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16. Abstract Texas cities are currently considering the managed lane concept on major freeway projects. As a new concept of operating freeways in a flexible and possibly dynamic manner, it has a limited experience base, thereby creating a knowledge vacuum in emerging key areas that are critical for effective implementation. Complicating the effort is the rapid progress of several freeway improvement projects in Texas in which managed lane operations are proposed. The operational experience both in Texas and nationally for managed lanes is minimal, particularly for extensive freeway reconstruction projects. The objectives of this research project are to investigate the complex and interrelated issues surrounding the safe and efficient operation of managed lanes using various operating strategies and to develop a managed lanes manual to help the Texas Department of Transportation (TxDOT) make informed planning, design, and operational decisions when considering these facilities for its jurisdiction. This document presents three years of research in the form of a draft manual for managed lanes. It includes three chapters in draft form, which include a guide to the manual, an introduction to managed lanes, and design. This document includes research in a usable format, providing a clear, concise, and step-wise approach to planning, designing, operating, and enforcing a managed lanes facility. It also refers the user to other pertinent documents which provide additional detailed information on various aspects of managed lanes.					
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INTERIM MANUAL FOR MANAGED LANES

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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. This project was conducted in cooperation with the Texas Department of Transportation (TxDOT) and the U.S. Department of Transportation, Federal Highway Administration (FHWA). The contents do not necessarily reflect the official view or policies of the Federal Highway Administration or the Texas Department of Transportation. The report does not constitute a standard, specification, or regulation. The engineers in charge of the overall project were Beverly T. Kuhn (Texas P.E. #80308) and Ginger Daniels Goodin (Texas P.E. #64560). Other engineers leading portions of the research effort were Kay Fitzpatrick (Texas P.E. #86762), and Steven Venglar (Texas P.E. #84027).

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

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Chapter 1 – Guide to the Managed Lanes Manual

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Section 1 – Overview

A viable method for meeting mobility needs in Texas is the concept of “managed” lanes. This concept is growing in popularity across the country because they maintain free-flow travel speeds on designated lanes or facilities by providing controlled service to eligible groups of vehicles. These eligible user groups can vary by time of day or other factors depending on available capacity and the mobility needs of the community.

This manual provides a comprehensive guide to developing policies, planning, designing, implementing, marketing, operating, enforcing, evaluating, and monitoring managed lane facilities. The Managed Lanes Manual is a practical and easy-to-use reference for transportation professionals at all levels and with a variety of backgrounds. Policy makers can also use the manual to review the key elements associated with various aspects of managed lane projects.

This chapter provides a quick guide to the topics covered in the individual chapters and the format used throughout the manual.

- ◆ **Overall Conceptual Framework.** This manual is based on an overall framework for the comprehensive development of managed lanes projects. This section briefly describes this framework and the interrelated process for project development.
- ◆ **Chapters at a Glance.** This section provides a quick guide to the major topics covered in each of the chapters in the manual.
- ◆ **Chapter Format.** A common format is followed in the individual chapters to allow users to easily find topics of interest. This section highlights the major elements covered in each chapter.

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Section 2 – Overall Conceptual Framework

The process of developing a managed lanes project is complex and involves numerous steps. The type of users authorized to use a managed lane facility plays a critical role in the feasibility, design, and operation of a managed facility. A matrix of possible operating strategies for various eligible user groups can correlate eligibility decisions with realistic considerations for planning, designing, and operating a managed lane facility.

This manual was developed around a framework for supporting decisions related to the development of managed lane projects that depicts the sequential elements considered in implementing a managed lanes project. Features of the framework include the following:

- ◆ incorporation of financial goals, particularly those involving revenue generation, into the general policy framework;
- ◆ objective-based decision-making in determining potential user groups and the use of pricing for demand management and/or revenue generation;
- ◆ the combination of vehicle user groups and operating strategy as the basis for determining design parameters for the project;
- ◆ the involvement of other agencies in the process, as well as multiple opportunities for public input;
- ◆ a strong link between design and operations in the development of schematic design; and
- ◆ a re-evaluation process if expected performance does not meet desired outcomes.

As the backbone of the Managed Lanes Manual, this framework is the foundation of a user-friendly computer-based decision support system (DSS) or expert system that provides links to supporting resources and information within a constructed database and/or on the Internet. [Figure 1-1](#) illustrates this framework.

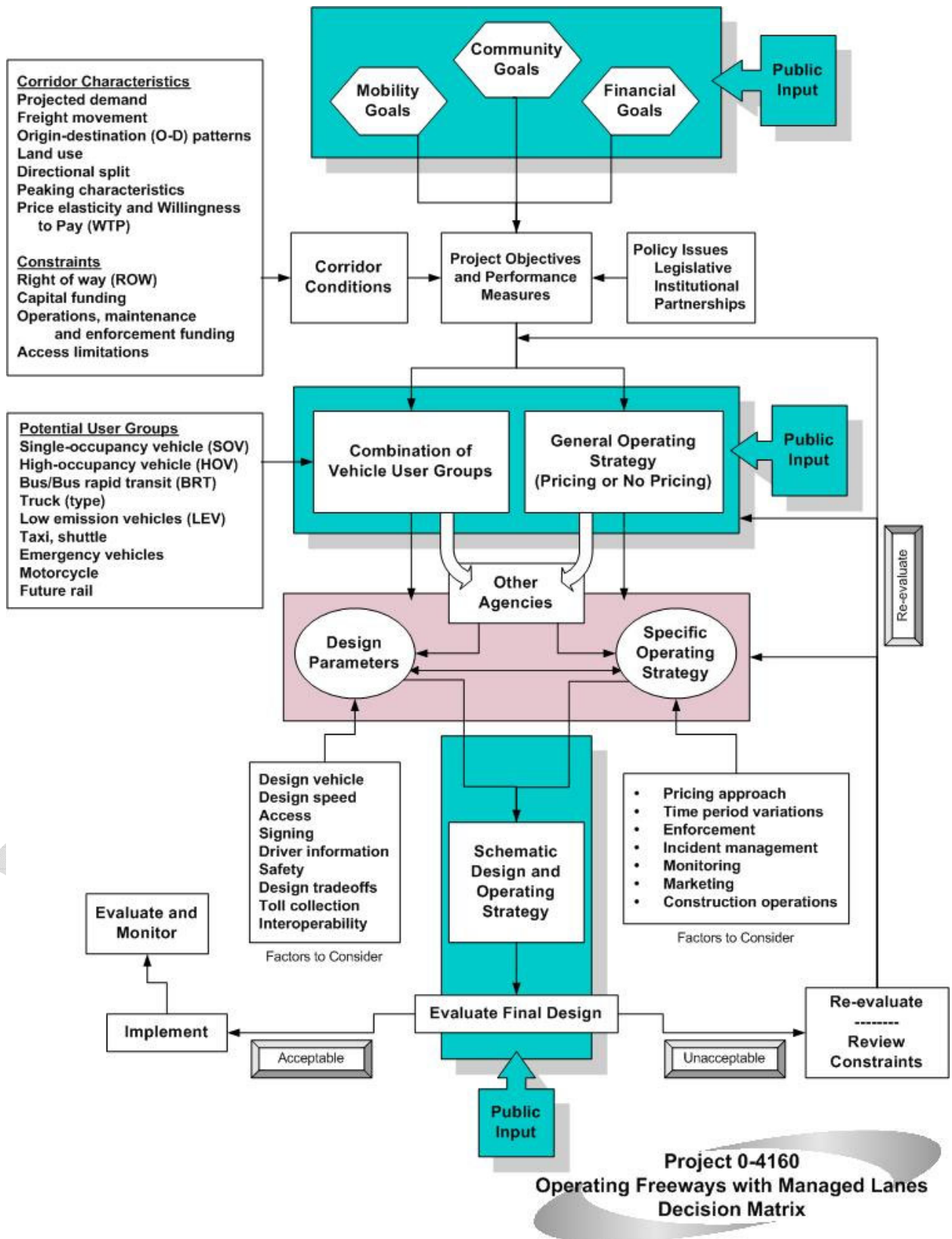


Figure 1-1. Overall Conceptual Framework.

Section 3 – Chapters at a Glance

The manual is divided into the following nine chapters. The titles of each chapter and the major topics covered are highlighted.

Chapter 1 – Guide to the Managed Lanes Manual. Provides a quick guide to the topics covered in the individual chapters and the format used throughout the manual.

Chapter 2 – Introduction to Managed Lanes. Discusses the definition of managed lanes, highlights the various types of managed lane operational strategies, and gives examples of them.

Chapter 3 – Planning Managed Lanes Facilities. Provides guidance on planning managed lanes projects, including identifying goals, objectives, information and data needs; selection of operational strategies and users; institutional partnerships and agency roles; and public input and outreach.

Chapter 4 – Managed Lanes Facility Design. Presents information on the basic elements of the geometric design considerations for managed lane facilities, including cross sections and design considerations for terminal and access treatments.

Chapter 5 – Enforcement

Chapter 6 – Incident Management

Chapter 7 – Interim Use and Special Operations

Chapter 8 – Monitoring and Evaluation

Chapter 9 – Administration and Staffing

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Section 4 – Chapter Format

The individual chapters follow a common format. This section highlights the elements included in the individual chapters.

Table of Contents

A table of contents is provided at the start of each chapter allowing users to easily find topics of interest.

List of Figures and Tables

Lists of figures and tables included in each chapter are provided for quick reference by the user.

Overview

Following the table of contents, an overview highlights the major topics covered in the chapter.

Specific Elements and Case Studies

The elements, issues, and activities related to the specific topic comprise the major portion of each chapter. Case study examples and information on specific projects are provided where appropriate.

References and Additional Information

The references used are provided at the end of each chapter. A listing of additional sources of information on topics covered in the chapter is also provided as needed within each chapter.

Cross-References

The manual provides cross-references to material contained in other sections as appropriate. In some instances, information discussed extensively in one chapter is briefly highlighted in another. In these cases, a reference to the more detailed description is provided.

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Section 1 – Overview

The increasing population growth in Texas has placed enormous demands on the transportation infrastructure, particularly the freeway systems. There is a growing realization that the construction of sufficient freeway lane capacity to provide free-flow conditions during peak travel periods cannot be accomplished in developed urban areas due to cost, land consumption, neighborhood impacts, environmental concerns, and other factors. Like other transportation agencies nationwide, TxDOT is searching for methods to better manage traffic flow and thus improve the efficiency of existing and proposed networks.

A viable method for meeting mobility needs is the concept of “managed” lanes. Managed lanes maintain free-flow travel speeds on designated lanes or facilities by providing controlled service to eligible groups of vehicles, which can vary by time of day or other factors depending on available capacity and the mobility needs of the community.

Sections in this chapter cover:

- ◆ Definition of Managed Lanes,
- ◆ Managed Lane Operational Strategies,
- ◆ High-Occupancy Vehicle Lanes,
- ◆ Value-Priced Lanes and High-Occupancy Toll Lanes,
- ◆ Exclusive Lanes,
- ◆ Separation/Bypass Lanes,
- ◆ Lane Restrictions, and
- ◆ Dual Facilities.

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Section 2 – Definition of Managed Lanes

The term “managed lanes” is ambiguous and can mean different things to different stakeholders in the transportation industry. One managed lane facility might cater to commuters while another might provide preferred service to heavy trucks. The user groups they serve are a function of a region’s mobility needs and the policies of operating agencies. The broad meaning of managed lanes emphasizes their usefulness as a tool to enhance mobility.

TxDOT Definition

TxDOT defines a managed lane facility as one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals.

Focus on Flexibility

This definition is very general, yet it reflects the complex and flexible nature of managed lanes. It allows each district across Texas to determine what “managed lanes” means for that jurisdiction. It respects the needs of the community without requiring the application of a specific strategy that does not meet those needs. It also encourages flexibility, realizing that the needs of a corridor, region, or district may change over time, thereby requiring a different managed lane operational strategy or combination of multiple strategies.

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Section 3 – Managed Lane Operational Strategies

Managed lane operational strategies include high-occupancy vehicle (HOV) lanes, value-priced lanes or high-occupancy toll (HOT) lanes, exclusive-use lanes such as bus or truck lanes, separation and bypass lanes, dual-use lanes, and lane restrictions. Managed lanes support increased efficiency of traffic on existing roadways and generally meet the following transportation systems management goals outlined in the Guide for the Design of High Occupancy Vehicle Facilities (1), which were originally developed for HOV lanes:

- ◆ improve operating level of service for high-occupancy vehicles, both public and private, thereby maximizing person-moving capacity of roadway facilities;
- ◆ provide fuel conservation;
- ◆ improve air quality by reducing pollution caused by delay and congestion; and
- ◆ increase overall accessibility while reducing vehicular congestion (1).

Variety of Terms

Strategies, terms, and acronyms are often used interchangeably to describe a particular managed lane action or variation of a design without strict adherence to definitions. For example, what may be described by one jurisdiction as a high-occupancy toll lane is described by another jurisdiction as a value express lane. Meanwhile, a third entity might use the term value express lane for a totally different strategy. Within this manual, the various strategies are defined for use in Texas, which may not necessarily coincide with traditional definitions for all areas of the country.

Managed Lane Operational Strategies

The remainder of this chapter discusses in detail the different types of managed lane operational strategies, including various operational issues related to their implementation. Those strategies discussed in the following sections are:

- ◆ HOV lanes,
- ◆ value-priced and HOT lanes,
- ◆ exclusive lanes,
- ◆ mixed flow separation/bypass lanes,
- ◆ lane restrictions, and
- ◆ dual facilities.

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Section 4 – High-Occupancy Vehicle Lanes

HOV lanes are separate lanes that are restricted to vehicles with a specified occupancy and may include carpools, vanpools, and buses (2). They are designed to increase the person-moving capacity of the existing infrastructure (3). Most HOV facilities require that vehicles have two or more (2+) occupants to legally use the facility; however, some facilities require three or more (3+) occupants during peak travel times (4).

HOV lanes can be implemented on either arterials or freeways. When implemented on freeways, three types of facilities are used—separated roadway, concurrent flow lanes, and contraflow lanes (1). Also, the separated roadway facility may be either a two-way facility or a reversible-flow facility.

Separated Two-Way HOV Lanes

The separated HOV facility is physically separated from main lanes or general-purpose lanes of the freeway with either a concrete barrier or a wide painted buffer. The lanes may be either two-way or reversible. Two-way separated HOV lanes usually consist of one lane in each direction, often have limited access, and may have their own direct ingress and egress treatments (3). Figure 2-1 illustrates a two-way barrier-separated HOV lane in Los Angeles on IH-10 (El Monte). Note that in this segment of the facility, the two directions of flow are reversed so that the bus doors align with the center bus platforms (5).



Figure 2-1. IH-10 (El Monte) Two-Way, Barrier-Separated HOV Lane, Los Angeles, California (5).

The reversible lane is the most common type of separated lane HOV facility. As illustrated in [Figure 2-2](#), the reversible lane consists of a separated lane or lanes where the direction of travel changes by time of day. A reversible HOV lane typically operates as an inbound lane in the morning and reverses to an outbound lane in the afternoon. This flow reversal allows maximum use of the lane during peak hours.

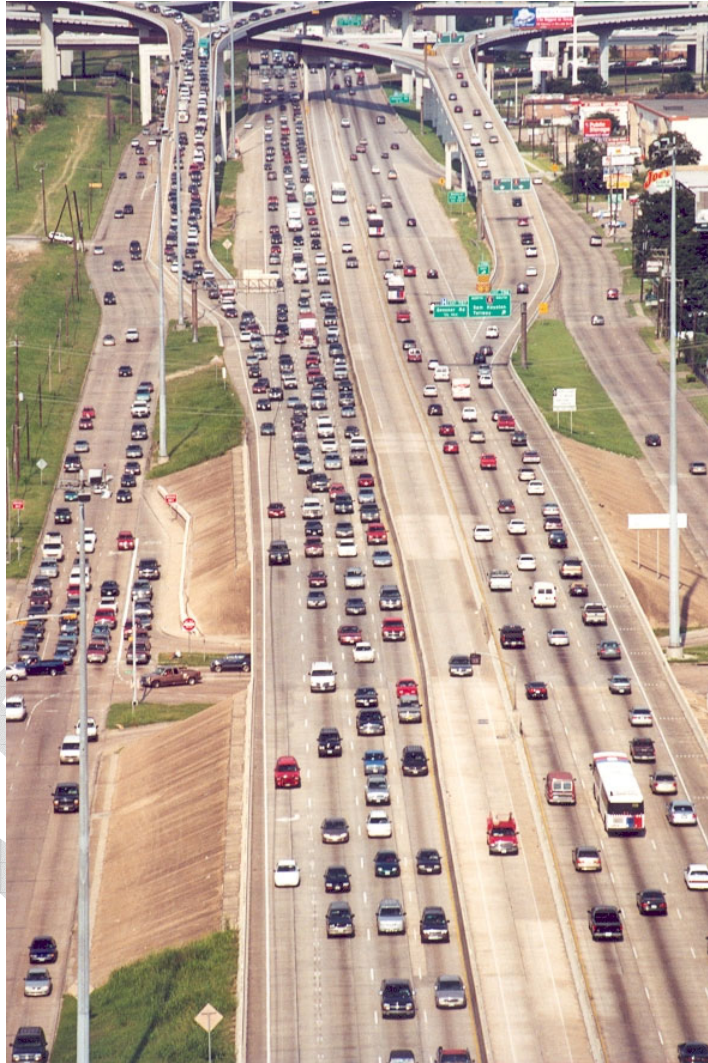


Figure 2-2. IH-10 (Katy) Reversible, Barrier-Separated HOV Lane, Houston, Texas.

Concurrent Flow HOV Lanes

A concurrent flow HOV lane is a freeway lane that flows in the same direction as the rest of traffic and is not physically separated from the main lanes of the freeway. Either a buffer or distinctive paint striping may separate the HOV lane from other traffic lanes. The lane, also referred to as a “diamond” lane, is often the inside lane of the roadway (3). This is the most common type of HOV lane. [Figure 2-3](#) illustrates a concurrent flow HOV lane in each direction in the center of the roadway. In this example, the HOV lanes

are separated from the general purpose lanes with a buffer that is marked with white striping.



Figure 2-3. IH-635 (LBJ) Concurrent Flow, Buffer-Separated HOV Lane, Dallas, Texas.

Contraflow HOV Lanes

A contraflow HOV lane is a freeway lane in the off-peak direction of travel that is used for travel by vehicles in the peak direction. For example, an inbound lane is used for outbound travel from the downtown area during the afternoon peak period. The inside lane of the off-peak segment is normally the lane selected, and the lane is separated from off-peak traffic by some type of changeable or moveable barrier or physical treatment (2). Although buses primarily use this type of HOV lane, some contraflow lanes allow use by all multiple occupant vehicles. Figure 2-4 illustrates an early contraflow lane in Houston from the late 1970s that was originally only open to buses and authorized vanpools. A current contraflow HOV lane in operation in Atlanta on IH-75 is shown in Figure 2-5 where the lanes are separated by a distinct pavement striping pattern.



Figure 2-4. IH-45 (North) Contraflow HOV Lane, Houston, Texas (5).



Figure 2-5. IH-75 Contraflow HOV Lane, Atlanta, Georgia (5).

Expectations and Constraints

The number of operating HOV lanes being proposed and implemented throughout North America is steadily increasing. This trend in popularity indicates that HOV lanes are a widely accepted strategy for addressing traffic mobility in metropolitan areas. However, HOV facilities are not appropriate for all situations, and each facility should be evaluated and monitored to ensure the facility is meeting the goals and expectations of the community (6). Expectations and objectives for a successful HOV lane include moving people, benefiting transit, and improving overall roadway efficiency. Constraints that may affect the successful implementation of strategies involving HOV lanes include adverse impact on general-purpose lanes, cost-effectiveness, public acceptance, and the environmental impact of implementation (2).

Section 5 – Value-Priced Lanes and High-Occupancy Toll Lanes

A HOT lane is an HOV lane that allows vehicles with lower occupancy to have access to the lane by paying a toll. Variations of HOT lanes are value-priced, value express, and fast and intertwined regular (FAIR) lanes, which may or may not be occupancy driven depending on the region or state. Value express lanes, as proposed by the Colorado DOT, are similar to HOT lanes (7). In most cases, value lanes and FAIR lanes are toll lanes. However, some jurisdictions use these terms to describe strategies similar to a HOT lane. Figure 2-6 shows the HOV and express toll lanes in operation on IH-15 in San Diego, California, where single occupant vehicles (SOVs) are tolled and HOV 2+ travel on the lanes for free.



Figure 2-6. IH-15 HOV/HOT Lanes, San Diego, California (5).

