Guidelines for Implementing Managed Lanes

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 835

Guidelines for Implementing Managed Lanes

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Lawrence D. Goldstein
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Numerous domestic and international agencies either have constructed or are planning to implement systems of managed lanes; however, experience has demonstrated that each system is unique, designed in response to issues and challenges that emerge when these projects are implemented in high-demand, congested, or constrained travel corridors. Despite earlier efforts and despite an apparent need, there is currently no comprehensive resource available to assist transportation agencies when planning and implementing managed lanes. Various guides that do exist contain some information about various aspects of the program, but they do not explicitly address the wide range of issues and complexities in sufficient detail to serve as an effective, widely applicable implementation guide. *NCHRP Research Report 835: Guidelines for Implementing Managed Lanes* fills that void with a comprehensive set of guidelines addressing a broad array of issues affecting design, implementation, operation, and maintenance of managed lanes. Steps range from defining initial objectives, outlining the necessary decision-making process, and addressing safety concerns, through the process of detailed design configuration and operation. These guidelines can serve as the primary reference on managed lanes—complementing other national guidelines—and they are applicable to practitioners at all levels of experience when designing and implementing managed lanes on freeways and expressways.

Managed lanes are highway facilities or a set of travel lanes where operational strategies—such as pricing (e.g., tolls, value pricing), vehicle eligibility (e.g., vehicle occupancy, vehicle type), access control (e.g., limited entry/exit points, use of shoulders), traffic control (e.g., variable speed limits, reversible lanes), or a combination of these—are proactively implemented. Managed lanes employ operating strategies for the proactive management of both the facility and travel demand in a continuing effort to improve or maintain system performance. Given the expanding development of managed lanes, there is a growing need for a better understanding of the unique planning, design, operations, and maintenance procedures and how these various procedures interact. Managed lanes have unique aspects related to financing, project delivery, public outreach, enforcement, and system integration that should be considered in each step of the development process. In response to this need, the Texas A&M Transportation Institute, under the direction of Dr. Kay Fitzpatrick, with assistance from WSP | Parsons Brinckerhoff, Chuck Fuhs, and Herb Levinson, transportation consultants, prepared this guide to support decision-making strategies by practitioners at all levels of experience.

This study was divided into two phases. In Phase I, the research team compiled existing information from published literature and existing manuals and policy documents, emphasizing sources published in the last 10 years. Using information obtained in this review, the research team conducted a series of focused studies in Phase II to fill identified knowledge gaps with respect to trade-offs of geometric design elements, access design, and other factors that affect speed and traffic flow on managed lanes. The activities and findings of the research team, along with a discussion of additional research needs and suggested changes to existing reference documents, are documented within this research report, with additional support material included in the contractor's final report and its appendices. The contractor's final report, *NCHRP Web-Only Document 224: Research Supporting the Development of Guidelines for Implementing Managed Lanes,* accessible from TRB.org, includes detailed background material, gap analysis, design elements, safety performance parameters, and additional related information that emerged through the case studies.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Guidelines for Implementing Managed Lanes

Managed lanes are highway facilities or a set of lanes where operational strategies, such as pricing, vehicle eligibility, access control, traffic control, or a combination of these strategies, are proactively implemented. Numerous domestic and international agencies either have constructed or are planning managed lanes. Each facility is unique and presents issues and challenges since these facilities are often implemented in high-demand, congested, or constrained corridors. There has been no singular national guidance to assist transportation agencies implementing managed lanes. Some information on managed lanes has been included in American Association of State Highway and Transportation Officials and Federal Highway Administration guides, but they do not explicitly address the wide range of issues and complexity associated with the planning, design, operations, and maintenance of managed lanes, and how these factors interact, in sufficient detail to serve as a national guide on the subject. Managed lanes also have unique aspects related to financing, project delivery, public outreach, enforcement, and system integration that should be considered in each step of the project development process.

The objective of National Cooperative Highway Research Program (NCHRP) Project 15-49 was to develop guidelines for the planning, design, operations, and maintenance of managed lanes. This final product—*NCHRP Research Report 835: Guidelines for Implementing Managed Lanes*—was developed to become the primary reference on managed lanes and complement other national guidelines. It was designed to be applicable to practitioners at all levels of experience with managed lanes and to be used to support informed decision making. The scope of this project was limited to managed lanes on freeways and expressways. The tasks and activities completed in NCHRP Project 15-49 to create these guidelines are documented in a separate research report (*NCHRP Web-Only Document 224: Research Supporting the Development of Guidelines for Implementing Managed Lanes*).

Chapter 1 of the guidelines provides an introduction to managed lanes. The initial overview includes an abridged history of managed lanes in the United States, definition of key terms and concepts, and context within which to consider managed lanes. This introductory chapter provides a high-level discussion of some common managed lane designs and strategies, the decision-making process involved in implementing managed lanes, and some safety performance considerations. The chapter concludes by describing the intended audience of the guidelines as practitioners involved in the planning, design, implementation, or operation of a managed lane facility, and it briefly lists topics included and not included within the scope of the document.

Chapter 2 focuses on considerations for appropriately planning a managed lane using experience from past projects and other national guidance. Planning a managed lane project usually consists of the following components:

- Identifying goals and objectives.
- Conceptually planning and testing feasibility.

- Refining feasibility to define a project or program.
- Developing an appropriate concept of operations and preliminary design that address the project or program.
- Developing an implementation plan.
- Developing a financing or funding plan.
- Pursuing an environmental review (e.g., National Environmental Policy Act, California Environmental Quality Act), if required.

Guidance related to each of these components is provided in Chapter 2, along with a discussion of policy and legislative considerations and a discussion on incorporating public involvement and support in the planning process.

Chapter 3 contains guidance on the design of managed lane facilities. Intended user groups and design vehicles are presented in the initial section of the chapter, followed by a description of a variety of geometric design considerations. These considerations include consistency among applicable local, regional, state, and national guidelines; design speed; cross section and alignment; location of managed lanes with respect to general-purpose lanes; treatments for separating managed lanes and general-purpose lanes; reversible and contraflow lanes; pullouts for enforcement or refuge; and issues when converting a high-occupancy vehicle lane to a high-occupancy toll lane. The chapter also provides a section on the provision of access to and from managed lane facilities, including consideration of limited versus continuous access and applicable corresponding treatments. The chapter concludes with a brief discussion of operational impacts on design, including appropriate references to other chapters and sections within these guidelines.

Chapter 4 provides information and guidance on appropriate traffic control devices. A description of relevant sections in the *Manual on Uniform Traffic Control Devices* is provided for the reader's reference. The chapter describes multiple categories of signs (i.e., guide, regulatory, and changeable), signals, and pavement markings, including devices specific to reversible and contraflow lanes. Additional methods of disseminating information to road users are discussed, along with guidance for installation and maintenance as well as trade-offs to consider in facilities with constrained designs.

Chapter 5 focuses on implementation and deployment of managed lane facilities. Guidance in this chapter includes topics such as reviewing the design and providing for appropriate testing of the system (including toll collection hardware) to accomplish system acceptance. The chapter also includes a brief overview of the importance of accommodating improvements and upgrades, as well as a discussion of the project delivery process.

The theme of Chapter 6 is operations and maintenance of managed lane facilities. General issues related to operations include the development of a concept of operations for a facility, considerations for toll operations, and considerations for high-occupancy vehicle eligibility. Additional topics include considerations at startup as well as ongoing operations, business rules for managed lanes, operation of managed lane systems, and performance monitoring and evaluation. The chapter concludes with a discussion of maintenance considerations.

This guideline document concludes with a list of commonly used acronyms, a glossary of key terms, and a list of references of other published sources used to develop the guidelines.

CHAPTER 1

Introduction to Managed Lanes

Overview

Subject Context

Managed lanes in the context of these guidelines are designated (also defined as preferential) lanes and roadway facilities located on or adjacent to controlled-access urban/suburban metropolitan highways that are actively operated and managed to preserve operational performance over comparable general traffic lanes. Operational performance implies more optimal travel speeds and reliability than would be observed on adjacent general-purpose lanes that are not subject to the same level of active management. Various operational strategies are applied to preserve these benefits in response to specific goals and objectives. Most managed lanes serve long-distance mobility needs and are often the leftmost lanes next to the median barrier. These lanes are typically located within a public right-of-way defined as a freeway corridor. They may include provisions to address needs of specific users, such as transit stations for express bus transit. They may be adjacent to other lanes and/or physically separated.

Definitions of Managed Lanes

While the application of managed lanes dates back almost 50 years and covers early busway, bus lane, and high-occupancy vehicle (HOV) lane treatments, the term "managed lanes" was not commonly applied until the late 1990s. While technical and operational practitioners apply the expression "managed lanes" to a wide variety of dedicated or preferential lane treatments found on urban freeways and arterials, the public may be exposed to a wider range of terms based on how the projects are marketed and implemented locally.

Some consistency of use is also found in terms that the *Manual on Uniform Traffic Control Devices* (MUTCD) gives to managed lane signing (*1*). In the MUTCD, managed lanes serving carpools and buses are termed "HOV lanes," while priced managed lanes are termed "express lanes" because they often serve long-distance trips and have more restricted access than other freeway lanes. Within each locale or state, locally recognized names may be applied, such as "diamond lanes" in Texas or "carpool lanes" in California. These legacy names now recognized by generations of motorists do not necessarily need to be consistent with terms that technical practitioners apply to define a particular type of facility or operation.

Within the transportation practitioner community, various definitions are ascribed to managed lanes for general and specific design and operational applications. Some terms are applied specifically by the technical practitioner community at a national level (i.e., practitioners who are planning, implementing, and operating managed lanes). Other terms are sometimes applied by practitioners within a designated region and are locally familiar. Still other terms are locally or regionally applied to aid in branding for public understanding and customer marketing. Thus, similar managed lanes are labeled by different names based on the practitioner and customer understandings and preferences. Each perspective is highlighted in the following sections.

Overall Concept Definitions

The 2013 Federal Highway Administration (FHWA) *Priced Managed Lane Guide* (*2*) provides perhaps the most succinct definition for managed lanes:

> Managed lanes are designated lanes or roadways within highway rights-of-way where the flow of traffic is managed by restricting vehicle eligibility, limiting facility access, or and in some cases collecting variably priced tolls.

Managed lanes over the first 30 years were typically termed "bus" or "HOV" lanes; they reserve lanes for bus, vanpool, and carpool use during periods of greatest demand. By offering reserved lanes for multi-person vehicles, HOV lanes emphasize *person movement* rather than traditional *vehicle movement,* thus improving the roadway's ability to move more people in fewer vehicles. The following definition for HOV lanes is from *NCHRP Report 414: HOV Systems Manual* (*3*):

> A lane(s) or roadway dedicated to the exclusive use of specific high-occupancy vehicles, including buses, carpools, vanpools or a combination thereof, for at least a portion of the day.

Borrowing from referenced sources that follow, and based on prior references and prior definitions adopted by the Transportation Research Board (TRB) Committee on Managed Lanes, the research team offers the following definition of managed lanes for this guide:

> Managed lanes are dedicated lanes or roadways implemented in congested freeway corridors that are actively controlled through a variety of strategies to limit flow rates and thereby preserve an acceptable level of service. By taking such measures, managed lanes generate significant travel benefits, including time savings and improved reliability and operational efficiency to the roadway system. Such lanes can be added either along with new roadway facilities or as modifications to existing facilities; they should not typically be converted from existing general-purpose lanes. Managed lanes can be considered for specific bottlenecks, as corridor treatments, or as networks or systems in a metropolitan region.

FHWA (*2*):

> defines ***managed lanes*** as highway facilities or a set of lanes in which operational strategies are implemented and managed (in real time) in response to changing conditions. Managed lanes are distinguished from other traditional forms of lane management strategies in that they are proactively implemented, managed, and may involve using more than one operational strategy.

States may apply their own definitions. For example, the Texas Department of Transportation (TxPUBLIC–PRIVATE) has developed the following definition for managed lanes (*4*):

> A managed lane facility increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals.

As specific managed lane projects in Texas undergo planning and development, this definition is tailored to address specific project needs. For example, the following variation was developed for the I-635 Lyndon B. Johnson (LBJ) Freeway managed lane project in Dallas (*4*):

> Managed lanes increase freeway efficiency by offering a predictable trip with little congestion for commuters to carpool, ride bus transit, ride a motorcycle, or drive alone for those willing to pay a toll. Lane management operations and pricing structures may be adjusted at any time to better serve modal needs.

The preceding Texas project definition specifically addresses priority user groups and the use of variable pricing to achieve objectives for the project.

The Washington State Department of Transportation (WSDOT) developed the following definition of managed lanes in 2010 (*5*):

> Managed lane facilities include any roadway lane that can be managed to prevent congestion from occurring. In managed lanes, one or more of these techniques is used to control the number of vehicles using the lane or roadway:
>
> - Limiting access—providing infrequent on-ramps, as on the I-5 and I-90 express lanes.
> - User eligibility requirements—such as HOV only, truck only, permit only, etc.
> - Pricing—tolls can be varied by time of day to control traffic volumes.

By considering different forms of traffic management, it is possible to utilize the best combination of tools to keep a roadway from becoming congested over time and to optimize traffic to achieve the best person and vehicle throughput.

A common element in the definitions is a broad range of potential strategies and user groups. An emphasis is made on achieving a preferential operating condition within the managed lanes, either explicitly stated within the definitions (freeway efficiency, reduction in congestion and optimized throughput) or through implicit qualities such as travel time savings, travel time reliability, free-flow speeds, or higher speeds than adjacent lanes.

Definitions for Facility Types

From a practitioner's perspective, HOV lanes have historically been the most widely applied form of managed lanes fitting the previously described definitions. However, HOV lanes are only one of many dedicated lane applications that currently exist or are proposed. The facility types listed in Table 1 could be considered managed lanes if they employ an operational strategy that preserves an enhanced travel condition. As described later in this chapter, the most common operational strategies include restricting vehicle eligibility, access control, or variable pricing through electronic toll collection.

As noted, more than one term may describe the same general concept. For example, depending on who is tolled or who is given free use, the terms "high-occupancy toll (HOT) lane," "express lane," and "express toll lane" may all describe the same general operation. More complete definitions for each type of managed lane are found in the glossary.

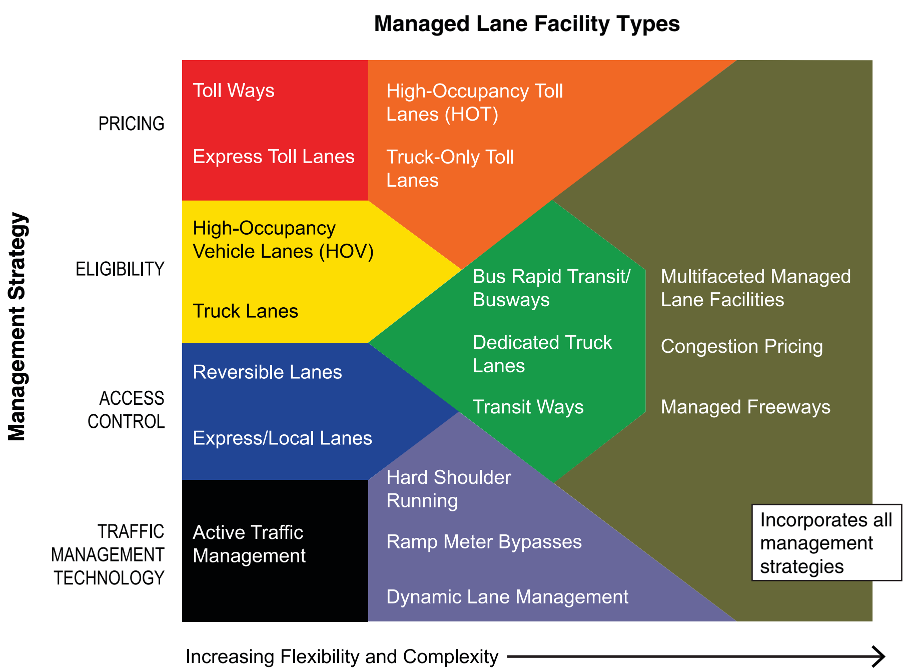
Table 1 contains the adopted terms and definitions used within this guide and are terms consistently applied in many prior national guidance documents sponsored by NCHRP (*3*),

Table 1. Brief definitions for various managed lanes.

Type of Facility	Brief Definition
High-occupancy vehicle lane	Managed lane restricted primarily to high-occupancy vehicles (no tolling applied)
High-occupancy toll lane (also referred to as value-priced lanes)	HOV lane that is electronically tolled for single- or lower-occupancy vehicles and free to higher-occupancy vehicles
Truck lane/roadway	Dedicated lane(s) for trucks
Bus lane, busway, or transitway	Managed lane dedicated primarily for buses
Express lane	Managed lane that restricts access or, according to the MUTCD definition, a managed lane that employs electronic tolling in a freeway right-of-way with or without access restrictions
Toll lane (or road)	Any lane/road that employs manual or electronic tolling (may not be a managed lane if travel benefits are not assured)
Express toll lane(s)	Managed lane employing electronic tolling that charges users a toll except those exempted

the American Association of State Highway and Transportation Officials (AASHTO) (*6*), the Institute of Transportation Engineers (ITE) (*7*), and FHWA (*2*).

To give some framework to these different facility types and the management strategies that most influence what they are called, Figure 1 was generated. Historically, the strategies relied upon limited access, borrowed from early interstate express lanes that were constructed in such cities as Seattle (I-5 north) and Chicago (I-90 Dan Ryan and Kennedy), and restricted use by eligibility, which included widespread application of bus and HOV lanes nationwide. As electronic toll collection technology emerged in the mid-1990s and was adopted among a wide range of tolled facilities, it offered improved lane management and led to the creation of HOT lanes where HOVs were given preferential pricing treatment. Active traffic and demand management is a fourth tool that offers various ways to dynamically manage traffic under changing conditions [see FHWA, Office of Operations (*8*)]. The latest applications of pricing strategies are leading to more extensive use of access, eligibility, and related active traffic management strategies on both corridor projects and regional systems that are currently being implemented. As these tools are enhanced and new technologies that influence these management strategies emerge, greater opportunities



Source: Adapted from Collier and Goodin (*9*), Figure 1. This material is based upon work by the Federal Highway Administration. Any opinions, findings, conclusions, or recommendations, and translations thereof, expressed in the FHWA publication are those of that publication's author(s) and do not necessarily reflect the views of FHWA.

Figure 1. Managed lane facility types and management strategies.

may be created to expand the range of managed lane facility types and applications.

Locally Recognized Terms

Some local and state agencies have used other terms from time to time to substitute for the generally recognized types of facilities described previously. Many examples where public branding is used to substitute for a specific term can be found. Table 2 lists several of these examples found in various guidance documents and published reports.

Select components of managed lanes also have variations in the terms used to describe them. For the device used as a separation treatment installed in a buffer section between a managed lane and a general-purpose lane, terms that have been used include (in alphabetical order) the following: channelizer, channelizing device, delineator, express lane marker, flexible delineator, lane separator, plastic delineator, plastic pole, plastic pylon, plastic traffic channelizer, plastic wall, pole, pylon, tubular marker, vertical channelizing device, and vertical panel. Another example of a feature that has different names is the device that electronically collects tolls. Transponder is the most common term; however, toll tag, tag, and pass are also used in different regions of the country. Even HOV lanes have been known by different names (e.g., carpool lanes or diamond lanes). For this document, the terms pylon, transponder, and HOV lane will be used, respectively.

Managed Lanes Within the Broader Context of Transportation Demand and Congestion Management

Managed lanes attempt to meter through eligibility, or in more recent examples involving pricing, actively manage lane capacity in order to promote a preferential level of service, and thus they can be and often are complementary to many other transportation demand management (TDM) strategies commonly applied for congested metropolitan areas. Some of these measures, including rideshare promotion, preferential parking, or parking pricing programs, have related benefits when implemented in conjunction with managed lanes. These and many other strategies are referenced in *TCRP Report 95: Traveler Response to Transportation System Changes* (*10, 11*).

Managed lanes are also applied as part of corridor congestion management programs, which typically involve a combination of strategies to address recurring and non-recurring congestion (i.e., crashes, weather, and special event incidents). These strategies are aimed at addressing overall management of traffic conditions and include both typical and emerging examples such as improved traffic surveillance and incident management, freeway service patrols, ramp metering, variable speed control, and a wide variety of advanced operational approaches. These and many other strategies are highlighted in the 2011 edition of the *Freeway Management and Operations Handbook* (*12*).

Table 2. Examples of different terms used for the same facility.

Locale/Project	Common Term	Regional Term (Technical)	Branding Term (Public Use)
California, all HOV lanes	HOV lane	Carpool lane (1988–2012)	Carpool lane prior to 2012
California, Los Angeles (until 2013), I-10	HOV lane	El Monte Busway	El Monte Busway
California, Orange County, SR-91	HOT lanes	Express lanes, HOT lanes	91 Express
Colorado, Denver, I-25	HOT lanes	Express lanes	Express toll lanes
Florida, Ft. Lauderdale, I-595	Express toll lanes	Express lanes	595 Express
Florida, Miami, I-95	HOT lanes	Express lanes	95 Express
Georgia, Atlanta, I-75, I-575, I-85	HOT lanes	Express lanes	Peach Pass Lanes
Massachusetts, Boston, I-93	HOV lane	HOV lane	Zipper lane
Minnesota, Minneapolis, I-394, I-35W	HOT lanes	MnPass lanes	MnPass lanes, diamond lanes
New Jersey, SR-495	Bus lane	XBL (exclusive bus lane)	XBL
Texas, Dallas, I-635	Express toll lanes	Express lanes	LBJ TEXpress
Texas, Ft. Worth, SH-183/I-820	Express toll lanes	Express lanes	North Tarrant Express, TEXpress
Texas, Houston, I-10	HOT lanes	HOT lanes	Katy Tollway
Utah, Salt Lake City, I-15	HOT lanes	Express lanes	Express lanes
Washington, Seattle, SR-167	HOT lane	HOT lane	Good-to-Go, HOT lane

Attributes Critical to the Success of Managed Lanes

There are implicit conditions that should exist for managed lanes to be considered viable. These include the following:

- Recurring congestion (level of service [LOS] D or worse, or average travel speeds below 30–35 mph) within a corridor or region for a significant period of time.
- Significant backlog of unmet travel demand.
- Lack of available resources (right-of-way, funding, environmental, and public support) to address capacity needs in a more conventional manner that involves adding general-purpose road or fixed-guideway transit capacity.
- Interest and ability to minimally increase or alter existing roadways by managing their use for specific dedicated purposes to ensure that a high level of service can be provided as an alternative to recurring congestion.
- Consideration of managed lanes within the overall framework of congestion management and TDM strategies (i.e., managed lanes are not a stand-alone solution).

Legacy of Managed Lanes

The need to consider managed lanes occurred in parallel with the growth of demand on America's newly created system of interstate highways that were being extended into and through major urban areas in the 1960s. Many treatises have documented the prevalence of recurring urban traffic congestion that soon followed. While some corridors were designed flexibly enough to allow for conventional roadway widening to meet added growth in demand, some early planning efforts were undertaken to make initial freeway corridors better suited to serving bus rapid transit. These efforts aimed to make urban freeways more capable of meeting future growth by serving person movement as a higher priority than vehicle movement.

Notable corridors advancing this concept included the I-95/I-395 corridor (Shirley Highway) in suburban Northern Virginia (near Washington, DC; see Figure 2) and I-10 (San Bernardino Freeway) in Los Angeles (see Figure 3). Both projects involved reconstruction of the roadways to create dedicated lanes for express buses. Some of the earliest guidance issued to help practitioners included *NCHRP Report 143: Bus Use of Highways: State of the Art* in 1973 (*13*) and *NCHRP Report 155: Bus Use of Highways: Planning and Design Guidelines* in 1975 (*14*). This guidance included many design attributes still being applied today for in-line transit facilities and direct-access treatments.

Simultaneously, corridors suffering from recurring congestion that included high volumes of bus commuters began to receive attention. The country's largest patronized bus corridor, SR-495 approaching the Lincoln Tunnel in northern New Jersey, suffered from daily morning commute delays averaging more than 20 min for over 35,000 commuters (*13*). The westbound side of the facility was converted as a contraflow lane and opened as an eastbound-only bus lane on December 18, 1970. Figure 4 shows a photo of the contraflow bus lane in operation.

Source: Chuck Fuhs.

Figure 2. Managed lanes on I-395 in 1980, Virginia.

The exclusive bus lane was one of several U.S. Department of Transportation (U.S. DOT) urban corridor demonstration projects to test new ways of moving people on dedicated lanes. This 2.5-mi-long project continues to serve over 35,000 commuters daily. Other similar demonstrations for express bus transit on dedicated lanes followed in Boston, Miami, Seattle, and Houston through the 1970s. The I-10 Los Angeles El Monte busway opened in 1975 at the same time as the I-95/I-395 Shirley Highway reversible lanes. Both projects were subsequently opened to carpools carrying three or more (3+) or four or more (4+) occupants per vehicle, respectively.

Source: Chuck Fuhs.

Figure 3. Managed lane on I-10 in 1980, Los Angeles.

Source: Chuck Fuhs.

Figure 4. Example of exclusive bus lane in 1985, New Jersey.

