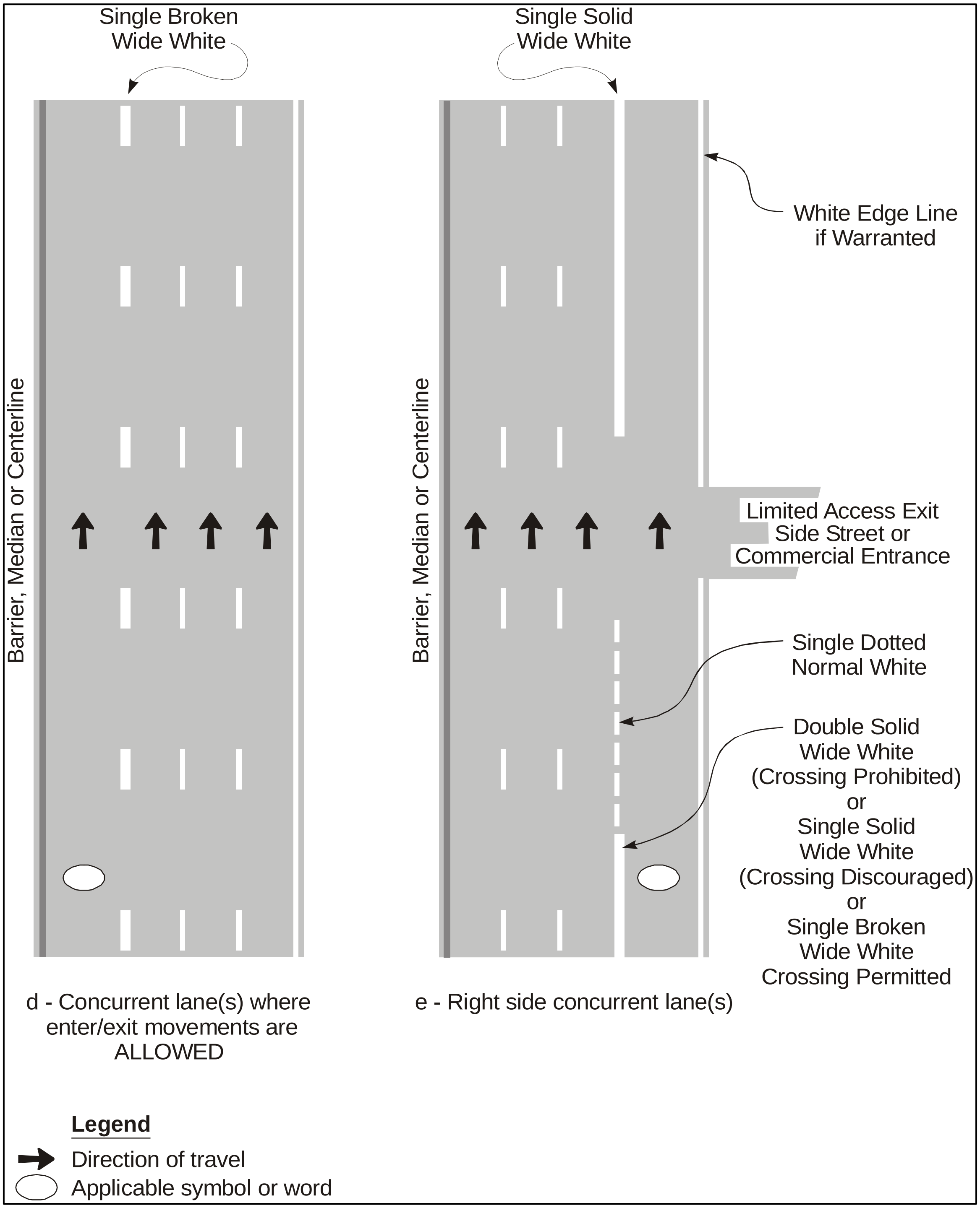


Figure 5-16. Pavement Markings for Concurrent Lanes (Continued)
(Adapted from Reference *18*).

CHAPTER 6

ADDITIONAL RESEARCH NEEDS

6.0 BACKGROUND AND PROJECT OBJECTIVES

Several areas for additional research for managed lane facilities have been identified in the *HOV Systems Manual* (*4*). More recently, the Transportation Research Board's HOV Systems Committee has identified research topics in the area of managed lanes (*19*). This chapter summarizes some of these research needs as well as items identified during the completion of this research effort.

Operational Elements. Additional research is needed to assess the full range of approaches for managing demand on managed lane facilities and the operational steps required to implement these techniques. Strategies to be considered include changing vehicle-occupancy requirements, variable time of day restrictions, allowing lower occupancy or single-occupancy vehicles to use the facility for a fee, or other options.

Design. There is a need for work that investigates where to locate general-purpose access locations to the freeway upstream and downstream of access locations from general-purpose lanes to managed lanes. There is also a need for investigating the location and design of electronic transponders, the possible use of toll booths, and other related elements for managed lanes where priority pricing is planned.