The idea behind HOT lanes is to improve the HOV lane utilization and sell unused lane capacity (2). For a HOT lane to be successful, the following assumptions should be present:

- ◆ HOT lanes should be incorporated with HOV lanes that are currently in existence or planned for construction.
- ◆ There must be recurring congestion where the HOT lanes could help drivers avoid congestion by paying a toll.
- ◆ HOT lanes cannot take away an existing main lane in order to be created.
- ◆ HOT lanes are not self-supporting (7).

The key to success for HOT lanes is to manage the number of vehicles to maximize the use of the HOV lane without exceeding capacity and creating congestion. One way to manage a HOT lane is through the use of dynamic toll pricing. The toll is a variable toll that changes frequently, as often as every 5 minutes, with the price of the toll increasing with the level of congestion. As the toll increases, the number of motorists willing to pay the toll will decrease, thereby managing lane use (7).

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Section 6 – Exclusive Lanes

The operational strategy of exclusive lanes provides certain vehicles, usually designated by vehicle type, an exclusive operational lane. The most common types of vehicles designated for this strategy are buses and large trucks. Buses are often given exclusive lanes to provide an incentive for riders by decreasing delay, whereas trucks are separated in an attempt to decrease the effects of trucks on safety and reduce conflicts by the physical separation of truck traffic from passenger car traffic.

It should be noted that until recently, very few truly exclusive facilities existed, and many of those facilities actually restricted trucks and/or buses to specified lanes and allowed other vehicles to use any lane (8). In recent years, a number of truly exclusive busways have been implemented in various metropolitan areas.

Exclusive Busways

A busway is a bus-only roadway that is separated from the rest of the traffic. The busway, which acts like a “surface subway,” allows buses to receive traffic signal preference, thus bypassing stoplights, or to cross over intersections on overpasses (9). Busways may be considered a cost-effective alternative to either subways or light rail and are being implemented by a number of cities. Advantages of busways include flexibility, self-enforcement, incremental development, low construction costs, and implementation speed (10). Figure 2-7 shows a busway in operation in Pittsburgh, Pennsylvania, constructed in various rail rights-of-way.



Figure 2-7. East Busway, Pittsburgh, Pennsylvania (5).

Exclusive Truck Lanes

The issue of increasing truck traffic is of vital concern to both traffic managers and the general public. Highway traffic operations are the “yardstick” by which the user measures the quality of the facility. The characteristics that matter most to the driver are speed of travel, safety, comfort, and convenience. As a result of increasing demand on highways, many transportation agencies have implemented a variety of strategies or countermeasures for trucks in an attempt to mitigate the effects of increasing truck traffic, including exclusive truck lanes.

For example, California operates a truck roadway on IH-5 in the Los Angeles area, as shown in [Figure 2-8](#). While passenger cars are allowed to use the facility, trucks are the primary users. This roadway is a segment of controlled access facility involving significant grades, so truck speeds are slower than free-flow speeds of passenger cars especially in the northbound (uphill) direction. The truck roadway allows trucks to regain speed at the top of the hill before merging with other traffic.



Figure 2-8. IH-5 Truck Roadway, Los Angeles, California.

Feasibility studies regarding restrictions and exclusive lanes found that exclusive barrier-separated facilities were most plausible for congested highways where three factors exist: truck volumes exceed 30 percent of the vehicle mix, peak-hour volumes exceed 1800 vehicles per lane-hour, and off-peak volumes exceed 1200 vehicles per lane-hour (11).

Theoretically, truck facilities could have positive impacts on noise and air pollution, fuel consumption, and other environmental issues. Creating and maintaining an uninterrupted flow condition for diesel-powered trucks will result in a reduction of emissions and fuel

consumption when compared to congested, stop-and-go conditions. However, the creation of a truck facility may also shift truck traffic from more congested parallel roadways, thereby shifting the environmental impacts. There may also be increases in non-truck traffic on automobile lanes due to latent demand.

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Section 7 – Separation/Bypass Lanes

The separation or bypass lane is a treatment for a specific section or segment of roadway. Several areas have successfully used this management strategy that often addresses a roadway segment that has a unique feature or characteristic, such as a weaving area, a significant grade, high percentage of truck traffic, and/or congestion. For example, weaving areas present an operational concern because the “crossing” of vehicles creates turbulence in the traffic streams. Trucks limit the visibility and maneuverability of smaller vehicles attempting to enter and exit the freeway system. An indication of the barrier effect is an over-involvement of trucks in weaving area crashes, rear-end collisions, and side collisions. Some studies have shown that this problem may be magnified when a differential speed limit is present (12, 13).

Figure 2-9 illustrates a ramp meter bypass lane in use in Minneapolis near downtown on I-35 West near the I-94 interchange. The purpose of this particular lane is to provide special priority to transit vehicles and allow them to bypass the ramp meters that control the two general purpose lanes providing access to the freeway.



Figure 2-9. Ramp Meter Bypass Lane, Minneapolis, Minnesota (5).

Figures 2-10 and 2-11 show other uses of bypass lanes to provide priority access to identified user groups. Figure 2-10 illustrates the use of bypass lanes to provide priority for carpools and buses with three or more occupants approaching the toll plaza on the San Francisco/Oakland Bay Bridge. The bypass lanes provide a time savings for HOVs anywhere from 10 to 20 minutes during the morning peak period. Figure 2-11 shows how Seattle provides queue bypass lanes for HOVs at ferry landings, thereby reducing the wait time for HOVs during the peak travel period.



Figure 2-10. IH-80 Bay Bridge Queue Bypass, Oakland, California (5).



Figure 2-11. HOV Queue Bypass, Coleman Dock Ferry, Seattle, Washington (5).

A truck bypass facility exists on a section of northbound IH-5 near Portland, Oregon, at the Tigard Street interchange; it is similar to some of the California facilities. The bypass lane requires trucks to stay in the right lane, exit onto a truck roadway, and reenter traffic downstream of the interchange. Passenger cars are also allowed to use the bypass

facilities. One reason this facility is needed is that a significant grade exists on the main lanes of IH-5. Without the truck roadway, larger vehicles would be forced to climb a grade and then weave across faster moving traffic that enters the main lanes from their right. The resulting speed differentials caused by trucks performing these maneuvers created operational as well as safety problems prior to the implementation of the bypass facility. Truck speeds are now typically 50 mph in the merge area; prior to implementation of the bypass lane, truck speeds were 20 to 25 mph. There were no specific cost data available for construction of the bypass lane (14).

Interstate 5 north of Los Angeles is a corridor with a very heavy volume of truck traffic. In the 1970s, Caltrans built truck bypass lanes on IH-5 near three high-volume interchanges. The lanes were built to physically separate trucks from other traffic and to facilitate weaving maneuvers in the interchange proper. The first truck facility encompasses the section of IH-5 that includes the Route 14 and Route 210 interchanges. The other truck facilities are at Route 99 near Grapevine and at the interchange of Route 110 and IH-405. Although these facilities were built for trucks to bypass the interchanges, automobiles and other vehicles also use the lanes to avoid the weaving sections (14).

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Section 8 – Lane Restrictions

Lane restrictions are management strategies that limit certain types of vehicles to specified lanes. The most common type of lane restriction addresses truck traffic. A large presence of trucks, both in rural and urban areas, can degrade the speed, comfort, and convenience experienced by passenger car drivers. Some states, to minimize these safety and operational effects, have implemented truck lane restrictions or have designated exclusive truck lane facilities. In 1986, the Federal Highway Administration asked its division offices to conduct a survey and report on experiences encountered by states with lane restrictions. This survey indicated a total of 26 states used lane restrictions. The most common reasons for implementing lane restrictions were:

- ◆ improve highway operations (14 states),
- ◆ reduce accidents (8 states),
- ◆ pavement structural considerations (7 states), and
- ◆ restrictions in construction zones (7 states).

Some states provided more than one reason for the restriction (15).

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Section 9 – Dual Facilities

Dual facilities are managed lane strategies that have physically separated inner and outer roadways in each direction. The inner roadway is reserved for light vehicles or cars only, while the outer roadway is open to all vehicles. The New Jersey Turnpike has a 35-mile segment that consists of interior (passenger car) lanes and exterior (truck/bus/car) lanes within the same right-of-way, as shown in [Figure 2-12](#). For 23 miles, the interior and exterior roadways have three lanes in each direction. On the 10-mile section that opened in November 1990, the exterior roadway has two lanes, and the interior roadway has three lanes per direction. Each roadway has 12-ft lanes and shoulders, and the inner and outer roadways are barrier separated. The mix of automobile traffic is approximately 60 percent on the inner roadways and 40 percent on the outer roadways ([14](#)).

These facilities, referred to as dual-dual segments, were implemented to relieve congestion. Other truck measures that have been implemented on the turnpike are lane restrictions and ramp shoulder improvements. The restriction implemented in the 1960s does not allow trucks in the left lane of roadways that have three or more lanes by direction. On the dual-dual portion of the turnpike from Interchange 9 to Interchange 14, buses are allowed to use the left lane. The resulting effect is that the left lane becomes a bus lane with the right lane(s) occupied by trucks. The New Jersey Turnpike Authority (NJTA) rates compliance for truck lane restrictions as high ([12](#)).

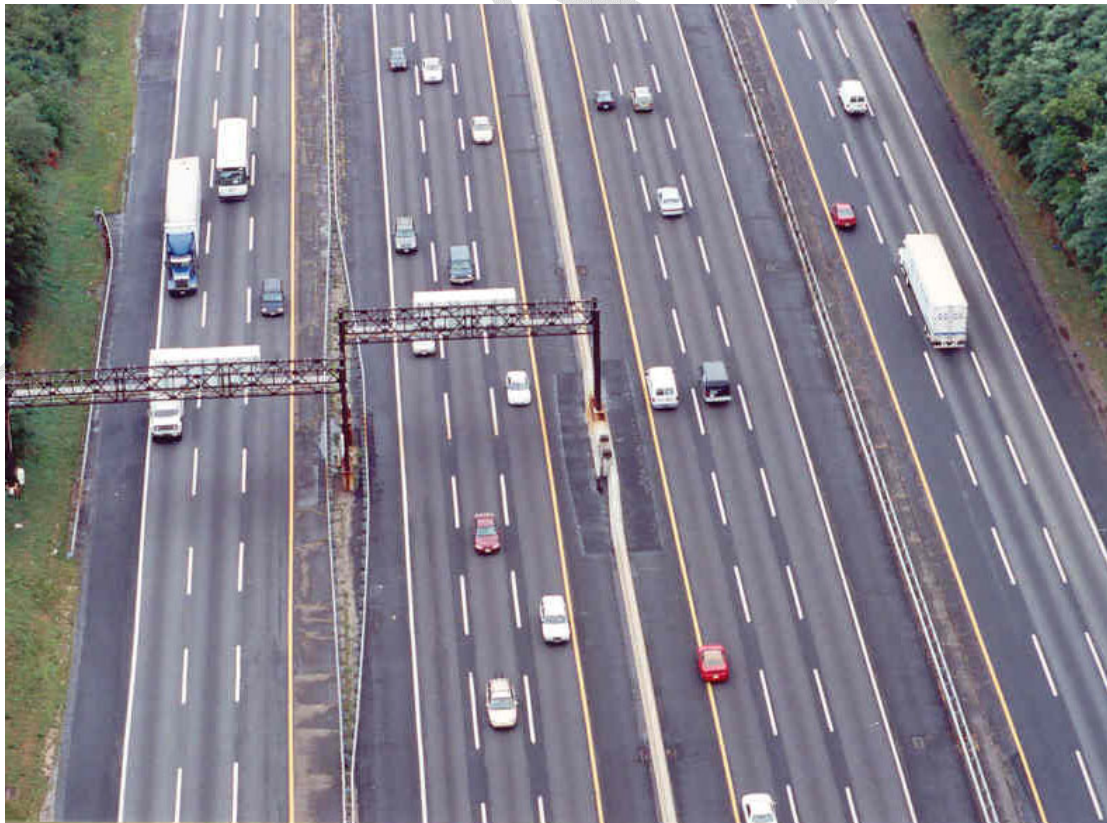


Figure 2-12. New Jersey Turnpike Dual Facility.

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Section 1 – Overview

This chapter presents information on the basic elements of the design of managed lane facilities including appropriate design values and cross sections. The sections address the most frequently encountered design issues but do not attempt to address every possible design unique to the specific situation. Additional discussions on issues associated with high-occupancy vehicle facilities are contained in the *HOV Systems Manual (1)*.

This chapter contains the following sections:

- ◆ [Geometric Considerations for Managed Lanes Facilities,](#)
- ◆ [Cross Sections for Managed Lanes Facilities, and](#)
- ◆ [Design Considerations for Terminal and Access Treatments.](#)

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Section 2 – Geometric Considerations for Managed Lanes Facilities

Overview

Engineers should consider several elements, criteria, and controls in the design process. In many cases, right-of-way limitations and roadway constraints may make it difficult to meet all desirable design standards. Many groups have an interest in how a facility is designed and operated, and these interests may require compromises during the testing phase. [Table 4-1](#) lists groups and agencies with interests in how managed lanes facilities are designed.

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. To accommodate the fact that using desirable design elements may not always be realistic, this chapter 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 American Association of State Highway and Transportation Officials (AASHTO) and other standards.

Designs with reduced features reflect the inability to meet the desirable criteria due to lack of available rights-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 practices. The reduced values presented in this chapter are not intended as a standard of practice, and practitioners should use desired values whenever practical.

The design and operational components of a managed lane facility must be considered simultaneously. Right-of-way constraints will normally dictate the extent of design that is possible. A full design requires fewer operational treatments. When reduced design standards are implemented, the operations component of the managed lane development becomes increasingly important. For each cross section shown throughout this chapter, operational treatments should be incorporated if the reduced design cross-section values are used. [Table 4-2](#) lists examples of the operational treatments needed for full and reduced designs on a managed lane. Reduced designs must be decided by each local area and situation and acceptable to the Federal Highway Administration, Federal Transit Administration (FTA), Department of Transportation (DOT), transit agency, city, and others with a stake in the facility.

Table 4-1. Agencies and Groups Involved in Designing Managed Lanes Facilities (Adapted from Reference 2).

Agency or Group	Potential Roles and Responsibilities
State Department of Transportation	<ul style="list-style-type: none"> • Overall project management responsibilities with freeway projects • Supporting role if transit agency is lead on projects in separate rights-of-way • Responsible for design of facilities on freeways • Staffing of multi-agency or multi-division team
Transit agency	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Provide information on trucking origins and destinations • Training of drivers on facility use for trucks
Toll authority	<ul style="list-style-type: none"> • Introduce tolling technologies • Revenue generation • Pre-operational testing
State and local police	<ul style="list-style-type: none"> • Assist with design, especially enforcement elements • Participate on multi-agency team
Metropolitan planning organization	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Assist with design of projects • Participate on multi-agency team
Local municipalities	<ul style="list-style-type: none"> • Assist with design of projects • Coordinate with local managed lane facilities • Participate on multi-agency team
Federal agencies (FHWA and FTA)	<ul style="list-style-type: none"> • Funding support for facility design • Technical assistance • Possible approval of design or steps in design process • Participate on multi-agency team
Other groups	<ul style="list-style-type: none"> • EMS, fire, and other emergency personnel • Tow truck operations • Businesses • Neighborhood groups • Judicial system—state and local courts
<p>Note: Depending on an area's institutional relationships, the roles may be different.</p>	

Table 4-2. Operational Treatments Needed for Full and Reduced Design Standards (Adapted from Reference 1).

Design Standards	Level of Operational Treatments	Example Operational Treatments
Full	Low	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Items noted above for full standards • Automatic vehicle identification (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

The following sections describe the various design and control criteria that designers should consider with managed lanes facilities. The design vehicle criteria are presented first, followed by a discussion of design driver criteria, design speed, and roadway alignment elements.

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. Table 4-3 lists the dimensions for these vehicle types. The typical dimensions and turning radii for design vehicles are included in the AASHTO *Green Book* (3) and values are also included in the National Cooperative Highway Research Program (NCHRP) *Report 414* (1). Designers should use these dimensions, which will also accommodate vanpools and carpools, to assist with the design of managed lane projects on freeways.

The designer can use the AASHTO *Green Book* templates in determining turning paths, lateral and vertical clearances, bus stops, and other elements associated with a project. The design process should also account for the path of the vehicle overhang beyond the outside turning radius.

The design vehicles should be used to control the geometrics of the different managed lane facility design elements. Acceleration and deceleration lanes and corner radii should be based on a bus or other large design vehicle while alignment geometry is based on the stopping sight distance of a passenger car driver, which is lower to the ground. Larger design vehicles are not usually used in alignment design because the higher eye height of their drivers 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 (2).

If the managed lane will be used for general-purpose vehicles during off-peak periods or during incident management situations, consider using a semitrailer 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, is designed for the semitrailer truck design vehicle.

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

Design Vehicle Type (Symbol)	U.S. Customary (ft)							Metric (m)						
	Ht.	Width	Length	Overhang		Wheelbase		Ht.	Width	Length	Overhang		Wheelbase	
				Front	Rear	WB ₁	WB ₂				Front	Rear	WB ₁	WB ₂
Passenger Car (P)	4.25	7	19	3	5	11	--	1.3	2.1	5.8	0.9	1.5	3.4	--
Van	6.5	7.5	17.0	2.5	4.0	10.5	--	2.0	2.3	5.2	0.7	1.2	3.2	--
Inner-city Bus ¹ (Bus-40 or Bus-12)	12.0	8.5	40	6	6.3*	24	3.7	3.7	2.6	12.2	1.8	1.9*	7.3	1.1
Inner-city Bus ¹ (Bus-45 or Bus-14)	12.0	8.5	45	6	8.5*	26.5	4.0	3.7	2.6	13.7	1.8	2.6*	8.1	1.2
Articulated Bus ¹ (A-Bus)	11.0	8.5	60	8.6	10	22.0	19.4	3.4	2.6	18.3	2.6	3.1	6.7	5.9
Interstate Semitrailer Truck ² (WB-67 or WB-20 ^{**})	13.5	8.5	73.5	4	4.5-2.5*	21.6	43.4-45.4	4.1	2.6	22.4	1.2	1.4-0.8*	6.6	13.2-13.8

¹Exact dimension may vary by bus manufacturer.

²Managed lane facilities may allow truck vehicles, and the proper design vehicle should be selected.

*Combined dimension is 19.4 ft (5.9 m) and articulating section is 4 ft (1.2 m) wide.

**Design vehicle with 16.16 m (52.9 ft) trailer as grandfathered in with 1982 Surface Transportation Assistance Act (STAA).

Design Speed

In most cases, the design speed of managed lanes will be the same as that used on the adjacent general-purpose lanes. However, there may be limited instances where the design speed of the managed lanes is lower than the adjacent general-purpose lanes, due to the geometrics of the managed lane facility or other limitations. The designated design speed of the facility should relate to the maximum speed the facility is expected to accommodate. Further, the design speed should accommodate the vast majority of users (e.g., the anticipated 85th percentile speed).

The TxDOT *Roadway Design Manual (RDM)* states that the design speed of freeways should reflect the desired operating conditions during non-peak hours (4). Table 4-4 lists the desirable and minimum design speeds. Table 4-5 summarizes the design speeds associated with various types of managed lanes as reported in NCHRP Report 414 (1). This information provides general ideas of potential design speeds; however, 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.

Table 4-4. Design Speed for Controlled Access Facilities (Adapted from the TxDOT RDM Table 3-17, Reference 4).

U.S. Customary (mph)			Metric (km/h)		
Facility	Desirable	Minimum	Facility	Desirable	Minimum
Mainlanes – Urban	70	50	Mainlanes – Urban	110	80
Mainlanes – Rural	70	70	Mainlanes – Rural	110	110

Table 4-5. Examples of Typical Design Speeds for Managed Lanes Facilities (Adapted from Reference 1).

U.S. Customary (mph)			Metric (km/h)		
Types of Managed Lanes	Typical Design Speed		Types of Managed Lanes	Typical Design Speed	
	Reduced	Desirable		Reduced	Desirable
Barrier-separated	50	70	Barrier-separated	80	110
Concurrent flow	50	60	Concurrent flow	80	100
Contraflow	30	50	Contraflow	50	80

Horizontal Clearance

For horizontal clearances, 5 ft (1.5 m) is the desired clearance; however, as a minimum, at least a 2-ft (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.