The Federal Role

Federal policy and funding legislation have played an important role in the managed lane evolution up through the most recent priced managed lane projects that have opened. Selected events that appear to have the most significant impact on this evolution include the following:

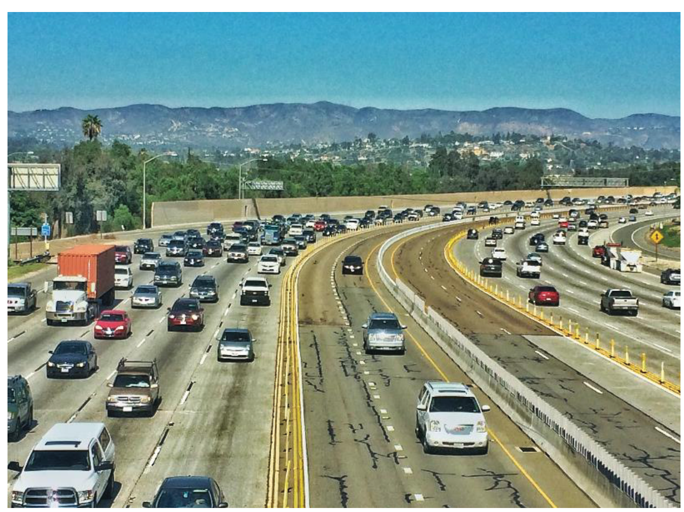
- Federal Clean Air Act, as amended, that set the stage for air quality monitoring, mitigation plans for areas meeting nonattainment, and use of Congestion Mitigation and Air Quality (CMAQ) funds by state departments of transportation (DOTs) to implement HOV lanes as a mitigation measure.
- Federal policies that encouraged consideration of bus and HOV lanes as a congestion management measure for corridors facing mobility challenges. Rules governing the expenditure of federal funds were relaxed in stages, and, by 1987, FHWA Division policies were allowing state DOTs to determine operation rules governing HOV lanes, including allowance for lowering minimum occupancy requirements to HOVs with two or more (2+) occupants. In the 1990s, federal legislation provided for motorcycle and inherent low-emission vehicle use of HOV lanes. Coupled with federal policies, states began to adopt policies supporting the consideration of HOV lanes. Early states to adopt such policies were California, Minnesota, Florida, Virginia, and Washington.
- Federal legislation in the 1990s encouraged improved multimodal planning through corridor major investment studies. These studies in a number of locales often found that managed lanes were a particularly cost-effective strategy to preserve future travel demand in lieu of conventional roadway widening.
- Federal legislation over the past 15 years allowed pilot programs to test variable pricing in a variety of freeway locations. This program was expanded to include subsequent solicitations and grants for urban partnership agreements (UPAs) and congestion reduction demonstrations (CRDs).

Project demonstrations from the 1970s through UPAs and CRDs issued in the mid-2000s have offered the most visible and recurring examples where the state of the art has been noticeably moved forward and subsequently adopted as the latest evolution in lane management practice. Such practices include variable tolling in many forms, tolling and signing for multiple access zones, provisions for active traffic management, innovative use of marketing and social media, switchable transponders, bus transit enhancements, credit provisions for disadvantaged populations, and automated enforcement.

Growth of Managed Lane Projects

In 1970, only three HOV projects were operating on freeways. Today, there are over 200 managed lane facilities. California leads the nation in managed lane mileage with about 36% of the national total. California was also the first state to introduce variable pricing on managed lanes. In the mid-1990s, SR-91 in Orange County became the first managed lane to be constructed as a public–private partnership with construction and operation funded through pricing (see Figure 5). I-15 in San Diego followed as the first HOV lane to be retrofitted with electronic toll collection to promote better corridor utilization in a two-lane reversible facility.

These two examples generally reflect the dual practices since repeated in various other states of either constructing new managed lanes that are variably priced without carpool incentives or improving operational performance on exist-



Source: Steven Yoshizumi.

Figure 5. Priced managed lanes on State Route 91 in California.

Source: Chuck Fuhs.

Figure 6. I-405 HOV lanes in southern California.

ing HOV lanes through variable pricing (e.g., allowing solo vehicles to pay a toll while allowing HOVs to travel free or at a discount). The vast majority of projects are concurrent lanes operated next to the median barrier as either HOV or express lanes (see Figure 6). They may operate part time or full time with a narrow buffer differentiating them from adjacent lanes.

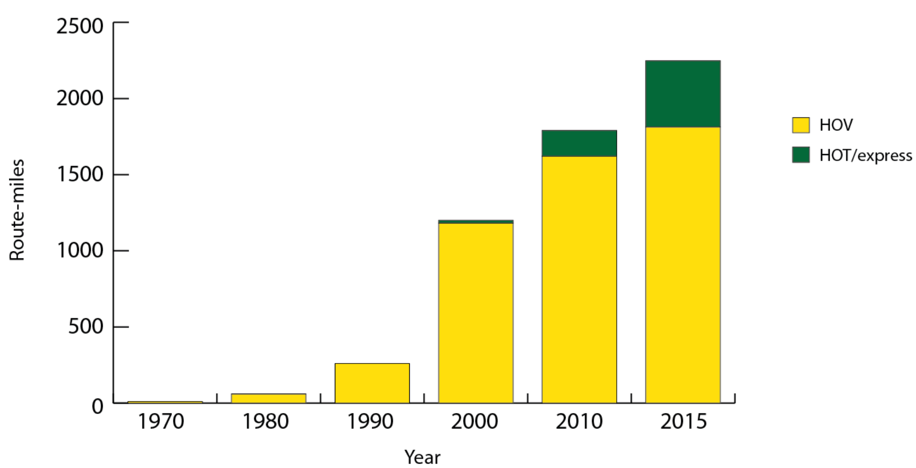
Thousands of miles of managed lanes are in operation in congested metropolitan areas (*15*). Figure 7 shows growth in development of managed lanes from 1970 to 2015. While the majority of projects operate as HOV lanes, since 1995 the number of projects applying tolling either as HOT or express lanes has grown. This trend is expected to continue. Practically all managed lanes are added-capacity facilities, not converted from existing general-purpose lanes. Conversion has been tried, and except for isolated cases where no negative operational impacts resulted, the adverse traffic and political issues created were too great. This is often because a congested traffic lane that is converted will result in low initial levels of vehicle use, causing noticeable worsening of traffic conditions on remaining lanes and thoroughfares. Tolling a converted lane—managed lane or general-purpose lane—poses even greater challenges because citizens and drivers believe what was previously constructed and paid for with tax dollars should not be tolled.

Managed lanes can provide benefits only when an assured level of service is preserved and time savings and reliability that encourage demand are realized. To provide these time and reliability benefits, managed lanes must be regulated at a flow rate that is below traditionally defined highway capacity. This flow rate is typically around 1600 to 1800 vehicles per hour per lane and can vary based on design and vehicle mix. When managed lanes are operated at acceptable flow rates, reliability can be assured and benefits sustained. For the subcategory of HOV lanes, moving more persons than a traditional general-purpose lane has been a benchmark for successful operation; for priced managed lanes, optimizing vehicle flow rates while preserving travel benefits has been important, particularly if project goals include generating revenue to offset implementation and operation costs.

Framing the Concept: Goals and Objectives

The needs and purpose commonly assessed early in corridor and regional planning studies often frame whether managed lanes are appropriate to consider in the broad mix of potential solutions. Typically, the needs and deficiencies that best characterize managed lane consideration include the following:

- Need for improved corridor/regional travel mobility and reliability, often associated with advanced traffic management.
- Need to manage travel demand growth.



Source: Chuck Fuhs.

Figure 7. Route-miles of managed lane facilities, 1970 to 2015.

- Need to manage at least some roadway capacity in perpetuity.
- Need to increase access controls.
- Desire for increased person movement/vehicle throughput.
- Need for more modal choices.
- Lack of funding and need for revenue generation.
- Lack of available right-of-way and related resources to meet forecast demand.
- Inadequate transit service coupled with potential markets and supportive land uses.
- Need to support throughput for longer-distance travel.

Purpose

Goals for the implementation of managed lanes can vary by corridor and regional context. The following performance goals that help determine conceptual feasibility for both concept designs and operations are commonly found in many planning studies (*16*):

- Sustain or improve mobility, particularly during periods of peak demand, by preserving options.
- Improve roadway efficiency, safety, and reliability.
- Improve air quality.
- Promote bus transit and ridesharing.
- Improve operational safety.
- Provide travel options to meet user needs, such as time-sensitive travel.
- Generate revenue.

Common themes echoed in such studies include trying to obtain more performance out of the existing roadway pavement or public right-of-way; making improvements that generate more benefit for less cost; developing projects that can stand on their own merit (i.e., physically, operationally, and financially); and examining technologies, solutions, and delivery approaches that help manage traffic better. These themes universally recognize the limitations faced in a post-Interstate-building era where the existing roadways that convey people, goods, and services into and through metropolitan areas are a precious resource and need to be treated with a high level of attention in how they are designed to promote optimized performance. These themes recognize that managing congestion (not always removing or relieving it) is often the only practical goal since the effects of increasing demand will often outpace any modest capacity that can be provided. This reality is implicit in a range of corridor management strategies that include managed lanes.

Objectives

The developed objectives tend to be even more corridor specific and have a threshold that specifies a metric for achievement. An example objective would be the following: "The managed lane is expected to move 50% of its total volume as carpools." Example metrics currently applied include the following:

- Increasing or optimizing person and vehicle movement capacity.
- Enhancing service to bus transit and rideshare modes.
- Fitting improvements within the existing pavement or right-of-way.
- Incentivizing the use of selected vehicles, such as motorcycles or low-emission vehicles.
- Promoting travel time savings, reliability, or efficiency for selected travel modes.
- Promoting air quality based on modal shifting.
- Generating revenue to cover construction and/or operation, maintenance, and enforcement costs.
- Improving performance efficiency or enforcement on an existing HOV lane.
- Improving the movement of commerce (goods and services).
- Supporting community land use and development goals, particularly in major areas of employment.

Adoption of emerging technologies such as driverless vehicles may result in consideration of other metrics. (More details on the planning process associated with establishing goals and objectives are discussed in Chapter 2.)

Managed lane implementation may be represented by improvements to existing projects or new projects. For the period from 1995 through 2015, a number of existing HOV lanes were modified to incorporate tolling, add capacity, and improve performance with anticipated short-term benefits. Objectives common with such operational changes are highlighted by representative projects in Table 3. New projects may address broader and more long-term objectives than represented by projects in Table 3.

To evaluate effectiveness, goals and objectives need to be tied to that which can be measured. Linking goals and objectives to outcomes can help agencies respond to the following key questions: "Is the facility working as planned, and are the initial operational goals being met?" Not all measures may be quantifiable, and some may be generated from attitudinal input such as public and customer feedback. Chapter 2 (planning) and Chapter 6 (performance monitoring) offer further insights into the need to study and measure performance related to stated goals and objectives.

Iterative Process

Goals and objectives for a corridor improvement or managed lanes project should inform the design, operational strategy, and project delivery approach that is employed. Expe-

Table 3. Examples of objectives for new construction of managed lanes.

Project and Location	Add Capacity	Manage Added Capacity	Vehicle Throughput	Reliability	Minimize On-Site Enforcement	Generate Revenue	Leverage Private Funding	Promote Transit Service	Bus Rapid Transit	Handle Special Events
I-75/I-575 Atlanta	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
I-75 South Atlanta	Yes	Yes	Yes	Yes	Yes	Yes		Yes		Yes
I-635 LBJ Dallas	Yes	Yes	Yes	Yes	Yes	Yes	Yes			
SH-183/I-820 Ft. Worth	Yes	Yes	Yes	Yes	Yes	Yes	Yes			
SH-114/SH-121 DFW connector Dallas–Ft. Worth	Yes	Yes	Yes	Yes	Yes	Some				
I-35E Dallas–Denton	Yes	Yes	Yes	Yes	Yes	Yes				
I-35W Ft. Worth	Yes	Yes	Yes	Yes	Yes	Yes	Yes			
SH-183 extension Dallas	Yes	Yes	Yes	Yes	Yes	Yes				
I-405 Seattle	Yes	Yes	Yes	Yes		Yes		Yes		
SR-167 southbound extension Seattle	Yes	Yes	Yes	Yes		Yes				
I-15 San Diego	Yes	Yes	Yes	Yes				Yes	Yes	

rience over the past 40 years suggests that reaching this determination involves simultaneous attention to both design and operation needs and is iterative successively through some, and perhaps many, stages of concept screening, refinement, and project development. This process will be addressed in more detail in Chapter 2 (planning).

As a backdrop to this process and based on 40 years of project experience reflected in prior guidance, an implicit set of conditions that typically exist for any form of managed lane to be considered include the following:

- **Congestion.** A recurring congestion problem to LOS D or worse (defined as average speeds below 30 mph) within a corridor or region during the defined peak hours each weekday.
- **Limited resources.** A significant backlog of unmet travel demand and lack of available resources (right-of-way, funding, regional consensus, or environmental issues) to address deficiencies in a more conventional means through adding roadway or transit capacity.
- **Desire to promote mobility.** An interest and ability by agency stakeholders to minimally or incrementally increase roadway capacity by managing its use to specific dedicated purposes to ensure that a high level of service can be provided as an alternative to recurring congestion for at least some users. The public must support this approach.

Managed Lane Designs

Most managed lanes are retrofitted to existing corridors. Design concepts typically applied include the following:

- Concurrent flow lane.
- Separate roadway.
- Reversible lane.
- Contraflow lane.
- Queue bypass.
- Part-time shoulder use.

These terms are applied in this guide for describing specific types of managed lane designs. The order presented generally corresponds to the magnitude of application in terms of lane-miles of facilities as of 2015. Each is briefly described in the following subsections.

Concurrent Flow Lane

Adding a dedicated left-side-oriented concurrent lane in each direction next to the median barrier has become the

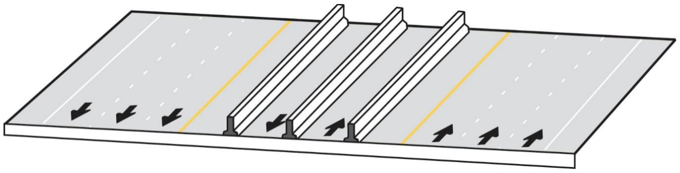


Figure 8. Graphic example of concurrent flow lanes with concrete barrier separation.

Source: Chuck Fuhs.

Figure 10. Example of concurrent flow lanes in California.

most widely applied concept. The popularity of this concept is due to the symmetrical layout of urban freeways with a center barrier, center-oriented bridge columns, and sign gantry columns; the availability of median shoulders, which are often converted to travel lanes; and a direction split in travel demand that is often balanced. Concurrent flow lanes can be separated from adjacent traffic by differentiating pavement markings, a painted buffer (with or without pylons), or a concrete barrier. Illustrative layouts are shown in Figure 8 for a concrete barrier and in Figure 9 for a painted buffer. Specific cross sections detailing layouts are provided in the design discussion (Chapter 3). The physicality of separation is influenced by the concept of operations. Figure 10 shows an example of concurrent flow lanes that were retrofitted onto a freeway. Concurrent HOV lanes are found in Atlanta, Miami, Charlotte, Phoenix, Nashville, Memphis, Seattle, Dallas, Houston, Portland (Oregon), Norfolk, and Washington, DC metro areas, and most metropolitan areas in California.

Separate Roadway

Managed lanes can take the form of either separate roadways or a freeway within a freeway. They may be oriented in a wide median or outer separation area or located over or under the existing freeway alignment. Increasingly, a wide variety of design concepts are being applied to separate roadways that include two-, four-, and six-lane sections with an equal number of lanes in each direction. Some are implemented as two- and three-lane reversible facilities (see the following section on reversible lanes). If located alongside the freeway general-purpose lanes, they may be separated by pavement markings, pylons (example shown in Figure 11), or concrete barriers. By their nature, separate roadways have very infrequent access and typically employ grade-separated or median flyover ramps for access to handle large volumes of traffic. Examples include I-10 in Houston, I-635/I-35E/Loop 12 in Dallas, I-35W/SH-183/I-820 in Ft. Worth, I-95 and I-495 in Northern Virginia, I-595 near Ft. Lauderdale, I-75/I-575 in Atlanta, and SR-91 in Orange County, California. Such designs may require their own interchanges with other managed lanes on intersecting freeways.

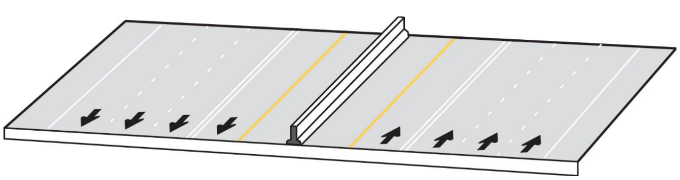


Figure 9. Graphic example of concurrent flow lanes with buffer separation.

Reversible Lane

As implied, a reversible facility is one to three lanes operating in one direction (typically inbound) in the morning

Source: Chuck Fuhs.

Figure 11. Example of roadway separated by pylons on I-10 in Houston.

Source: Chuck Fuhs.

Figure 12. Example of reversible lanes on I-395 in Virginia.

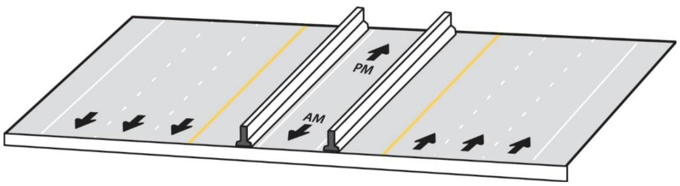


Figure 13. Graphic example of reversible-flow median lane.

and the other direction in the afternoon. Permanent concrete barriers separate these lanes to prevent oncoming traffic conflicts. Reversible lanes are typically located between opposing directions (examples shown in Figures 12 and 13), but some projects, such as the I-75/I-575 Northwest Corridor in Atlanta, are elevated or located in the outer roadway right-of-way in a design setting representing a separate roadway. Gates and other forms of attenuation are employed at reversible ramps to safely channelize traffic into and out of the reversible lanes (Figure 14). Ramps can be channelized from the left of the general-purpose lanes, or flyover ramps might be provided to/from the right side. Most reversible roadways employ a wide enough typical section to include the travel lane(s) and breakdown shoulder(s). Examples include I-279 in Pittsburgh, I-395/I-95 in Northern Virginia, I-25 in Denver, I-394 in Minneapolis, I-5 and I-90 in Seattle, I-595 in Ft. Lauderdale, I-75 north and south in Atlanta, and various projects in Houston and Dallas.

Source: Chuck Fuhs.

Figure 14. Example of entrance gate on I-5 in Seattle.

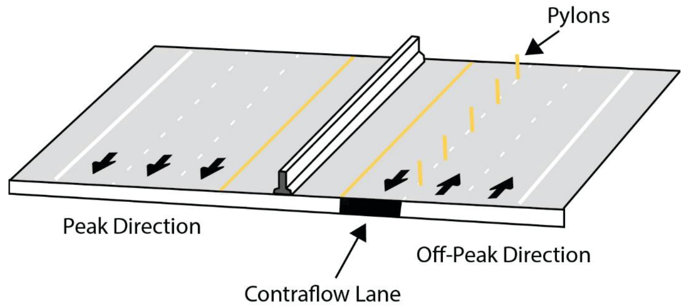


Figure 15. Graphic example of contraflow lane.

Contraflow Lane

Where the directional split is uneven, typically with 60% or more of the peak-hour traffic traveling in the peak direction, there may be an opportunity to borrow an off-peak direction lane for peak direction flow. Contraflow lanes may be separated by traffic pylons placed in the pavement (SR-495 in New Jersey), as shown in the graphical example in Figure 15. They may also be separated by movable barrier (I-30E in Dallas or I-93 in Boston), as exemplified in Figure 16. Either form of deployment requires a regiment of support staff to safely close off and reopen the lane to general-purpose traffic before and after each operating period.

Source: Chuck Fuhs.

Figure 16. Example of contraflow lane in Dallas.

Queue Bypass

A short, dedicated lane may be implemented around a point-specific traffic bottleneck. This bottleneck may be operational or geometric in nature. The most common queue bypasses exist on approaches to bridges and tunnels, approaches to toll plazas, and metered entrance ramps. The bypass may be functional only for the period of time that a queue typically forms, and some queue bypasses are now tolled at a differential rate from other lanes if implemented at a toll plaza. Examples include most bridge approaches in the San Francisco Bay Area, and many ramp meters located throughout California. A photo example is shown in Figure 17, and a graphic example is shown in Figure 18.

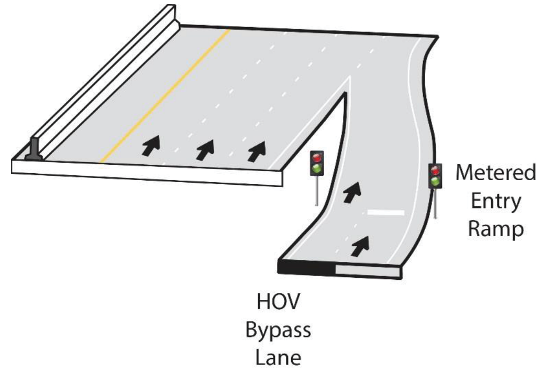


Figure 18. Graphic example of queue bypass.

Part-Time Shoulder Use

In a few locations, vehicles are allowed to travel on emergency breakdown shoulders (also known as part-time shoulder use or dynamic shoulder lanes) under specific conditions. A left shoulder may be converted and posted for part-time shoulder use operation using a variety of traffic control devices, as is represented by the I-35W HOT lane project in Minneapolis (see Figure 19). Other right shoulders in Minneapolis–St. Paul are conditionally used by transit buses whenever congested speeds fall below a given threshold. A right-side shoulder was opened to general-purpose traffic on I-66 in Northern Virginia during the same hours that a left-side general-purpose lane was restricted for HOV-only use (see Figure 20).

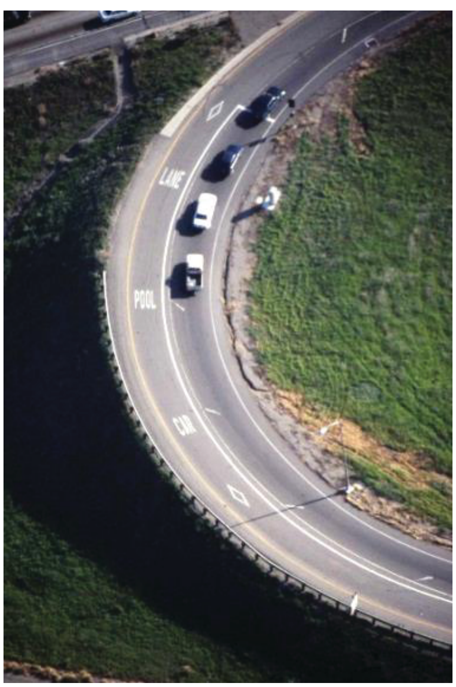
One or more facility types may be found in a given project, corridor, or regional system. There are various ways to safely transition from one facility type to another.

Managed Lane Strategies

Common managed lane strategies used to regulate demand fall into three broad categories:

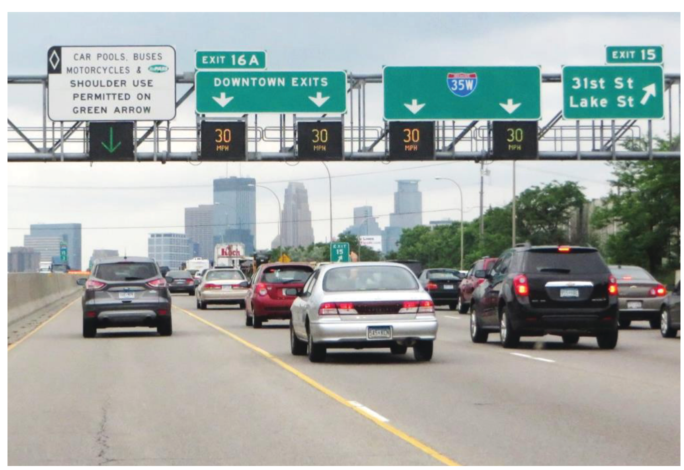
- Vehicle/user eligibility.
- Access control.
- Variable pricing through electronic toll collection.

Historically, before the mid-1990s, managed lanes applied vehicle/occupancy eligibility often in combination with access control to regulate lane demand. Figure 21 shows example facil-



Source: Chuck Fuhs.

Figure 17. Example of queue bypass in California.



Source: Kay Fitzpatrick.

Figure 19. Example of left shoulder used as a managed lane in Minneapolis.

Source: Chuck Fuhs.

Figure 20. Example of part-time shoulder use sign in Virginia.

ity regulatory signage. After the advent of electronic toll collection, pricing became a demonstrated and adopted strategy that continues to gain interest and practice. While these strategies are applied in other traffic management applications and may offer unique benefits in these other settings, they have specific relevance to actively managing lane demand in this context. A wide variety of emerging projects are expanding how each strategy is applied. Each strategy can be applied and implemented individually or in combination, depending on the unique travel demand conditions associated with each project setting.