Enforcement. There is a need to reexamine automated technologies for enforcement of managed lane facilities and for information about the legal and legislative issues to providing ticketing by mail. There is also a need for further work that investigates the enforcement of managed lane facilities in retrofit locations.

Safety. There is a need for research that identifies the safety differences between various types of managed lanes (e.g., barrier-separated versus non-barrier-separated facilities) and operating scenarios.

Monitoring and Evaluation. There is a need for updates to managed lane monitoring, evaluation, and reporting practices that include all user groups and revenue generation for toll facilities.

Air Quality. Fuel consumption and emissions modeling tools to identify the cost effectiveness of managed lane alternatives are needed.

Simulation Tools. Improvements in existing simulation models and new models are needed to better access managed lane alternatives, access options, and operational strategies.

Assessment of Low-Emission Vehicles (LEVs) on Managed Lanes. Many issues related to allowing LEVs on managed lanes need to be addressed, including how to identify the vehicles and legal and legislative needs.

Handling Revenue. In addition to the physical considerations of transponder reader locations and access design, there are many issues related to pricing projects that require additional research. Monthly account management, distributing transponders, and where the revenue goes must be considered. For example, for public projects, if there is additional revenue beyond operation, debt, and maintenance, the money can be returned to the corridor in numerous ways (e.g., transit improvements).

Signing and Driver Information. Techniques for communicating managed lane-operating conditions, toll amount, eligible vehicles, etc. with the driver are also needed.

REFERENCES

1. Technical Memorandum. Project 0-4160, *Operating Freeways with Managed Lanes*. Memorandum 4160-2, Definition of Managed Lanes. Texas Department of Transportation. January 10, 2001.

2. Stockton, W.R., G.F. Daniels, D.A. Skowronek, and D.M. Fenno. *An Evaluation of High-occupancy Vehicle Lanes in Texas, 1997*. Research Report 1353-6, Texas Transportation Institute, College Station, Texas. November 1999.

3. Turnbull, K.F. Evolution of High-occupancy Vehicle Facilities: Maximizing Efficiency and Effectiveness. In *TR News*, TRB, National Research Council, Washington, D.C., May-June 2001, Number 214.

4. Texas Transportation Institute, Parsons Brinckerhoff Quade and Douglas, and Pacific Rim Resources. *NCHRP Report 414: HOV Systems Manual*. TRB, National Research Council, Washington, D.C., 1998.

5. *Guide for the Design of Park-and-Ride Facilities*. American Association of State Highway and Transportation Officials. Washington, D.C., 1992.

6. American Association of State Highway and Transportation Officials. *Guide for the Design of High-occupancy Vehicle Facilities*. American Association of State Highway and Transportation Officials, Washington, D.C., 1992.

7. Institute of Transportation Engineers Technical Committee 6A-37. *The Effectiveness of High-occupancy Vehicle Facilities*. Institute of Transportation Engineers, Washington, D.C., 1998.

8. Mounce, J.M. and R.W. Stokes. *Manual for Planning, Designing, and Operating Transitway Facilities in Texas*. Publication No. *FHWA/TX-851425-2*. Texas State Department of Highways and Public Transportation, Austin, Texas, September 1985.

9. California Department of Transportation (Caltrans) Division of Traffic Operations. *High-Occupancy Vehicle (HOV) Guidelines for Planning, Design, and Operations*. California Department of Transportation, Sacramento, California, July 1991.

10. Washington State Department of Transportation. *HOV Direct Access Design Guide*. Report No. M22-98. Washington Department of Transportation, Olympia, Washington, April 1998.

11. *New York State Department of Transportation Design Manual*. Transportation Research and Development Bureau, New York State Department of Transportation, State Campus, Albany, New York, May 1998.

12. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, D.C., 1994.

13. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, D.C., 2001.

14. Fuhs, C.A. *High-Occupancy Vehicle Facilities: A Planning, Design, and Operation Manual*. Parsons Brinckerhoff, Incorporated, New York, New York, 1990.

15. Lomax, T.J. *I-15 Corridor Advance Planning Study: High-occupancy Vehicle Facilities Review of Design Practice*. Prepared for Metropolitan Transit Development Board. August 1994.

16. *East R. L. Thornton Freeway (I-30) Interim Contraflow HOV Lanes Operating Manual.* Texas Department of Transportation and Dallas Area Rapid Transit. Revised February 1996.

17. Turnbull, K.F., K.M. Hall, and M.R. Ringrose. High-occupancy Vehicle Treatments on Toll Facilities. In *Transportation Research Record 1446*. TRB, National Research Council, Washington, D.C., 1994.

18. *MUTCD 2000: Millenium Edition with Errata No. 1 Changes*. United States Department of Transportation, Federal Highway Administration, June 14, 2001.

19. *Managed Lane Issues List*. TRB HOV Systems Committee. Draft. May 2001.

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