Vertical Clearance

The TxDOT *Roadway Design Manual* states that all controlled access highway grade separation structures should provide a 5 m minimum vertical clearance over the usable roadway (4). Structures over the mainlanes of interstate or controlled-access highways must meet the minimum vertical clearance requirement except within cities where the 5 m vertical clearance is provided on an interstate loop around the particular city. In some locations, the height of the tallest vehicle anticipated to operate in the managed lane facility is 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 ft (5 m) used for the adjacent freeway lanes will also be used for the managed lane (3). In situations of restricted vertical clearance, a minimum of 14.5 ft (4.4 m) is acceptable per the AASHTO *Green Book*, which includes an allowance of 6 inches (0.2 m) in anticipation of future resurfacing (3,5). This may also be an issue where an overcrossing road is widened; the cross slope on the wider road will result in clearance at the edges of the roadway.

Stopping Sight Distance

The design of a managed lane facility should provide adequate stopping sight distance (SSD) for all vehicle types (e.g., bus, truck, van, car) using the facility. Due to the driver's eye height, the automobile is usually used as the design vehicle for determining stopping sight distance. TxDOT's *Roadway Design Manual* should be used in determining stopping sight distances for various travel speeds. Table 4-6 lists the SSD values adopted by TxDOT in July 2001. The TxDOT *Manual Notice 2001-2* states that the old or new SSD values may be used on projects through December 2003 and that projects let after January 2004 must meet the new SSD criteria or have an approved design exception. The stopping sight distances should be checked if barriers are used as they may restrict the available sight distances (2).

Table 4-6. Stopping Sight Distance (Adapted from the TxDOT RDM Table 2-1, Reference 4).

U.S. Customary					Metric				
Design Speed (mph)	Brake Reaction Distance (ft)	Braking Distance on Level (ft)	Stopping Sight Distance		Design Speed (km/h)	Brake Reaction Distance (m)	Braking Distance on Level (m)	Stopping Sight Distance	
			Calculated (ft)	Design (ft)				Calculated (m)	Design (m)
30	110.3	86.4	196.7	200	50	34.8	28.7	63.5	65
35	128.6	117.6	246.2	250	60	41.7	41.3	83.0	85
40	147.0	153.6	300.6	305	70	48.7	56.2	104.9	105
45	165.4	194.4	359.8	360	80	55.6	73.4	129.0	130
50	183.8	240.0	423.8	425	90	62.6	92.9	155.5	160
55	202.1	290.3	492.4	495	100	69.5	114.7	184.2	185
60	220.5	345.5	566.0	570	110	76.5	138.8	215.3	220
65	238.9	405.5	644.4	645	120	83.4	165.2	248.6	250
70	257.3	470.3	727.6	730	130	90.4	193.8	284.2	285
75	275.6	539.9	815.5	820					
80	294.0	614.3	908.3	910					

Note: Brake reaction distance predicated on a time of 2.5 s; deceleration rate 11.2 ft/sec² (3.4 m/sec²).

Superelevation

Superelevation rates on managed lanes must be applicable to curvature over a range of design speeds. Designers must give consideration to the higher center of gravity for buses, vans, and trucks, which will result in superelevations slightly higher than otherwise justified (5). Table 4-7 presents recommended superelevation rates for managed lanes.

Table 4-7. Recommended Managed Lanes Superelevation Rates (Adapted from Reference 5).

U.S. Customary			Metric		
Managed Lane Design Speed (mph)	Maximum Superelevation, <i>e</i> (ft/ft)		Managed Lane Design Speed (km/h)	Maximum Superelevation, <i>e</i> (m/m)	
	Allowable	Desirable		Allowable	Desirable
40 - 50	0.06	0.04	70 - 80	0.06	0.04
50 - 70	0.08	0.06	80 - 110	0.08	0.06

Cross Slope

The cross slope of a managed lane facility should generally follow the adjacent freeway, which is commonly 2 percent. However, for a facility located in a median that straddles the crown of the roadway, it is acceptable to crown the facility with a 2 percent crossfall to either side if drainage requirements permit (example shown in Figure 4-1). For typical sections with five or more lanes, the uniform cross slope of 2 percent may not be sufficient and the outside lane(s) cross slope may require modification. For concurrent-flow facilities, the designer should extend the existing crossfall of the freeway mainlanes.

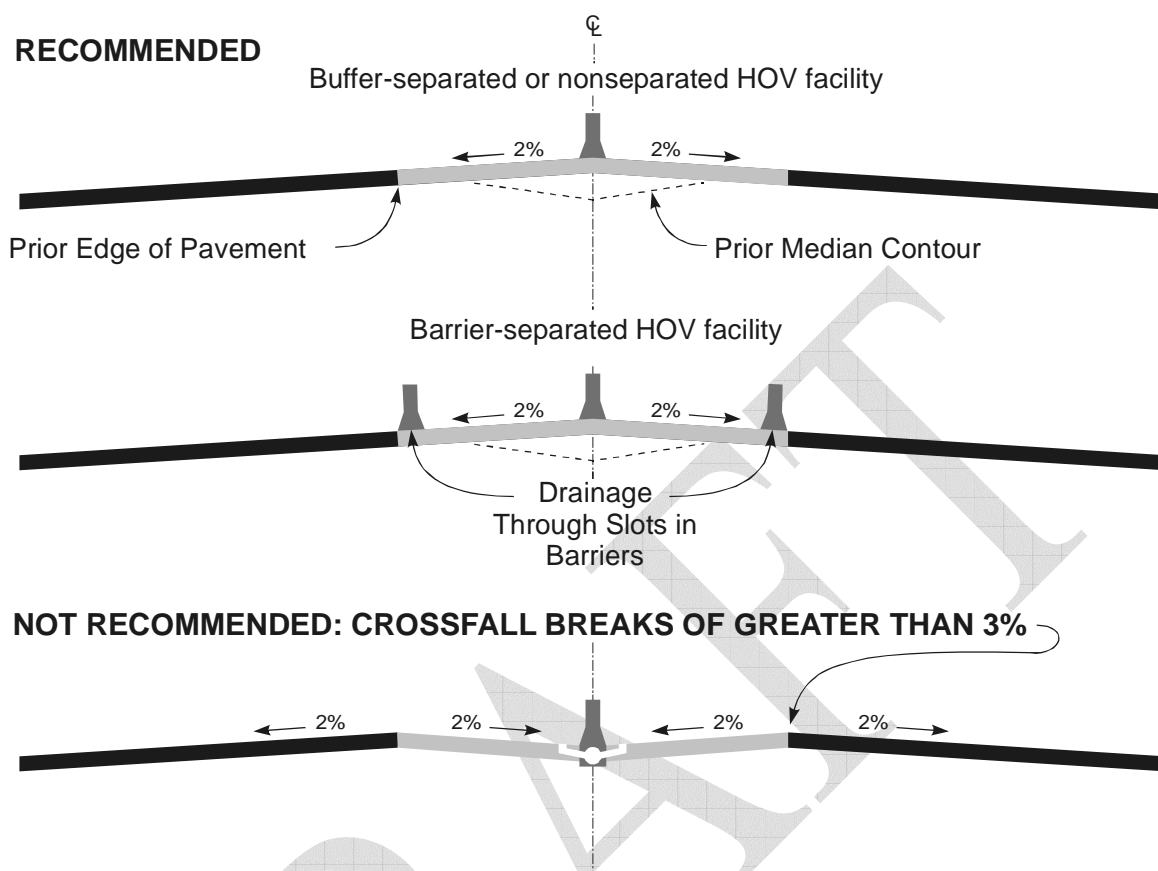


Figure 4-1. Cross-Slope Alternatives for Median Retrofit Projects (Adapted from Reference 2).

Minimum Turning Radius

Generally, a 50-ft (15.2-m) minimum radius (inner wheel path) is considered desirable at low speeds (10 mph [16 km/h]); this will accommodate most urban transit buses. For a radius below this value, the designer should consider the possibilities of a compound curve or approach and departure tapers to avoid increasing the outside radius and resulting in vehicle overhang. This condition is likely to be encountered at managed lane ramp intersections with local streets and possibly at ramp intersections with the mainlane facility. These recommended radii might differ if the managed lane facility is designed to accommodate semitrailers (2).

Horizontal Curvature

The horizontal alignment of a managed lane should be designed to ensure that all design vehicles, including buses and semitrailers, if applicable to the managed lane facility design, may safely negotiate all curves. Table 4-8 presents 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 (1, 2, 5).

Managed lanes on curves should provide additional lateral width for maneuvering and for the overhang of various parts of a bus. Table 4-9 recommends pavement widening for managed lanes for various horizontal curve radii and design speeds. Likewise, ramps on curves must also have sufficient width 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 operations and varying ramp radii. Designers should consider providing extra lane width on curves to accommodate semitrailers on a full- or part-time basis (1, 2, 5).

Table 4-8. Recommended Minimum Radii for Managed Lane Horizontal Curvature (Adapted from Reference 3).

U.S. Customary			Metric		
Design Speed (mph)	Radii (ft)		Design Speed (km/h)	Radii (m)	
	Reduced ¹	Desirable ²		Reduced ¹	Desirable ²
45	600	660	70	175	195
50	760	835	80	230	250
55	965	1065	90	305	335
60	1205	1340	100	395	435
65	1485	1660	110	500	560
70	1820	2050	120	665	775
75	2215	2510	130	830	950
80	2675	3060			

¹Reduced radii are obtained from Reference 3 pages 160 and 161 with $e_{\max} = 8$ percent.
²Desirable radii are obtained from Reference 3 pages 158 and 159 with $e_{\max} = 6$ percent.

Table 4-9. Pavement Widening Recommended for Horizontal Curvature (Adapted from Reference 2).

Managed Lane Mainline									
U.S. Customary					Metric				
Design Speed (mph)	Pavement Widening for Single-Lane, One-Way Curve with Radius of (in ft):				Design Speed (km/h)	Pavement Widening for Single-Lane, One-Way Curve with Radius of (in m):			
	500	750	1000	2000		150	230	305	610
40	2.0	1.0	1.0	0.0	70	0.6	0.3	0.3	0.0
50	N/A	1.5	1.0	0.5	80	N/A	0.5	0.3	0.2
60	N/A	N/A	1.0	0.5	100	N/A	N/A	0.3	0.2
70	N/A	N/A	N/A	N/A	110	N/A	N/A	N/A	N/A
Managed Lane Ramps									
U.S. Customary					Metric				
Ramp Type	Pavement Widening for Curve with Radius of (in ft):				Ramp Type	Pavement Widening for Curve with Radius of (in m):			
	100	250	500	1000		30.5	76	152	305
Single-lane, one-way	8	6	4	2	Single-lane, one-way	2.4	1.8	1.2	0.6
Multiple-lane, one-way	6	4	3	2	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.

Vertical Curvature

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 and 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 ft (1080 mm) (passenger cars being the most critical vehicles), object height of 2.0 ft (0.6 m), parabolic curvature, and the presence of fixed-source lighting for an urban environment. Table 4-10 presents recommended K-factors for the length of the managed lane vertical curves over a range of design speeds and both crest and sag conditions (3). 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 (3). 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 4-10. Vertical Curve Criteria (K-Factors) for Managed Lane Facilities (Adapted from Reference 3).

U.S. Customary				Metric			
Design Speed (mph)	Minimum Length (ft)	Minimum K-Factors (ft/Percent Change in Algebraic Difference of Gradients)		Design Speed (km/h)	Minimum Length (m)	Minimum K-Factors (m / Percent Change in Algebraic Difference of Gradients)	
		Crest Stopping	Sag Comfort			Crest Stopping	Sag Comfort
70	225	247	181	110	70	74	55
60	200	151	136	100	60	52	45
50	150	84	96	80	50	26	30
40	125	44	64	70	45	17	23
30	100	19	37	50	30	7	13

Note: Length of curve is three times the design speed (see page 280, Reference 3).

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 4-11 indicates desirable and maximum grades to be used on managed lane mainlanes 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 km/h) considering the length and percentage of the grade.

A minimum longitudinal grade of 0.35 percent is controlled by the need to provide adequate drainage and to prevent water retention (i.e., ponding) on the roadway surface. For median facilities retrofitted at grade, the minimum grade follows the existing freeway gradient (2, 5).

Table 4-11. Recommended Maximum Grades.

Facility Type	Grade		
	Freeway Level ¹	Freeway Rolling ¹	HOV Maximum ²
Mainline (70 mph [110 km/h])	3 percent	4 percent	6 percent
Ramp (40 mph [65 km/h])	Preferably limited to 4 percent ¹		8 percent

¹See TxDOT Roadway Design Manual.
²See References 2 and 5.

Summary of Managed Lanes Mainline Design Guidelines

Table 4-12 provides a summary of alignment and other typical factors controlling the design for mainline managed lanes facilities.

Table 4-12. Summary of Managed Lanes Mainline Design Criteria (Adapted from References 2, 3, 5).

Design Speed	U.S. Customary		Metric	
	Desirable	Reduced	Desirable	Reduced
	70 mph	50 mph	110 km/h	80 km/h
Alignment				
Stopping Distance	730 ft	425 ft	220 m	130 m
Horizontal Curvature (radius)	1820-2500 ft	760-835 ft	500-560 m	230-250 m
Superelevation	0.06 ft/ft	0.08 ft/ft	0.06 m/m	0.08 m/m
Rate of Vertical Curvature				
Crest, k	247	84	74	26
Sag, k	181	96	55	30
Gradients				
Maximum (%)	5	6	5	6
Minimum (%)	0.5	0.5	0.3	0.3
Clearance				
Vertical	16.5 ft	14.5 ft	5 m	4.4 m
Lateral	4 ft	2 ft	1.2 m	0.6 m
Lane Width				
Travel Lanes	12 ft	11 ft	3.6 m	3.4 m
Cross Slope				
Maximum	0.020 ft/ft	0.020 ft/ft	0.020 m/m	0.020 m/m
Minimum	0.015 ft/ft	0.015 ft/ft	0.015 m/m	0.015 m/m
Turning Radius Minimum	N/A	N/A	N/A	N/A
Superelevation: Depends on curve radii and design speed (0.10 ft/ft [0.10 m/m] maximum).				

Section 3 – 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.

Design Considerations for Exclusive Freeway Managed Lanes

Exclusive freeway managed lanes are physically separated from the adjacent freeway general-purpose lanes by a barrier or wide buffer. There are two types of exclusive freeway management lanes:

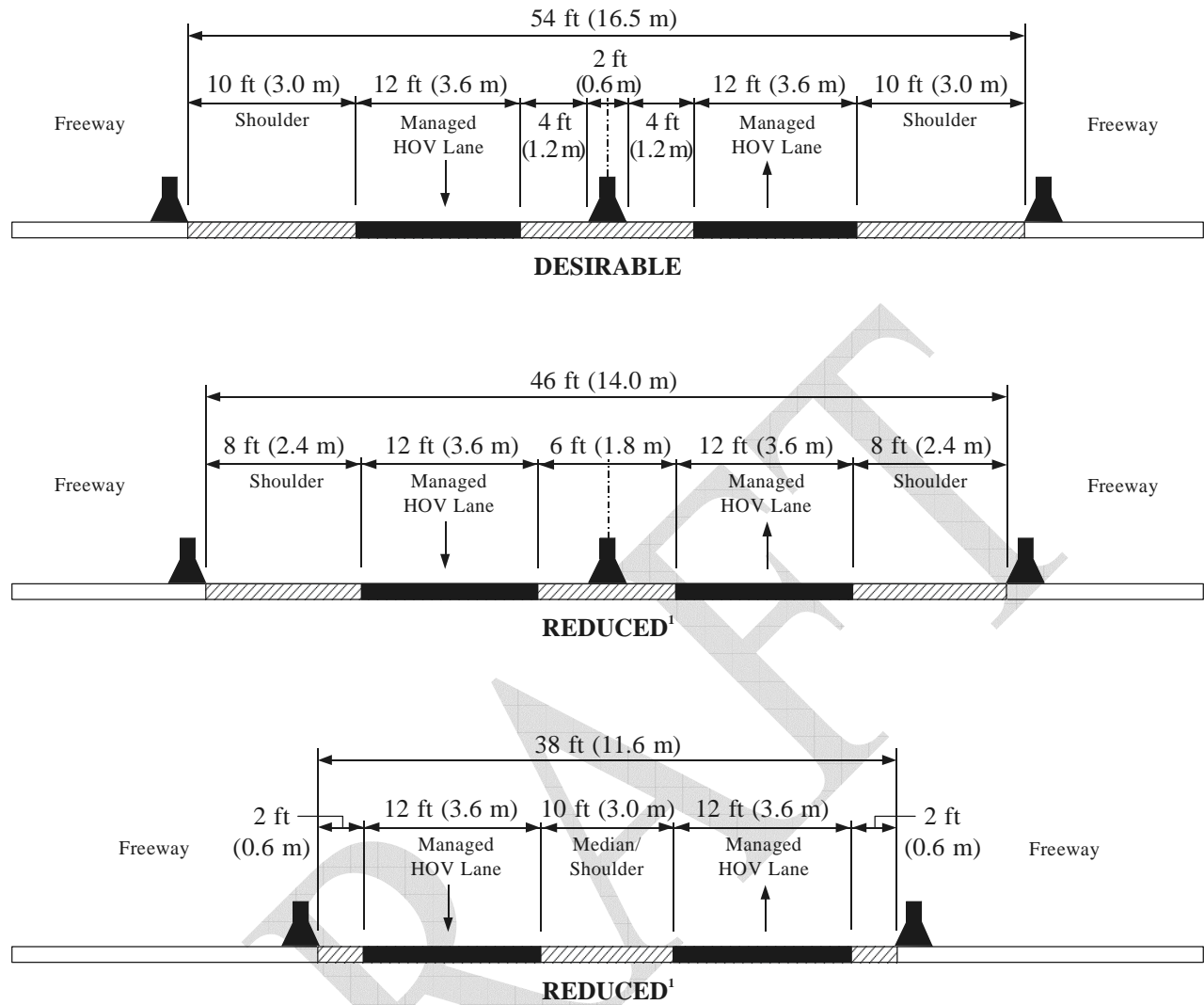
- ◆ two-way, and
- ◆ reversible.

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.

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 generally 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 a 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 4-2](#) highlights these elements in a sample cross section.



¹ Operational treatments should be incorporated if the reduced design cross sections are used.

(Suggested operational treatments are listed in [Table 4-2](#).)

Figure 4-2. Examples of Cross Sections for Exclusive Two-Way Managed Lane Facilities (Adapted from Reference 1).

- ◆ **Median Component.** Opposing-direction managed lanes are normally separated from each other by a median barrier. AASHTO and federal guidelines should be used to design the median barrier (6). A 2- to 4-ft (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 ft (3.0 m) may be considered as shown in Figure 4-2. 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.** Exclusive two-way managed lane facilities should have 12-ft (3.6 m) travel lanes. Designers should consider narrower lane widths only in special circumstances or for short distances due to limited right-of-way.
- ◆ **Lane Separation Component.** As shown in Figure 4-2, a 2-ft (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 ft (11.6 to 16.5 m) will be needed for a two-way exclusive managed lane facility. Reduced design standards should be considered only in special circumstances.
- ◆ **Design Tradeoffs.** Table 4-13 shows an example of an 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, operational treatments should be considered prior to using a reduced design cross section. Table 4-13 is only an example; the designer must consider each facility and consult with all involved agencies to decide what will be approved.

Table 4-13. Example Design Tradeoffs for Two-Way Barrier-Separated Managed Lanes Facilities (Adapted from Reference 2).