Vehicle Eligibility

The purpose of restricting vehicle eligibility in a managed lane has been primarily to encourage more person movement over solo driver vehicles on constrained corridors where limited capacity is available. This purpose dovetails well into the goals of transportation demand management and requires users to switch modes (i.e., into carpools, vanpools, or transit from private solo commuting) during periods of peak demand. HOV lanes serve this purpose as a typical application. Other eligible users, notably motorcyclists and low-emission vehicles, have also been allowed as exempt from the minimum occupancy restriction on HOV lanes. In this context, encouraging rideshare formation and use of transit and low-emission vehicles can also fit well as a mitigation measure to improve a region's air quality goal.

Safety also plays a role, as segregating motorcycles into a dedicated lane from the general traffic stream can promote a safer operation. Other occupancy-exempt vehicle classes include emergency vehicles, deadheading buses, and paratransit vehicles. Eligibility restrictions can be in effect 24 hours a day or vary by time of day or day of the week. A managed lane using a variable eligibility strategy may restrict use to 3+ occupant HOVs during the peak commute hours and relax restrictions to include lower-occupancy vehicles during off periods or weekends.

Experience from almost 40 years of HOV lane operation suggests that this concept has worked well and is transferable into a number of operational and design settings. HOV lanes are found in at least 29 metropolitan areas in the United States and Canada, with additional implementation in Australia and Europe. Some projects stretch more than 50 mi in length, while others may only serve as short queue bypasses on ramps and on approaches to bridges and tunnels. Typical experiences reflect the following overall findings:

- The typical project is usually at least 8 to 10 mi in length.
- Time savings generated average about 0.5 min per mile during peak hours.
- The vast majority of HOV lane projects are operated concurrent flow (i.e., with the flow of traffic and often separated by pavement markings or a marked buffer).
- About half of all projects operate in the peak periods only, reverting to a general-purpose lane in the off-peak period; the other half operate full time.
- Most HOV projects were sponsored, implemented, and operated by the respective state DOT.

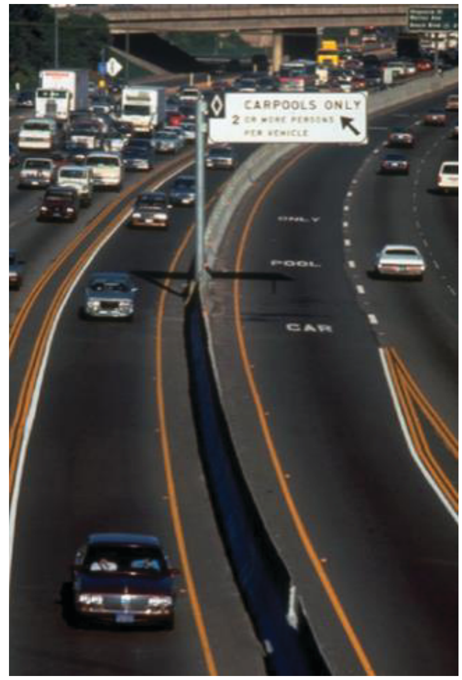
HOV lanes are examples of limiting use to specific vehicle classes such as carpools based on the number of persons they are carrying. In the example in Figure 22, buses operated on reversible express lanes. Most commonly, user restrictions on HOV lanes have taken the form of eligibility requirements based on the requisite minimum number of people traveling in a vehicle.

Source: Chuck Fuhs.

Figure 21. Occupancy restrictions on HOV lanes in Santa Clara County, California.

Source: WSDOT.

Figure 22. Express lanes on I-5 North in Seattle with bus-only ramp (in 1980).



Source: Chuck Fuhs.

Figure 23. Typical HOV lane access in California.

Access Control

Some practitioners may consider the first managed lanes to have been express lanes incorporated into controlled-access urban roadways in the late 1950s and early 1960s. Such projects as the I-70 Daniel Boone Expressway in St. Louis, I-94 Dan Ryan and Kennedy Expressways in Chicago, and I-5 express lanes in Seattle conceived designs that limited access to a few designated locations, thereby achieving a high level of service for longer-distance travelers. (Note that the term “express lane” found on signs in this early context was likened to express buses that traveled the same corridor but had limited stops, rather than the definition of express lane currently found in the MUTCD for tolled managed lanes, which applies the same terms.)

Access control has been similarly applied to many managed lane projects since then, but always in context with other strategies. For example, the reversible lanes on the I-5N HOV lanes in Seattle, by the very nature of operating a roadway that reverses by time of day, must be barrier separated from other lanes and thus limit access to a very few designated locations. The most widespread use of access control is associated with concurrent flow managed lanes located next to the median barrier where an access restriction is more liberal, providing for ingress/egress or weave movements about every 1 to 3 mi. Many projects restrict access to reduce friction caused by indiscriminate entering and exiting; to discourage shorter-distance travel, which can promote an excessive number of weaving movements; and, for tolling purposes, to make toll collection easier to manage by having fewer toll zones than might otherwise be required.

Limiting access has traditionally been applied to HOV and express lanes as a means of regulating entry and exit movements. Restricting access by this method helps ensure that dedicated lanes do not become overloaded regardless of the level of demand they generate. Access restrictions may also help alleviate specific traffic bottlenecks where short-distance trips cause a lane to exceed its capacity. As an example, as Figure 23 illustrates, HOV access restrictions are applied on many projects in the Los Angeles area where demand is high. Access is also restricted in various multilane facilities and on reversible facilities where positive separation between opposing flow is required. Access can be restricted by design or dynamically managed by (a) metering demand at entrance ramps via the use of traffic signals or gates, (b) limiting access at specific ramps to selected users like HOVs (e.g., I-5 Seattle downtown ramps), or (c) limiting the number of entrance and exit ramps so that free-flow is ensured (e.g., I-5N in Seattle and I-15 in San Diego). Access control is not required for electronic tolling or variable pricing, and some projects such as SR-167 express lanes in Seattle have adopted a more open-access strategy since opening.

Electronic Tolling and Variable Pricing

The adoption of electronic toll collection technology has allowed variable pricing to become an increasingly practical and more precise way of regulating demand in real time. Examples of signs are shown in Figures 24 and 25. Variable pricing, where tolls vary in accordance with a fixed schedule or demand, can help maximize the use of available lane capacity while continu-

Source: Chuck Fuhs.

Figure 24. Example of electronic toll collection sign in Minneapolis.

ing to prioritize operation for users. This type of tolling offers an opportunity to manage a preferential lane or roadway in real time as capacity allows.

Tolling in general can be a crude or fine-tuned tool. If fixed tolling is applied, it simplifies the message to users but limits the ability to regulate demand. Varying tolls by a fixed schedule that rises and falls in accordance with observed demand can accomplish the desires of managing demand and assure the customer of the toll that will be charged at a selected time. Dynamically varying tolls in accordance with real-time demand is often a better solution from the operator's perspective but makes communicating the toll to users potentially harder, particularly if there are multiple toll zones involved. The primary purpose of variable pricing in most applications is to keep the lane(s) from becoming congested and assure a high degree of reliability.

U.S. federal law, current as of the Fixing America's Surface Transportation (FAST) Act of 2015, requires a 45-mph minimum speed threshold for managed lanes approved under Title 23 U.S. Code (U.S.C.) Section 166, including all federally funded HOV lanes and some priced managed lanes. Additionally, many priced managed lanes that have been approved under 23 U.S.C. Section 129 have adopted the same minimum threshold as for Section 166 facilities. Taken together, most priced managed lanes in operation by 2015 maintain this 45-mph minimum speed threshold, and do so through the use of variable pricing. Higher tolls are usually charged when congestion is heaviest and delay is at its worst, while lower tolls are often posted during off-peak periods of low demand. Higher levels of tolling can encourage some peak-period users to shift their trip to lower-demand periods or shift into the managed lane with the belief that the toll reflects degraded mainlane conditions ahead.

If the priced managed project allows free or discounted use to HOVs with a certain minimum number of persons, then it may be referred to as a HOT lane. In the MUTCD (*1*), all priced managed lane projects are referred to as express lanes on signs and may carry the locally recognized project brand and pictograph of the toll transponder program(s).

In 2015 variable pricing was in use on 30 projects nationally, employing electronic toll transponders based on pre-established customer accounts. These projects reflected both new capacity treatments like SR-91 express lanes in Orange County and conversions of prior HOV lanes like SR-167 HOT lanes in the Puget Sound region.

Traffic Management Technology

A wide variety of traditional and emerging intelligent transportation system (ITS) strategies are employed on managed lanes. Posting travel time on changeable message signs was perhaps one of the earliest applications. More recently, active traffic management concepts are being applied on corridors such as I-5S in Seattle (see Figure 26) and I-35W in Minneapolis (see Figure 27). In both cases, active traffic management employed for the entire roadway is designed

Source: Kay Fitzpatrick.

Figure 25. Example of electronic toll collection on a managed lane in Atlanta.

Source: WSDOT.

Figure 26. Dynamic speed signs in Seattle (HOV lane is leftmost with higher speed).

Source: Kay Fitzpatrick.

Figure 27. Dynamic speed signs in Minneapolis.

to complement the respective HOV or express lane operation. Tools employed include dynamic advisory speed limits (e.g., in Minnesota; see Figure 27), dynamic regulatory speed limits (e.g., in Washington State; see Figure 26), queue warnings, lane controls advising of closures, and dynamic pricing information.

Combining Strategies—Looking Forward

Many managed lane projects employ multiple strategies. Since a high percentage of future managed lane projects will include some application of variable pricing or tolling, the practitioner can expect to see most projects continue to embrace all of these tools for the foreseeable future. In the extreme, pricing may only be employed on some HOV lanes to smooth out periods of excessive use when lane operations are degraded and infill demand when available space allows. For tolled facilities needing to meet revenue targets, free use (if any) may be limited to registered transit buses.

Observed trends looking forward, based on projects being planned and in development, suggest that managed lanes will continue to expand. Managed lanes also appear to be the focus of attention for the next adopted technology, whether it be simply making enhancements to toll collection and account management or implementing automated vehicle–highway strategies to improve operational performance.

Tolling enhancements will likely involve easier means for customers to use toll facilities throughout the United States, based on federal legislation requiring interoperability among tolling agencies. Mobile applications that permit easier customer account management and use of tolled managed lanes through mobile devices also appear to be on the threshold of adoption. These and other means will give users more ways to use managed lanes.

Automated vehicles (AVs, also referred to as "automated vehicle–highway technology" or "autonomous vehicles") may address a wide range of markets within managed lanes. The National Highway Traffic Safety Administration issued a preliminary statement of policy concerning AVs in which different automation levels and possible contributions of automated vehicles are explained. Potential benefits of vehicle automation are enhanced safety, reduced fuel consumption, enhanced mobility for motorists with disabilities, and reduced congestion (*17*).

In addition to the automation of vehicles, there are connected vehicles (CV), which are able to communicate with each other [vehicle to vehicle (V2V)] and with the roadway infrastructure [vehicle to infrastructure (V2I)]. FHWA estimates that V2I has the potential for advancement in safety and operations of surface transportation. This automation service will improve traveler information and service by making it possible for infrastructure and vehicles to communicate and cooperate (*18*). A study for the Metropolitan Transportation Commission in the San Francisco–Oakland Bay Area identified nine use cases for V2I technologies on managed lanes. These uses include toll collection, dynamic pricing, in-vehicle account management, back-office toll processing, vehicle occupancy, automated enforcement, probe vehicles, traveler information, and traffic management for the region and the corridor (*19*).

While some AV applications may be ready for demonstration soon, other applications to expand throughput or to permit reduction of lane widths to squeeze in additional managed lane capacity may be several or perhaps many years ahead. Some practitioners believe these applications may be better suited for initial demonstrations in the segregated design environment of managed lanes before being more widely adopted. These applications have many policy implications and may be demonstrated within the next few years before more widespread adoption.

The past 40 years show how many times managed lanes have evolved in embracing new strategies while preserving the overall intent of maintaining mobility to the greatest number of users.

Decision-Making Process

Traditional Process for New Projects

Historically, the decision-making process for managed lanes follows a project development path that traditionally involved a design–bid–build–operate–maintain paradigm not unlike any other highway in an urban setting. The nuances often missed included a much greater need to focus on public and political support; marketing and outreach to customers prior to opening; costs that were difficult to predict for long-term dedicated operation, enforcement, and maintenance; and regular performance monitoring to address changing traffic and demand conditions.

Planning decisions were often the result of opportunities based on either funding or policy, or resulted from a program to rehabilitate or rebuild a corridor. Decisions were generally made within the state DOT or with transit, state police, or regional/municipal agencies that were local partners. In some areas, a transit or regional transportation agency would take the lead on an HOV or transit-oriented managed lane within the state's right-of-way. These early partnerships proved what was possible. Many such projects were and have been legacy successes and, for the most part, transcended original agency staff that made them happen.

The adoption of pricing and funding limitations have greatly expanded the decision-making process to include a wider array of potential funding, delivery, and partnership arrangements. It is noteworthy that the first public–private partnership in California involved a managed lane project in Orange County in the mid-1990s. The most creative and dynamic project to attempt to adjust to future demand—a four-lane facility in San Diego that could become a 2-2 or 3-1 configuration throughout the day—was born out of a unique local partnership between the California Department of Transportation (Caltrans) and the San Diego Association of Governments, an agency that serves as the metropolitan planning organization (MPO), transit provider, and toll operator, as well as local funding implementer. The bulk of such public–public and public–private partnerships in California, Colorado, Florida, Georgia, Texas, and Virginia similarly involve managed lanes.

Traditional and newly organized state and regional transportation and toll authorities are playing an increasing role in partnering with state DOTs in the implementation and operation of tolled managed lanes. Each area appears to have unique partnering resources that, when taken as a whole, show funding decisions gravitating to local and state agencies, in concert with traditional federal participation. This decision-making process is allowing projects to be tailored to each region, and consistency of practice occurs at a regional rather than project-specific or state level.

Based on past and recent experiences, the decision-making process for managed lanes needs to engage the agencies and operators who have the greatest potential for making the project successful, and they need to be involved at the outset during the planning process. These agencies include the MPOs, implementing agencies (typically the state DOT and any regional transportation implementing agencies), transit operators, enforcement personnel, tolling providers if the facility is likely to be priced, and rideshare services if incentives to carpools and vanpools are envisioned. Decisions need to engage these participants actively. Inevitably, project experiences show that tough trade-offs are required to achieve a balance between desired operations, designs, financing, and policy considerations on how the managed lane is able to meet stated goals. The following planning (Chapter 2) and implementation (Chapter 5) discussions offer further insights into how decision making occurs.

Decision Making for Operational Changes

The large number of managed lanes in operation—some for many decades—has led practitioners to make improvements to these projects to enhance performance and embrace the latest technology. While some operational changes may rise to the scope of representing new construction, most are modest changes with commensurately minor design impacts focused on near-term benefits and a short anticipated life cycle. Such changes may include addition of tolling infrastructure and changes in access or separation with adjacent lanes, signing, and other design and operational features. These changes often have minimal impact on corridor demand, particularly when examining the overall freeway. For these settings, the decision-making process should be simpler than what is currently occurring. Unfortunately, interviews with practitioners in 2015 as part of this guidance development indicated that decision making was being unnecessarily complicated. Some practitioners were trying to look at long-term impacts, which are frequently overshadowed by macro-level traffic growth that the modest changes cannot affect. Some improvements can be controversial, requiring the same level of public dialogue that a full project might require.

Safety Performance

Managed lanes can provide safety and operational performance benefits over general-purpose facilities, but the managed lane strategy must be appropriate for the intended user group. Specific benefits in crash reduction seen at one facility do not necessarily translate to another facility, so the selected strategy must account for the conditions unique to a particular facility.

Crashes Within the Facility

Crashes on managed lanes can be related to access, congestion, and sight distance (see Chapter 3). These factors are compounded by failure to appreciate driver expectancy that differs for managed lanes as compared to general-purpose lanes. Adequate attention to placement of traffic control devices can help (see Chapter 4). In addition to crashes near access points, crashes can also occur within a managed lane facility. Common types of crashes within a facility include the following:

- Rear-end crashes due to congestion.
- Sideswipe crashes due to passing on two-lane facilities or within access zones.
- Crashes caused by drivers making unexpected maneuvers at the point where access restrictions apply or to avoid debris or disabled vehicles that may block the travelway.

Crashes such as these underscore the need to have a cross section (e.g., number of lanes plus shoulder and buffer offset widths) that is sufficient to meet the needs of the expected users of the facility.

A safety study for the I-394 MnPass Lanes in Minnesota (*20*) found the overall number of crashes to be reduced by 5.3%. A 4-year observation period was used before the start of tolling, as well as a 2-year post-deployment observation period. The economic benefit was found to be $5 million during the period of 2006 to 2008. The authors of the paper are not confident their results can be generalized to other HOT lane projects because of limited research on this issue (*20*).

A 2013 paper (*21*) reported on an evaluation of the relationship between cross-section design (i.e., lane width, shoulder width, and buffer width) and safety performance for HOV lanes. The authors used 3 years (2005 through 2007) of crash data for 13 Southern California segments totaling 153 mi. The segments were buffer separated between the HOV lanes and the general-purpose lanes. Crashes included those that occurred on the median shoulder, in the HOV lane, or in the adjacent general-purpose left lane. Independent variables included geometric attributes and annual average daily traffic (AADT). The authors found that wider HOV lane width and wider shoulder width were associated with lower crash frequencies. For their dataset, buffer width and the width of the lane next to the HOV lane were not found to be statistically significant. The authors also provided case study examples of preferred cross-section allocation if converting a section from an HOV lane and left shoulder to a section having a buffer, HOV lane, and left shoulder. In all examples, the authors recommended the inclusion of a buffer by reallocating some of the shoulder width to the buffer.

A Florida study (*22*) developed crash prediction equations for freeway facilities with HOV and HOT lanes by number of freeway lanes. Models were developed for 6-, 8-, 10-, and 12-lane freeways (number of lanes reflect both directions and include the managed lanes). For all the models, segment length and AADT were significant and included. For most of the models, left shoulder width was the only other significant variable. An increase in left shoulder width was associated with decreases in crashes. The effect of buffer type on crashes was found to be statistically significant only in the model for 10-lane freeways. The inclusion of a 2- to 3-ft buffer was associated with fewer fatal and injury crashes.

The findings from the safety literature—along with guidance in the *Highway Safety Manual* (*23*)—are clear in that a reduction in a freeway left shoulder width is associated with an increased number of crashes. Safety studies for general-purpose freeway lanes also have found that reduction in lane width is associated with more crashes. Some of the increases in crashes due to reduction in lane or shoulder widths could be offset if the reductions are due to including an additional freeway lane (*24*).

The evaluations of the safety benefits of buffers are limited. For the two studies that included buffer-separated projects within the evaluations (*21, 22*), there was only one case (on 10-lane freeways) when the variable was statistically significant. Limitations in sample size along with the distribution of the buffer widths available may be affecting the results.

Crashes at Access Points

Access points are common sites for crashes, just as crashes can commonly be found at intersections on surface streets. Crashes near access points can involve vehicles entering or leaving the managed lanes (e.g., sideswiping another vehicle, striking separation device, etc.), and crashes can involve vehicles that are not changing facilities (e.g., rear-end crashes caused by drivers braking to avoid a vehicle entering the facility in front of them). Volume of traffic, type of access and separation provided, and proximity of managed lane access to general-purpose entrance and exit ramps may all influence crashes, and these effects may vary from one facility to another.

A California study (*25*) described comparisons of traffic safety during the morning and afternoon peak hours in extended stretches of eight HOV lanes with two different types of access—four corridors with continuous access and the others with limited access. Traffic collision patterns in the two different types of HOV lanes were investigated by evaluating (a) the differences in collision distribution, severity, and type, along with per-lane traffic utilization; (b) the spatial distribution of collision concentrations by using the continuous risk profile approach; and (c) the collision rates in the vicinity of access points in HOV lanes with limited access. In their study, the researchers conducted detailed analysis on collision data occurring during peak hours in relation to geometry and traffic features. Based on the findings from the assessment on eight routes, the limited-access HOV lanes appeared to offer no safety advantages over the continuous-access HOV lanes. The finding was attributed to more frequent and sporadic distribution of collision concentration in limited-access HOV lanes. In other words, the controlled-access HOV lanes had a similar frequency of crashes as the continuous-access lanes; however, the crashes were concentrated at the access points.

Driver Expectancy

Driver expectancy reflects the driver's readiness to respond to situations, events, and information in predictable and successful ways (*26*). Providing a roadway network that conforms to a driver's expectancy should result in a better operating and safer system. Uniformity can improve expectancy, which supports having traffic control devices in conformance with the MUTCD. Violations of driver expectancy can lead to erratic movements, which can cause crashes, and can result in decreased use of the managed lane system because drivers do not understand it. Left exits and entrances are unexpected and can cause erratic movements; however, left exits and entrances are common on managed lanes because many managed lanes use the leftmost lane of a freeway. Additional guidance on human factors concepts is available in *NCHRP Report 600: Human Factors Guidelines for Road Systems* (*26*).

Addressing driver expectancy issues may include one or more of the following considerations:

- Trying to meet as many desirable design attributes as possible for project retrofits.
- Ensuring more weave distance for at-grade slip ramps where the highest volumes are anticipated.
- Posting advisory speeds, flashing beacons, and diagrammatic signs on direct ramps that tee into an intersecting street that the driver cannot see in advance.
- Designing wider-than-standard shoulders in curves and areas of limited sight distance next to median barrier walls.
- Keeping drainage inlets and pavement swales in the median out of the travelway.
- Avoiding signage information overload by adopting principles beyond MUTCD guidance that prioritize driver information needs.
- Building in design provisions, such as pullouts, for on-site enforcement where full and continuous shoulders cannot be provided.
- Minimizing temporary and permanent termini conditions that do not provide sufficient downstream merge capacity.
- Providing a buffer for improved sight distance, even for part-time operations.
- Designing for most vehicles, even if the intended users are limited to specific vehicle classes.
- Providing illumination at ramp gores and enforcement areas.
- Designing for flexibility, which may include consistent depths of pavement for travelway and shoulders, at-grade access treatments that can be easily modified, and signing gantries that can accommodate potentially larger, heavier signs when rules change.
- Highlighting potential driver expectancy concerns in public outreach materials. As an example, public outreach material that highlights the need for a managed lane vehicle to exit a greater distance upstream than would be expected so that the managed lane driver is in position for the needed general-purpose lane exit could be provided.

Audience and Organization of Guidance

Audience

This guide is written to primarily address technical practitioner needs in planning, evaluating, implementing, designing, operating, and maintaining managed lane facilities on urban freeways. The guide attempts to answer what the practitioner needs to know in order to confidently engage in implementation of managed lane facilities, with recognition that best practices are often adopted from peer projects within the region or other locales that share similar operational or design attributes. In various chapters, the practitioner is referenced to other parallel documents and resources that are available and, in some cases, offer more depth on a particular subject than can be found in this guide. The intended audience includes practitioners primarily involved in planning, implementing, and operating managed lanes on an access-controlled facility. Practitioners include engineers, planners, environmental specialists, operators, enforcement agents, and public relations professionals. The focuses of this audience of practitioners can be categorized as follows:

- Agency: federal, state, and local planning, financing, and implementing agencies; public and private perspectives (MPOs, DOTs, and state/local/regional toll and mobility agencies, transit agencies, municipalities).
- Planning: highway, bus transit, MPOs, TDM providers.
- Design: highway, bus transit, toll agency, consultants, toll system providers.
- Operations: traffic, enforcement, maintenance, tolling system providers, maintenance services.

Topics Included/Organization

The topics include all types of dedicated lane treatments currently being applied and located on urban access-controlled (high-speed) roadways that employ various traffic and pricing tools to manage demand and provide travel reliability. Each topic will generally include an introductory discussion, why the topic is important, options in practice, a synthesis of practice highlighting pros and cons for different options, and references to resource documents where more detailed information can be found.

The guide consists of six chapters that generally frame the topic areas applied to project implementation. To properly address the close synergies between design, traffic control devices, operation, and implementation, the reader is encouraged to explore these topic areas in tandem because each is heavily influenced by the others in the iterations required to reach consensus on a best approach for a particular project. The chapters of this guide are as follows:

- **Chapter 1** provides an orientation to the managed lane concept and background, as well as a contextual understanding of the role managed lanes serve as one component associated with corridor congestion management and TDM.
- **Chapter 2** addresses the planning process and highlights unique planning issues commonly confronted in managed lane project development.
- **Chapter 3** covers design elements to consider in managed lanes and related supporting transit, enforcement, access, and tolling infrastructure.
- **Chapter 4** addresses the parallel design needs associated with traffic control devices used on managed lane designs.
- **Chapter 5** focuses on implementation and deployment.
- **Chapter 6** covers operations and maintenance.

A list of commonly used abbreviations and a comprehensive glossary of terms related to managed lane practice are included after Chapter 6. Many of these definitions are borrowed and referenced from parallel documents including *NCHRP Report 414* (*3*), the FHWA *Priced Managed Lane Guide* (*2*), and various state DOT guidance publications.

Topics Not Included

The following topic areas are not included, primarily because either (a) the applications are not dedicated lanes located in a freeway setting or (b) more detailed guidance can be found in other treatises. Where appropriate, references are provided to other guidance documents.