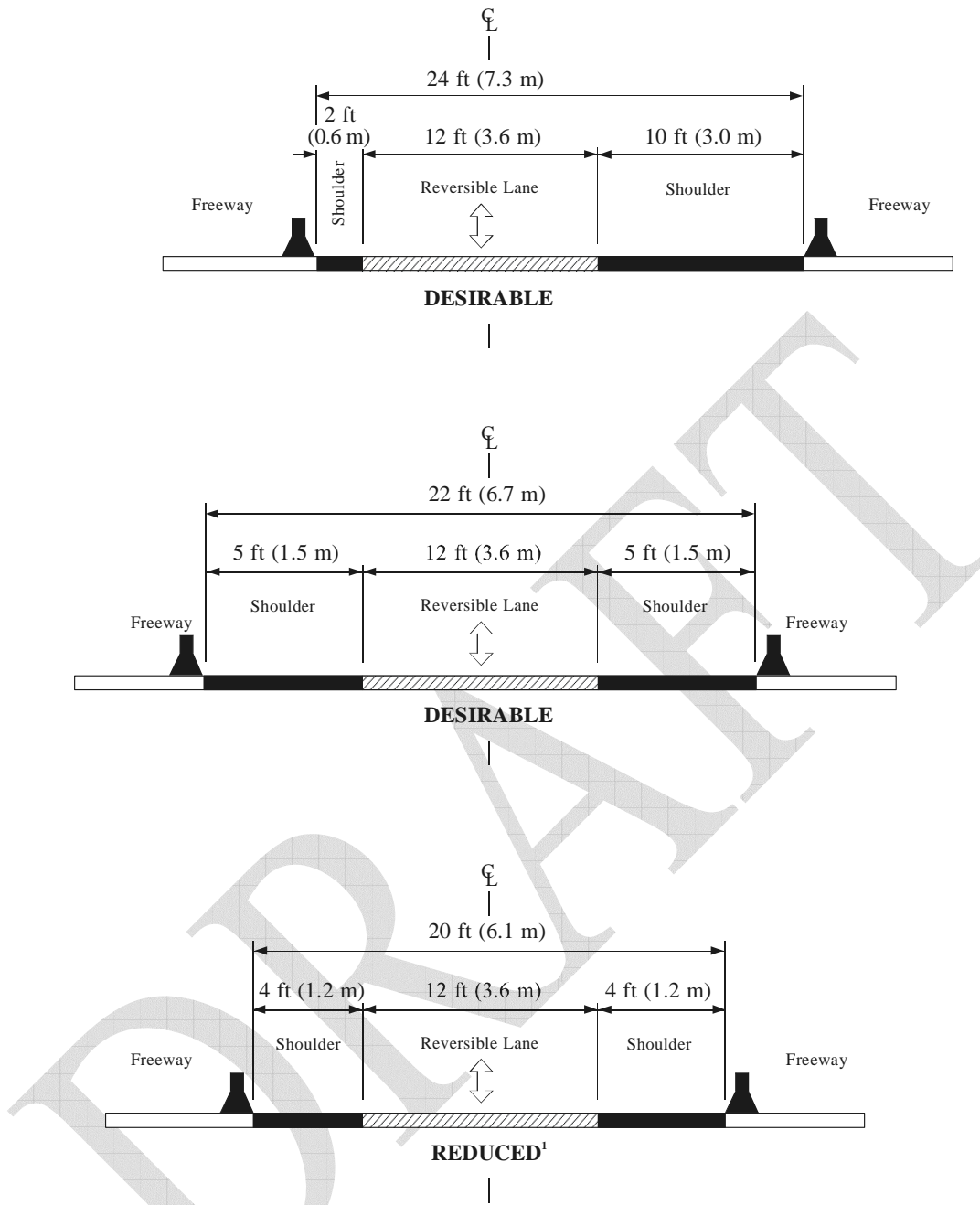
Ordered Sequence	Cross-Section Design Change
First	Reduce left managed lane lateral clearance to no less than 2 ft (0.6 m).
Second	Reduce right managed lane lateral clearance to no less than 8 ft (24 m).
Third	Reduce freeway left lateral clearance to no less than 2 ft (0.6 m).
Fourth	Reduce freeway right lateral clearance (shoulder) from 10 ft (30 m) to no less than 8 ft (24 m).
Fifth	Reduce managed lane width to no less than 11 ft (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 ft (34 m). (Leave at least one 12-ft (36-m) outside lane for trucks).
Seventh	Reduce freeway right lateral clearance shoulder from 8 ft (24 m) to no less than 4 ft (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 is (are) physically separated from the general-purpose freeway lanes and is (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 Central Business District (CBD) or other major activity center in the morning and outbound in the afternoon. Daily reconfiguration 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. Either manual or automated techniques may be used to open and close reversible managed lane facilities.

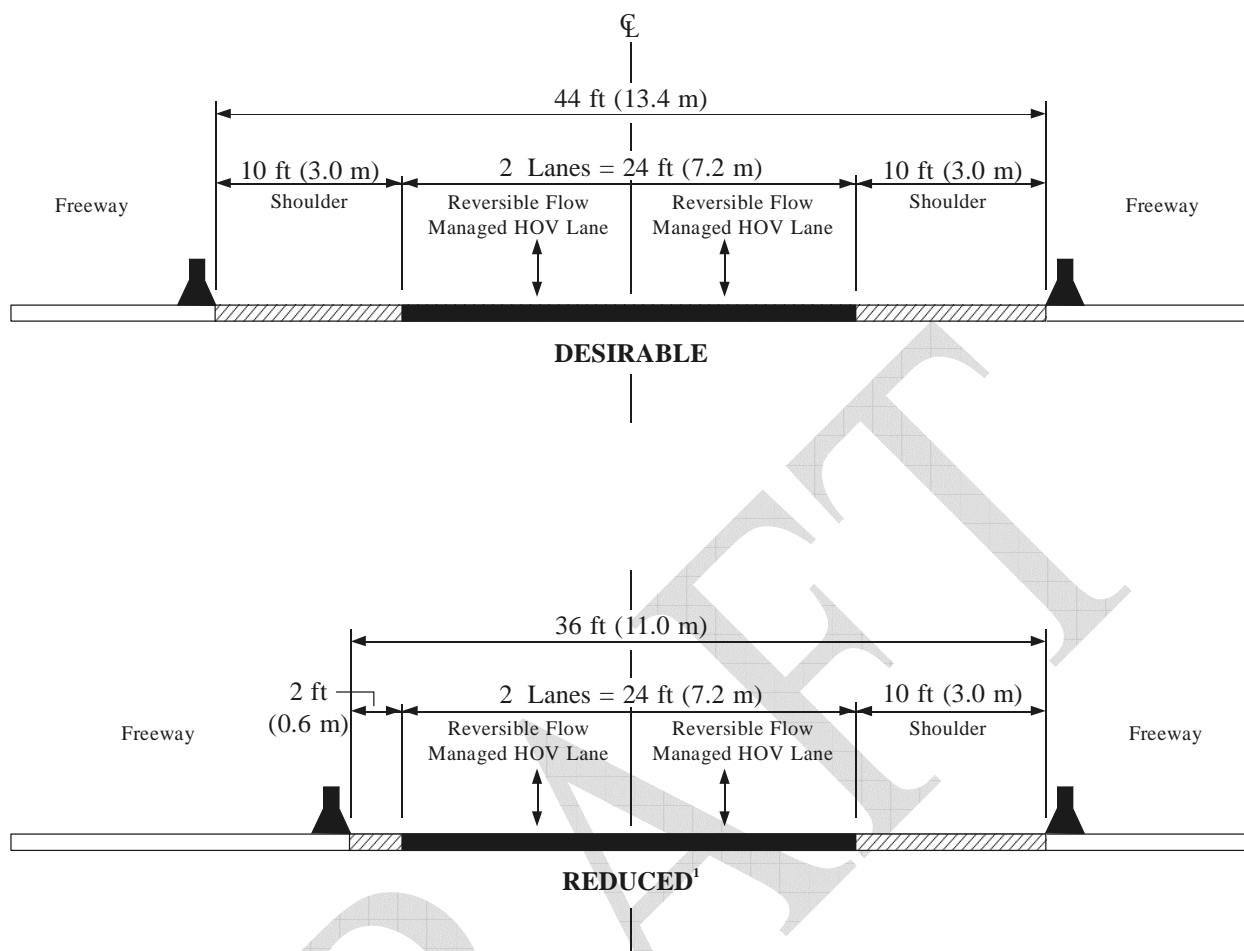
[Figure 4-3](#) illustrates cross-section examples of the design components for a single-lane barrier-separated reversible facility, and [Figure 4-4](#) illustrates a two-lane facility. The following items highlight the design elements associated with these types of projects.



¹ Operational treatments should be incorporated if the reduced design cross sections are used.

(Suggested operational treatments are listed in [Table 4-2](#).)

Figure 4-3. Examples of Cross Sections for Single-Lane, Exclusive Reversible Managed Lanes Facilities (Adapted from [Reference 1](#)).



¹ Operational treatments should be incorporated if the reduced design cross sections are used.

(Suggested operational treatments are listed in [Table 4-2](#).)

Figure 4-4. Examples of Cross Sections for Two-Lane Exclusive Reversible Managed Lanes Facilities (Adapted from [Reference 1](#)).

- ◆ **Lane Component.** Designers should use 12-ft wide (3.6 m) managed lanes for either a single- or two-lane facility.
- ◆ **Cross-Section Design Summary.** A design envelope of 22 ft to 24 ft (6.7 m to 7.3 m) should be used for a single exclusive reversible managed lane ([2](#), [3](#), [8](#)). A reduced envelope of 20 ft (6.1 m) may be considered. A design envelope of 44 ft (13.4 m) is recommended for a two-lane facility with a reduced design envelope of 36 ft (11 m).
- ◆ **Shoulder, Lateral Clearance, and Separation Component.** The designer should use at least one 10-ft (3 m) shoulder. Shoulder widths between 4 ft (1.2 m)

and 8 ft (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 Table 4-2 should be considered prior to using reduced design cross sections. Table 4-14 is only an example; the designer must consider each facility and consult with all involved agencies to decide what will be approved.

Table 4-14. Example Design Tradeoffs for Reversible-Flow Managed Lanes Facilities (Adapted from Reference 2).

Ordered Sequence	Cross-Section Design Change
First	Reduce single-lane managed lane envelope to no less than 20 ft (61 m), or two-lane envelope to no less than 28 ft (85 m).
Second	Reduce freeway left lateral clearance to no less than 2 ft (0.6 m).
Third	Reduce freeway right lateral clearance (shoulder) from 10 ft (3 m) to no less than 8 ft (24 m).
Fourth	Reduce managed lane width to no less than 11 ft (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 ft (33 m). (Leave at least one 12-ft (36 m) outside lane for trucks).
Sixth	Reduce freeway right lateral clearance shoulder from 8 ft (24 m) to no less than 4 ft (12 m).
Seventh	Convert barrier shape at columns to a vertical face.

Design Considerations for Concurrent Flow Managed Lane Facilities

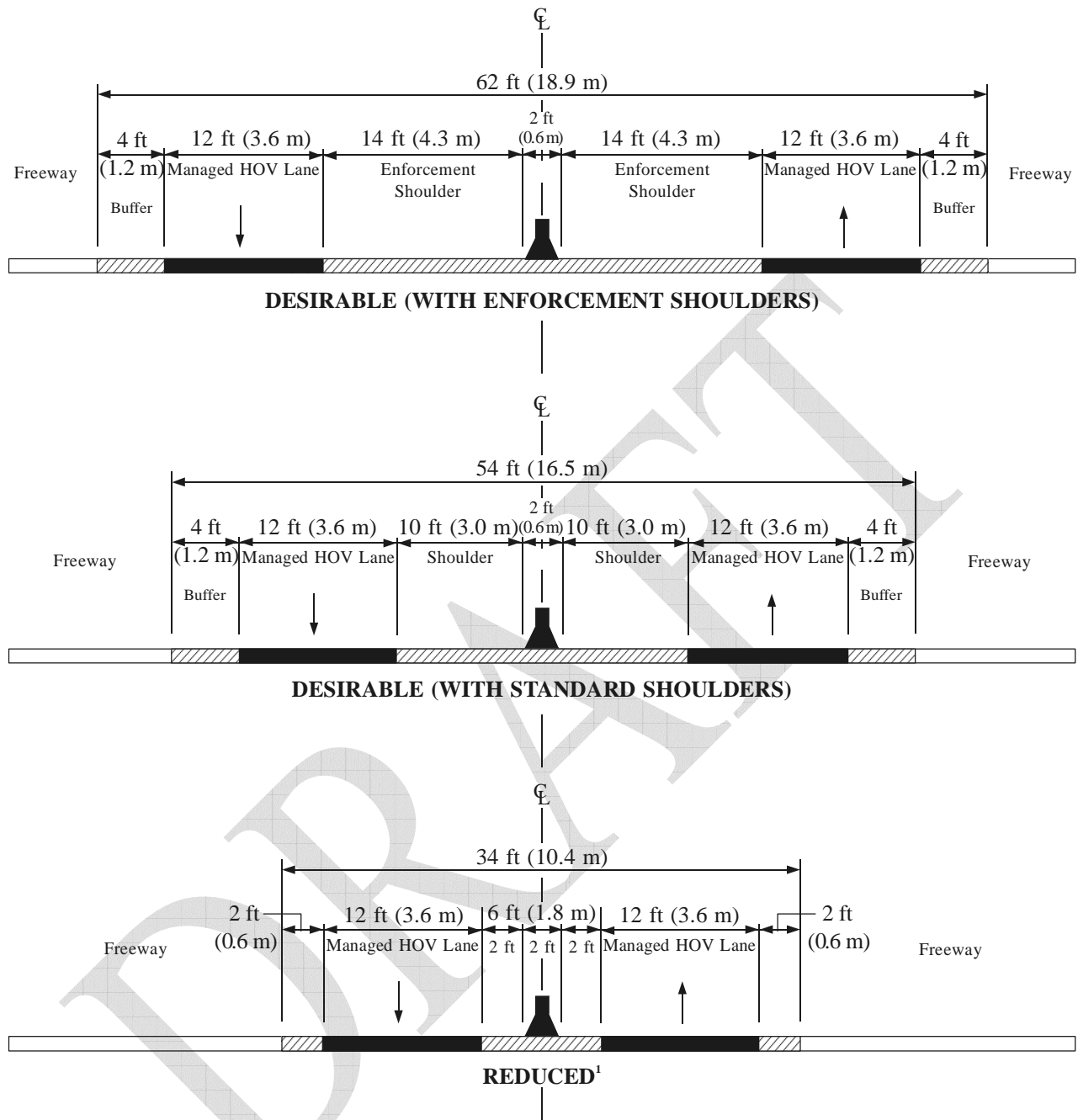
Concurrent flow managed lanes are defined as freeway lanes in the same direction of travel, not physically separated from the general-purpose traffic lanes, and designated for exclusive use by eligible vehicles for all or a portion of the day. A few facilities are open only to buses, allowing transit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

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. 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 [Figure 4-5](#).

- ◆ **Median and Shoulder Component.** As illustrated in [Figure 4-5](#), the desirable cross section for a concurrent flow lane located on the inside includes an enforcement or standard shoulder. The desirable shoulder width next to the median barrier is 10 to 14 ft (3.0 to 4.2 m). Operational allowances should be considered prior to using reduced design cross sections (see [Table 4-2](#)). The application of reduced shoulders or limited lateral clearances should be examined carefully on a project-by-project basis. [Figure 4-5](#) 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.
- ◆ **Lane Component.** A concurrent flow managed lane should be designed to the same standards as the freeway general-purpose lanes. A 12-ft (3.6 m) travel lane is desired. Narrower lanes should be used only in special circumstances.
- ◆ **Separation from General-Purpose Lanes.** As illustrated in [Figure 4-5](#), a 4-ft (1.2 m) buffer is desirable. Smaller separation widths may be considered if necessary.
- ◆ **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 of these elements is 54 to 62 ft (16.3 to 18.8 m). Designers may consider reducing some of these elements under special circumstances. A reduced design envelope as narrow as 34 ft (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.
- ◆ **Design Tradeoffs.** [Table 4-15](#) shows an example of an 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 2](#) should be considered prior to using reduced design cross sections. [Table 4-15](#) is only an example; the designer must consider each facility and consult with all involved agencies to decide what will be approved.



¹ Operational treatments should be incorporated if the reduced design cross sections are used.

(Suggested operational treatments are listed in [Table 4-2](#).)

Figure 4-5. Examples of Cross Sections for Concurrent Flow Managed Lane Facilities Located on the Inside of a Freeway (Adapted from [Reference 1](#)).

Table 4-15. Example Design Tradeoffs for Concurrent Flow Managed Lanes Facilities (Adapted from Reference 2).

Ordered Sequence	Cross-Section Design Change
First	Reduce left managed lane lateral clearance to no less than 2 ft (0.6 m).
Second	Reduce freeway right lateral clearance (shoulder) from 10 ft (3 m) to no less than 8 ft (24 m).
Third	Reduce buffer separation to no less than 1 ft (0.3 m).
Fourth	Reduce managed lane width to no less than 11 ft (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 ft (33 m). (Leave at least one 12-ft (36 m) outside lane for trucks.)
Sixth	Reduce freeway right lateral clearance shoulder from 8 ft (24 m) to no less than 4 ft (12 m).
Seventh	Transition barrier shape at columns to vertical face or remove buffer separation between the managed lane and mixed-flow lanes.

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. [Section 3](#) of this chapter discusses access treatments.

Figures [4-6](#) and [4-7](#) provide examples of cross sections for contraflow managed lane facilities using both types of treatments. These elements are described next.

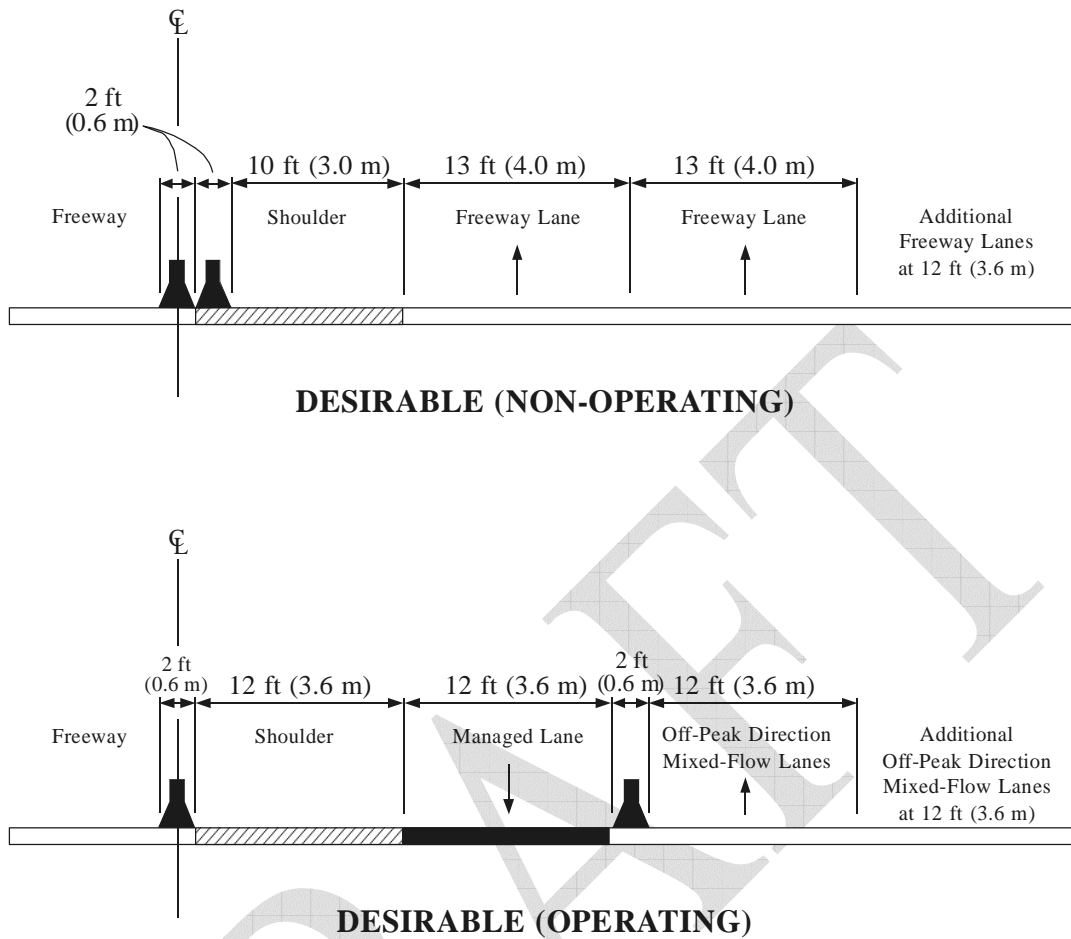
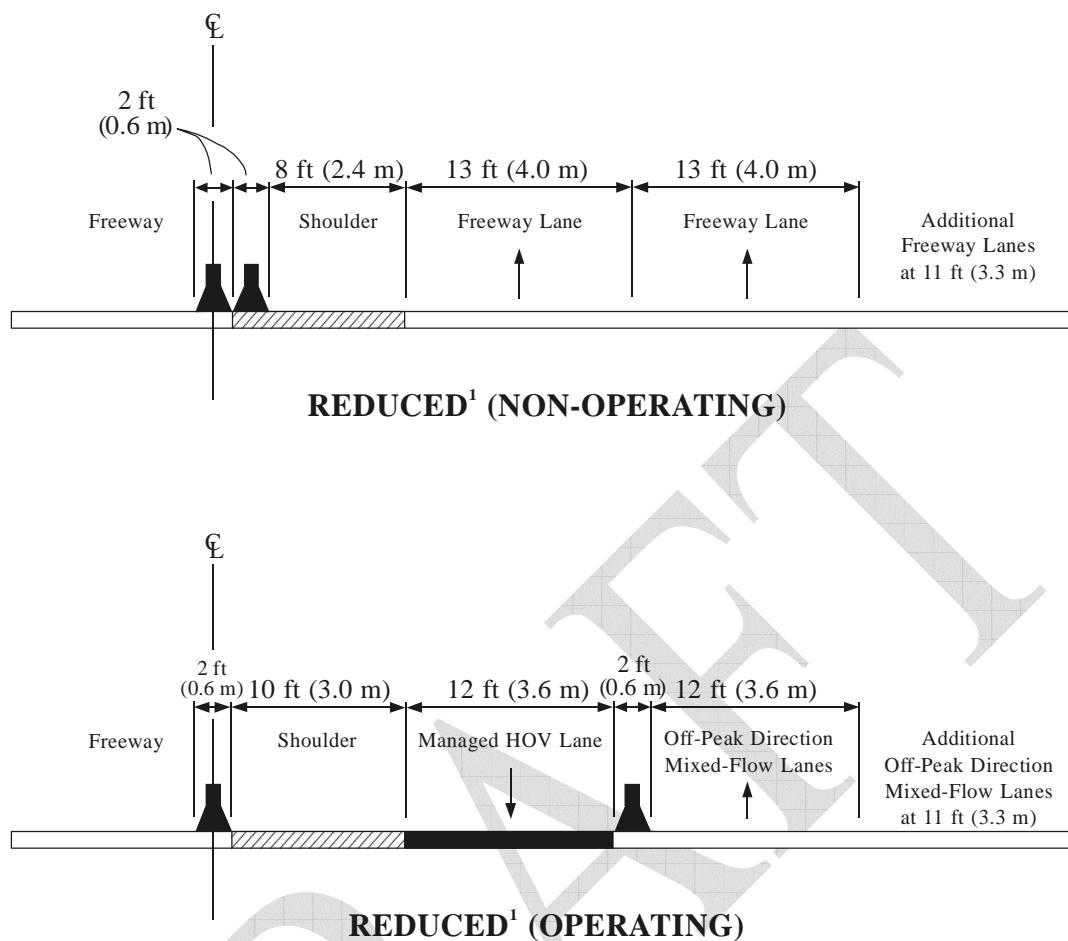


Figure 4-6. Desirable Cross Sections for Contraflow Managed Lanes (Adapted from Reference 1).



¹ Operational treatments should be incorporated if the reduced design cross sections are used.

(Suggested operational treatments are listed in [Table 4-2](#).)

Figure 4-7. Reduced Cross Sections for Contraflow Managed Lanes (Adapted from Reference 1).

- ◆ **Median and Shoulder Component.** As illustrated in Figures 4-6 and 4-7, 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-ft (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. The width of these lanes should be equal to the width of the general-purpose lanes, which on most projects is 12 ft

(3.6 m). [Figure 4-6](#) shows desirable cross sections for contraflow facilities that provide for a 12-ft (3.6 m) shoulder during operation of the lane. [Figure 4-7](#) shows the reduced cross section during non-operating and operating conditions. It operates with a 10-ft (3 m) shoulder.

- ◆ **Lateral Clearance Component.** A lateral clearance of 2 ft (0.6 m) should be used next to the pylons or moveable barrier. A similar lateral clearance should also be used for the general-purpose lane adjacent to the plastic pylons or the moveable barrier. The designer should take into consideration the limits of the existing right-of-way.

DRAFT

Section 4 – Design Considerations for Terminal and Access Treatments

Overview

This section examines the design elements for different types of terminal and access treatments associated with managed lane facilities. Vehicles may enter a managed lane facility at the beginning of, 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 rights-of-way, and funding. The designer should follow these general guidelines for the design of access treatments.

- ◆ 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. 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.
- ◆ 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, storage, and enforcement.
- ◆ If direct 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.
- ◆ 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 access locations using the same warrants applied for urban freeway entrance and exit ramps.

Selecting Ramp Type

All aspects of managed lane design must be considered in light of the operation and enforcement of the facility. Full standards for access include direct ramps to park-and-ride facilities or local streets with barrier-separated facilities. 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.

Multi-lane managed lane facilities may be necessary for large demands. The fundamental design of these facilities should follow the same geometric criteria for freeway ramps with locally recognized entrance and exit standards. For maximum travel time savings and trip reliability benefits, the facility should be located where the primary critical volume and/or mode of travel is most congested. Direct access and direct connections of managed lane facilities provide the best accommodation for multi-lane geometrics.

[Table 4-16](#) provides guidelines for selecting ramp types. Each type of ramp will be described in the following discussion.

Table 4-16. Guidelines for Selecting Ramp Type (Adapted from Reference 2).

Objective	Type of Ramp 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 ramp design speed (> 35 mph [60 km/h])	-	-	+	+
Low ramp design speed (< 35 mph [60 km/h])	+	+	N/A	-
Retrofit compatibility with exiting freeway	0	+	0	+
Flexibility to modify later	-	-	-	+
+ = 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.				

Design Speed

There should be a definite relationship between the design speed on a ramp or direct connection and the design speed on the intersecting highway, frontage road, or street to a park-and-ride. The TxDOT *Roadway Design Manual* states that all ramps and connections should be designed to enable vehicles to leave and enter the traveled way of the freeway at no less than 50 percent (70 percent usual, 85 percent desirable) of the freeway's design speed (4). Table 4-17 shows guide values for ramp/connection design speed. The design speed for a ramp should not be less than the design speed on the intersecting facility. AASHTO's *A Policy on Geometric Design of Highways and Streets*

provides additional guidance on the application of the ranges of ramp design speed shown in [Table 4-17 \(3\)](#).

Table 4-17. Guide Values for Ramp/Connection Design Speed as Related to Highway Design Speed (Adapted from the TxDOT RDM Table 3-20, [Reference 4](#)).

[Desirable based on $e_{max} = 6\%$]

Highway Design Speed	U.S. Customary (mph)					Metric (km/h)			
	50	55	60	65	70	80	90	100	110
Ramp ¹ Design Speed:									
Upper Range (85%)	45	48	50	55	60	70	80	90	100
Mid-Range (70%)	35	40	45	45	50	60	60	70	80
Lower Range (50%)	25	28	30	30	35	40	50	50	60

¹Loops: Upper and middle range values of design speed generally do not apply. The design speed on a loop is usually 40 km/h (55 m minimum radius). Particular attention should be given to controlling superelevation on loops due to the tight turning radii and speed limitations.

Direct Access Ramps

Grade separated or direct access ramps are desirable and should be considered when the anticipated volume attempting to access a managed lane facility exceeds 275 veh/hr. They provide access for eligible vehicles where high vehicle volumes are anticipated or where additional time savings and operational efficiencies can be gained. Direct-access ramps are usually found with exclusive managed lanes, but they may be used with any type of lane, and they may be used at the start, end, or intermediate locations along a managed facility. Direct connections can be the most efficient means of managing conflicting movements at locations where there is substantial congestion and they facilitate enforcement.

A variety of managed lane ramp alignments exist. Examples of direct-access connections include:

- ◆ T-ramps,
- ◆ drop ramps,
- ◆ flyover ramps, and
- ◆ Y-ramps.

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 and available right-of-way. The following information provides design examples for these types of access treatments.

T-Ramps and Drop Ramps

This type of direct access ramp 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 4-8 shows an example T-ramp design from a reversible-flow managed lane to a park-and-ride lot or arterial street. Figure 4-9 presents a schematic of the managed lane acceleration lane, deceleration lane, and taper lengths for a T-ramp.

Table 4-18 shows the recommended acceleration and deceleration lane lengths for managed lanes for providing access with a T-ramp. The lengths shown are based upon acceleration and deceleration rates for single-unit buses of 2 mph/s (3.2 km/h/s) and 2.5 mph/s (4 km/h/s), respectively, on a level grade. The effective reduction for the length of a deceleration lane on an upgrade is approximately 5 percent for every 1 percent positive grade (9). 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 1000 ft (300 m) or less (8).

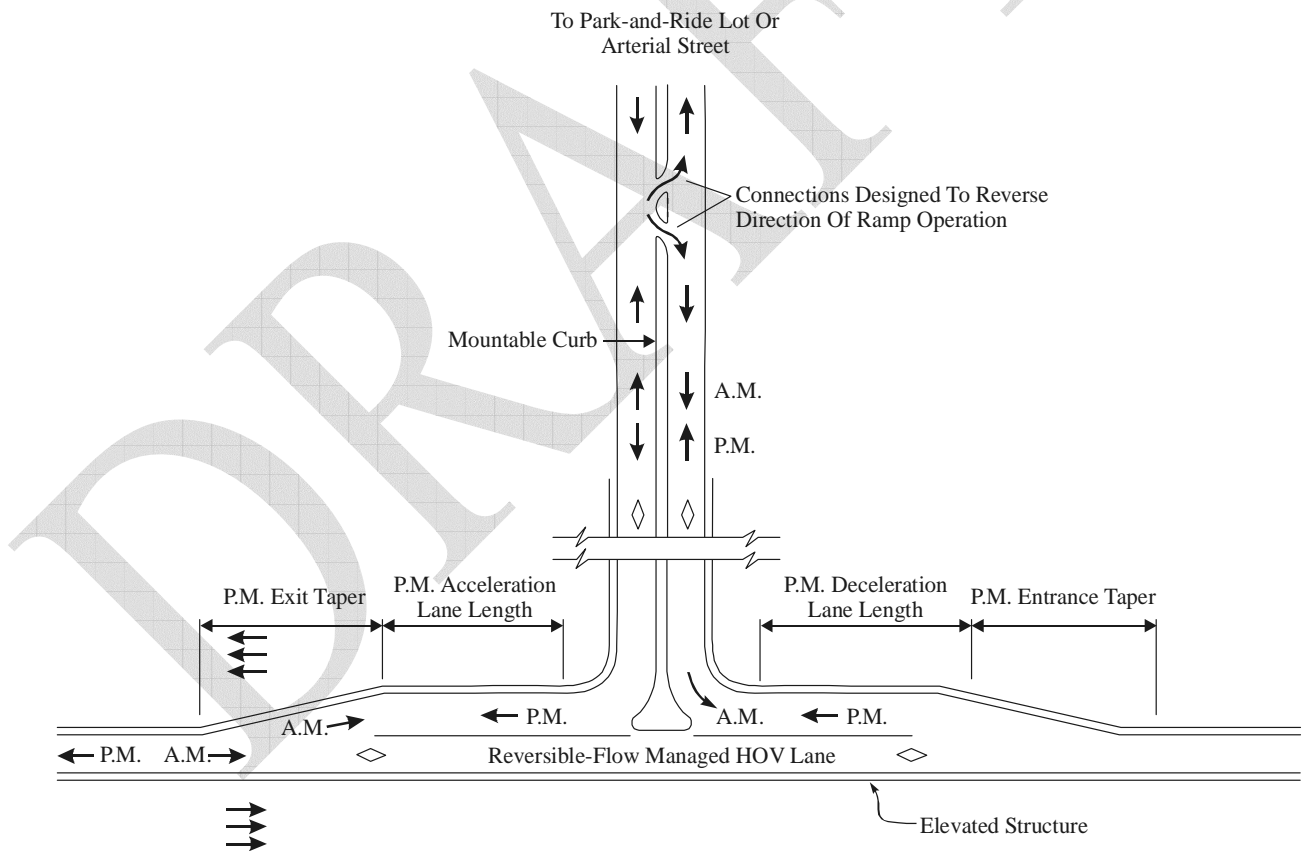


Figure 4-8. Typical T-Ramp for Reversible Managed Lanes Facility (Adapted from Reference 1).

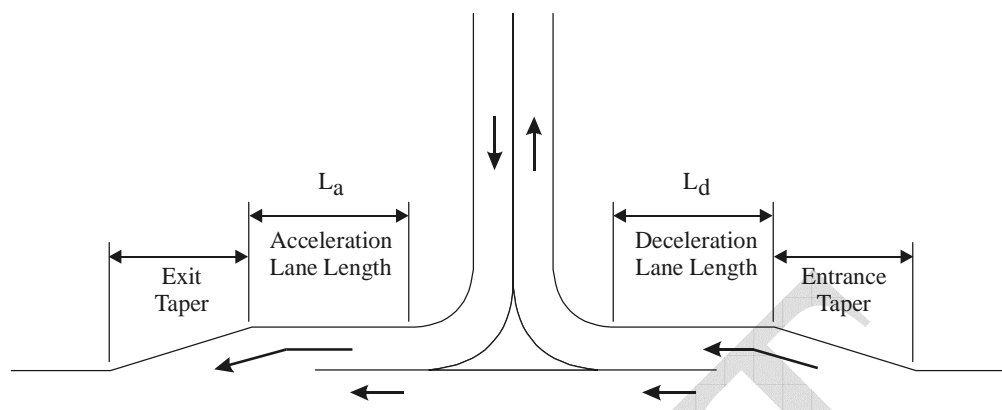


Figure 4-9. Managed Lane Acceleration Lane, Deceleration Lane, and Taper Lengths (Adapted from Reference 9).

Table 4-18. Recommended Acceleration/Deceleration Lane Lengths for T-Ramps (Adapted from Reference 9).

U.S. Customary					Metric				
Mainlane Managed Lane Speed	Managed Lane Entering Speed ¹	Length of Acceleration/Deceleration Lane	Length of Taper ²	Rec. Total Length	Mainlane Managed Lane Speed	Managed Lane Entering Speed ¹	Length of Acceleration/Deceleration Lane	Length of Taper ²	Rec. Total Length
(mph)	(mph)	(ft)	(ft)	(ft)	(km/h)	(km/h)	(m)	(m)	(m)
35	25	250	170	420	60	40	75	50	130
40	30	400	190	590	65	50	120	60	180
45	35	700	210	910	70	55	210	65	275
50	40	975	230	1205	80	65	300	70	365
55	45	1400	250	1650	90	70	425	75	505
60	50	1900	270	2170	100	80	580	80	660
65	55	2400	280	2680	105	90	730	85	815
70	60	3000	290	3290	110	100	915	90	1000

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

Figure 4-10 shows a schematic of the morning and afternoon operations on a T-ramp crossover at a transit center. Figure 4-11 shows a schematic of an alternate T-ramp treatment. Entering traffic from the T-ramp merges downstream from the elevated section.

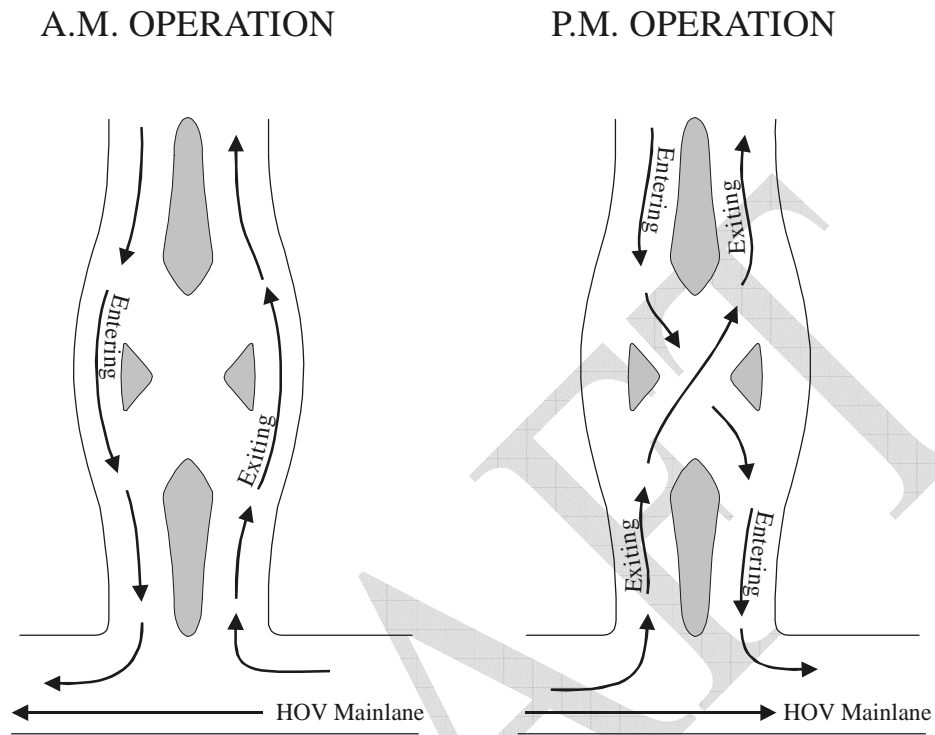


Figure 4-10. Schematic of Morning and Afternoon Operation on T-Ramp Crossover.

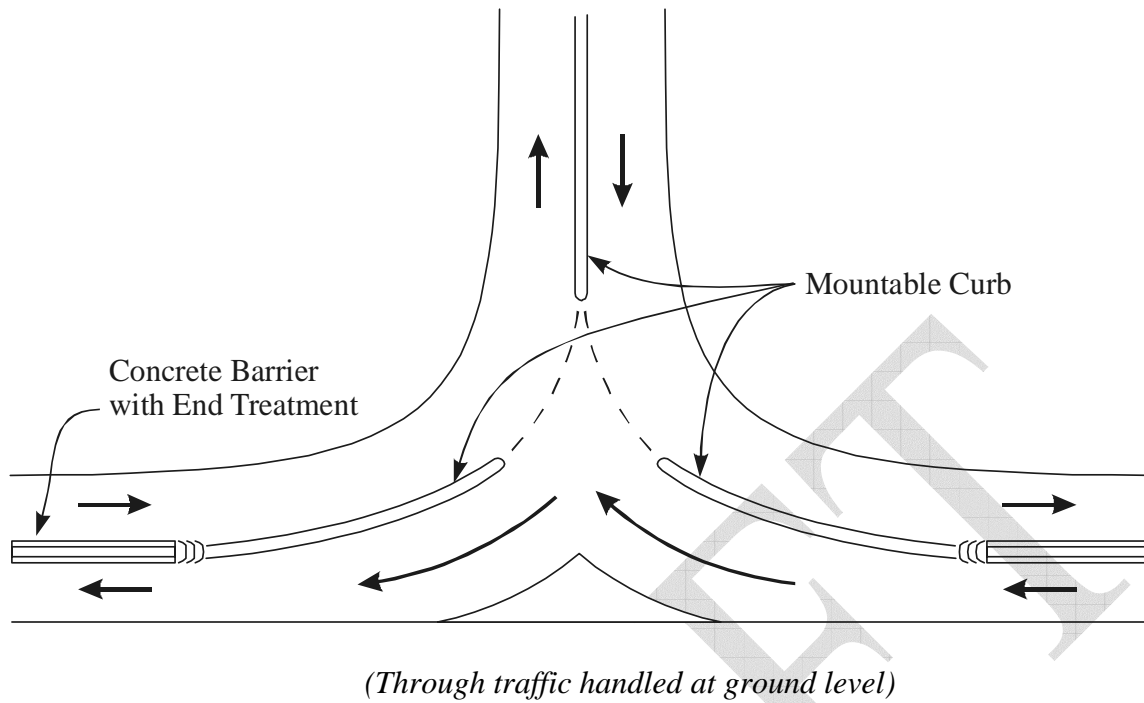


Figure 4-11. T-Ramp Design for Entrance/Exit Only (Adapted from Reference 10).

Figure 4-12 shows a drop lane that provides access to a two-lane reversible-flow HOV lane facility. Figure 4-13 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.