- General freeway geometric and design considerations not unique to managed lanes (*27*).
- General signing (*1*).
- Demand forecasting and capacity associated with managed lanes, including detailed discussion of weaving associated with managed lane access.
- Managed lanes not located in a controlled-access environment, such as busways in separate rights-of-way and on arterials (*28*).
- Conventional toll roads (including variably priced toll roads).
- Rural and intercity highways.
- Other congestion pricing or tolling strategies not affiliated with managed lanes.
- Public–private project implementation not applied to managed lanes.
- Smarter roadway concepts that address all freeway lanes. An example reference includes Highways England's guidance on how to drive on a smart motorway (http://www.highways.gov.uk/our-road-network/managing-our-roads/improving-our-network/smart-motorways/).
- Active traffic management [except for specific examples applied to managed lanes; see FHWA, Office of Operations (*8*)].
- Broad applications of TDM strategies and concepts (*10*).
- Broad applications of corridor congestion management (*12*).
- Transit facilities located off a controlled-access roadway (*28*).
- Fixed-transit guideways (bus, light rail, commuter rail) located within or outside a controlled-access roadway.
- Topics already addressed thoroughly in parallel or legacy guidance and readily available to the practitioner.

CHAPTER 2

Planning Considerations

Overview

Planning a managed lane project or system is the first step toward determining if the concept is feasible for implementation. This process helps project sponsors identify the key goals for the project and whether they can be met, determine the roles and responsibilities for those involved, and assess the feasibility of the project to be built and operated. Successful planning activities often attempt to address specific policy and legislative issues early on and involve public engagement throughout all stages of development. These steps help ensure a successful project during implementation.

This chapter provides guidance on how to appropriately plan a managed lane using experience from past projects and other national guidance. Parts of this chapter are supported by existing guidance contained within the FHWA *Priced Managed Lane Guide* (*2*), the FHWA *Freeway Management and Operations Handbook* (*12*), the AASHTO *Guide for High-Occupancy Vehicle Facilities* (*6*), and *NCHRP Report 414: HOV Systems Manual* (*3*).

Planning and Programming

Overall, the process for planning a managed lane can vary considerably between projects. The reason for the difference usually stems from how a project is financed. The ability for a project to be financially supported can have a major impact on the planning process as well as the design, operation, and maintenance of a project. Project developers should expect a nonlinear process, particularly for project types not previously attempted. Project sponsors should expect to be flexible during planning efforts to adapt to changes in financial support.

Therefore, managed lane projects need to consider a number of caveats during development. For these projects, public engagement and agency stakeholder dialogue should occur at the onset. The preliminary design needs to reflect the operational and enforcement needs, and vice versa. Financing is critical at an early stage during the development of the MPO's long-range transportation plan (*6*).

Planning a managed lane project usually consists of the following components:

- Identifying goals and objectives.
- Conceptually planning and testing feasibility.
- Refining feasibility to define a project or program.
- Developing an appropriate concept of operations and preliminary design that address the project or program.
- Developing an implementation plan.
- Developing a financing or funding plan.
- Pursuing an environmental review [e.g., National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA)], if required.

Identifying Goals and Objectives

Establishing goals and objectives is a crucial early step in the planning and development of managed lanes. Defining goals should be a collaborative and iterative process between the project sponsor, regional entities, local communities, and key stakeholders critical to the project (e.g., elected officials, business associations). These goals may be closely aligned with the goals defined by a long-range plan or may be strongly influenced by state-based legislation. Additionally, project sponsors should characterize traveler expectations within the goals and objectives. Travelers and adjacent communities typically want benefits that specifically impact them. Common expectations fall in the areas of reliability, safety, mobility, and economic impact. The use of working groups and interagency committees is beneficial during this stage as an engagement tool to help determine the needs of various stakeholders and policy makers. Discussing goal-setting frameworks that have been used elsewhere can serve as a useful way to start the process (*2, 6, 29, 30*).

After the goals for a project have been identified, the sponsors and planning organizations draft a set of objectives to assess and measure the effectiveness of each alternative. Agencies usually select a series of objectives with the understanding that a few may conflict. For example, improved traffic performance and revenue maximization are not directly correlated objectives (*31*). These objectives are used throughout the feasibility analysis. Common objectives include the following items:

- Maximizing person throughput.
- Maximizing vehicle throughput.
- Improving travel time reliability.
- Maintaining a minimum speed threshold.
- Optimizing revenue (if project is to be priced).
- Improving transit serviceability and increasing ridership.
- Incentivizing the use of low-emission vehicles.
- Improving air quality.
- Improving movement of commercial goods and services.
- Supporting community land use and development goals, particularly for major areas of employment.

Potential Customers

Many different users can use a managed lane. These individuals may be grouped into users of specific modes or share common demographic characteristics. Common user groups include the following:

- Transit buses (including deadheading buses).
- Vanpools.
- Private employer shuttles.
- Low-emission and energy-efficient vehicles.
- Taxis.
- Motorcycles.
- HOVs (typically with 2+ or 3+ persons per vehicle).
- Single-occupant vehicles (SOVs).
- Law enforcement and emergency vehicles.
- Low-income travelers.
- Commercial vehicles and trucks.

Managed lane projects often assign priority to select user groups during project development. In many cases, federal and state policies mandate parts of the decision-making process for who should receive priority. Moving Ahead for Progress in the 21st Century (MAP-21) outlines a number of regulations, and the FHWA provides guidance for ensuring compliance and handling priority for HOV and HOT lanes. Sponsors should work closely with their local FHWA division office for assistance. Otherwise, the sponsor and its partners have the discretion to designate priority.

Establishing priorities can help agencies make appropriate decisions about how to operate a facility to meet its stated goals. Sponsors should understand that priorities can change over time and that sponsors should continually reassess the user groups that receive preference. Priority can come in the form of no tolls or reduced tolls, closed access (e.g., HOV-only status), or permission to use special access points (e.g., on- and off-ramps). The groups that typically receive priority are those that constitute the bulk of traffic or are seen as important to the local and regional community (*2*, *4*, *32*).

Agencies need to consider a number of factors when planning a managed lane that will be used by different customers. The design vehicle should be kept in mind if trucks and other heavy vehicles are permitted. For example, trucks need to have enough space at access points for entering and exiting and a wide enough shoulder for breakdowns. The level of existing carpooling and transit programs needs to be considered because alternative mode use can have a significant impact on operation. The proportion of tolled to non-tolled vehicles for dynamically priced facilities can also have a similar impact because toll-exempt vehicles are inelastic to price changes (*2*, *32*, *33*). The designation of access points needs to be selected based on the composition of users traveling on the corridor and where they would prefer to exit and enter the lane. A potential means to assess current demand would be to conduct an origin–destination survey to examine where users may start and end their trips on the corridor (*34*).

Regional Planning

The planning for managed lane facilities often begins at the regional level and focuses on the needs, goals, and objectives for improving transportation performance within a metropolitan area. Planning for managed lanes is usually a part of the long-range planning process performed by the local MPO, an effort to create a unique system, or a part of another regional or state-based initiative. Regional planning involves representatives from the MPO, state DOT, transit authorities, tolling entities, and municipal transportation or county partners (*6*). If a region has a diverse set of stakeholders that are defined by a broad geography, then special consideration should be given to include all the entities and organizations that are impacted by transportation policy and the planning processes. Early participation from these entities is critical for successful implementation.

The components of regional planning focus on an assessment of where the implementation of managed lanes would be feasible. The critical question asked at this stage is whether managed lanes could be appropriately applied across a network of freeway facilities. Oftentimes, there is a tendency to focus on consistency across a region when considering design and operational elements. However, circumstances on select corridors may cause inconsistencies in operating guidelines that are the result of many factors including facility design, market demand, and local policies. For example, an existing corridor with an occupancy rule of HOVs with two or more passengers (HOV2+) in a region may attempt to convert the rules for all HOV facilities to three or more passengers (HOV3+). Travelers on existing lanes may not comprehend the rationale for increasing an occupancy requirement, especially when some facilities appear to be underused. Careful consideration and analysis should be done with effective public engagement to understand user behavior and what changes could be readily accepted.

Creation and adoption of policies supporting project development are good—up to a point—for consistency and guidance. Too much policy development can restrict the flexibility needed for the design, operation, and procurement processes. Performance monitoring can help to streamline the policy development process and help to flag critical issues that are highly sensitive. Common sensitive issues have included tolling, access design (e.g., placement of direct-connect ramps), lane separation treatments, and construction phasing.

Corridor-Level Planning

Corridor-level planning requires a greater level of detail than regional planning. Planning at this scale is commonly done through specific studies that identify and evaluate suitable improvements. The overall elements of a corridor study include identifying the problem, developing alternatives, and assessing the alternatives. The evaluation criteria should be based on general guidance treatises that are tailored to the region and the preferences of the affected agencies. At a minimum, criteria addressing feasibility need to reflect the key goals common to most managed lanes: safety, reliability, travel time savings, person and vehicle throughput, cost-effectiveness, and constructability. Different design concepts should be assessed for practicality and be based on the specific corridor characteristics. Trade-offs should be defined from the safety, cost, constructability, and impact perspectives. Not all corridors are feasible. The projects that are not feasible should be dropped from consideration or potentially reconsidered in the future when factors influencing the project change (*6*).

The planning scope must address each component of feasibility to some extent, and the decisions made during this step are often subjective. The scale of planning a project should be customized to either the local or regional setting. In other words, managed lane systems can either be conceptualized as individual projects applied to a single corridor or be an integrated network of facilities that attempt to function and operate in the same manner.

Conceptual Planning

The conceptual planning part of developing a managed lane project helps to evaluate alternatives through a defined lens or framework (*12*). This process entails asking questions about specific traits of feasibility that will guide the refinement of a comprehensive managed lane plan. That plan, in many cases, may be part of a larger process. Common questions asked during conceptual planning include:

- What are the goals and objectives?
- Who should be provided preferential access?
- How does this concept fit into existing regional and corridor-planning efforts?
- Do managed lanes make sense?
- Is there enough demand to warrant managed lanes?
- If so, what types of managed lanes make sense?
- How should they look and operate?
- Can they be constructed, and if so, how?
- What delivery approach is appropriate?
- What are the costs, revenues (if any), benefits, and impacts?
- Do key stakeholders support the concept?

Based on the findings generated from the conceptual planning analysis, an implementation plan will emerge that should be in concert with regional or local planning efforts. Each successive question needs to be affirmatively addressed for the planning study to proceed. If applicable, the environmental review (e.g., NEPA, CEQA) process may be undertaken specifically for a project or each project in a network that has independent utility. Other projects may have to consider unique population or user characteristics, such as freight if the managed lane will primarily serve trucks.

Managed lane planning includes many feasibility considerations, including the following:

- Institutional feasibility—assessing whether the project sponsor or other partner entities could support the actual implementation.
- Design feasibility—testing whether a managed lane can be physically built and operated in the selected corridor.
- Operational feasibility—assessing the practicality of a functioning managed lane, which is usually scoped in a concept of operations.
- Implementation feasibility—determining the practicality of constructing and maintaining the overall design and operational concept.
- Financial feasibility—assessing the predicted fiscal performance of a managed lane, with respect to funding and financing, to support construction, maintenance, and operation.
- Public and political support—evaluating the potential acceptance of a project to be supported by the public and political stakeholders, often defined as a separate feasibility assessment.

Good planning incorporates an iterative decision-making process. During the feasibility phase, it is beneficial to reach out to all affected parties, agencies, and entities. Gaining support during early stages on broad-reaching goals and basic design and operational elements can ease the implementation process. Public engagement throughout the planning phase should also be actively pursued, with meaningful opportunities to provide input for those who are not principally involved (*2*). Conceptual planning may also benefit from planning and environment linkage (PEL) studies. PEL studies are a type of assessment that enables partnering entities to build relationships early in the development process and to improve project delivery timelines. The approach enables sponsors to minimize duplication of efforts during the environmental review process, if required, by creating one cohesive flow of information.

Some states and regions have specific guidance that outlines additional steps to determine feasibility. Caltrans issued *Updated Managed Lane Design: Traffic Operations Policy Directive 11-02* (*35*), which focuses on engineering study requirements for managed lanes. The guidance states that a traffic study should be conducted for all managed lane projects and include an operational and safety analysis. Caltrans states that a traffic study has to be completed early, within reason, in the project development process. Specific requirements outlined in Policy Directive 11-02 include the following:

- Volumes are to be estimated for the managed lanes, adjacent general-purpose lanes, and corresponding ramps.
- The entire freeway facility has to be incorporated into the analysis, including both the managed lanes and general-purpose lanes.
- A 20-year design year is to be used, based on the date of expected completion.
- Different types of design vehicles, including trucks, are to be considered in the analysis.
- Geometric constraints have to be considered, including locations where bottlenecks and queues are expected to form.
- A merge/diverge analysis has to be completed for associated drop ramps and direct connectors.
- The operational impact of intermediate-access openings for limited-access managed lanes has to be evaluated.
- A safety analysis that focuses on the safety impacts of the proposed improvements on operating conditions and collision potential has to be performed.

Institutional Feasibility

Institutional feasibility is the determination of whether a sponsor agency, including its partners, could support the actual implementation of a managed lane project. In this context, the sponsor agency leads the development of the project, and supporting agencies assist in this task. The assessment for institutional feasibility focuses on the capabilities of sponsors and partners to implement, operate, maintain, and enforce the project. A key question in this process is whether the involved entities have the appropriate authority to be involved in the development of a managed lane. The answer comes from understanding each agency's roles and responsibilities, mission, and legal authority. This evaluation should emphasize resource capacity, financing ability, and tolling authority and organizational structure (if the facility is tolled). Additionally, to ensure consistency, an assessment should examine the policies and business rules that may need to be vetted at the regional or state level.

Design Feasibility

Completing a preliminary design can be seen as offering an early assessment of whether the managed lanes can be physically built and operated. The main activity during this stage is evaluating the different design concepts and making a determination for viability and estimating overall project costs. If the basic concept can work, producing a synopsis of how the lanes function can help during later parts of the development process. If specific trade-offs need to be made in the design, then a framework listing the positive and negative aspects of each should be developed. For example, providing additional access points on a limited-access facility would allow more users to travel on the lanes; however, trips would become shorter, and enforcement could become more difficult. Specific thought should be given to trucks because the design vehicle requires additional consideration for lane access, turning radii, and breakdown shoulders. Truck facilities, based on studies to date, typically need to have two or more directional lanes unless the facility is an access ramp or other isolated design treatment.

Other notable design considerations should address the following:

- Physical lane separation.
- Direct-access ramps (e.g., ramps to other corridors and park-and-ride lots).
- Active traffic management treatments.
- Signage.
- Toll gantries and equipment.
- Intelligent transportation systems and associated conduit.
- Enforcement provisions (e.g., pullout areas).
- Mitigation treatments (e.g., sound walls).
- Incident management and emergency response.
- Maintenance.
- Overall and order-of-magnitude costs.

Operational Feasibility

Sponsors need to conduct a feasibility assessment at some point in the implementation of managed lanes to test a wide range of operational and policy decisions (*2*). Planners need to understand how geometric design affects the operation of a managed lane facility. This process should be done in tandem with assessing design feasibility since both areas are interrelated. The assessment for operational feasibility should begin with determining the operational needs of the facility. The key questions asked during the process should include the following:

- How are these needs best addressed within the constraints of the existing facility (if the project is retrofitting an existing roadway design)?

- What operational periods meet demand?
- What are the optional plans for operation?
- What management tools are required: eligibility, access control, or pricing?
- How will the facility be enforced?
- What is the best mix of these tools?
- What are the likely impacts to adjacent general-purpose lanes?
- What are the likely impacts on parallel arterials and surrounding communities?
- Are trucks included or excluded, and why (most operation plans exclude trucks on single-lane facilities, particularly where lane widths are below standard)?

The operational assessment usually results in the creation of a concept of operations document that specifies how the managed lanes will operate. Oftentimes, this document is presented to stakeholders and other decision makers as a way to solicit their input on the project and to improve the operational plan (*2*). The concept of operations will likely be amended as the concept is refined through the project development process. Chapter 6 of this report provides detailed guidance on how to draft a concept of operations. Overall, the scope of the document should include the following characteristics:

- Demonstrate consistency between project goals and objectives and the operating plan.
- Able to be used to help plan operations and maintenance early in project development.
- Start as an overarching flexible framework that constantly evolves as planning and design work progress.
- Apply to a single corridor or a region, such as a regional concept of operations, if necessary.
- Consider the system architecture, variable pricing structure (if proposed), incident management, and enforcement of the managed lanes.

The concept of operations is a critical tool for the development of a successful project, particularly for a design–build or a public–private partnership project. The document can help formalize the roles and expected responsibilities of different partnering entities on a project. It can also help serve as a timeline for handing off key components to other partners. For example, the lead agency may be very familiar with geometric design and construction but may not be familiar with tolling or financing. The concept of operations can specify the roles of specific project partners and the dates by which project partners must fulfill certain responsibilities to ensure on-time project delivery.

Implementation Feasibility

Implementation feasibility is the determination of whether the proposed design and operational concept can actually be put into place. This aspect addresses how the project should be delivered, the associated costs for each delivery alternative, and the issues associated with construction. The concept of project phasing is often brought up, and a determination is made regarding whether different components should be built and operating before the entire project is complete. In the case of a managed lane network, this aspect could be expanded to evaluate which corridors should be planned and constructed first. Project funding and financing are often a major consideration during this phase. In the case of priced facilities, toll revenue can be used to support an expansion of the system and corresponding network, but only after the existing priced managed lanes are deemed to be properly maintained according to 23 U.S.C. Section 129 (*36*). Concern should also be given to mitigation strategies during construction, including provisions for handling existing traffic and staging areas for materials and equipment.

Financial Feasibility

When planning a managed lane facility, the topic of financial feasibility is often a major factor in the development of a project. Financial feasibility is the ability of a project to be self-supported through dedicated monetary contributions or generation of revenue from users of the facility. Restricted or limited funding for construction is an increasing trend for all roadway projects, including managed lane projects. Commonly, lead agencies have had to collaborate with other entities to obtain sources of funding or develop financing agreements. Each partner that brings a source of funding also typically requires a set of additional rules or stipulations for operating a managed lane. For example, a transit agency that provides funding may want special access for buses, or a private partner may require that a portion of the toll proceeds be dedicated for reimbursement. Project developers should expect a nonlinear financing process, particularly for project types not previously attempted. Financing arrangements from prior projects may not be practical due to statewide or regional policy changes (e.g., restrictions from select funds) and market changes (e.g., financing rates).

The financial evaluation should include all of the costs and any savings expected to occur during the life cycle of the project, including initial capital and ongoing operational and maintenance costs. Conducting an estimate of the cost–benefit ratio may be beneficial to emphasize the benefits of a project to stakeholders. The FHWA *Priced Managed Lane Guide* (*2*) and *NCHRP Report 722: Assessing Highway Tolling and Pricing Options and Impacts, Volume 1: Decision-Making Framework* (*34*) provide a comprehensive overview for planning the funding, financing, and pricing components, with a focus on tolled systems.

Financing and Funding Considerations

A wide array of revenue sources, financing tools, and agreements can be used to support the construction, operation, and maintenance of a managed lane facility. Some projects may use a combination of support from the federal-aid program and state funding programs, or be partially or principally backed by toll revenue bonds. In a few cases, private-sector participation may be sought for the delivery of public–private partnerships.

Managed lane facilities can differ from other traditional transportation projects in that toll revenue can be generated. The quantity of revenue that can be generated can depend on the project's demand characteristics, the number of managed lanes provided, and the policies regarding payment by users of the facility. Geometric design factors that affect the location of toll gantries may also play a role.

Revenue Sources

Revenue sources for managed lanes can include designated federal and state funding, discretionary grants, tolls, private equity payments, and other revenue sources. Traditional federal and state funding is typically supported by federal and state motor fuel taxes, vehicle registration fees, driver license fees, and sales taxes. Federal and state revenue sources usually follow a prescribed process that allocates resources based on metrics such as roadway mileage and population. In urban areas, MPOs are responsible for the decision-making process to allocate funding for transportation projects. State DOTs are often responsible for areas that are outside of urban regions. In the future, other non-toll methods may become a revenue source for managed lanes, including road user charges and weight-based cargo fees.

Discretionary grants have provided financial support to a number of managed lane projects. In the past, projects were supported under the Value Pricing Pilot Program, but the program is not anticipated to be a substantial source of future funding because additional federal funds were not authorized beyond fiscal year 2012 (*37*). Recent programs in Miami, Minnesota, Atlanta, and Los Angeles were supported through Urban Partnership Agreement/Congestion Reduction Demonstration (UPA/CRD) grants. The programs were all initiated in 2007 or 2008, and the last project opened for operation in early 2013. The UPA/CRD programs were one-time discretionary grants appropriated outside of the traditional surface transportation reauthorization legislation (*38*).

Transportation Investment Generating Economic Recovery (TIGER) began as a discretionary grant program in 2009 under the American Reinvestment and Recovery Act. The TIGER program awarded grants to recipients based on competitive criteria that focused on whether the project had significant national, regional, or local impact. Virginia (I-95 HOT lanes), Denver (US-36 managed lanes), and Riverside County, California (expansion of the SR-91 express lanes), host examples of managed lane projects that received TIGER grants (*2*).

Priced managed lanes have the capability of generating **revenue through tolls,** if any users pay a toll to use the facility. Segments 1 and 2W of the North Tarrant Express (NTE) within the Dallas–Ft. Worth region generated $43 million in toll revenue during the first year of operation (from October 2014–September 2015). The NTE was a project with a 52-year private concessionaire agreement that cost $2.05 billion to construct, with an anticipated $1.18 million annually for operation and maintenance costs (*39*). Federal law (23 U.S.C. Section 129, *36*) requires that public authorities use toll revenue only for select purposes. Toll revenue can be used to service project debt; provide a reasonable rate of return for private investors; and support improvement, operation, and maintenance. States may also have additional laws that place restrictions on the use of toll revenues. Based on the U.S. Code, agencies have the option of applying toll revenue for any purpose for which federal funds may be obligated by a state, but only after adequate maintenance is certified for the managed lane. For example, revenue from existing priced managed lanes can be pooled together to support the expansion and creation of additional facilities under a managed lane network—a method that is sometimes referred to as system financing. In other cases, tolls can provide support toward an equity payment to make a project financially feasible.

For projects that are principally supported by toll revenue, special consideration should be given to the number of toll-exempt users who are expected to travel on the facility. These projects pose a greater financial risk if a large percentage of users do not pay tolls. In addition to HOVs, transit vehicles, and motorcycles, exempt users may also include enforcement personnel, emergency vehicles, and veterans. Identification and verification of exempt users is a challenge that can lead to additional toll revenue loss, referred to as leakage. Project sponsors may not have exclusive control over some exempt groups due to federal and state statutes.

State and local sales taxes have also been used as financial support. Sales taxes have typically been used after voters pass a special initiative in an election. California is an example of a state where voters have passed many measures that impose taxes at the local level. The items referred on the ballot usually incorporate a list of specific transportation projects. The I-580 express lanes, I-680 express lanes, and I-15 express lanes are managed lanes funded, in part, with local sales taxes (*2*).

Value capture is a method of generating revenue that is based on the value of land surrounding a transportation project. Examples of this method include special assessments, tax increment financing, development impact fees, and developer contributions. Special assessments are defined as taxes that are levied on specific parcels within a zone. The amount of the tax is based on the estimated benefit for each unit of development. Tax increment financing allows for a percentage of future property tax increases to be diverted toward transportation projects. Development impact fees are one-time fees paid by developers near a project to help recover the additional burden that is placed on public services due to the growth of the development. Managed lanes are not typically financed though value capture, but future projects may seek to use this method as an alternative as more traditional sources become unsustainable.

Financing Tools

Priced managed lanes can leverage additional financing to help pay part of the implementation costs of a project. Financing is common with large capital projects that require significant construction costs. The viability of financing is dependent on the amount of revenue that is expected to be generated by or allocated to the project. Some managed lanes do not generate enough revenue to support toll-revenue-backed bonds. Projects that are expected to generate millions of dollars per year can attract the participation of private-sector partners, who can provide equity payments in return for future toll revenue.

Numerous bond and debt arrangement options are available to project sponsors. Different instruments include municipal revenue bonds, Grant Anticipation Revenue Vehicle (GARVEE) bonds supported by future federal funds, private activity bonds, state bonding programs (e.g., state infrastructure banks), and commercial bank loans (in cases with a private partner arranging for project financing).

Credit assistance through the federal government is possible through the **Transportation Infrastructure Finance and Innovation Act (TIFIA),** which offers lines of credit, loan guarantees, and direct loans to projects that are classified as having regional or national significance. TIFIA helps to provide better access to the capital markets, adjustable repayment terms, and more favorable interest rates. Many managed lane projects have been financed under TIFIA, including the LBJ Express near Dallas, the North Tarrant Express near Ft. Worth, and the I-495 Express Lanes in Northern Virginia (*2*).

Revenue bonds are considered a valuable tool for state and local governments to finance public works projects. The income earned from revenue bonds can come from tax receipts, tolls, transit fares, or other sources of repayment. Municipal bonds have the advantage of being exempt from federal taxes as well as state and local taxes if the investor lives in the same locality as the grantee. This benefit incentivizes investors to accept lower interest rate payments as opposed to other instruments of comparable risk.