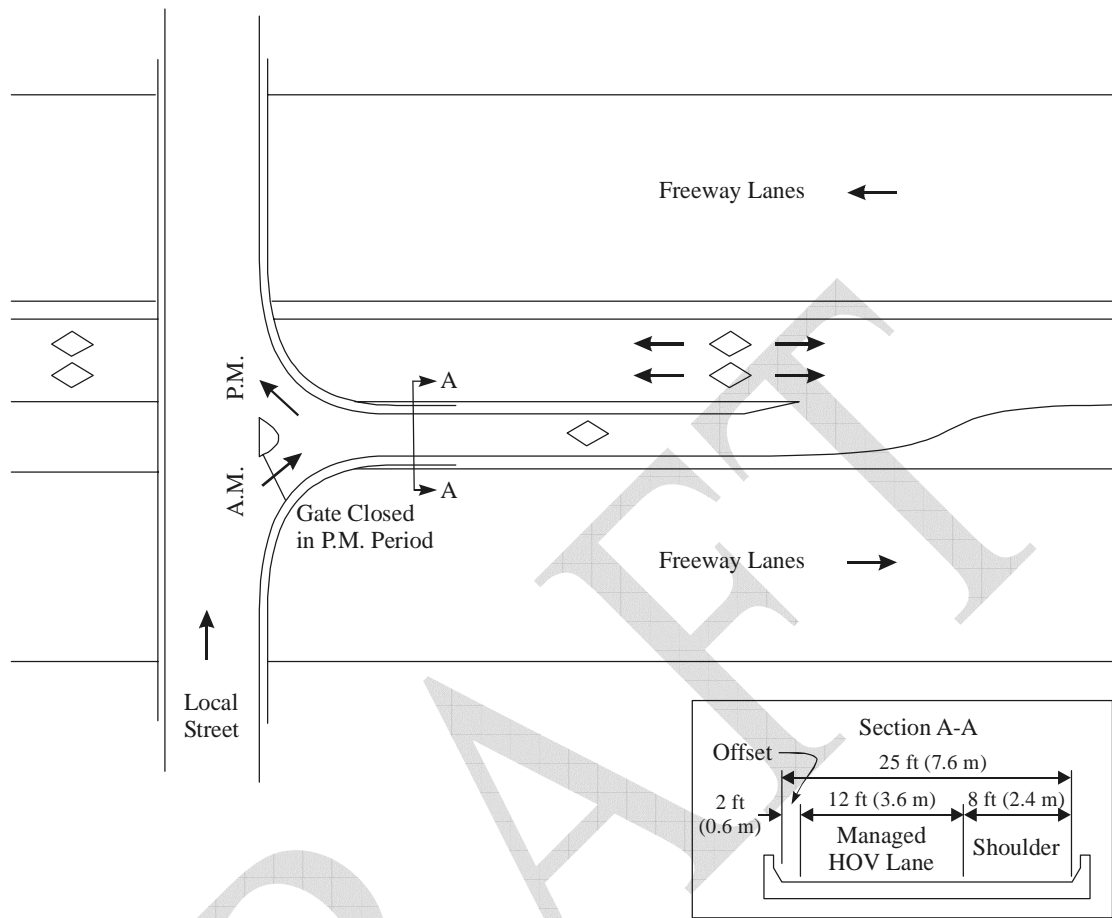
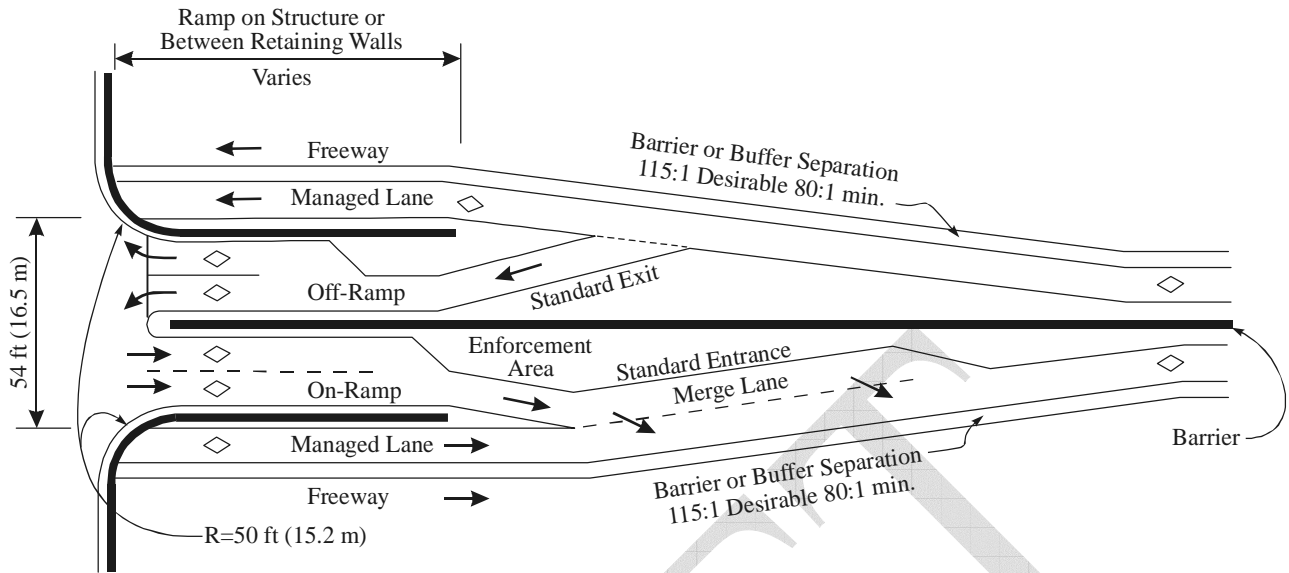
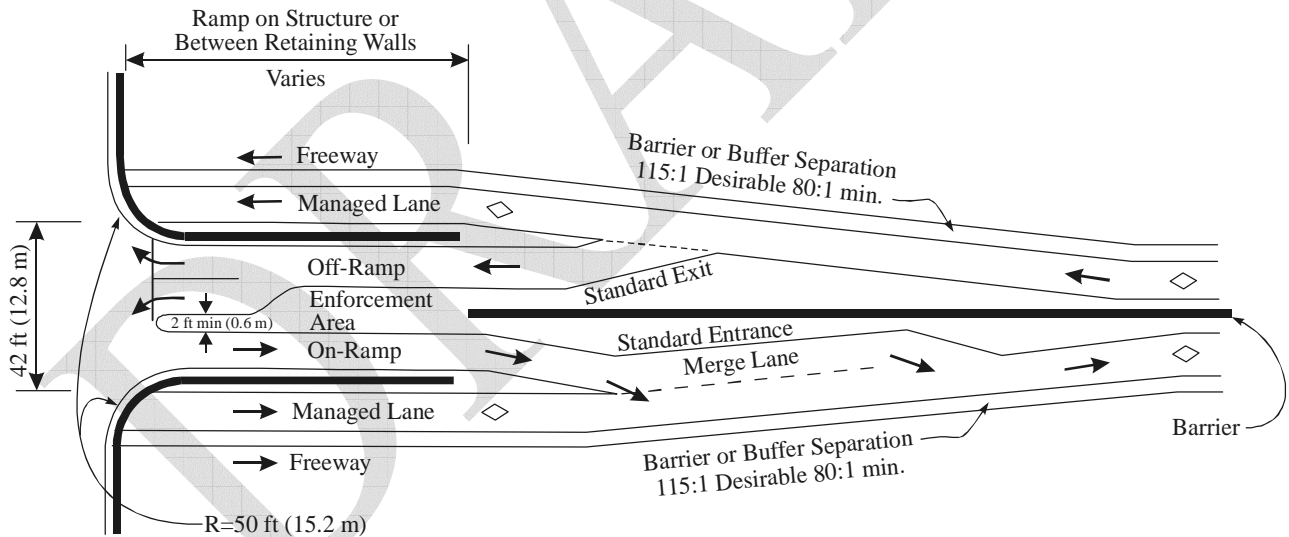


Figure 4-12. Drop Ramp Providing Access to a Two-Lane Reversible-Flow Managed Lane Facility (Adapted from Reference 2).



Barrier-Separation on Ramp



No Barrier-Separation on Ramp

Figure 4-13. Two-Way Drop Ramp (Adapted from Reference 2).

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 mainlane should not be adversely affected by the ramp design speed. It is required to provide acceleration and deceleration lanes along the facility in order to help ensure the safe and efficient operation of the managed lane facility.
- ◆ **Shoulder.** Designers should provide a shoulder 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 ft (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 ft (13.7 m) for two 12-ft (3.6-m) lanes, two 4-ft (1.2-m) shoulders, and a 10-ft (3.0 m) buffer between the opposing lanes. A reduced cross-section width of 38 ft (11.6 m) for a two-way ramp may be considered in certain instances where low speeds are anticipated.

Flyover and Y-Ramps

This ramp design accommodates high-speed, high-volume access to and from a managed lane facility. The function of a flyover ramp is to provide direct, high-speed connections between the managed lane facility and the general-purpose freeway lanes, park-and-ride lot, or other roadway. A variety of design treatments can be used with flyover ramps.

Figure 4-14 shows a schematic of a flyover ramp that provides access to a single-lane reversible-flow managed lane. Figure 4-15 shows a flyover ramp to a single-lane reversible-flow facility at its terminus. Figure 4-16 shows a flyover ramp (Y-ramp) from a two-lane reversible facility, and Figure 4-17 illustrates flyover ramps. Finally, Figure 4-18 illustrates a flyover ramp terminus for a buffer-separated HOV lane.

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

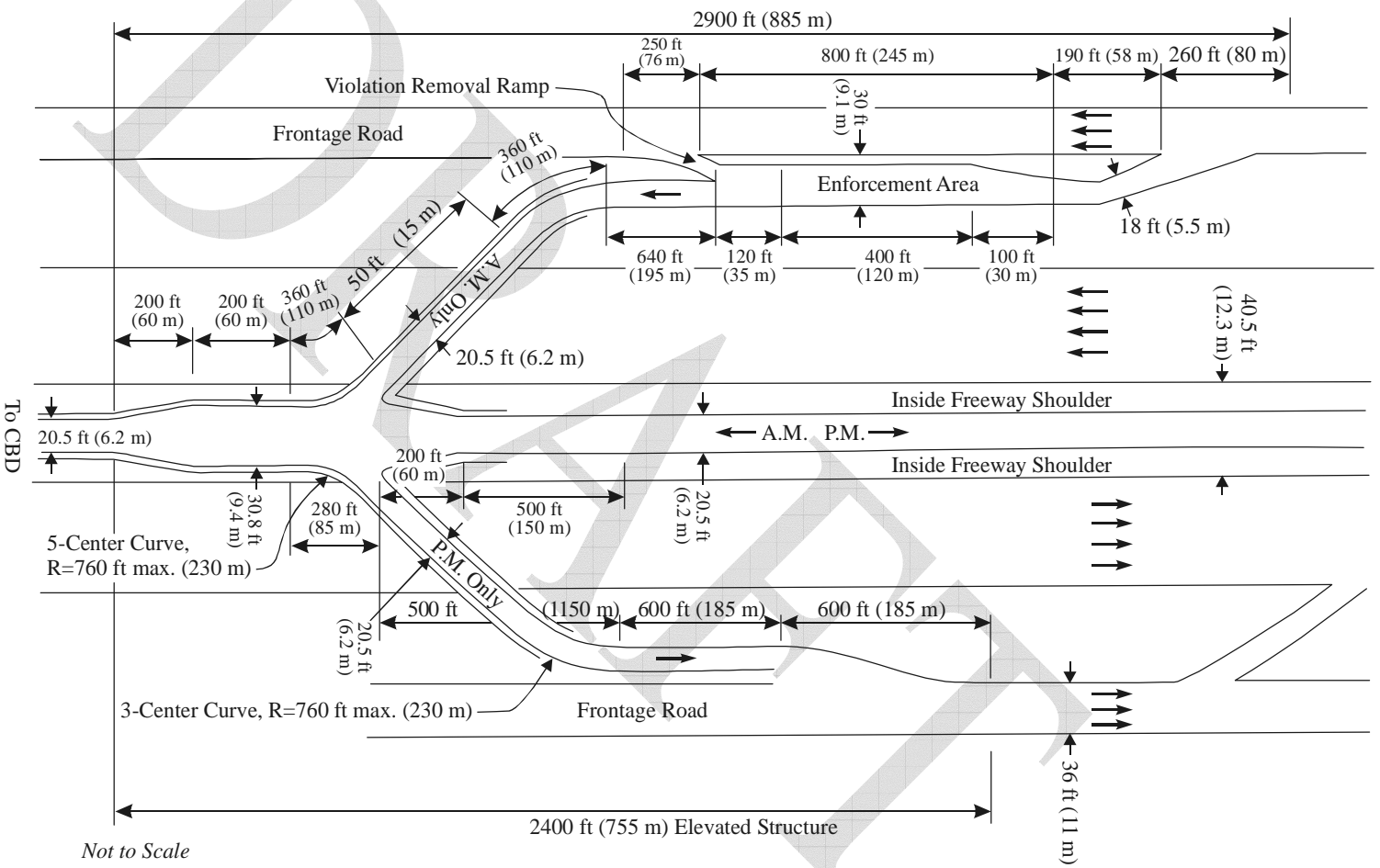


Figure 4-14. Flyover Ramp to Single-Lane Reversible Flow Managed Lane
(Adapted from Reference 2).

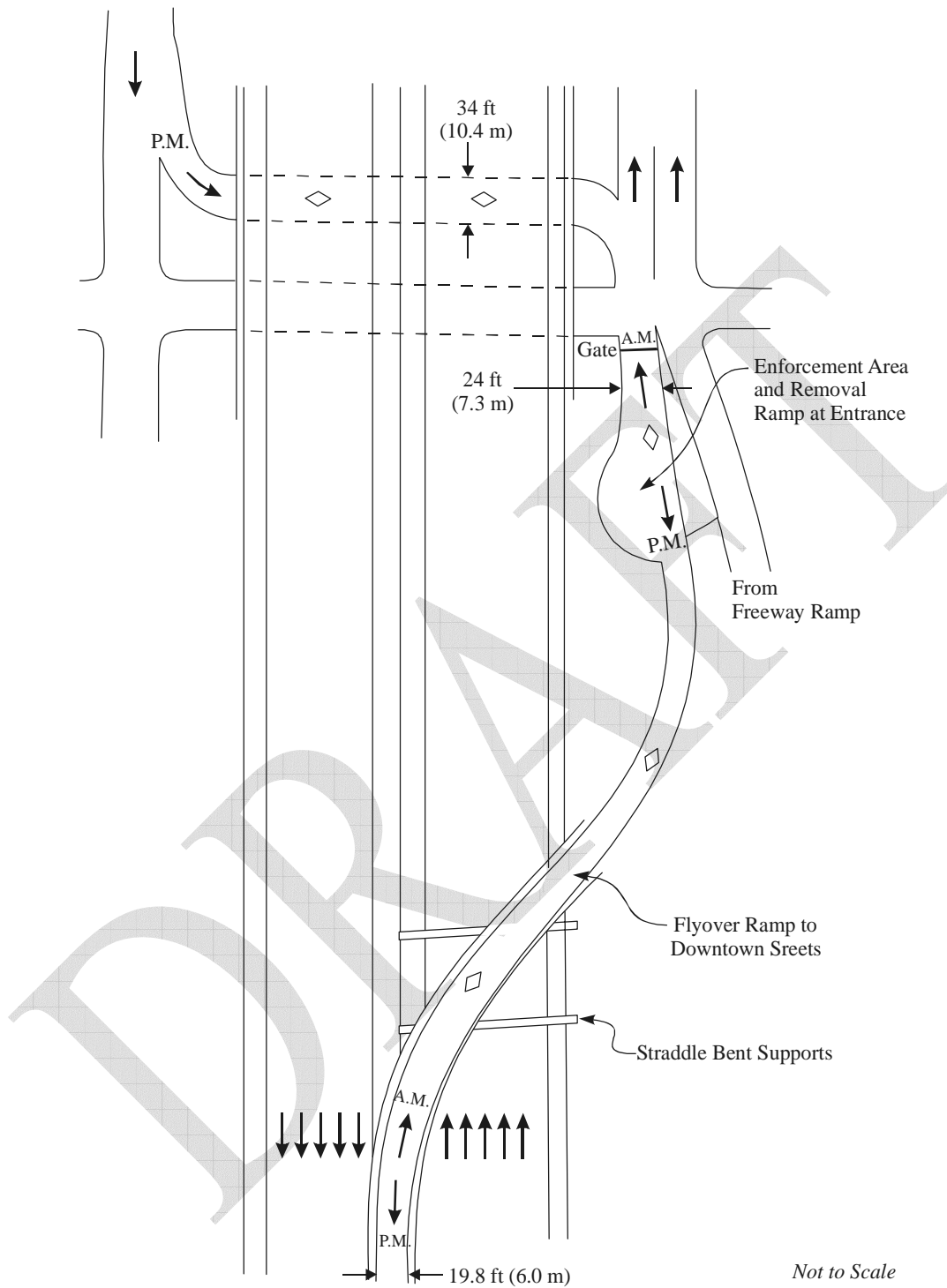


Figure 4-15. Example of a Flyover Ramp Used at Terminus of Managed Lane (Adapted from Reference 2).

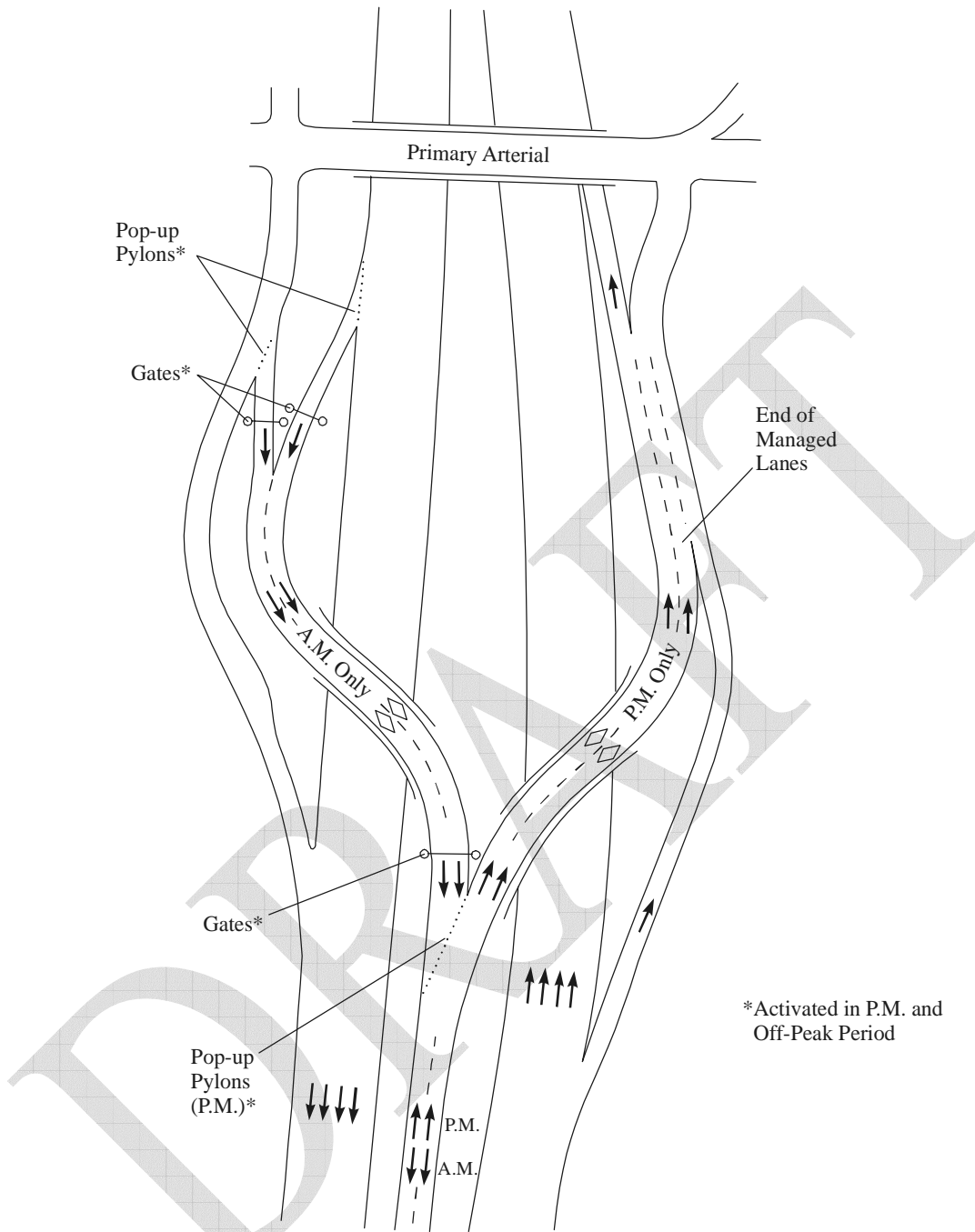


Figure 4-16. Flyover Ramp (Y-Ramp) for a Two-Lane Reversible Managed Lane (Adapted from Reference 2).

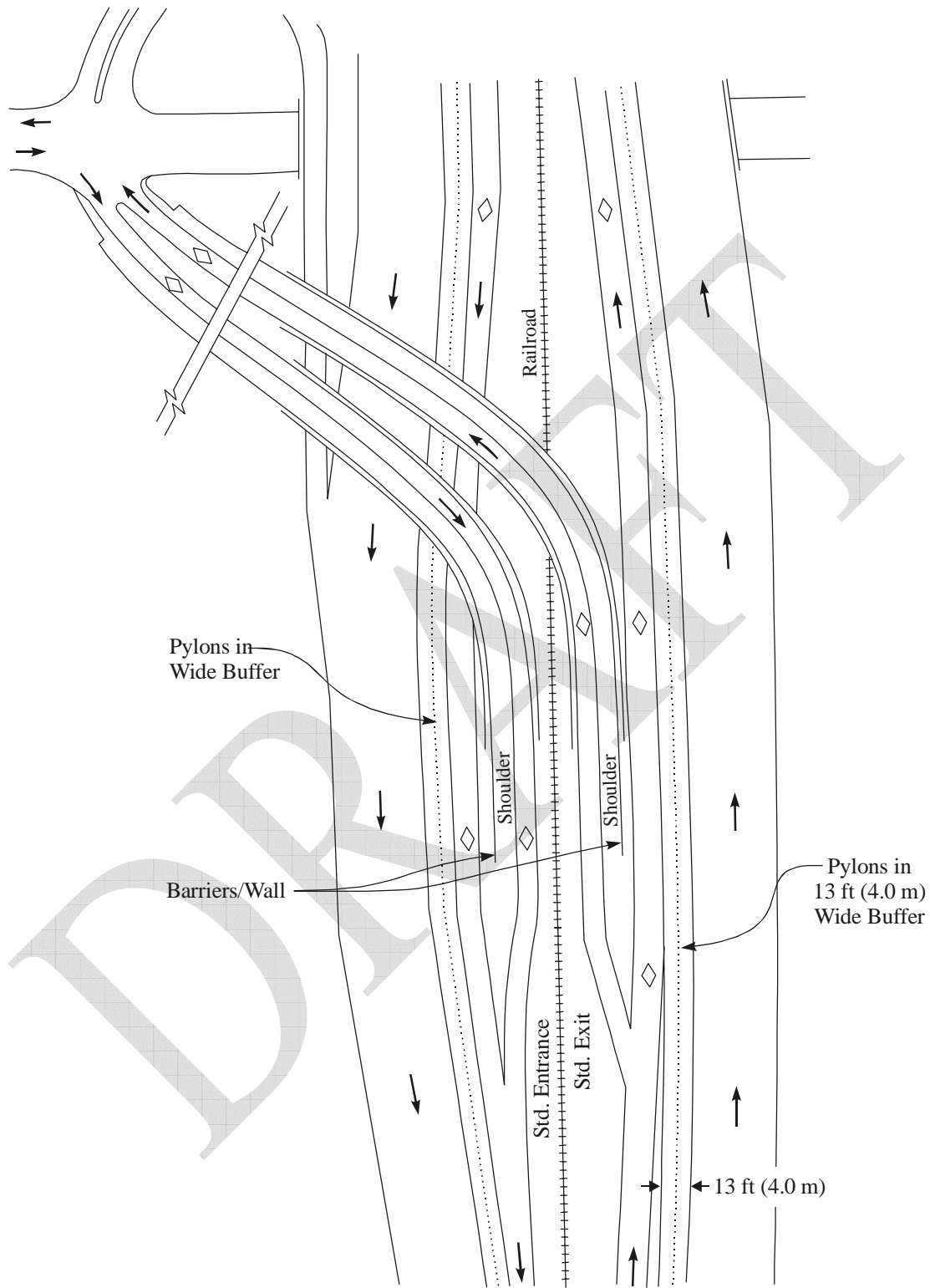


Figure 4-17. Two-Way Flyover Ramp from Managed Lane (Adapted from Reference 2).

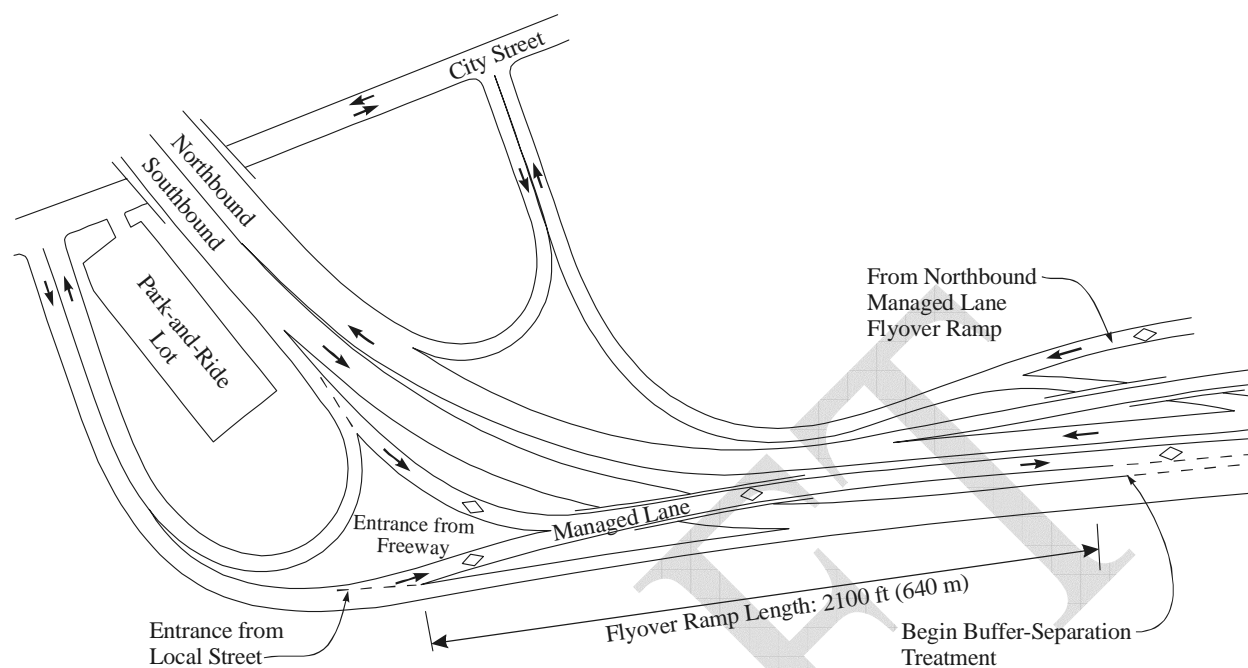


Figure 4-18. Flyover Ramp Terminus for a Buffer-Separated Managed Lane (Adapted from Reference 2).

Managed-Lane-to-Managed-Lane Connection

The development of a coordinated managed lane system may include linking managed lanes on multiple freeways. 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 400 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 4-19 provides an example of a layout for this type of facility.

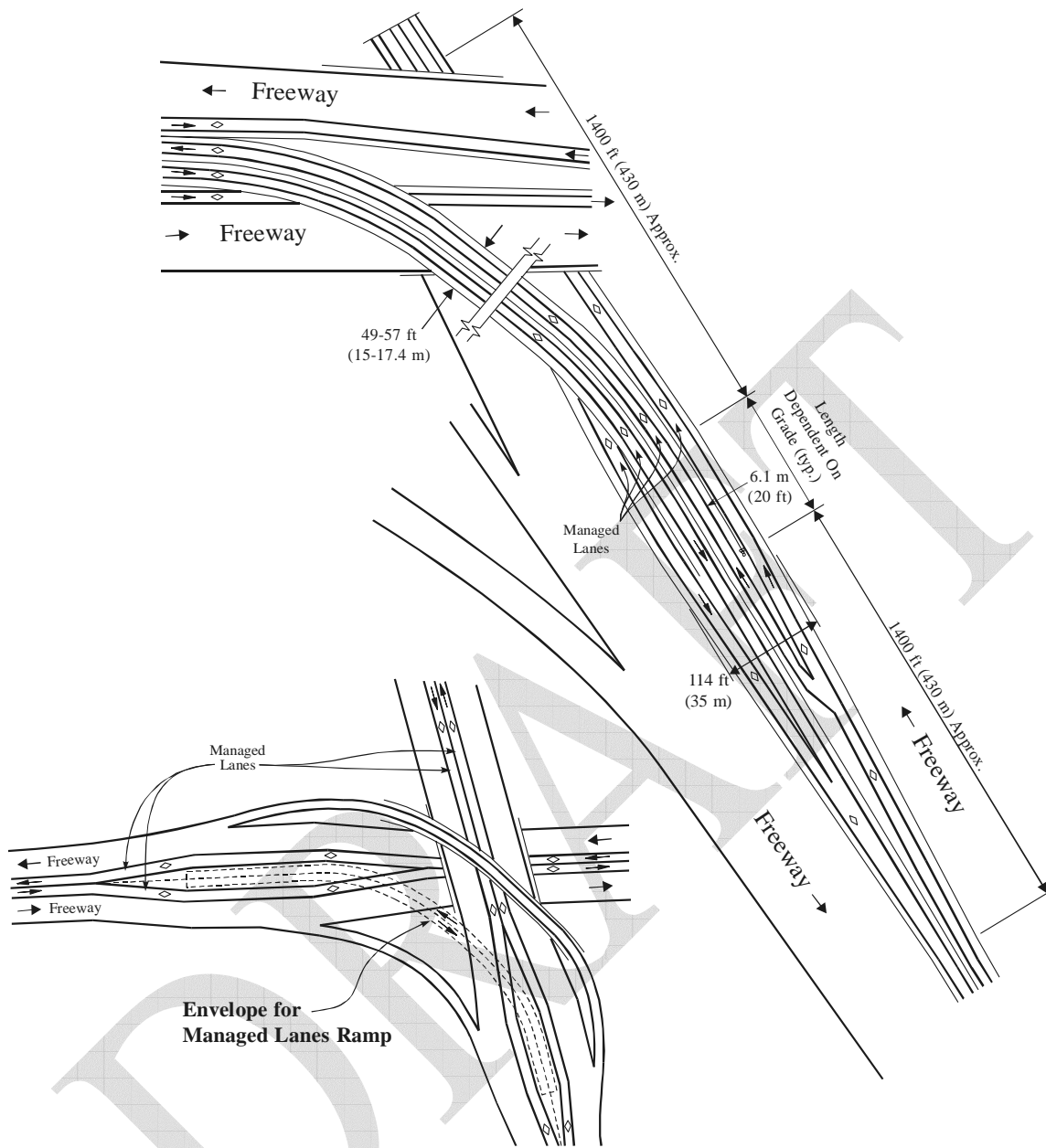


Figure 4-19. Illustration of Managed-Lane-to-Managed-Lane Ramp (Adapted from Reference 1).

At-Grade Access

At-grade access represents the most commonly used treatment with concurrent flow managed lanes. There are two main types of approaches: unrestricted or unlimited (continuous) access, and restricted or limited access. For peak-only operations with no buffer treatment, continuous access is recommended; the managed lane is easily converted to a general-purpose lane at other times. Conversely, full-time operation and restricted access are desirable for lengthy commute periods (typically between 6 to 11 hours of congestion) and short off-peak traffic hours. For a 24-hour operation with a buffer treatment, limited access locations are recommended.

Continuous access allows eligible vehicles to enter and leave the lane at any point. No weave, acceleration, or deceleration lane is provided. 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.

Restricted or limited access regulates the locations where 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. An opening or merge area of 1300 to 1500 ft (400 to 460 m) is desirable. [Figure 4-20](#) illustrates a schematic for a buffer-separated option with and without a weave lane.

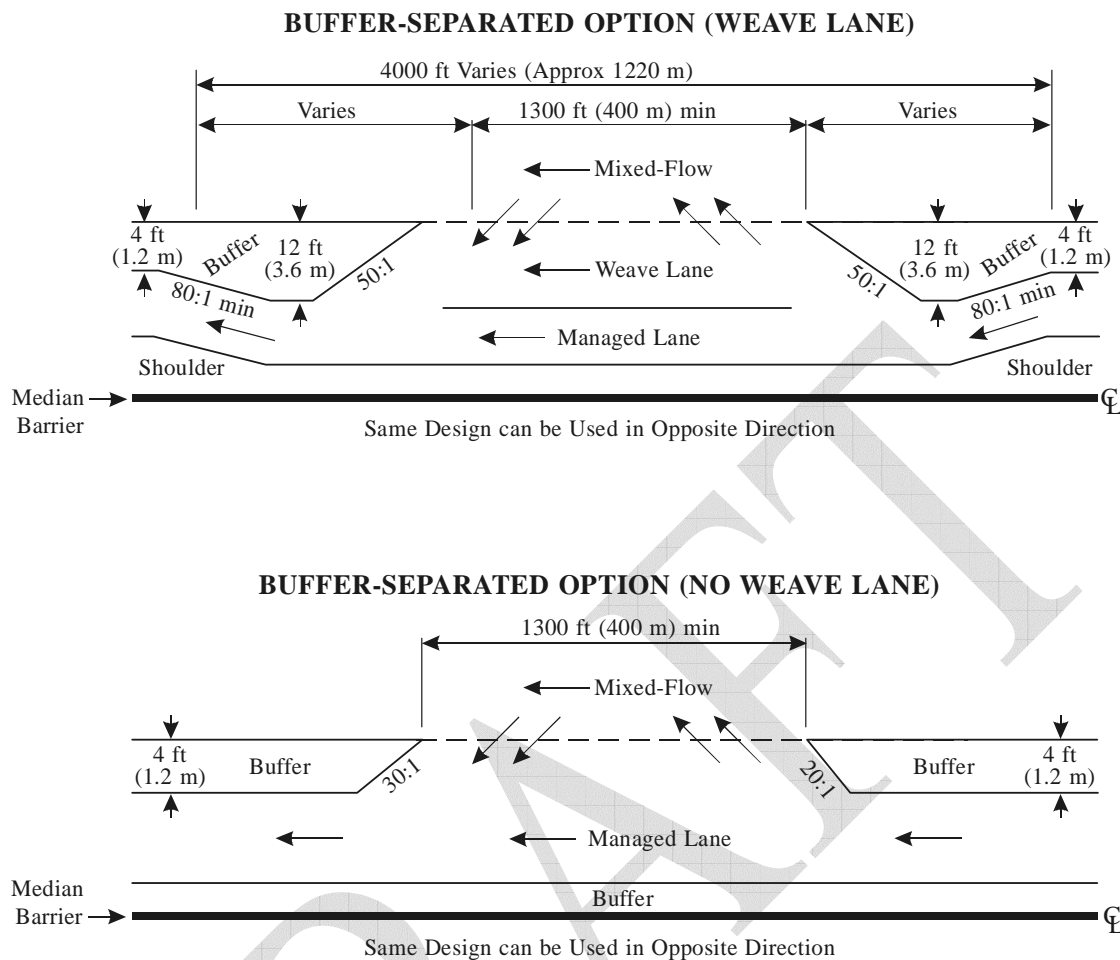


Figure 4-20. Buffer-Separated Intermediate Access with and without Weave Lane (Adapted from Reference 1).

When using at-grade access, consider the volumes in the general-purpose lanes that will be merging with the managed lane facility vehicles. Relatively long 2- to 3-mi (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 4-21 shows the termination of a managed lane as a “free” lane to the inside. Recent research in Texas determined weaving distances for managed lane cross-freeway maneuvers (10). Table 4-19 lists these weaving distances.

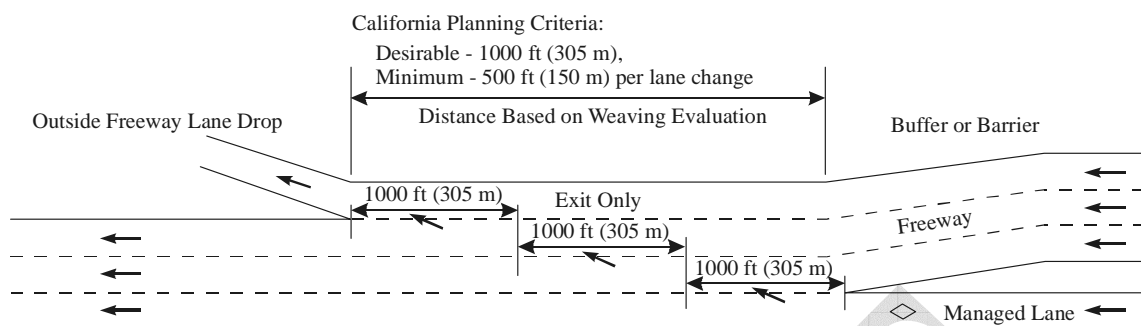


Figure 4-21. Termination of Managed Lane as a “Free” Lane to Inside (Adapted from Reference 2).

Table 4-19. Weaving Distances for Managed Lane Cross-Freeway Maneuvers (10).

Design Year Volume Level	Allow up to 10 mph (16 km/h) Mainlane Speed Reduction for Managed Lane Weaving?	Intermediate Ramp (between Freeway Entrance/Exit and Managed Lanes Entrance/Exit)?	Recommended Minimum Weaving Distance Per Lane ft (m)
Medium (LOS C or D)	Yes	No	500 (153)
		Yes	600 (183)
	No	No	700 (214)
		Yes	750 (229)
High (LOS E or F)	Yes	No	600 (183)
		Yes	650 (198)
	No	No	900 (275)
		Yes	950 (290)

Note: The provided weaving distances are appropriate for freeway vehicle mixes with up to 10 percent heavy vehicles; higher percentages of heavy vehicles will require increasing the per lane weaving distance. The value used should be based on engineering judgment, though a maximum of an additional 250 ft (76 m) per lane is suggested.

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, or if it is 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 4-22 illustrates an at-grade intermediate access for a single-lane reversible-flow HOV lane facility. If an entrance ramp is also necessary at a location where an exit is provided, 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.

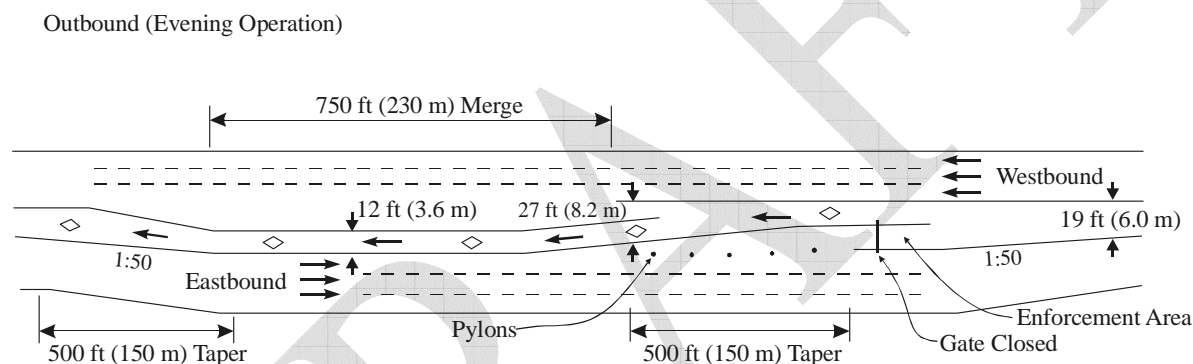
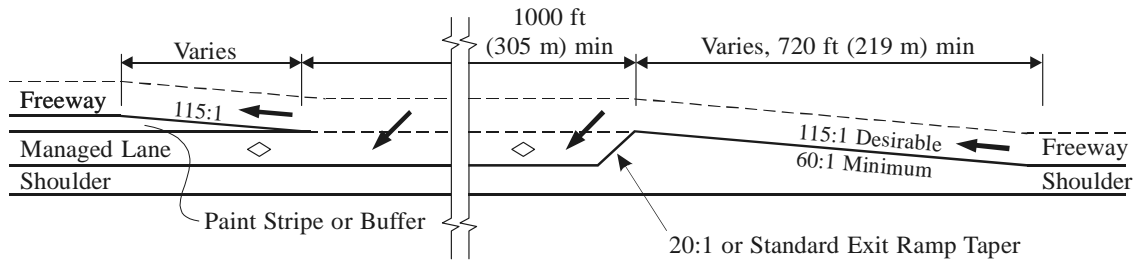
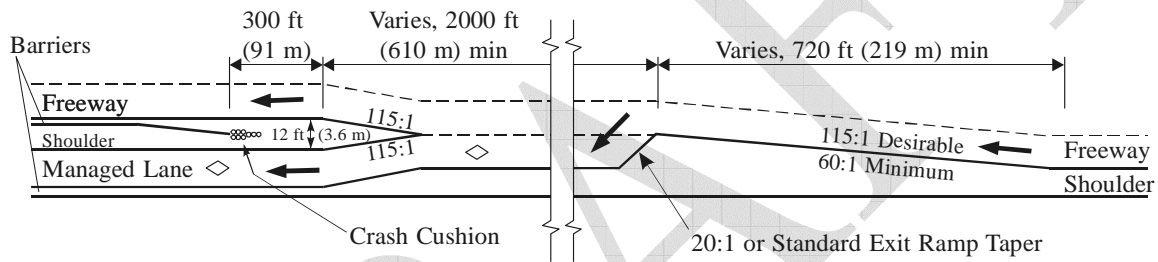


Figure 4-22. Intermediate Slip Ramp for Barrier-Separated Single-Lane Reversible-Flow Managed Lane Facility (Adapted from Reference 2).

Figures 4-23 and 4-24 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 recommended. If the managed lane volumes do not exceed 1000 vehicles per hour, a merge area of approximately 1500 ft (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 mi (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. Entrances to the managed lane facility shall be designed as lane changes to prevent motorists from entering the facility unintentionally.