GARVEE bonds are debt instruments that are backed by the future promise of proceeds that are expected to be received by states under 23 U.S.C. Section 12. In order for a project to receive financing with GARVEE bonds, state-enabling legislation must be passed to ensure that financing can occur on a programmatic basis. These bonds are considered general obligation state bonds, despite being supported by federal funds. GARVEE bonds can cover the entire cost of a project or can be combined with other instruments to help finance a larger project (*2*).

State and local governments that have significant involvement from a private partner use **private activity bonds (PABs)** to help finance and deliver a project. PABs are a low-cost option that can be used for varying transportation projects, including water and sewer facilities. For the first time, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) permitted the use of PABs to go toward privately developed highway and freight-related projects. A cap of $15 billion limits the amount of PABs that can be used to finance projects nationally, and this cap was unchanged by MAP-21. These bonds are attractive to investors because they are tax exempt and reduce the overall costs of borrowing compared to standard issued commercial debt (*2*).

Availability payments are an attractive financing option because project sponsors are able to capitalize on private-sector involvement while retaining control over toll rates and the collection process. By definition, availability payments are payments made to a private partner that are based on project milestones or specific performance measures. They can be used to support the costs of design, construction, operation, and maintenance, and federal-aid grants can be used to support capital-related costs. Availability payments can be reduced in the event that standards or project goals are not met. The I-595 Express Lanes in Miami is an example of a managed lane project financed by using availability payments (*2*).

Forecasting and Pricing

If a project is planned to be tolled, then pricing should be considered as part of the financial feasibility analysis. This component should, at a minimum, be included within the concept of operations. Travel forecasting models are used to determine the demand for a project under a number of different traffic conditions and alternatives. These models are mathematical tools that estimate performance using population and employment data, land use patterns, roadway and transit network files, travel cost, and traffic conditions. The demand estimations can then be used to generate a financial forecast. Practitioners should have a firm understanding of user value of time and the basic equation used to set toll prices. Most financial models are proprietary, and their owners are unlikely to divulge key details.

Applying traditional forecasts for managed lanes is a challenge because common techniques that are used for traditional toll roads are simplified and limited. These approaches do not account for how travelers will respond to different design characteristics, mode options, operating rules, and pricing structures. The operation of managed lanes is very sensitive to demographic changes and macro-economic shifts (e.g., an increase in fuel prices). The complexity is enhanced when considering that managed lane performance is closely associated with traffic conditions in the general-purpose lanes. Additionally, HOT lanes are different from traditional tolled facilities because of the potential for high demand from toll-exempt vehicles, particularly HOVs and alternatively fueled vehicles for facilities that provide for toll exemption (*34*).

Traffic and revenue forecasts are toll studies that primarily assess the effectiveness of using pricing on managed lanes to manage demand and generate revenue. These reports are commonly referred to as traffic and revenue studies. A traffic and revenue study is different from a traditional state DOT transportation forecast since a formal analysis has to be acceptable to the financial market. Each tier of the traffic and revenue report is defined by the level of analysis used and provides increasingly refined forecasts:

- Level 1 studies—studies performed in an introductory, or sketch-level, analysis. These can be completed within a 1- or 2-month time frame using existing data sources and are used to screen different alternatives during an early stage of the planning process to provide high-level estimates of potential revenues.
- Level 2 studies—studies that are still preliminary in nature and use existing travel demand models to create new forecasts. Level 2 studies usually take 3 to 6 months and incorporate data elements from sources such as origin–destination surveys, stated-preference surveys, toll sensitivity analyses, and economic reviews.
- Level 3 studies—investment-grade traffic and revenue studies that provide a certified forecast to bond rating agencies and potential investors. Level 3 studies can take up to a year to complete and are essential for projects that are dependent on using toll revenue for financing (*34*).

A number of key insights could be helpful when reviewing a traffic and revenue forecast during the planning process:

- The assumptions used in the traffic and revenue study can be similar to those used in other projects. However, each managed lane project is unique, so careful consideration should be given when determining which aspects are replicable.
- Forming a peer review group may be helpful to assess whether the assumptions being used are valid.
- The willingness to pay for priced users tends to vary across an entire population, so there are limitations to using a single value of time in the analysis. Value of time is also not solely dependent on traffic conditions and can be influenced by changes in seasonal demand (e.g., school schedules), traffic reports on the radio, trip purpose and importance, and other factors.
- Using traffic and revenue forecasts is not advised for environmental review. Oftentimes, traffic and revenue studies generate conservative results that are not appropriate for inclusion in either a noise or air quality study.

Environmental Review (NEPA) Leading to Project Development

Federal and state environmental reviews are not mandated for all managed lane projects. Federal regulations specify that states have the sole authority to set occupancy requirements and exemptions. However, many managed lane projects involve the use of federal-aid funding or amend previous NEPA commitments, which requires FHWA approval and a NEPA evaluation. Other managed lane projects may require federal action if that project is part of meeting certain air quality conformity requirements within a region (*36*).

The basis for environmental review is derived from NEPA and, in some cases, regulation from the state where the project is located (e.g., CEQA). The environmental review documentation can include subject matter that is pertinent to air quality, noise, endangered species, and environmental justice. A project is defined at the beginning of the environmental review as needing one of the following categories of environmental review: environmental impact statement, environmental assessment, finding of no significant impact, or categorical exclusion (*3*).

The challenge for managed lane projects centers on the issue of timing and coordination because undergoing an environmental review can be lengthy. Interaction with the MPO planning process is crucial, as is preparation of long- and short-range transportation plans. Regional and statewide planning is often cyclical in nature (*3*). PEL studies can be used as a technique to improve the NEPA approval timeline by reducing duplication of effort and better managing the flow of information.

NEPA can be either applied to specific projects or optionally prescribed to a more general corridor analysis to help determine the location and extent of changes. The details of a project scope can be identified through the NEPA process, including specifics related to access points, interconnected transit facilities, and direct-access ramps. Design is typically done to a preliminary level (30% or less) when the final review documentation is submitted. However, NEPA documentation is not required for camera installations, some access treatments, changes in separation type (e.g., barrier or buffer with pylons), or changes in operational policy (e.g., increased occupancy requirement from HOV2+ to HOV3+). Planners should consider the scale of the proposed change before defaulting to a detailed, NEPA-based planning process.

FHWA has provided *Interim Guidance on the Application of Travel and Land Use Forecasting in NEPA* (*40*), which cites the issues related to evaluating managed lane and pricing strategies. In its guidance, FHWA notes the difference between investment-grade forecasts to support project financing and NEPA forecasts to address environmental clearance. Both types of studies use different methodologies and produce different results. FHWA suggests that if investment-grade forecasts are released during the NEPA process, the project team should explain the differences inherent with each.

For projects larger than $500 million in total costs, FHWA has issued the Memorandum on Interim Major Project Financial Plan Guidance (*41*), which describes how a phasing plan is supposed to be outlined and offers guidance on how to conduct an assessment of the appropriateness for public–private partnerships. The phasing plan should include components that describe each phase, including the scope, cost estimate, and schedule. The plan also has to demonstrate that each phase can be opened to the public without other phases being completed, have dedicated funding through the Statewide Transportation Improvement Program, and show consistency with the NEPA decision document. For public–private partnerships, FHWA will only approve of a financial plan if an assessment of appropriateness is submitted. The assessment has to include a review of all cost estimates and evaluate the allocation of risk throughout project delivery.

Additionally, the AASHTO *Practitioner's Handbook: Managing the NEPA Process for Toll Lanes and Toll Roads* (*42*) provides guidance that relates to the implementation of priced managed lanes. The handbook provides useful insight for handling tolling during the NEPA process. Some key suggestions from the handbook include the following:

- The concept of tolling can be included within the purpose and need of a document.
- Tolling can be included for all of the alternatives.
- It is possible to issue a request for proposal (RFP) for a design–build contractor, or private-sector partner, and select a contractor based on that RFP before the NEPA process is complete.
- The timing of an RFP and the announcement of the preferred alternative needs to be considered. An RFP that is issued and awarded may require the modification of alternatives.

Incorporating Equity

Equity and environmental justice are important factors to consider when planning a managed lane. Successful projects typically address several dimensions of equity, including geographic, income, racial/ethnic, and access equity. Each dimension is formed by varied concerns and requires different mitigation approaches. This is especially true for priced facilities because of the public and political concern that tolls may impose an unjust burden on low-income and underrepresented groups. Some managed lanes designate priority access specifically to low-income groups, such as the I-10 and I-110 Metro ExpressLanes in Los Angeles. Those facilities have a program in place that allows low-income users (defined by household income thresholds) to apply for an equity plan that provides $25 in toll credits every month. Only residents from Los Angeles County are qualified to participate in the assistance program, financially supported by the Los Angeles County Metropolitan Transportation Authority (LA Metro) (*43*).

Access equity is a particular concern with managed lanes because the locations of specific entry and exit points to the managed lane have a sociological impact beyond the operation of the facility. Local communities have an interest in ensuring that traffic does not intentionally bypass commercial businesses. In particular, equity impacts are a sensitive area for reconstruction projects that take additional right-of-way away from commercial interests. However, allowing more access limits the ability to provide benefits for longer-distance trips. Successful projects have attempted to address the needs of different user groups or markets that travel in the corridor. An example would be to classify long-distance travelers as a market for managed lanes and local travelers as a market for general-purpose lanes. Specific geometric features such as collector–distributor roads and frontage roads can improve access. Collector–distributor roads may improve overall traffic operation, or may shift weaving and place additional demand on signalized arterials. Creating an access treatment plan can help formalize the partnership that a managed lane operator has with the community and with the different markets that use the facility.

The *Guidebook for State, Regional, and Local Governments on Addressing Potential Equity Impacts of Road Pricing* (*44*) is a document published by FHWA that offers guidance on how to address equity concerns when planning priced facilities. The basic principles presented in the document can also be applied for non-priced facilities. The guidebook provides examples for completing an equity analysis through an outline of the scoping process, identifying the potential for impacts, and determining actions for mitigation. Analytical frameworks and geographic information system (GIS) based tools are referenced as mechanisms to help guide the process. Overall, the guidebook presents five steps to conducting an equity evaluation:

1. Consider any potential equity impacts of pricing early in the project development—during the planning and design phases.
2. Determine who may potentially be impacted by the project and what kind of equity is important.
3. Evaluate potential equity impacts of the base case or no-build alternative to compare against the equity impact of the road pricing project.
4. Consider a variety of perspectives and impacts.
5. Measure effects.

Sponsors should consider the long-term implications on equity when planning a project. The original goals and purpose of a managed lane project could change due to shifting user perceptions after a project starts operating. For example, a priced managed lane may plan to operate with a limit on how high the tolls charged to users can be. A limit may be placed to mitigate concerns about the effects that high tolls will have on low-income users. The inability to raise tolls for high-demand facilities can lead to congestion, cause restricted mobility benefits for carpools, and worsen transit service performance. Additionally, degraded HOV facilities, and most HOT lanes, can subject the state DOT to loss of funding from the federal government.

Operating agencies should proactively alleviate the risk of negative public reaction concerning high toll prices. For priced projects, sponsors should spend considerable effort on explaining how tolling can meet the goals and objectives of the project. Agencies that have stated that users can "buy their way out of congestion" have not been successful. WSDOT had some moderate success when communicating that pricing enables more people and vehicles to move in HOT lanes. WSDOT supported that claim by regularly reporting on managed lane performance and on the greater impact to the transportation system (e.g., adjacent general-purpose lane, parallel arterials). In contrast, a poor strategy of communicating the impact to congestion is to emphasize the number of users who acquired toll transponders. The number of travelers does not show the managed lane is improving congestion.

Project Delivery

Project delivery refers to the process of how transportation projects are implemented from inception to construction. Different procurement options that specify distinct roles for the design, operations, maintenance, ownership, and finance of a project have been used for managed lanes. A traditional type of contract that has been used historically is the design–bid–build contract. A design–bid–build is a type of arrangement where a state DOT enters into different contracts for each component. At times, the project can be designed within the agency. The construction contract follows, with prequalified contractors submitting their bids to work on the project.

A newer type of arrangement that is becoming more common is the design–build contract. In comparison, a design–build contract differs by combining the design and construction activities into a single contract. This type of contract is often a fixed-fee contract and is usually awarded based on a best-value approach that considers total estimated costs and the qualifications of the bidders. The sponsor may prefer a design–build option because the arrangement transfers the risk from the public sector to a private contractor (*2*). The 95 Express in Miami was implemented using a design–build–finance arrangement that was very similar to a design–build approach but included additional financing risk to the contractor during the procurement process. Project managers from Florida DOT (FDOT) learned that every project requires unique attention and securing of outside experts, and based on their experience, they recommended comparing delivery options for cost-effectiveness and value for money early in the development process. Additionally, FDOT managers noted a belief that a properly structured deal can be financed, even during tough market periods (*45*).

The design–build–operate–maintain (DBOM) and design–build–finance–operate–maintain (DBFOM) contract arrangements are other delivery mechanisms that increase the involvement and responsibilities of private-sector entities. A DBOM contract integrates the operations and maintenance components into a design–build contract. It incentivizes a private partner to make capital investments up front during construction—thereby accelerating project implementation and reducing the risk of making costly repairs in the future. A DBFOM contract adds a finance component to a DBOM contract, with the private partner being required to secure financing for the project. All DBFOM projects are financed by leveraging debt from dedicated revenue streams, such as tolls or availability payments (*2*).

The I-635 LBJ Express in Dallas, Texas, is an example of a successfully implemented DBFOM project. A lesson learned from the LBJ Express was the critical importance of discussing toll servicing agreements, transaction costs, and interoperability early and often during the development process. Sponsor agency representatives from the LBJ Express project strongly recommended making a decision about who should carry the risk for revenue generation early in the development process. Sponsors who do not transfer revenue risk will likely have an entirely different relationship with the DBFOM partner (*46*).

Managed lane projects can be delivered in different ways. The method selected for project delivery can depend on the scale of the project, the entities involved, the scope of the project goals, and legislative authority. The type of funding and financing arrangement also plays a significant role in determining delivery model. Smaller projects are typically delivered by using a conventional funding process, and larger projects commonly seek the participation of additional or private partners. Some agencies try to define the type of delivery method when evaluating the implementation plan.

The sponsor can be responsible for a majority of activities during the development and planning phases, including conducting feasibility studies, submitting environmental documentation, and overseeing construction. For priced managed lanes, a project sponsor (or partner) has to have the legal authority from the state to collect tolls from the facility. All sponsors must be able to gather public and political backing to ensure that a project can be realized.

State DOTs, tolling and/or regional mobility authorities, transit agencies, MPOs, county governments, and cities could serve as project sponsors. State DOTs are often seen as a logical sponsor because they have experience with planning, designing, and operating limited-access facilities. They are currently the owners and/or operators of a great majority of managed lane systems throughout the country. For priced facilities, the involvement of the appropriate local or state toll authority may be beneficial in gaining public understanding and acceptance of the project. In areas where toll roads exist, motorists are typically familiar with paying tolls to existing establishments, and the appropriate authorities usually have experience in the design, implementation, and operation of toll systems. MPOs and local entities (e.g., counties and cities) have been logical sponsors, in some cases, of implementing managed lane projects if the project goal is to retain local control. The I-10 Katy Freeway Managed Lanes (branded as Katy Tollway), sponsored by the Harris County Toll Road Authority in Houston, is an example of a local county supporting a project.

Policy and Legislative Considerations

Sponsors and partnering agencies need to have the appropriate authority from federal, state, and local legislation to implement managed lanes. Unique legislative issues arise from managed lanes because these facilities are distinctly different from freeways. Oftentimes, legislation that is specific to managed lanes is tied to specific goals. Other considerations may address vehicle occupancy requirements, enforcement, and tolling authority.

Federal Policies

Various federal guidelines, legislation, and codes authorize the construction and operation of HOV lanes. The term "managed lanes" does not appear in federal legislation or codes, but the terminology for HOV lanes and tolling is mentioned and has a direct influence on the implementation of managed lanes. FHWA has provided guidance on the implementation of HOV lanes as it pertains to the Federal-Aid Highway Program (*36*). Federal-Aid Highway Program Guidance on High-Occupancy Vehicles (HOV) Lanes outlines the concept of HOV lanes, relevant legislation, implementation issues, and additional resources. Before implementing a managed lane, the agency should review all of the appropriate federal codes and regulations pertaining to HOV lanes and tolling, and consult FHWA representatives.

Title 23 U.S.C. Section 166 lists the regulations that are the most pertinent for operating HOV facilities in the United States. The authority and jurisdiction for state agencies to have HOV facilities and to undergo HOV-to-HOT lane conversions can be derived from Section 166. The federal code states that agencies have to give priority on existing HOV lanes to motorcycles and bicycles (unless a safety exemption is granted), public transportation vehicles, and HOVs. However, that same principle is not in place for express toll lane systems that require both SOVs and HOVs to pay a toll. States are granted the option of permitting preferential treatment for low-emission and energy-efficient vehicles.

A major requirement stipulated in Section 166 is that HOV facilities cannot operate under degraded conditions. Degradation is defined as an HOV facility operating below 45 mph for facilities with a speed limit of 50 mph or higher, or not more than 10 mph below the speed limit for facilities with a speed limit below 50 mph. The standard for defining degradation is the amount of time that an HOV facility operates above the speed threshold (e.g., 45 mph for a 60-mph speed limit) at least 90% of the time during a 180-day period.

FHWA guidance describes, in detail, that degradation is based on how users travel on the HOV lanes (whether they take short or long trips) and the location of congestion (*36*). For example, if many trips taken on the HOV lane are short and occur near a commonly congested bottleneck, then the facility is degraded. However, an HOV facility with many long trips and congestion on only a small portion is not degraded.

Under Section 166, states must annually certify that HOV facilities in their jurisdiction are not degraded, must meet vehicle eligibility requirements, and must maintain enforcement. As part of this process, state agencies have to establish and support a performance monitoring system to ensure that facilities are conforming to standards. If facilities are degraded, agencies have to submit a plan to implement mitigating measures to improve performance. Some of the measures recommended include increasing the occupancy requirement, varying the toll for priced facilities to reduce demand, discontinuing exempt vehicles (e.g., low-emission vehicles), and increasing capacity. FHWA imposes sanctions (e.g., withholding federal funds or delaying project approvals) on states that do not address degradation on HOV facilities (*36*). This is a stronger mandate that MAP-21 put into place.

Title 23 U.S.C. Section 129 applies to provisions for toll roads and has some policy items that directly influence the development of managed lanes. Most particularly, this section states that the number of toll-free lanes cannot be decreased when HOT or priced managed lanes are added onto a corridor. Section 129 also grants a public entity the authority to charge tolls on an HOV facility and includes provisions related to the ownership of toll facilities, the use of excess revenues, and project financing.

State, Regional, and Local Policies

Policies and legislation that are established by state, regional, and local authorities must be considered when developing a project. Existing policies that could impact project development focus on areas such as tolling, enforcement, and alternatively fueled or other exempt vehicles. A good reference to review when assessing how vehicle exemption policies impact operation is the FHWA report *Impact of Exempt Vehicles on Managed Lanes* (*47*). This document provides case studies of how 13 different states handle vehicle exemption and summarizes the key issues and considerations with hybrid use.

Topics that tolling policies and legislation tend to address include authorizing legislation, processing violations, and enforcement. State-based authorizing legislation permits agencies to start tolling in their state and to toll on selected facilities. State legislatures may also permit certain vehicles and user classifications to have priority in using the managed lanes. The user groups tend to include emergency services, military branches, and veterans. In some cases, these users tend to receive unrestricted access and no tolls. Policies can also be formed to direct specific agencies to enforce managed lanes and specify which policies should be handled by each agency (or if multiple agencies should be involved) (*4*).

States have the option of granting special priority treatment for low-emission and alternatively fueled vehicle classes, as outlined in 23 U.S.C Section 166. The U.S. Code states that vehicles in this group have to be chosen using a methodology approved by the Environmental Protection Agency (EPA). Since EPA has not made a final decision regarding this rule, FHWA guidance (*36*) states that agencies can follow the fuel economy requirements, as stated under Section 166. These include having less than a 50% increase in city fuel economy or a 25% increase in the combined city–highway fuel economy.

States have given different levels of priority for low-emission and alternatively fueled vehicles. California has an extensive and popular low-emission priority incentive with a clean air vehicle sticker program. As of July 2015, the California Air Resources Board allowed 85,000 vehicles to participate in the green sticker program, and all decals were issued to vehicles by the end of 2015. Common vehicle makes and models that are eligible for green stickers include the Chevy Volt, Nissan Leaf, and Toyota Prius Plug-in Hybrid (*48*). In contrast, Texas has no managed lanes that permit priority access for low-emission and alternatively fueled vehicles.

Public Involvement and Support

Public outreach and engagement are critical components in the implementation of managed lanes. Outreach helps to raise public awareness of the concept of managed lanes and assists in garnering popular and political support. Testing concepts with the public is a good way to gauge public support; methods to engage the public can include focus groups and surveys. These strategies can also help planners get an early indication of the willingness of users to pay tolls and how many might potentially carpool or use transit. Agencies can use public outreach and engagement before a NEPA decision to inform the public about traits of managed lane projects. Examples of appropriate outreach include defining a managed lane facility and how a managed lane could work. Attempts at marketing may be prohibited by law because of activities that advocate for specific alternatives. However, project sponsors can market and promote facilities after a NEPA decision to encourage use of the facility. FHWA has developed guidance on how to market the concept of priced managed lanes to the public in the High-Occupancy Toll (HOT) Lanes Marketing Toolkit (*49*). Additionally, *NCHRP Report 686: Road Pricing: Public Perceptions and Program Development* (*50*) provides a planning and decision-making guide for handling public perceptions of tolling and road pricing programs.

The outreach program can promote understanding of the concept to existing and potential new users. It is critical that engagement activities help the sponsor manage expectations for the project. Typically, a managed lane cannot and will not reduce long-term congestion for all users in the corridor. Therefore, project goals need to be aligned with the proposed concepts and public expectations. Outreach should also be conducted throughout the entire implementation process, from the start of problem and solution identification to the testing of operational and design concepts.

Public outreach activities can be separate from the NEPA review process. Components of a separate program can include telephone or mail surveys, stakeholder interviews, focus groups, social media, public workshops, and open houses. If public outreach is done before the NEPA review, the activities can be documented and kept to help with the actual environmental review (*2, 3, 6*).

Common Messages and Public Education

The outreach for managed lanes needs to be conducted differently from that for more traditional transportation projects because of the complexity of explaining the concept and how it impacts a diverse set of user groups. The public is very sensitive to system changes and usually reacts negatively toward restrictive access and tolling (*51*). There is a significant amount of pressure for the lanes to perform well after the opening of a new managed lane or the alteration of the operating rules for an existing facility. If the lanes appear to be empty or congested, the project sponsor will face severe scrutiny from political leaders who believe their constituents are not being served. At times, leaders have reduced tolls or changed occupancy requirements immediately after opening because of poor performance. It is critical to conduct market research and education throughout the development of a project. Additionally, special attention should be given to emphasizing the project goals and explaining how the system could work to meet those goals (*2, 49, 52*).

Project Champion

Having the support of a champion is very helpful when gathering support to implement a managed lane. A champion could be an elected official, community leader, or individual from the private sector who expresses support and organizes others to back the project. The champion's role can be to establish a very public persona or be influential behind the scenes. Having numerous champions can be useful during different stages of development. Some individuals may be more effective on the local level, whereas others can be persuasive with governors and legislators. While state DOTs, regional authorities, and MPOs might be publicly known project sponsors, it can be very helpful to have figures who are not transportation professionals to speak positively and influence the project (*2*).

Engaging Policy Makers and Stakeholders

The engagement of elected officials can be a very sensitive topic when developing a project, but it is often critical for success. Elected officials tend to evaluate a project from a variety of different angles as they consider the impacts to constituents and financial budgets. Elected officials' support or opposition may depend on specific project circumstances or other factors that are unrelated to the project. Therefore, outreach with elected officials, and their respective staffs, should be conducted early during the project development process. As part of the outreach process, the sponsor should discuss a wide array of issues that could be pertinent to the elected officials (*2, 3*).

Other stakeholders may have a vested interest in the project. These entities may include local towns, county governments, neighborhood groups, chambers of commerce, transit rider groups, newspaper editorial boards, and think tanks. Sharing information with these groups is helpful to inform individuals who are not intuitively engaged with the transportation planning processes. Creating citizen advisory committees or a community task force may be a beneficial medium to engage stakeholders through a more formal body. Advisory committees allow a diverse set of stakeholders to understand how others may view the project. Additionally, a project sponsor can show elected officials and potential critics that the viewpoints of an outside advisory committee were considered during project development (*2, 3*).

Engaging the Media and General Public

Successful facilities typically have an outreach plan that helps guide the media and educational activities of an engagement program. A good outreach plan should establish key objectives that define actions to be responsive and effective when communicating. Worthy points to consider include understanding the project from the user's perspective, articulating all key issues clearly, and nurturing credibility. Sponsors should establish partners with other entities to collaborate on a common message. A key component of a successful outreach plan is to have a timeline for both engagement and marketing activities, which should be separate. Before a NEPA decision, sponsors can engage the public to inform them about the managed lane concept and appropriate trade-offs within an alternatives analysis. Actively marketing and specifically advocating for managed lanes may be prohibited by law during the environmental review. Marketing is usually acceptable after a NEPA decision to promote use of the managed lane and to inform travelers of new and additional options.