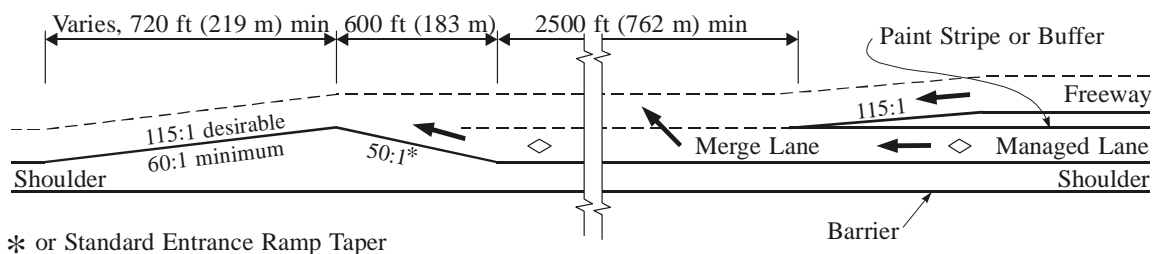


Example of Entrance to Concurrent Flow Managed Lane

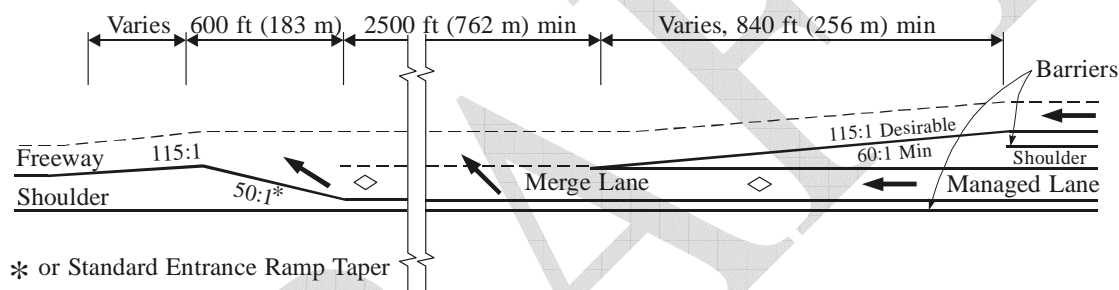


Example of Entrance to Barrier-Separated Managed Lane

Figure 4-23. Example of Layouts for Managed Lane Entry Terminal with Slip Ramps (Adapted from Reference 1).



Example of Exit from Concurrent Flow Managed Lane



Example of Exit from Barrier-Separated Managed Lane

Figure 4-24. Example of Layouts for Managed Lane Exit Terminal with Slip Ramps (Adapted from Reference 1).

Figure 4-25 illustrates an at-grade slip ramp to a two-lane reversible-flow HOV lane with the use of gates for traffic control. Figure 4-26 shows the origin of a contraflow lane within a freeway interchange with an enforcement area. The schematic in Figure 4-27 shows a terminus with morning and afternoon termination of the contraflow facility. Figure 4-28 illustrates another design of a terminus of a contraflow facility.

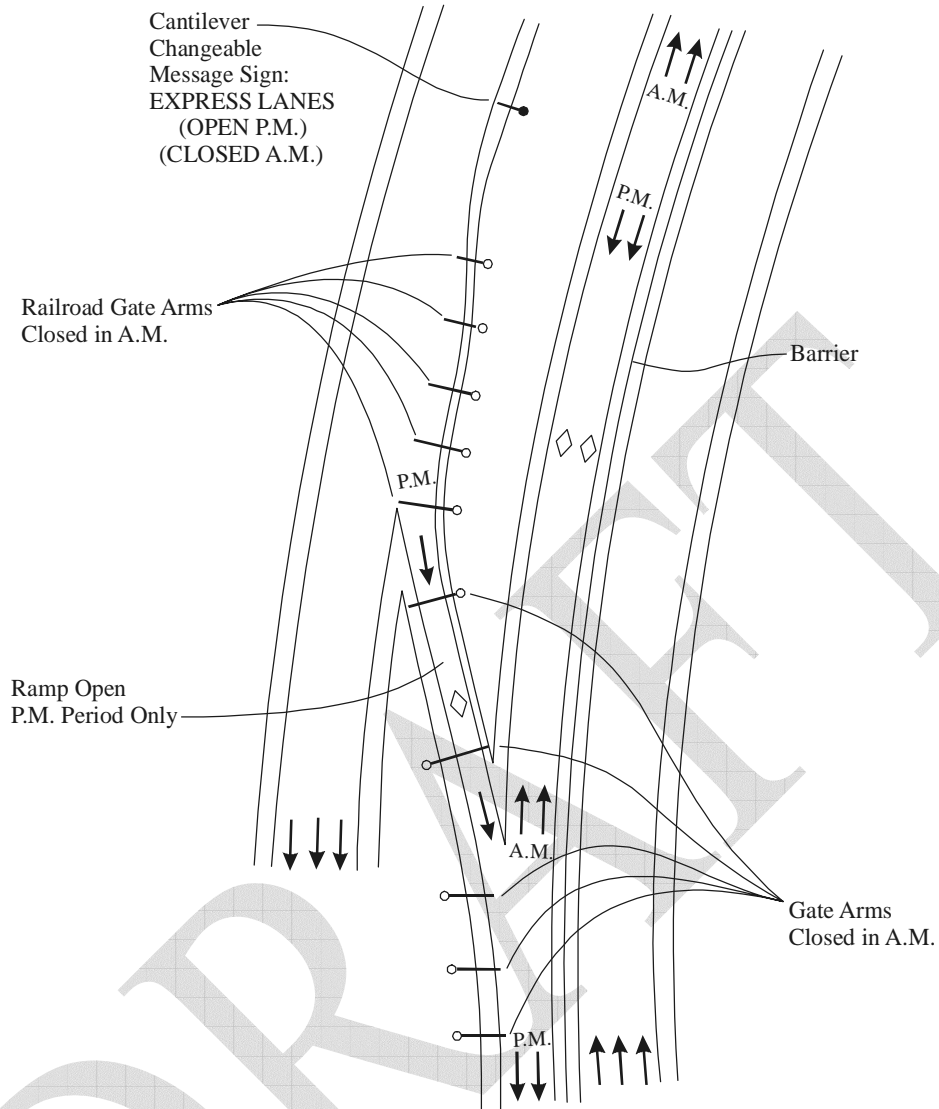


Figure 4-25. At-Grade Slip Ramp to Two-Lane Reversible-Flow Managed Lane (Adapted from Reference 2).

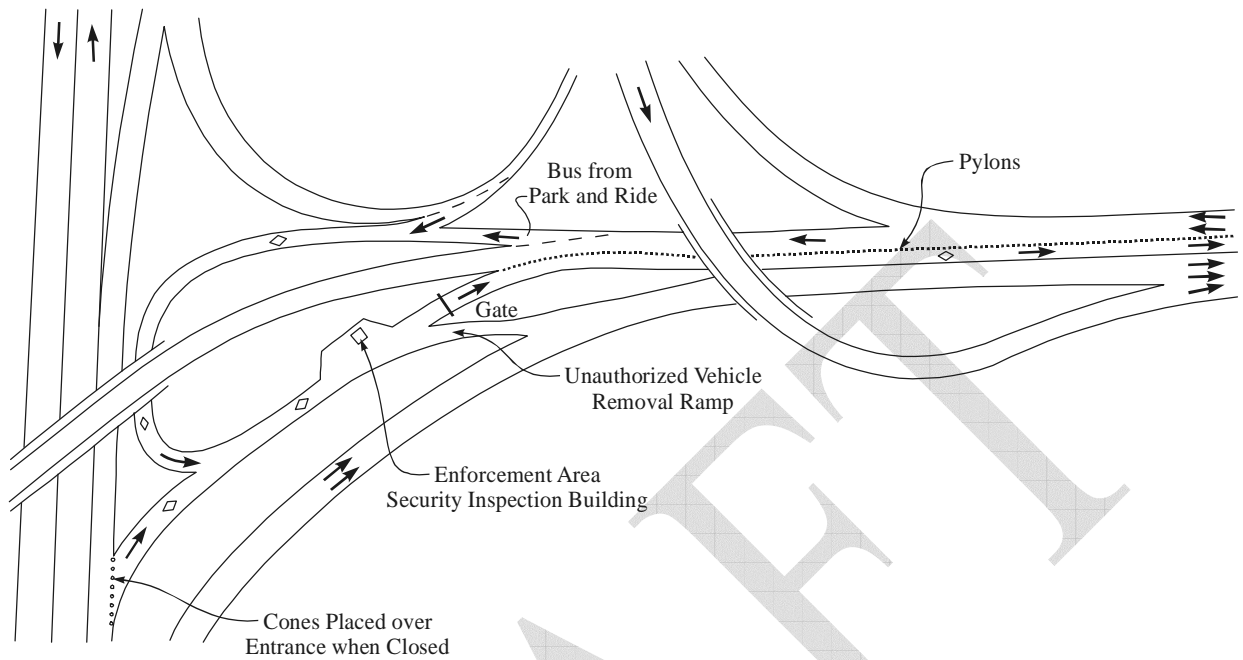


Figure 4-26. Origin of Contraflow within a Freeway Interchange (Adapted from Reference 2).

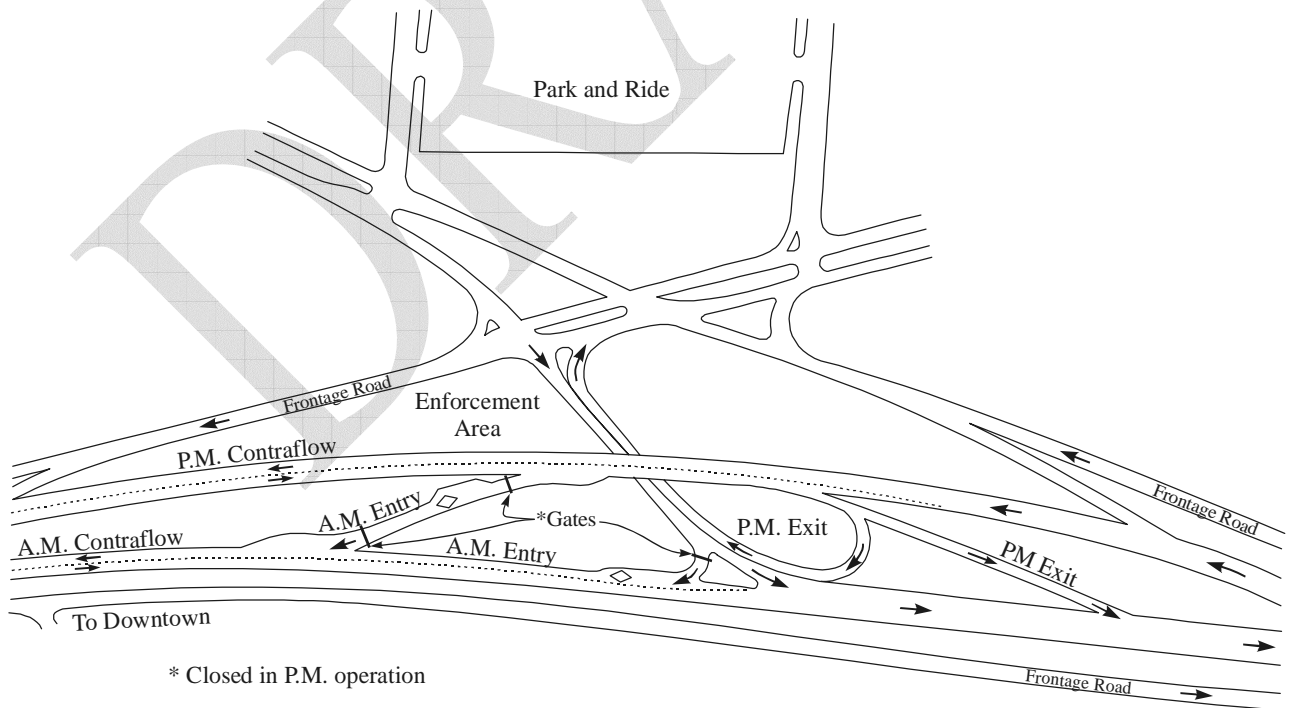


Figure 4-27. Morning Origin and Afternoon Termination of a Contraflow Facility.

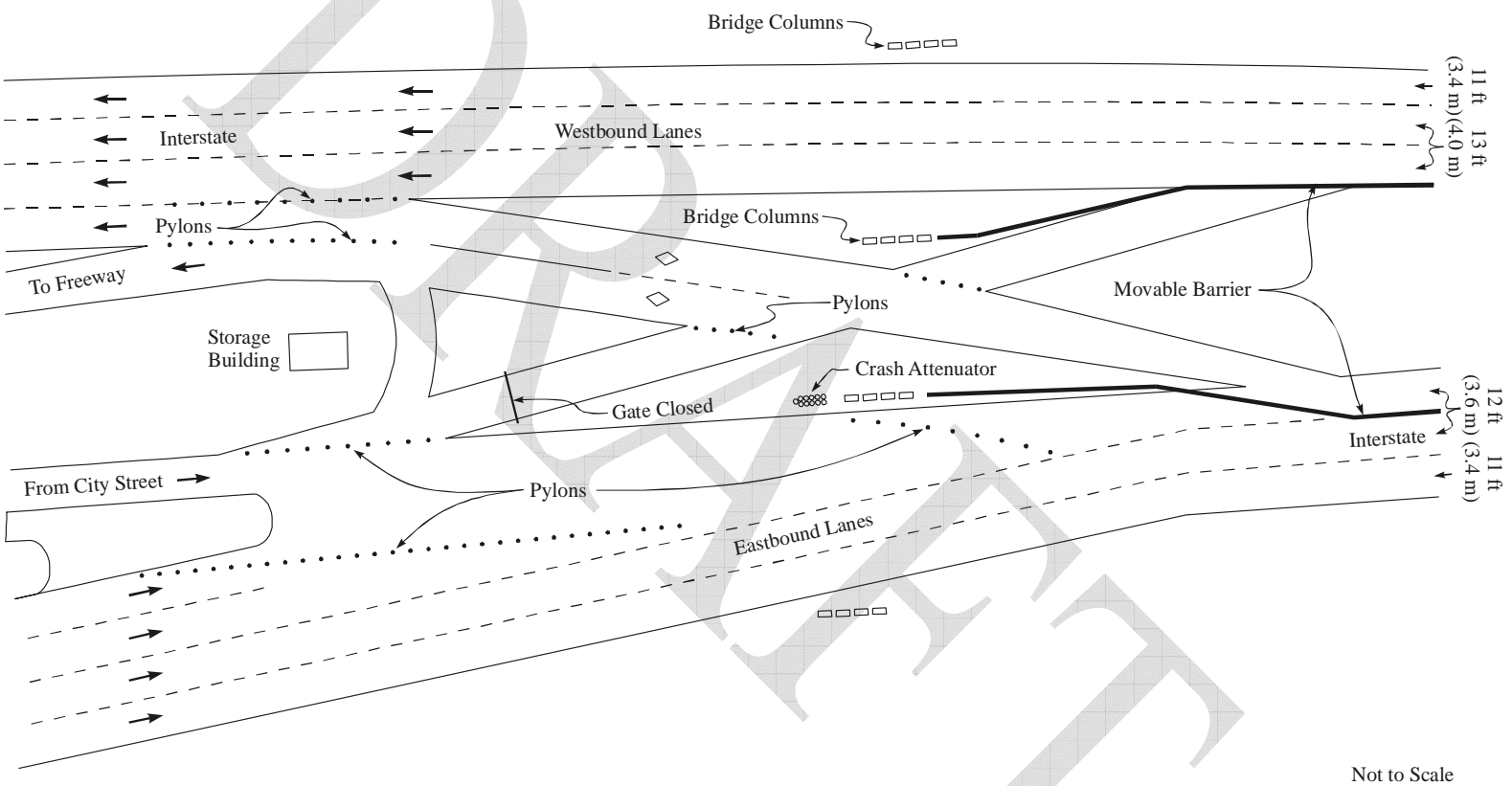


Figure 4-28. Downtown Terminus of Contraflow Facility (Adapted from Reference 11).

Design Considerations for Bypass Lanes at Ramp Meters

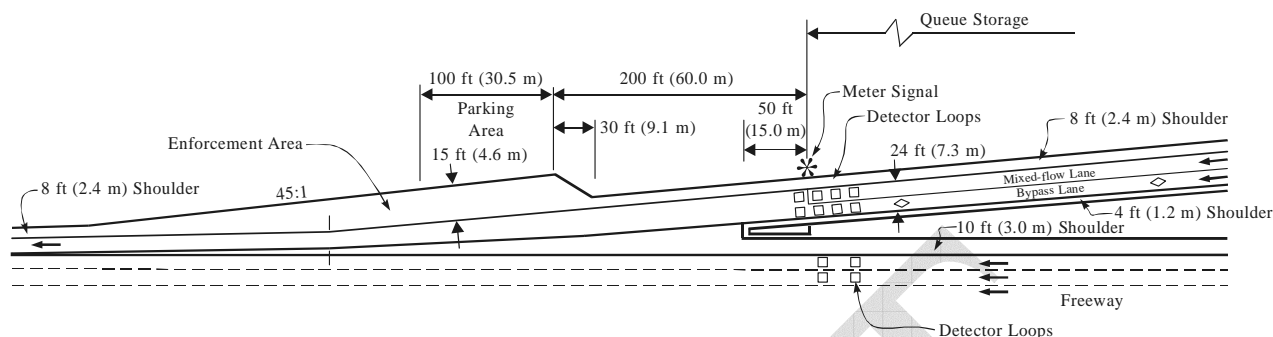
Metering traffic on entrance ramps can improve the overall level of service on a freeway by regulating the flow of traffic and by dispersing the platoons of vehicles that typically enter a freeway during the peak periods. Ramp metering may also discourage drivers from using a freeway for a short-distance trip that can be more effectively served on the local street system.

Providing managed-lane users with a way to bypass the queues that can 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 usually used with bypass lanes at metered freeway entrance ramps are:

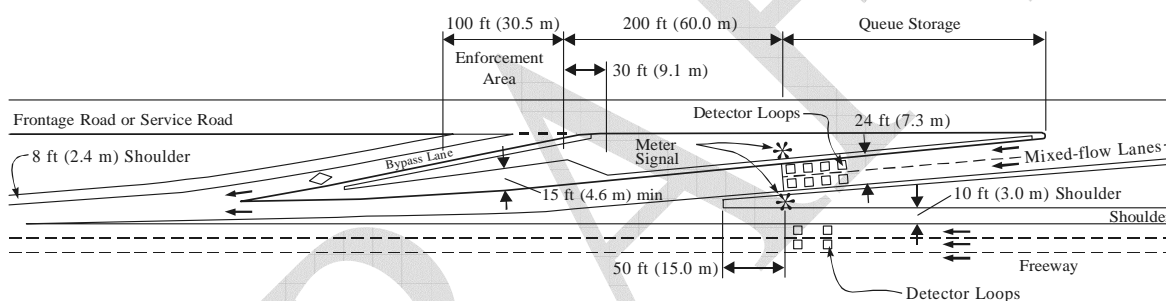
- ◆ an additional lane as part of the existing ramp, and
- ◆ a separate lane for eligible vehicles around the meter.

Figure 4-29 shows layouts of each type of bypass lane. The text that follows highlights the design elements associated with these treatments.



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 4-29. Example of Layouts for Bypass Lane at Metered Freeway Entrance Ramp (Adapted from Reference 1).

Bypass Lane on Exiting Ramp

As shown in the upper schematic of [Figure 4-29](#), one approach is a lane for eligible vehicles directly adjacent to the general traffic lane. A lane width of 12 ft (3.6 m) with ramp shoulders is recommended. However, adequate space within the existing freeway alignment or additional rights-of-way may not be available to meet these criteria. As a result, narrowing the lane to 10 to 11 ft (3.0 to 3.4 m) and dropping the shoulder may be considered in some cases. A distance of 300 ft (91 m) from the meter to the freeway is also recommended to allow the eligible vehicles to merge with the ramp traffic.

The striping detail should use a solid line to separate the eligible vehicle lane from the general traffic lane. 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.

A bypass lane can be located on either the left or right side of the existing general-purpose ramp lane. Right-side placement is preferred for enforcement purposes and high bus volumes; however, the design must have sufficient provision to prevent vehicles queued at the meter from blocking the bypass lane.

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

Separate Entrance Ramp

An alternative for providing eligible vehicles with preferential treatment is to provide a separate entrance ramp. The design of these ramps should also follow 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 desired 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. [Figure 4-29](#) shows the location and general design of enforcement areas.

Location of Bypass Lane

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 rights-of-way, ramp volumes, and the local street system should all be considered in the design of a bypass lane.

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Section 5 – References

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