Outreach plans benefit from research about customers and their awareness and knowledge of managed lanes. Research is vital to understanding the customers who are using or could use the facility and why users select different transportation options (e.g., carpooling versus driving alone). The information gleaned from research can then be used to determine what media outlets would be beneficial to incorporate into the marketing plan. Insights from research can also be used to gauge the level of an educational campaign and to tailor outreach material for a general audience. Surveys and focus groups are good instruments for assessing public engagement (*2*).

Effective branding is a component of successfully implemented managed lanes. When determining a brand, the agency should define what the user's experience will be when traveling on that facility. Components of a brand include the designation of a name, term, symbol, or design pattern. A slogan can also be integrated with a brand. Nationally, the MUTCD has specific labels and symbols for types of managed lane facilities. These names include a designation for express lanes (facilities that charge any group of users a toll) and a diamond symbol for HOV lanes. However, sponsor agencies have, at times, modified these terms, given local and political pressure when implementing a project. For example, the word "toll" can be included to create the term "express toll lanes" because stakeholders believe users need to distinctly know which facilities are tolled. Other entities have branded entire networks of managed lanes across a region, such as the Bay Area Infrastructure Financing Authority Express Lanes in the San Francisco Bay region and the TEXpress Lanes in the Dallas–Ft. Worth region.

Engaging in paid advertising to communicate the key aspects of a project may be advisable depending on the outcomes from market research. Paid advertising can be effective by using knowledge about the customer base to pursue the most critical issues of concern to the general public. Using this approach helps to maintain a reasonable and efficient advertising budget. Additional added-value items can also be included during the negotiation for buying media, including prize giveaways or other promotions (*2*).

Social media is a newer form of media that needs to be carefully monitored and managed because information can disseminate at a faster rate than other, more traditional mediums. Sponsors should note that while social media sites can communicate the benefits of managed lanes, others can use it to start a grassroots campaign against a project. Social media can take the form of blogs, websites, and popular sites such as Twitter, Facebook, and Reddit. Sponsors should be aware that new media outlets keep emerging, so establishing policies that are specific to single sites or media formats will likely be ineffective. Social media technology rapidly changes and evolves, so an individual, or a group of people, should maintain and monitor a social presence.

CHAPTER 3

Design Elements

Overview

This chapter provides guidance and relevant discussion of a variety of elements that need to be considered in the development and design of a managed lane facility. While aspects of some of the topics in this chapter are also covered in other chapters (e.g., planning and policy decisions, appropriate traffic control devices), the material in this chapter focuses on the issues that a designer will consider in designing a managed lane facility.

This chapter covers a variety of topics:

- Design considerations for specific user groups.
- Geometric design considerations.
  - Consistency.
  - Recommended values for specific design elements.
  - Issues related to conversion from HOV to other types of managed lanes.
- Access considerations.
  - Managed lane placement.
  - Separation treatments.
  - Access point design and locations.
- Operational impacts.

In a number of sections within this chapter, cross-references are provided to other chapters for additional support, such as Chapter 2 (planning), Chapter 4 (traffic control devices), and Chapter 6 (operations and maintenance). Those chapters, while not specifically focused on design, have information and guidance that are relevant to the material found in this chapter. Additional external supporting information for the guidance in this chapter is derived from national sources such as the AASHTO *Guide for High-Occupancy Vehicle Facilities* (*6*), state design manuals such as those from California and Nevada (*53, 54*), and published research that is cited where discussed.

User Groups

A managed lane facility should be designed with its intended user group(s) in mind. This section will discuss potential user groups that should be considered.

Design Vehicle/Eligibility

One important consideration when identifying relevant user groups is determining whether those groups have a particular vehicle type that should be accommodated in the design. The following section describes characteristics of design vehicles and considerations for vehicle eligibility.

Intended Users

To determine the most appropriate design vehicle, one must first identify the intended user group(s) of the facility. A road agency (e.g., DOT or regional authority) can make this decision based on a variety of criteria. Examples include the following:

- Selecting the vehicle occupancy or vehicle type that meets a potential management strategy goal such as providing for the maximum movement of people, vehicles, or goods in a corridor.
- Providing free-flow operations.
- Providing for the ability to accommodate future growth within a corridor.
- Being consistent with the regional transportation plans and the policies adopted by the relevant agencies (*55*).
- Where tolling is anticipated, determining restrictions needed for generation of sufficient revenue.

Conversely, the design context may rule out certain classes of vehicles. For example, if a managed lane is being created from a left-side shoulder and is likely to have a narrow width and limited sight distance, then large commercial trucks will likely be excluded as a design vehicle.

A private developer or a public–private partnership should carefully identify the likely users of the managed lanes, as well as their likely effects on revenue. In both cases, especially for a new facility, the selection of the facility's user group(s) is related to policy decisions on what type of facility will be developed (e.g., HOV, HOT, bus rapid transit, toll only, truck only) and what purpose the facility is intended to serve; those policy decisions are made during the development of the concept of operations before the design process begins in earnest. For an existing facility, the parties responsible may decide that a change in intended users is appropriate. Increasing HOV eligibility from 2+ to 3+ on an existing facility will not necessarily change the design vehicle, but if an HOV facility changes to a HOT facility, the appropriate design vehicle may indeed change due in part to expanded vehicle mix or higher volume of design vehicles than previously experienced, which could require making design modifications to the existing facility to accommodate the expanded user group.

When the intended users are identified, an informed decision about the appropriate design vehicle can be made. A bus rapid transit or truck-only facility will have a classification of bus or large truck as its design vehicle, while a facility that does not allow large vehicles can accomplish its purpose with a passenger car or light truck as its design vehicle. A common situation is an HOV or HOT facility that allows bus transit vehicles; for that facility, consideration must be given to the accommodation of buses, particularly in the design of access points, acceleration and deceleration lanes, lane and shoulder widths, and horizontal curves.

Accommodation for identification of different users within the managed lane traffic stream must be considered in the design of the facility. For example, correct identification of HOVs and SOVs determines which vehicles are assessed a toll for using a HOT facility. Similar considerations could be made for bus rapid transit facilities in which public transit buses travel at no charge but other buses might be charged a toll. Ease of intended user identification may stabilize user volume forecasts, reduce enforcement infrastructure, and otherwise provide better support for a particular managed lane strategy; additional discussion of vehicle identification is provided in Chapter 6.

Design Characteristics

The design vehicle should be used to establish the geometry of the facility's design elements. For example, intersection radii, where appropriate, such as off-ramp connections with arterials, should be based on a bus or other large design vehicle, while alignment geometry is typically based on the stopping sight distance of a passenger car driver. The speed and braking characteristics of a bus should be considered for sustained grades because they may exceed those of a passenger car (*6*). If the facility will be open to truck traffic, the entire facility, including all access points and horizontal curvature, is designed for the semitrailer truck design vehicle. For example, it is generally impractical to design long segments of the facility based on the semitrailer design vehicle and yet have select interchanges along the facility that do not accommodate that vehicle. It is possible that truck restrictions could be applied to selected locations within a corridor, but it should be done on a case-by-case basis and should be a result of a conscious decision within the design process after considering design alternatives and their trade-offs.

In general, design criteria for managed lane facilities that are part of general-purpose freeway corridors are the same as for the general-purpose lanes. These criteria apply to vertical and horizontal alignment, cross-slope, and lane and shoulder widths in particular. When proposed design elements do not meet these criteria, approval for a design exception or deviation process is typically required, although details vary among jurisdictions (*55*).

For stand-alone facilities that are in their own corridor (e.g., not adjoining a general-purpose freeway), the minimum criteria should be based on the intended design speed (i.e., typically freeway or arterial speeds similar to a general-purpose facility that would serve a user group with the same design vehicle). The benefit to designing a facility in a new controlled-access corridor rather than retrofitting a managed facility into an existing freeway corridor is that there are typically fewer restrictions within the available right-of-way and there is much more likelihood that the desired criteria can be accommodated.

The intended purpose of a facility will have some effect on the selection of certain design criteria, particularly for the design of access as well as any toll collection accommodation that needs to be made. Primary considerations are cross-sectional elements such as lane and shoulder width, buffer width, median width, drainage, cross-slope, and traffic control device accommodation, particularly if the facility is separated by buffers, pylons, or barriers. Other important design elements include sight distance, horizontal curve design, and vertical clearance under toll gantries, sign bridges, and overpasses. More detailed discussions of specific design elements are provided in the following sections of this chapter.

Transit Considerations

Transit vehicles (i.e., buses) have unique characteristics that should be considered if a managed lane facility is primarily intended for transit use. Buses operating in managed lanes can increase the productivity of the lanes in terms of person-trips completed. When bus volumes are high, a bus-only lane might be desirable. The following section describes characteristics of transit vehicles for the design of managed lanes.

Design Vehicle Considerations

When a facility's intended design vehicle includes buses, as described elsewhere in this chapter, several design considerations should be made in addition to those used for managed lanes that primarily serve passenger vehicles.

The design of managed lanes influences (and can be influenced by) the types of transit service that exist and can be provided. Each type of managed lane as a minimum has access to general-purpose lanes at its terminals. Intermediate-access points are often provided if the facility is not open to access throughout its length. For restricted-access designs, direct (i.e., grade-separated) access connections for major transit services, such as bus terminals, park-and-ride lots, and city streets, may be provided to eliminate the need for buses to weave across the general-purpose lanes and therefore reduce the potential for conflict with other freeway traffic.

Design guidance in Nevada states that bus turning radii are perhaps the most significant design vehicle issue for managed lanes since each bus type has a different turning radius (*54*). Turning requirements are particularly critical for applications of direct-access ramps from transit facilities or local roads, or where turning at low speeds is required. For single-lane facilities, visibility is adversely affected in a single platoon of vehicles; sight distance restrictions caused by the mix of buses and lower-profile vehicles may reduce vehicle headways, and thus affect the lane's operational performance measures. Since most managed lanes are located next to the median, the horizontal separation (or "shy" distance) to the median barrier, where full shoulders cannot otherwise be provided, may adversely affect sight distance around left-hand curves.

Managed lane planning and design should reflect the characteristics and capabilities that are in service. Examples of design vehicles and performance characteristics are given in the AASHTO Green Book (*27*); *NCHRP Report 414: HOV Systems Manual* (*3*); Volume 2 of *TCRP Report 90: Bus Rapid Transit* (*56*); and *TCRP Report 117: Design, Operation, and Safety of At-Grade Crossings of Exclusive Busways* (*57*).

Location of Transit Facilities

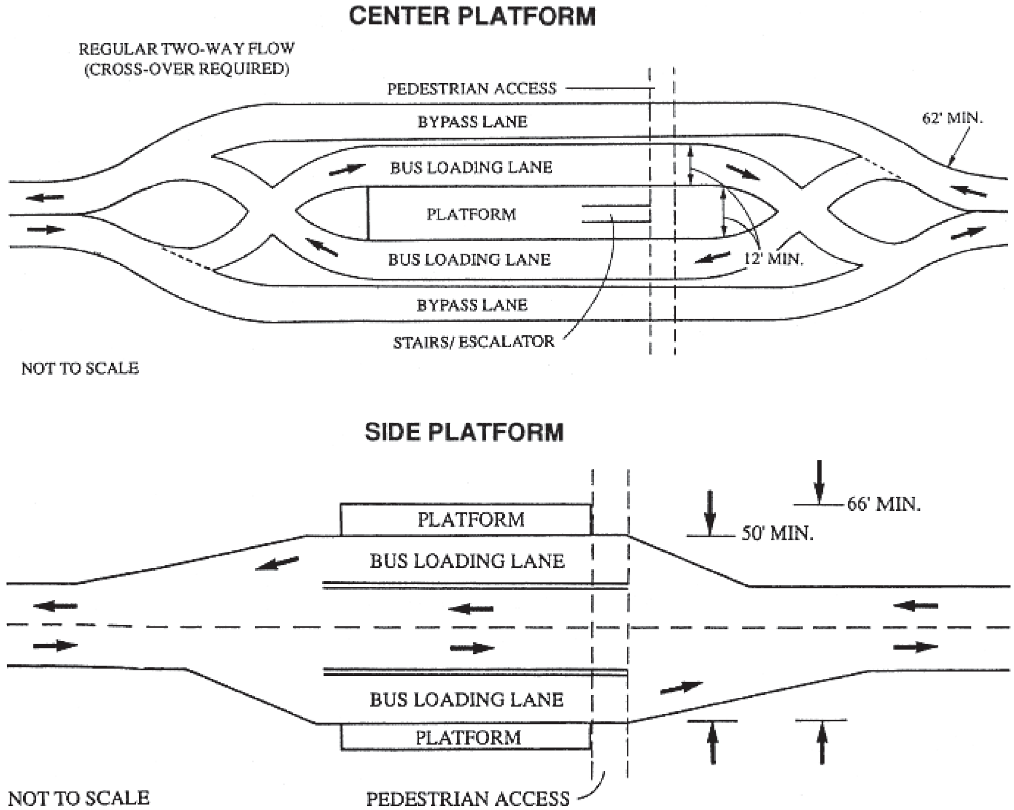
Transit stations along managed lanes, or in their immediate environs, help improve transit ridership and improve the productivity of the lanes in terms of passengers or passenger miles of travel carried. The stations can be located online (as along the I-110 Harbor Freeway in Los Angeles) or offline (as along freeways in Houston) or both (as along freeways in Minneapolis and Seattle). The buses using the managed lanes connect with various collection and distribution points and may operate point-to-point service between transit facilities or link service along a route. Preferential treatments may be provided to off-street terminals or via arterial bus lanes; refer to the AASHTO *Guide for Geometric Design of Transit Facilities on Highways and Streets* (*28*) for more information on arterial-based facilities. The design of online and offline bus stations along managed lanes should consider the following:

1. Locating stations adjacent to major activity concentrations, park-and-ride facilities, and interchanging bus lanes.
2. Maintaining the speed, reliability, and safety of the managed lanes by providing adequate spacing between stops, acceleration and deceleration lanes, and separate lanes for buses entering, exiting, and stopping at stations.
3. Providing adequate station platform capacity that conforms to Americans with Disabilities Act (ADA) requirements and prevents passenger overcrowding of platforms, which can be accomplished by:
   – Providing enough pedestrian access capacity to allow departing passengers to clear station platforms before the next bus arrives.
   – Providing attractive and convenient pedestrian connections to major activity concentrations adjacent to the managed lanes.
   – Utilizing barrier-free designs that meet ADA requirements.

Online stations are located along or adjacent to managed lanes either within the freeway right-of-way or in an exclusive right-of-way outside of the nominal freeway right-of-way envelope. The two platform orientations (side and center) are shown in Figure 28. Both of these orientations allow managed lanes to bypass the platform area. In both cases, the right-of-way must be sufficiently wide enough to accommodate the station and pedestrian access to it.

Center island platforms are used to minimize platform space since both directions share a common area for patrons that is removed as much as possible from freeway operations. They require only one set of vertical pedestrian access points. Because doors on buses are usually on the right-hand side, the center platforms require channelized crossovers on each end for bus drivers to negotiate. While it is possible to obtain bus designs with left-side doors, few operators currently operate this design because it complicates their fleet mix and requires dedicating specific buses to this facility. The crossover movement has to be taken at low speed and is less than desirable from a traffic operations perspective.

Side platforms eliminate the need for bus crossovers. However, they require two sets of vertical patron access points, they place patrons closer to high-speed traffic movements



Source: Fuhs (*59*).

Figure 28. Platform orientations for online transit stations.

(necessitating walls or screens), and they require more width. Both orientations can be found in freeway settings.

Offline stations are sometimes provided to serve as collection and distribution points (e.g., transit centers, intermodal centers, and/or parking facilities) that are located near the managed lanes. The stations can be incorporated into other land uses as part of parking facility design. Access to and from the managed lanes is either along local street connections or via direct ramps. The station may be somewhat removed from the freeway corridor, or the station may be adjacent to the freeway right-of-way. Offline transit stations often provide connections to a parking facility and rely on the local street network. Details on the design of transit stations, park-and-ride facilities, and other transit features not specifically related to the managed lanes can be found in other guidance documents (*28, 56, 58, 59*).

Truck Considerations (Including Freight/ Truck-Only Facilities)

Similar to transit vehicles, large trucks have unique characteristics that should be considered if a managed lane facility is intended to serve primarily or only trucks and freight vehicles. The following section describes characteristics of trucks for the design of managed lanes.

Design Vehicle Considerations

If a managed lane facility's primary design is to serve trucks, there are design considerations that should be made in addition to those used for facilities that primarily serve passenger vehicles. Nevada's design guidance states that the design of managed lane facilities must account for trucks from the outset (*54*). Nevada's reasoning is that if large trucks are not accommodated in the initial design of managed lanes, trying to add those accommodations to an existing facility, particularly a physically constrained corridor, can adversely affect the project's cost-effectiveness and ability to meet all design vehicle requirements.

Highway designers must make design trade-off decisions routinely on projects as they are developed within the context of the surrounding environment, particularly for those facilities that are retrofitted into existing freeways, which may limit the type of vehicles that can be accommodated in the facility (*60*).

Trucks generally require wider or longer geometric design features than do passenger vehicles. This need is attributed to trucks having longer wheelbases and greater minimum turning radii. Trucks are one of four general classes of design vehicles described in the Green Book (*27*). Within the truck class are the following seven design vehicles:

- Single-unit truck—SU.
- Intermediate semitrailer—WB-40 (40-ft wheelbase).
- Interstate semitrailer—WB-62 (62-ft wheelbase).
- Interstate semitrailer—WB-67 (67-ft wheelbase).
- Double-trailer combination—WB-67D (67-ft wheelbase).
- Triple-trailer combination—WB-100T (100-ft wheelbase).
- Turnpike-double combination—WB-109D (109-ft wheelbase).

The Green Book states that the interstate semitrailer WB-67 should generally be the minimum-size design vehicle for consideration at freeway ramp terminals intersecting with frontage roads or arterials on routes that provide access for trucks. Key design characteristics of the WB-67 and other design vehicles can be found in Chapter 2 of the Green Book (*27*).

Designers must consider horizontal and vertical clearance requirements for trucks. Horizontal clearance includes sufficient lane widths to account for possible offtracking on curves and shoulder widths to allow trucks to completely clear the lane in the event of a breakdown or emergency. Higher vertical clearance is necessary for trucks to safely pass under toll gantries, sign bridges, and overpasses. Access points require longer weaving areas and speed-change lanes for trucks than for passenger vehicles.

Because the performance characteristics of trucks are different from passenger vehicles, the designer should consider effects of grades on facilities with trucks as design vehicles. Prolonged grades should be avoided if possible because upgrades can lead to substantial speed differentials between trucks and passenger vehicles, and downgrades may require additional stopping sight distance for trucks.

The location of the managed lane facility should also be considered. A facility that is in proximity to a hub for commercial or industrial access needs a design that accounts for increased truck traffic. While the truck percentage of total traffic at a typical facility might commonly be less than 10%, such a facility near a shipping port or a distribution center could have a truck percentage as high as 50%. The design of this type of facility needs to account for variations in strength of pavement, lane width, turning radius, vertical clearance, and other characteristics to ensure that the facility meets the needs of the user group for which it is intended.

Geometric Design Considerations

This section describes key geometric design elements and related issues that should be considered in the design process for a managed lane facility. Some of the information presented here is applicable to freeway design in general, while other portions contain guidance specific to managed lanes.

Design and Operational Consistency

Whether a general-purpose facility or a managed lane facility, the geometric design should be based on principles that are appropriate for a freeway and are generally consistent with other freeways. This reinforces driver expectancy and promotes system connectivity when traveling from one facility to another.

System Integration Considerations

Managed lanes are often constructed as facilities that are dedicated lanes within a freeway or in some cases a freeway within a freeway. They are generally designed to appropriate state or national standards for the respective class of roadway. Managed lane design should match driver expectancy established by the presence of design elements and traffic control devices on nearby facilities. For example, if the adjacent roadway provides 50-mph ramps at major interchanges, a similar design should be considered for a managed lane ramp.

Research (*61*) has identified ramps as one of the most critical geometric aspects to consider in making a managed lane facility safe and functional with other facilities. In particular, the important aspects to consider in the geometric design of the ramps are ramp orientation (left versus right), type, and spacing. These guidelines typically vary by traffic level and appropriate design speed, so understanding both the current and future traffic impact of the facility is important to ensure geometric adequacy both at the time of construction and in future years of operation. Providing a design that is flexible enough to accommodate all design vehicles is best because experience has shown that a number of bus- or HOV-only facilities have over time been converted to serve a wider mix of design vehicles than was envisioned in the original design. For example, some HOV access ramps have low design speeds and reverse curves because they were designed for experienced bus drivers, but they now serve all traffic. Access to and from managed facilities should be designed so that drivers can travel from origin to destination as seamlessly as possible. Details of particular types of access ramps are discussed later in this chapter.

Other aspects of geometric interoperability include establishing techniques for separation of managed lanes with adjacent general-purpose lanes and consistent orientation and treatment for access, as well as considering within the design how enforcement, incident management, and maintenance of traffic control devices and tolling systems may be performed. For example, concurrent managed lanes are located adjacent to the median to best facilitate long-distance, high-speed operation, and even though some details of design specifications may change as new information is gained, drivers traveling from one managed facility to another can anticipate and expect that all such facilities in a region are constructed in a similar manner. Motorists benefit not only from having consistency between a managed lane and the adjacent infrastructure but also from having design consistency across all facilities within the region or area. Applying design consistency to a corridor or regional system involves a number of factors, including an appreciation of what will fit and how traffic will operate. Preferences in design practice can change over time, and managed lane systems can take many decades to implement. A perspective from one design practitioner in California (*67*) offers a way of appreciating how consistency should be treated:

> The whole evolution of what it means to be consistent is a question. The express lane project currently in development has all four . . . design options in play. The temptation is to say this is pretty inconsistent. From a driver's perspective what is going on? In one corridor this mix of designs may be inconsistent. But if we are sticking to the overall express lane concept, we are consistent with local standards of practice. The consistency becomes greater with a greater set of projects. But at a local level it might not look this way. There is this balance between what people consider is consistent and what the operational characteristics tell you will work or won't work. What is a good standard? It is not uniformity throughout. Every design concept requires you to adjust to changes in traffic behavior.

Local, Regional, and State Guidelines

In many cases, the local and regional jurisdictions that govern the design and construction of managed lane facilities do not have their own design guidelines, but rather they follow the design guidelines established by their respective state DOTs. However, the designer (e.g., government agency, private partner, design consultant) needs to know whether there are applicable manuals, standards, guidelines, and unpublished preferred design practice at the local or regional level that must be consulted and applied. If there is a local/regional design guidance policy that differs from a corresponding state policy, or if options exist, the designer needs to know which guidance or preference supersedes the other.

A number of state DOTs have design guidelines for some types of managed lane facilities (e.g., HOV and HOT lanes). Among the states with the most extensive guidelines are California (*53, 62*), Nevada (*54, 63*), Texas (*4, 64*), and Washington (*55, 65*). These guidelines cover fundamental geometric elements such as lane and shoulder width, horizontal and vertical alignment, and access design; some of them also provide guidance on specific features such as HOV bypass lanes on entrance ramps, enforcement treatments, and emergency/breakdown areas. It should be noted that the managed lane guideline documents referenced here typically contain numerous references to their more general counterparts (e.g., *Roadway Design Manual* in Texas, *Highway Design Manual* in California). Those design manuals provide the broader design basis on which the more specialized managed lane guidance is supplemental. In addition, some states have their own manual on uniform traffic control devices that contains guidance and standards on the appropriate signs, markings, and other devices specific to managed lanes (see Chapter 4). The designer needs to be familiar with the appropriate guidance documents that apply to the state in which the managed lane facility will be located.

Applicable policies change over time, so a set of guidelines that applied to a particular project may not completely apply to a subsequent project on the same corridor. In that sense, a measure of apparent inconsistency can arise from the driver's perspective (e.g., if the required minimum buffer width changes from one project to the next), but the consistency in practice still applies since the most current applicable guidelines are used at the time of each project.

National Guidelines

If no local, regional, or statewide guidance exists, the designer should consider using national guidance in designing managed lanes. In fact, the local/regional guidance may actually be to use national guidance. In either case, this guide and other national references should be useful to the designer:

- AASHTO *Guide for High-Occupancy Vehicle Facilities* (*6*).
- FHWA *Manual on Uniform Traffic Control Devices* (*1*).
- FHWA *Priced Managed Lane Guide* (*2*).

Design Variances and Flexible Design Philosophies

Particularly for retrofit facilities, trade-offs and accommodations may need to be made in comparison to applicable guidelines for affected design elements (e.g., lane width, shoulder width, lateral clearance). In many cases, a waiver, design exception, or deviation process must be completed to construct a facility that incorporates such trade-offs, though details vary among jurisdictions (*55*). The designer needs to know what trade-offs to consider, and what agency protocols must be followed to approve design variances. An example from the Nevada DOT of a series of possible trade-offs for designing the cross section for a concurrent flow HOV lane is shown in Table 4. Note that this list is provided as an example and is not intended to supersede engineering judgment in specific design applications.

As more states adopt policies of performance-based practical design (PBPD) or implement similar programs, the design philosophy of managed lane projects in those states may be more focused on how the completed project meets a stated purpose and need and fulfills the goals that were defined for the project. Indeed, setting specific performance measures (operational, economic, etc.) is a common practice for managed lane facilities, so implementation of PBPD principles may be a complementary strategy to the design process used on previous projects. The designer should be familiar with

Table 4. Suggested design sequence of trade-offs for concurrent flow HOV lanes.

Suggested Sequence	Cross-Section Design Change
First	Reduce the 14-ft median (left) shoulder (for continuous enforcement) to 8 ft. Provide designated enforcement areas instead.
Second	Reduce median shoulder to typical minimum width as per Nevada DOT Standard Plans.
Third	Reduce median shoulder to 2 ft.*
Fourth	Reduce outside (right) shoulder to typical minimum width as per Nevada DOT Standard Plans.
Fifth	Reduce managed lane to 11 ft.*
Sixth	Reduce general-purpose lanes to 11 ft starting from left and moving to the right as needed. The outside lane should remain 12 ft.*
Seventh	Transition barrier shape at columns to vertical face.

*Requires design exception.
Source: Nevada DOT (*54*).

applicable PBPD-related policies and programs that are in place within the jurisdiction of the project. More information on PBPD principles and related resources can be found through FHWA (*66*).

Design Speed

The Green Book guidance for freeway design speed, or appropriate state or local standards if applicable, should be used to provide for a high level of service. For managed lane facilities that are part of a general-purpose freeway corridor, it is preferable to use a design speed that is comparable to the adjoining freeway. This is especially true if there is the possibility of the facility being used by general-purpose traffic during the off-peak hours or at some time in the future. If there is no possibility that the facility will be used by general-purpose traffic, and if use of this facility is to be further limited to a single vehicle type such as buses, then the specific physical dimensions and operating characteristics of that vehicle should be considered in design. For example, the difference in driver eye height or braking characteristics may require a different roadway geometry than if the facility were to be used by all vehicle types.

The Green Book recommends design speeds of 60 mph to 70 mph on most urban freeways (*27*). This information is provided to give a general idea of potential design speeds. The design speed for a specific facility should consider the anticipated user groups, the application of transit facilities, gradients, and local conditions and requirements.

According to AASHTO (*6*), desirable ramp design speeds should approximate low-volume running speed on the intersecting highway. Using the middle range of ramp design speeds in the Green Book (*27*), for a 70-mph mainline design speed, minimum ramp design speed is 50 mph. For a 50-mph mainline design speed, minimum ramp design speed is 35 mph. For a direct-connect ramp, minimum design speed is 40 mph.

A suggested (*59*) design speed for ramp connections for HOV lanes is approximately 0.7 times the mainline design speed, or nominally in the 35-mph to 50-mph speed range. This criterion is applicable to flyover ramps and connecting drop ramps with local streets. At-grade access locations may use this criterion if dedicated weave lanes are provided, or they may be designed at a higher speed based on the specific location and operating characteristics of the freeway through lanes.

Some managed lane connections use grade-separated traffic intersections to connect directly with the local street network; such intersections require lower design speeds for turning maneuvers and good sight distance due to their median orientation. Adequate acceleration and deceleration lane lengths should be incorporated at these intersections for speed transition. Lower ramp design speeds may also be appropriate where restrictive geometry or right-of-way exist for connections; however, a negative trade-off is that travel time savings are reduced (*59*).

Stopping sight distance is often based on a passenger car as the design vehicle and is a function of the driver perception–reaction time and the driver comfortable deceleration rate. It is generally considered that the additional stopping sight distance a truck may need for slower deceleration rates is offset by the increased driver eye height; however, on downgrades, the added momentum of trucks compared to passenger cars makes it prudent to provide additional stopping sight distance. In all cases, stopping sight distance should be based on a national guideline, such as the Green Book, or applicable state or local standards. These guidelines should be applied with appropriate engineering design knowledge and judgment.

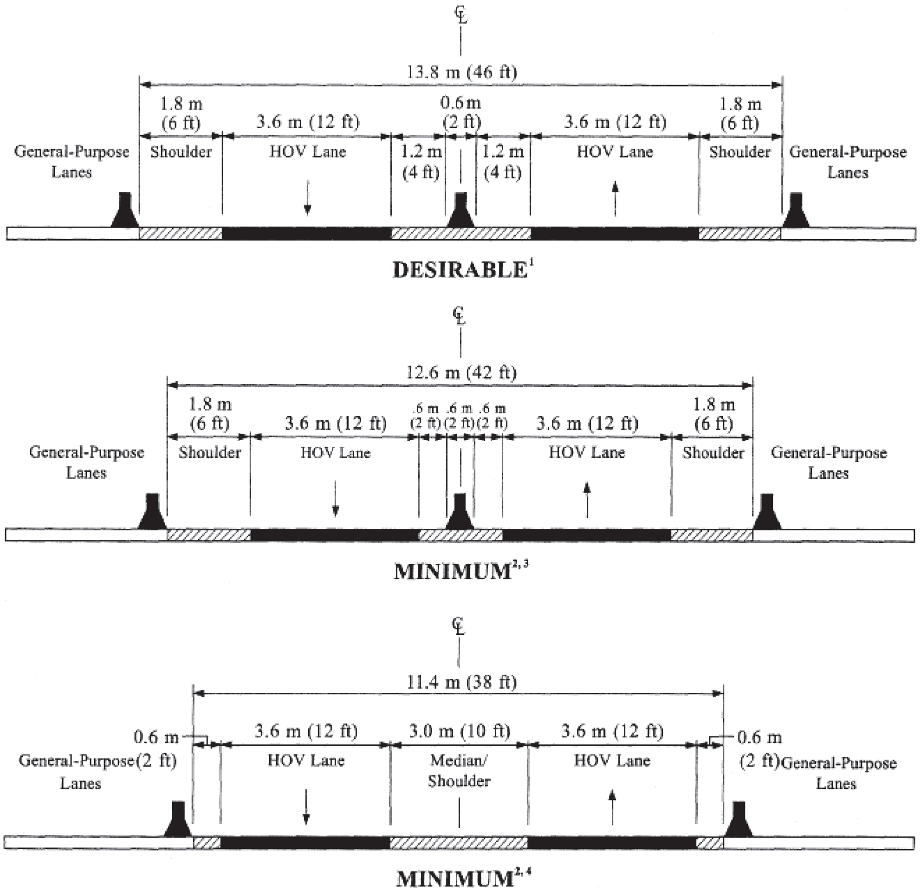
Cross Section and Alignment

There are multiple sources for design specifications. In many cases, the specifications for general-purpose lanes on a particular facility type apply to managed lanes. The following information is provided for general reference only. The practitioner should determine what national, state, or local standard applies to a particular facility.

Cross-Section Elements

Key elements of the managed lane cross section, as well as their effects on managed lane operations, are described in the following list:

- **Number of lanes**—Most managed lanes attempt to fit within available right-of-way, which is often quite constrained. For a majority of projects, this retrofit means adding one lane in each direction. Very few corridors have been able to retrofit two-directional lanes. Planning studies will help confirm the number of through lanes, particularly taking into account system-level demand inputs and outputs for any regional network. For managed lane facilities that are retrofitted into general-purpose freeway corridors, it may be difficult to accommodate one or two managed lanes in each direction and still provide the necessary shoulders and separation within the cross section. As a minimum, the same attention is needed for consideration of auxiliary lanes or treatment of lane drops downstream of any ramps that add high traffic volumes. The designer will have to consider the constraints of the corridor and then consider trade-offs to provide the best possible balance of managed lanes, shoulders, and separation in conjunction with the lanes and shoulders in the general-purpose facility. Some state DOTs (*53, 54, 55*) have developed their own process or preferences for making these trade-offs based on managed lane experiences.
- **Width of lanes**—The recommended lane width for a managed lane facility is 12 ft, just as with any other freeway lane. For a managed lane facility that includes a buffer that is 2 to 4 ft in width, some design guidelines allow up to 1 ft of lane width to be considered as part of this overall buffer dimension where full buffers and lane widths will not fit. This is because the managed lane driver perceives this space as part of the overall width used for horizontal sight distance. A lateral position study (*67*) modeled different scenarios to investigate whether it is better to have a 12-ft lane and 1-ft buffer or an 11-ft lane and 2-ft buffer. The predicted lateral position showed that drivers position the vehicle closer to the center of the lane when the extra foot is given to the buffer rather than the managed lane. The practice of reducing the lane width by 1 ft (from 12 ft to 11 ft) and providing that foot of width to the buffer between the managed lanes and the general-purpose lanes or to the inside shoulder is often appropriate. Figure 29 shows an example of cross-section options, including 12-ft lane widths, for barrier-separated, two-way HOV lane facilities. The AASHTO *Highway Safety Manual* (*23*) provides information on safety trade-offs by lane width for freeways.
- **Width of shoulders**—Ideally, managed lane shoulders should follow state DOT preferences, typically 10 to 12 ft, to provide ample clearance for disabled vehicles, enforcement activities, and emergency response. In practice, many retrofit applications have narrower shoulders so that the lane width is maintained and, to the extent possible, a shoulder width of at least 8 ft is maintained. For concurrent directional lanes, shoulders should be to the left, next to the median barrier. Shoulder space with a width between 4 and 8 ft should not be striped because drivers on a concurrent flow lane can misconstrue the space as wide enough to stop in, leaving their vehicles exposed to high-speed traffic that may not be able to negotiate around the exposed vehicles. Figure 29 shows an example of shoulder width options for barrier-separated, two-way HOV lane facilities. Where cross-section trade-offs result in a reduced-width inside shoulder, the operator of the facility can use strategies to mitigate related losses in sight distance that include spot widening, striping to create wider offsets in affected curves, and drainage treatments that reduce ponding. The *Highway Safety Manual* (*23*) and a field study on lateral position (*67*) indicate that maintenance of adequate shoulder width is desirable. The field study results demonstrated that vehicles traveling on a segment with a minimal shoulder on the left will shift closer to the right lane line, possibly due to limited sight distance and a driver's concern to avoid the concrete barrier. Research findings indicate that a 1-ft reduction in shoulder width results in greater changes in lateral position when the shoulder width is near minimal values (e.g., 2 or 4 ft) as compared to when the shoulder width is near desirable (e.g., 8 ft or 12 ft). The study findings support the idea that the buffer width should not exceed the shoulder width. In addition, it indicates that if extra space is available, it should be used for the shoulder rather than the buffer.
- **Width of median**—Medians on managed lane facilities should be designed in the same manner as other freeway medians. When right-of-way is constrained, the median should be designed with sufficient width to accommodate the pedestals and bases for gantries and traffic control devices, the median barriers, and the enforcement activities that will be required for the facility so that vehicles can travel in the leftmost lane or the left shoulder without their path being infringed upon by these or other required elements in the median.
- **Width of buffer and buffer separation**—A lateral position study (*67*) yielded the observation that managed lane drivers shifted away from the pylons placed in the buffer; however, a wider buffer can offset the impacts on lateral position.



[1] HOV envelopes in one direction over 6.7 m (22 ft) may invite passing. A full breakdown shoulder is not provided although vehicles can still maneuver around disabled vehicles. Enforcement of this facility is performed at the ends and access locations.

[2] Operational treatments should be incorporated if the minimum design cross sections are used. The minimum cross section should be used as an interim project or over short distances. Increased enforcement and incident management programs should be implemented to successfully operate the facility.

[3] The width of this cross section provides the minimum space required for a bus to pass a disabled bus at slow speed.

[4] Shared median minimum cross section should only be used for two-way ramps, short connector sections, low-volume HOV lanes, or other lower speed facilities.

Source: Adapted from AASHTO (*6*), Figure 3-3.

Figure 29. Examples of cross sections for barrier-separated, two-way HOV lane facilities.

In addition to the cross-section elements described in the previous list, there are additional design elements that are also considered in context as the design of the managed lane facility is developed. A selection of those elements and their effects on managed lane operations are listed below:

- **Horizontal alignment**—The radius of horizontal curvature used in a particular roadway design is a function of design speed, rate of superelevation, and side friction with practical limits due to right-of-way constraints (*6*). As design speed increases and the rate of superelevation decreases, the minimum radius of horizontal curvature required increases. Horizontal and vertical alignment should not be designed independently. A lateral position study (*67*) showed that horizontal alignment (tangent or curve) and direction of the horizontal curve (left or right) were influential on lateral position. The impact on lateral position was greater within the minimal values for shoulder, lane, and buffer widths. Drivers were closer to the left edgeline when on a curve to the left and farther from the left edgeline when on a curve to the right depending on assumed shoulder, lane, and buffer widths.
- **Vertical alignment**—Basing the minimum lengths of crest vertical curves (and the rate of vertical curvature) on

stopping sight distance criteria is usually sufficient from the viewpoint of comfort and appearance. For sag curves, the use of the stopping sight distance criteria for establishing minimum rates of vertical curvature is recommended. Horizontal and vertical alignment should not be designed independently (*6*).

- **Superelevation**—As with other facilities, the rate of superelevation used in a particular roadway design will be a function of design speed, radius of curvature, and side friction with practical limits based on driver comfort, safety, climate, and local agency guidelines. As design speed increases and radius of curve decreases, the need for superelevation increases. In an urban environment, a maximum superelevation rate (e_{max}) of 4% to 6% is common practice, but the applicable state design manual should be consulted to confirm what is expected for a particular location. Superelevations are typically projected for managed lane widenings. These projections can result in bridge structure conflicts where the resulting vertical clearance on the low end of the projection is compromised. In most cases the widening is modest enough that different structural approaches (such as box beams instead of "I" beams) are employed to hold the vertical clearance constant.
- **Horizontal clearance**—For facilities within other freeways, the horizontal clearance may be affected by right-of-way constraints, but it should be sufficient to prevent the design vehicle from colliding with signs, guardrails, and other roadside apparatus. For stand-alone facilities, the guidelines in the AASHTO *Roadside Design Guide* (*68*) for freeways are applicable.
- **Vertical clearance**—The appropriate vertical clearance depends on the design vehicle. The facility should have the necessary vertical clearance for the design vehicle to pass under toll gantries, sign bridges, and overpasses without striking them. It is recommended that for facilities within other freeways, the vertical clearance provided be the same as that provided on the general-purpose facility. The AASHTO HOV Guide (*6*) and the AASHTO Green Book (*27*) state that desirable clearance is 16 ft. Where this would be cost prohibitive in highly developed urban areas with existing structures, existing clearances may be allowed; the Green Book states that a minimum clearance of 14 ft may be used if there is an alternate freeway facility with the 16-ft clearance. Allowance should be made for future resurfacing, and additional clearance should be provided to structures with lesser resistance to impacts (e.g., sign trusses, pedestrian overpasses, and cross-bracing of through-truss structures); vertical clearance for these structures should be 17 ft or, on urban routes with less than 16-ft clearance, 1 ft more than the minimum clearance for other structures.
- **Cross-slope and drainage**—The cross-slope of a managed lane should generally follow the adjacent freeway, which is commonly 2%. However, adding managed lane facilities always expands the drainage run-off unless the prior space constituted a shoulder with impermeable surface. The added drainage caused by a longer crossfall presents a challenge to designers. Some states allow for extending the crossfall and adding specialized drainage treatments on the right (such as trench drains at ramp tapers), while others prefer to reverse the crossfall to the median barrier and break it in the middle of the managed lane or in the buffer area. In a few instances, supplemental drainage is placed in a wide buffer between parallel concurrent roadways, or barriers are employed with drainage provisions. Reversing cross-slope (i.e., creating a cross-slope break of greater than 4%) except along extremely wide buffer or barrier alignments is not desirable because it can affect driver expectations when crossing the buffer at designated access points and possibly degrade operational performance and safety. The AASHTO Green Book indicates that for intense rainfall areas, the cross-slope can be increased to 2.5%, resulting in a crossfall break of 5%. For a barrier-separated facility, drainage design under the barrier depends on the number of general-purpose lanes, cross-slope, and superelevation transitions to minimize hydroplaning. Shoulders should have a cross-slope at least 1% steeper than the adjacent travel lanes. Paved shoulders typically have a cross-slope between 2% and 6%. The Green Book indicates that the algebraic difference between the cross-slopes of a traveled lane and the adjacent shoulder should be below 8% at all points along the facility (*27*).

Each decision about cross section needs to be considered in the context of the other design elements and its potential effects on safety, operations, and maintenance. Table 5 describes some of the advantages and disadvantages to changes in cross section that should be considered; the designer should have an appreciation for the specific effects of cross-section changes that apply to a particular facility during the design process, and developing a list similar to Table 5 could be beneficial in that process.

Operational Effects of Cross Section for Weather Events, Special Events, Enforcement, and Maintenance

In addition to the items mentioned in the previous section, the effects of cross section on operations during maintenance activities—whether scheduled or due to special events, particularly weather events—must be considered. Additional discussion on some of these effects can be found

Table 5. Pros and cons of managed lane facility cross-section trade-offs.

Design Element	Pros	Cons
12-ft travel lane	• Matches typical guideline for general-purpose travel lanes on freeways • Ample for accommodation of buses and trucks	• May be difficult to achieve in a retrofit without taking width from other elements in the managed lane or general-purpose facilities
12-ft shoulder	• Matches typical guideline for general-purpose travel lanes on freeways • Provides refuge space for disabled vehicles • Provides space for enforcement activities • Provides space for temporary storage of snow removed from the travel lane • Provides option for throughput during incidents in the travel lane	• May be difficult to achieve in a retrofit without taking width from other elements in the managed lane or general-purpose facilities
11-ft travel lane	• Easier to provide in a retrofit than 12-ft lane, though there are safety trade-offs • May be acceptable if associated with a wider buffer	• Narrower than typical freeway lane • Less-than-minimum width in some guidelines; not always allowed or recommended • Associated with higher number of crashes (*23*)
10- or 11-ft shoulder	• Can accommodate passenger vehicles and most heavy vehicles • Easier to provide in a retrofit than 12-ft shoulder	• Narrower than typical freeway shoulder • Reduces the available space to store and/or attend to disabled vehicles and to store snow • Restricts ability of enforcement officers to conduct activities outside of the travel lane
8- to 9-ft shoulder	• Can accommodate most passenger vehicles • Easier to provide in a retrofit than 12-ft shoulder	• Not suitable for heavy vehicles • Very restrictive for refuge and enforcement • Minimizes usefulness in snow storage and incident management
Shoulder less than 8 ft	• Provides a measure of lateral clearance for drivers compared to no shoulder	• Not suitable for heavy vehicles • Not wide enough to store a passenger vehicle without encroaching on the travel lane • Not suitable for maintenance, enforcement, snow storage, or incident management • Can restrict sight distance in curves • Associated with higher number of crashes (*23*)
4-ft or wider buffer	• Provides separation between managed lanes and general-purpose lanes • Provides additional accommodation for vehicles to shift laterally within the lane in horizontal curves	• May be difficult to achieve in a retrofit without taking width from other elements in the managed lane or general-purpose facilities • Depending on width, may be seen as an additional travel lane for passenger vehicles or motorcycles without additional delineation or separation devices
Buffer less than 4 ft	• Provides a measure of separation between managed lanes and general-purpose lanes • Easier to provide in a retrofit than a wider buffer	• Reduces distance between traffic streams that could be traveling at greatly different speeds • May not be allowed in some jurisdictions

Source: Texas A&M Transportation Institute (TTI).

in their own respective sections of this and other chapters, but a selection of items are compiled here to provide examples of operations that can be affected by reduced lane or shoulder widths:

- Any hardware or equipment placed in the median (where there is no full-width shoulder or built-in maintenance access) or overhead will require lane closures for access to complete maintenance, which equates to a loss of operational time, particularly as the equipment ages (for more information, see the section later in this chapter on providing for associated equipment and devices).
- Reduced lane widths next to narrow or non-existent shoulders could reduce or eliminate the potential for enforcement activities (see the section on enforcement pullouts elsewhere in this chapter).
- Minimal or non-existent shoulders can negatively affect sight distance in curves, which can affect crash rate, crash frequency, and operational time of the managed lane, as well as operations in the adjacent general-purpose lane (see the discussion on characteristics of large design vehicles elsewhere in this chapter).
- Narrow shoulders will also create a higher potential for closure due to flooding, snow melt, and icing, particularly on barrier-separated or pylon-separated facilities that prevent moving the water or snow to a non-traveled portion of the right-of-way. Narrow shoulders limit their capability for storing snow removed from the travel lanes, which affects

operating conditions on the facility (see sections on buffer separation, pylon separation, and emergency refuge areas, as well as Table 5).

- In areas where managed lanes are in use all day with high volumes, there may not be an off-peak for maintenance and reconstruction. With narrow lanes and shoulders, maintenance on such facilities would require closures for sweeping, patching surfaces, applying pavement markings, and performing other scheduled maintenance activities.

Managed Lane Orientation with Respect to General-Purpose Lanes

The AASHTO *Guide for High-Occupancy Vehicle Facilities* (*6*) contains guidance on the placement or location of an HOV facility with respect to general-purpose lanes (or main lanes). Many of the principles described in the AASHTO HOV Guide may apply to other types of managed lane facilities and are discussed here along with other guidance applicable to managed lanes in general.

Location of Managed Lanes with Respect to Median

Locating managed lanes next to the median or median barrier of a freeway is the most common practice, found in an estimated 95% of existing facilities (*6*). Managed lanes located next to the median have a variety of alternative cross sections, whether it is the type of separation used between the managed lanes and general-purpose lanes or the way in which traffic is assigned to the managed lanes themselves.

Facilities constructed next to the median are within the freeway right-of-way and are separated from the general-purpose freeway lanes by either barriers or buffers (with and without pylons) or by broken- or solid-line pavement markings (see Chapter 4 for more details on separation pavement markings). Barrier-separated facilities may be two-way facilities (i.e., the facility operates in two directions all the time) or reversible facilities (i.e., the facility operates inbound toward the central business district or other major activity center in the morning and outbound in the afternoon). Facilities not physically separated from the general-purpose traffic lanes (i.e., separated only by pavement markings or buffers, with or without pylons, with lanes operating in the same direction as general-purpose traffic) are described as concurrent flow lanes (*6*).

Managed lanes adjacent to the median may be open for all or a portion of a day. Further discussion of separation treatments is provided elsewhere in this chapter.

Part-Time Shoulder Use

Part-time shoulder use (also called hard shoulder running or dynamic shoulder use) is a specific type of managed lane strategy where a shoulder (usually, but not always, the right shoulder of the freeway) is temporarily used as a conditional travel lane, typically during peak travel times and/or in response to incidents or other conditions.

Several components need to be considered when implementing part-time shoulder use:

- Operating conditions must be established and clearly communicated for determining when the shoulder will be opened and closed to traffic (e.g., time of day, level of service) and what kind of traffic will be allowed (e.g., buses only, passenger cars only).
- The operations plan must have provisions for accommodating traffic at freeway access points (i.e., entrance and exit ramps) so that entering and exiting traffic can complete their access maneuvers.
- The shoulder must have sufficient lateral (i.e., horizontal) clearance so that roadside apparatus (e.g., signs, guardrails) are not struck by vehicles traveling on the shoulder. If the available lateral clearance is less than applicable state or local guidelines require, consideration must be given to approving variances or making other accommodations.
- The shoulder must be sufficiently strong to withstand the impacts of the increased level of traffic, particularly if buses are considered as eligible users.
- Emergency refuge areas, or pullouts, must be planned so that disabled vehicles and emergency responders have a place outside of the traveled way to stop.

Traditionally, part-time shoulder use has been a strategy used in Europe (*69*), and there is an increasing number of applications in the United States. Minnesota and Virginia are two states with some of the earliest applications of part-time shoulder use in the United States, and guidance for implementing part-time shoulder use in other locations was underway at the time these guidelines were written. Practitioners are encouraged to review the forthcoming *Guidebook on Planning and Evaluating Active Traffic Management Strategies* from NCHRP Project 3-114 or FHWA's *Use of Freeway Shoulders for Travel* (*70*) for more information on part-time shoulder use.

Contraflow Lanes

Another strategy is the use of contraflow lanes, whereby a freeway lane in the off-peak direction of travel is reconfigured to allow use by eligible vehicles traveling in the peak direction. The lane is physically separated by movable concrete barriers or pylons from the off-peak-direction general-purpose lanes. Existing freeway contraflow lanes use the off-peak median general-purpose lane, and they operate only during the peak periods. Some operate only during the morning peak period. During other times of the day, the lanes revert to normal use in the direction of travel of the general-purpose lanes. Some contraflow lanes are open to buses only, and others are open to buses and HOVs (*6*). When developing contraflow lanes, it is important to consider the peak-hour directional split to ensure that sufficient capacity is available in the off-peak direction to allow one lane from the off-peak direction to be shifted to the peak direction without creating congestion in the off-peak direction.

Separation Between Managed Lane and General-Purpose Lanes

There are multiple ways to provide separation between managed lanes and the general-purpose lanes of a freeway. Each approach reflects different operational goals and needs. While all can be effective, the selection of separation type should take into account the design setting, business rules, design vehicles, and level of anticipated demand. Barriers, buffers, pylons, pavement markings, and separate facilities are all used, and some facilities may have a combination of separation types (e.g., a mixture of buffer separation and pavement marking separation where cross section is limited). Each option has its own potential advantages and disadvantages, and these should be considered early in the design of the managed lane facility to determine which treatment is best suited for that location. Each option is discussed in some detail herein, and Table 6 provides an overview of the operational impacts.

Barrier Separation

Concrete barrier separation provides the most positive separation between managed lanes and general-purpose lanes (see Figure 30), which makes it the easiest to enforce among managed lane facilities. It also leads to the fewest opportunities for crashes between vehicles in the managed lanes and vehicles in the general-purpose lanes because access is physically limited. Barriers mitigate the potential negative effects of speed differential between parallel traffic streams, so higher speeds can be sustained in the managed lanes regardless of conditions in the general-purpose lanes, and reliability is greater than for non-separated designs. Movable barriers also provide flexibility for reversible lanes, allowing lane balance to shift over time as the demand changes.

Barrier separation is the most costly of separation treatments because of the need for duplicate shoulders as well as the additional width of the barrier. It is also the least flexible treatment, with changes to access points for the managed lanes being the most difficult change. Sufficient shoulder width must be provided within the managed lane envelope to accommodate an emergency situation, a disabled vehicle, or other special event. For this reason, a barrier-separated facility should have sufficient shoulder width and preferably two travel lanes or a total clear width (i.e., envelope width) of at

Table 6. Operational impacts of separation options.

Separation Option	Potential Advantages	Potential Disadvantages
Barrier (concrete)	• Facilitates reversible lane • Physical separation from general-purpose lanes • Easier to enforce compliance	• Users have feeling of confinement following a crash or incident • No way out unless removable rail or gates are installed, which can be an issue in the event of a crash or other mishap
Buffer	• Inexpensive relative to other separation options • Vehicles have a way out • Drivers can more comfortably position their vehicle within the managed lane with respect to the median barrier	• Possible operational or safety issues due to increased number of access points • Extra right-of-way requirements
Pylons (flexible delineators)	• Less expensive than concrete barrier • Provides visible separation • Easy to remove • Provides a way out	• Frequent maintenance/replacement • Safety concerns due to vehicles able to drive through delineators • Possible flying hazard when hit by vehicles at speed
No buffer (pavement markings only)	• Inexpensive relative to other separation options • Vehicles have a way out • Easy to remove • Easy to install	• Safety and enforcement issues due to vehicles entering and exiting at numerous locations
Separate roadway facility (alongside or outside right-of-way, or elevated/depressed around general-purpose lanes)	• Can be designed to desirable dimensions, requiring fewer design exceptions • Easier enforcement • Highest potential operational performance	• Lengthy construction time • Must fit available right-of-way • More difficult for emergency access • Expensive • Limited and expensive to access

Source: Adapted from Sas et al. (*71*).

Source: Kay Fitzpatrick.

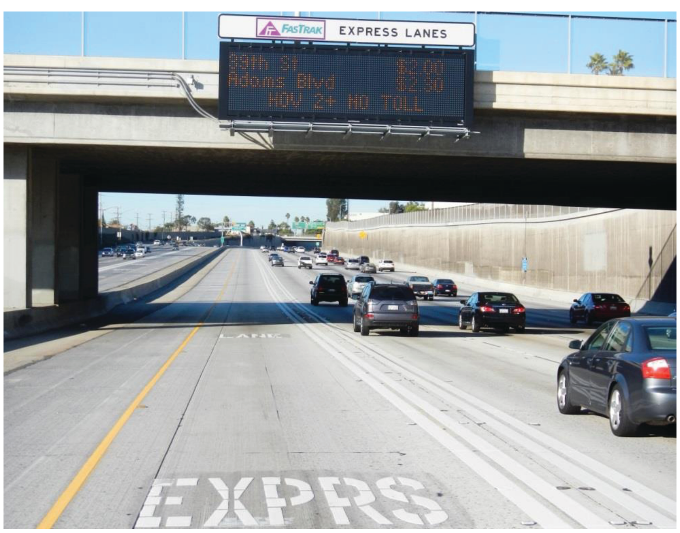
Figure 30. Example of barrier-separated managed lane on I-25 in Denver, Colorado.

least 20 ft (*71*) so that the design can accommodate two side-by-side vehicles in case of crashes or other incidents.

Buffer Separation

A buffer is a physical space between managed lanes and general-purpose lanes operating in the same direction that provides separation without a barrier. A buffer is defined by pavement markings to provide guidance to the driver (see Figure 31), and access points are defined by changes in those markings. Buffers promote more efficient traffic flow where travel speed differentials in adjacent lanes can be substantial but where a barrier is not a practical or desired solution. Buffers are less costly than barriers; however, depending on the width of the buffer provided, they may require additional right-of-way. A 4-ft buffer is commonly recommended (*6, 72*), though wider buffers can sometimes provide additional benefits in terms of drainage, snow storage, capability to expand the number of lanes in the future, and visual separation. However, a buffer that is too wide may encourage drivers to use it as an additional travel lane. Conversely, 2-ft buffers have been used in some locales and can still provide a measure of separation where a wider buffer is not possible due to cross-section constraints (*67*).

A consideration with buffer separation is the provision of access to and from the managed lane facility. If access is continuous, then the pavement markings must reflect that, and the buffer needs to incorporate broken striping to facilitate ingress and egress. If access is limited to certain locations, the buffer will involve solid and dashed striping to provide at-grade access to and from the managed lanes. Consideration must be given to enforcement for a buffer-separated facility with limited access because, with no physical barrier, drivers may attempt to drive through the buffer to access the managed lane regardless of pavement markings. Similarly, crashes involving vehicles entering and leaving the managed lane should be considered when designing access openings; openings should be provided where they will be most beneficial to users for access to and from the managed lanes, but openings should not be provided in locations with high weaving volumes if they lead to an increase in crashes.



Source: Darren Henderson.

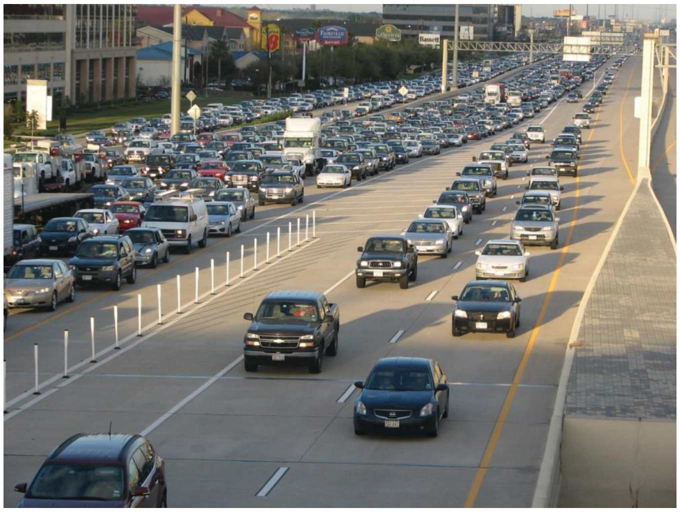
Figure 31. Example of buffer-separated managed lane on I-110 in Gardena, California.

Pylon Separation

Pylons (also called flexible delineators or tubular markers) are a supplemental separation device used in a buffer to provide additional physical and visual separation (see Figure 32). Pylons can help deter managed lane violations and restrict access, but they do not have the same physical separation as barriers.

There are differing opinions on the benefits, related to the cost, of the use of pylons versus the use of concrete barriers or other forms of separation. The true benefits of pylon access are difficult to assess due to the limited amount of data and difficulty in collecting the data to complete a comprehensive and conclusive evaluation. However, studies have shown that pylon maintenance and replacement can be costly, particularly when buffers are narrow (*73*). Some of the other benefits and disadvantages attributed to the use of pylons and concrete barriers include the following:

- Pylon benefits:
  - Incident management access—pylons are mountable/passable.
  - Emergency vehicle access—pylons are mountable/passable.
  - Lower initial cost.



Source: Marcus Brewer.

Figure 32. Example of pylons separating managed lanes from general-purpose lanes on the Katy Freeway (I-10) in Houston, Texas.

  – Sight distance improvement—no wall obstruction is present.
- Pylon disadvantages:
  – Ability of motorists to travel from general-purpose to managed lanes (or vice versa) in attempts to increase speed or avoid toll readers or managed lane enforcement by driving through the pylons.
  – Maintenance cost for repair/replacement of pylons.
  – Exposure of maintenance staff and contractors to moving traffic during maintenance activities.
  – Traffic control cost to accommodate maintenance activities (depending on buffer width).

Another consideration for the use of pylons is that, compared to barrier-separated facilities, a crash that occurs on the facility is more likely to affect traffic in both the managed lanes and general-purpose lanes. Pylons also introduce a potential obstacle in snow-plowing and road-sweeping operations. Therefore, the decision to use pylons for managed lane separation should be made with consideration of the expected maintenance cost and in conjunction with other factors that influence maintenance and operations.

When an agency determines that pylons may be a suitable device to provide lane separation for a managed lane facility, the agency needs to consider several aspects of these devices in order to implement them in the most efficient manner (*74*):

- Curb-mounted vs. pavement-mounted pylons (curbs can offer more barrier-like features but can increase maintenance costs).
- Longitudinal spacing (a minimum of 10 ft is recommended, though that length can be increased on tangents with unrestricted sight distance and where strict enforcement is regularly provided; spacing that is too large can encourage drivers to change lanes between pylons).
- Wider buffers (particularly on curves, but avoiding buffer widths that place pylons 4 to 8 ft from the edge of the travel lane because those widths may encourage drivers to stop in the buffer with insufficient space to safely attend to their vehicles).
- Pylon height [the 2009 MUTCD (*1*) specifies a minimum height of 28 in., but pylons that are too tall may be less durable when struck by vehicles].
- Running length (pylons should be used to restrict access where access is not desired, but the effective weaving area at access openings should be checked to ensure that the length of the pylons does not decrease the minimum required weaving distance given traffic volumes and speeds).
- Color and retroreflectivity (the designer should consult the MUTCD for appropriate specifications, such as using pylons that are the same color as the pavement markings they supplement).

In addition to the standards and guidelines provided by the MUTCD, some states and facility operators have their own requirements. There is not necessarily a definite value for minimum buffer width to use pylons; some projects have applied pylons in a 2-ft width, while other practitioners do not use pylons in buffers less than 4 ft in width (*67*). The California MUTCD describes characteristics of supplemental channelizing devices in Chapter 3H (*75*) for use on roadways in that state. For more discussion on these and other traffic control devices, refer to Chapter 4.

No Separation (Pavement Markings Only)

For the most constrained rights-of-way and for projects that only operate during peak periods and revert to general-purpose operation at other times, the separation between managed and general-purpose lanes may be only a single-lane line pavement marking (see Figure 33). At a minimum, the separation needs to be a pavement marking that is wider than a typical lane line. While this treatment is the least costly option for separation, it is also the least restrictive and may be hardest to enforce when compared to other options. For tolling purposes, it may require more frequent toll readers to be installed. A single pavement marking may still distinguish an access-restricted design, but drivers may attempt to access the managed lane regardless of pavement markings.

Reversible Lanes

Reversible lanes provide a managed lane treatment that can benefit a corridor with high directional splits

Source: Darren Henderson.

Figure 33. Example of pavement marking separation on Arizona Loop 202 in Maricopa County, Arizona.

Source: TTI.

Figure 34. Reversible lanes on I-35E/US-67 in Dallas, Texas.

where significant peak-direction volumes can be collected and distributed to other roadways. With this treatment, barrier-separated travel lanes are assigned to one direction of travel during a peak period (e.g., inbound traffic during the morning peak) and then reassigned to the opposite direction at a different time (e.g., outbound traffic during the evening peak). Reversible lanes often operate in the median and are separated from adjacent oncoming traffic by permanently placed barriers and channelized ramps. Reversible designs can accommodate single or multiple travel lanes. A variety of cross sections are common to both.

Positive control, usually in the form of a gate cushion capable of stopping freeway-speed vehicles, is essential to prevent wrong-way movements. Such vehicle-arresting barriers are a last resort to prevent wrong-way movements, and vehicles hitting these barriers are absorbed by a wire mesh so that extensive damage is avoided. This barrier should be preceded by a series of breakaway gates to alert even impaired drivers of the wrong-way movement prior to striking the final barrier. Chapter 4 provides more details on gates and positive control in the section on traffic control devices for reversible lanes.

An example of a reversible-lane facility serving HOVs is the I-35E/US-67 corridor south of downtown Dallas, Texas (see Figure 34). Access is limited to a few selected points.

Several components need to be included for reversible-lane implementation:

- The design vehicle will influence access and width (e.g., buses only, passenger cars only).
- A variety of traffic control devices including barricades, gates, and dynamic signs must be used at access points to communicate direction of flow and prevent unauthorized or wrong-way entry.
- The lanes must be separated by barriers from the adjacent lanes to minimize conflicts, and use of other types of separation must take into account the necessity of avoiding head-on collisions.

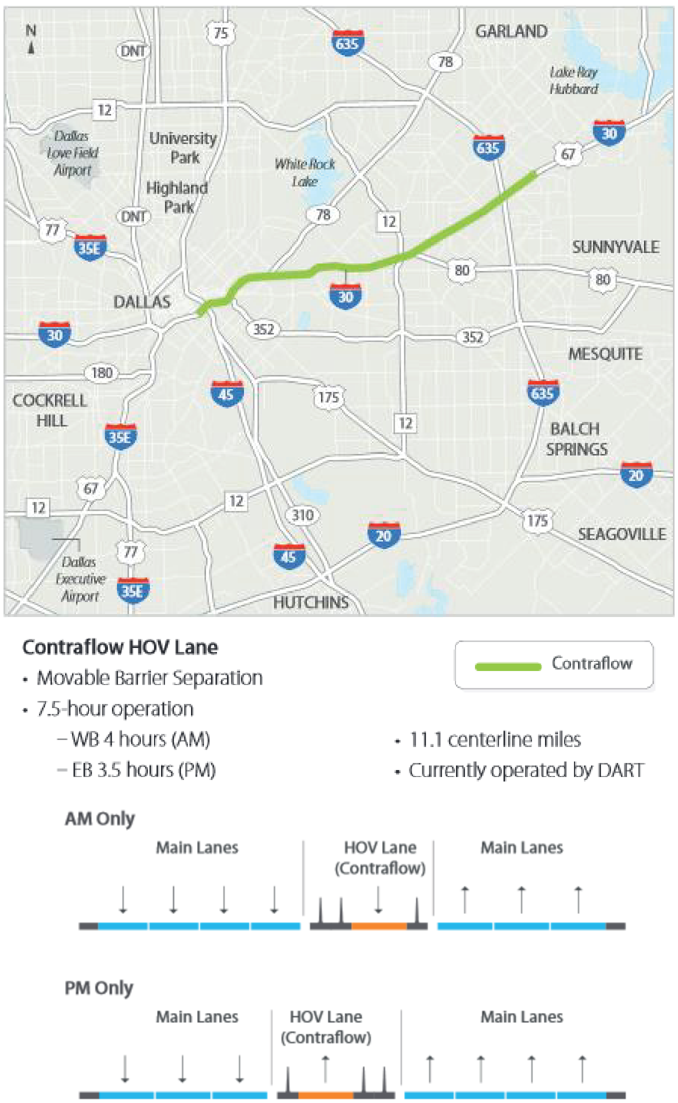
Contraflow Lanes

Contraflow lanes may be designed in two ways: (a) movable barriers or (b) portable pylon separation. In the 1980s, all contraflow operations on freeways employed placement of pylons in pre-drilled holes in the pavement. Spacing for pylons was about 20 ft, dropping to 10 ft at crossover transitions where they terminated. Proprietary technology for moving concrete barriers subsequently replaced some pylon treatments in such projects as the Long Island Expressway project in Queens and the Gowanus Expressway project in Brooklyn. However, some projects have such narrow pavement widths that pylon placement is still practiced, including the SR-495 project in northern New Jersey. Both approaches require a heavy investment in deployment crews who must place barriers or pylons before and after each operation period. This process requires specialized equipment, provisions for storing the equipment (often in the highway median), and extensive consideration of the safest design of the facility. The movable barriers provide the freeway corridor with added flexibility to provide capacity in the direction of travel that needs it most.

An example of such a facility is the I-30 corridor east of downtown Dallas, Texas (see Figure 35). The managed lanes operate as HOV lanes and are barrier separated to form their own corridor within the freeway. Access is limited to a few selected points.

Several components need to be included in contraflow implementation:

- There must be a way to store the barrier and barrier-moving equipment in the median and a safe way of implementing crossovers to allow peak-direction traffic to enter and exit the lane. The kind of traffic that will be allowed (e.g., buses only, passenger cars only) becomes a driving principle in the design.



Source: TxDOT (*76*).

Figure 35. Contraflow lanes on I-30 in Dallas.

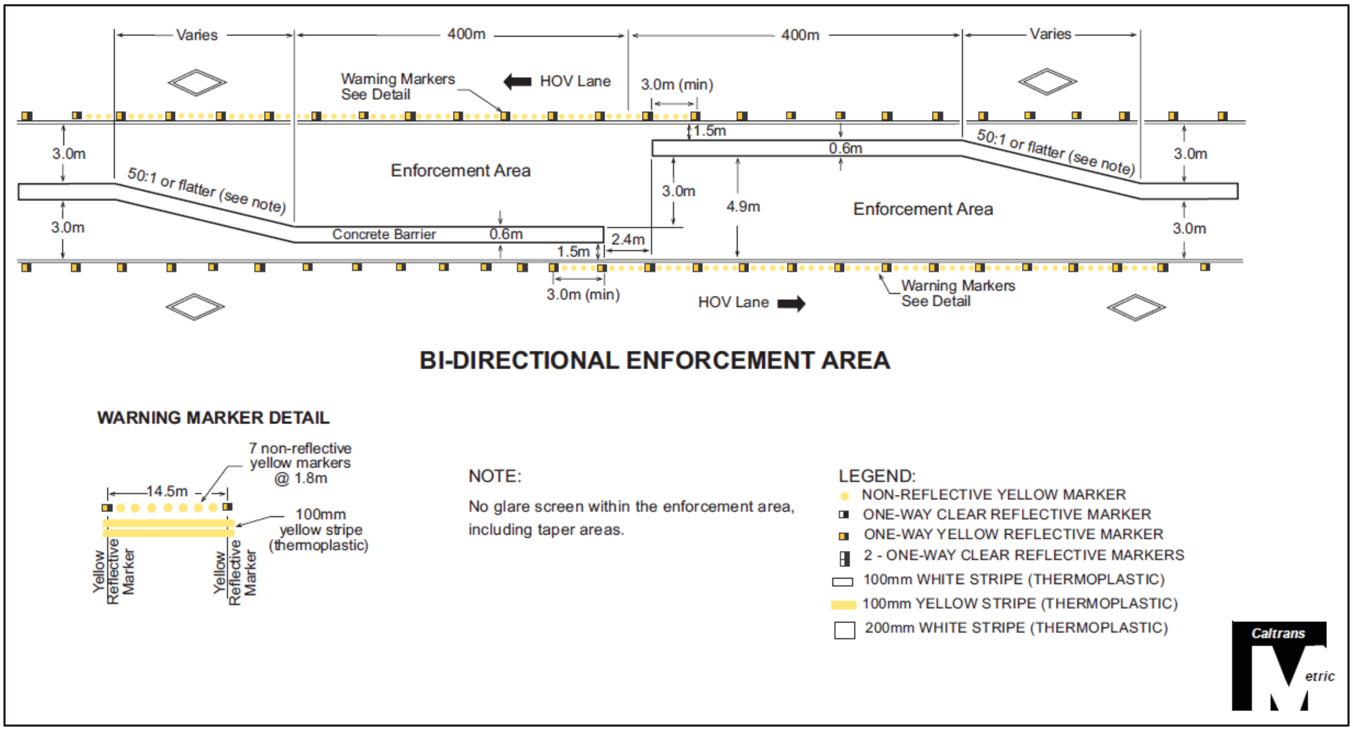
- Barricades or other treatments must be used at access points to prevent unauthorized or wrong-way entry during non-operating periods.
- There must be sufficient difference in directional split to borrow a general-purpose lane without creating congestion at the times contraflow operation is taking place.
- There must be a defined protocol for how and when to move the barrier to prevent disruptions in traffic and minimize the potential for conflicts and crashes.

Pullouts—Enforcement

With the vehicle restrictions that are inherent to managed lane facilities, enforcement is necessary to ensure that only authorized vehicles are using the facility. Managed lane restrictions are in addition to traditional traffic violations (e.g., speeding, reckless driving) that must also be addressed. Enforcement is best performed without the need for field presence such as systems that manage toll evaders, but some on-site enforcement presence is still a requirement to manage various types of violations to operation rules. As a result, enforcement officers need accommodation to safely perform their field enforcement duties within the managed lane facility. A treatment that can provide these benefits, particularly in constrained rights-of-way, is an enforcement monitoring and pullout area. These are paved areas, typically in the median, that allow emergency vehicles to park within them, separating them from adjacent traffic.

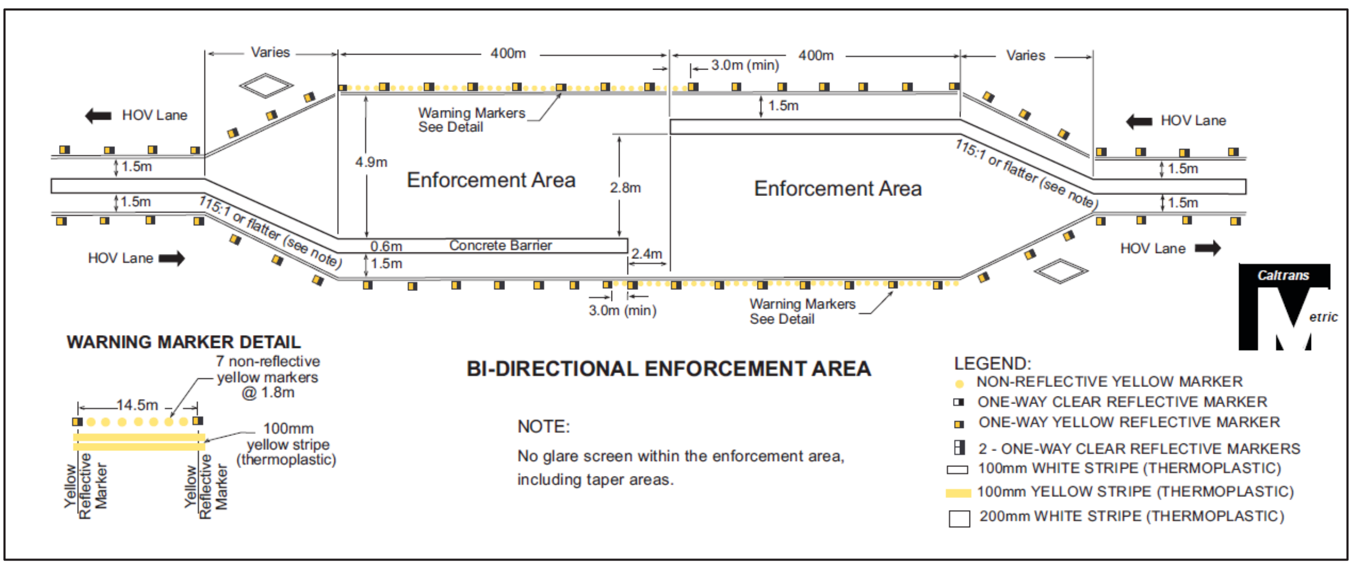
Some states provide guidance on the design and placement of enforcement pullouts; more details can be found elsewhere in this chapter. In general, though, pullouts should be considered at regular intervals in facilities that do not have adequate shoulder width to store a vehicle outside of the travel lane. California (*53*) and Washington (*55*) guidelines recommend enforcement areas be located at intervals of 1 to 3 mi. For median-located managed lane facilities, the pullouts should also be located in the median. For part-time shoulder use facilities or stand-alone facilities, roadside pullouts would be more appropriate. Pullouts may also be provided on exit ramps if right-of-way is unavailable within the freeway corridor.

When designing pullouts, the designer must include sufficient width to allow storage of the vehicles using the pullout, along with additional width to allow enforcement officers, emergency responders, and others to walk outside their vehicles without having to enter the adjacent travel lane. California (*53*) calls for a 23-ft (7.0-m) width for its median enforcement areas. Pullouts must also be designed with sufficient length to allow proper acceleration and deceleration for vehicles entering and exiting. California (*53*) and Washington (*55*) guidelines have lengths of 1300 ft for their enforcement pullouts (Washington allows a minimum of 1000 ft) in addition to the entry and exit taper lengths. Examples of bi-directional median enforcement areas found in California are shown in Figure 36 (for median widths of at least 23 ft) and Figure 37 (for median widths of less



Source: Caltrans (*53*). This figure is solely intended for use in the California Department of Transportation's ("Caltrans") High-Occupancy Vehicle Guidelines as examples of high-occupancy vehicle lanes used within California. It is neither intended as, nor does it establish, a legal standard for use in other environments. The figure is for the information and guidance of the officers and employees of Caltrans. The figure is not a substitute for engineering knowledge, experience, or judgment. The examples given herein are subject to amendment as conditions and experience may warrant. Copyright 2003 California Department of Transportation, all rights reserved.

Figure 36. Bi-directional enforcement area for wide median.



Source: Caltrans (*53*). This figure is solely intended for use in the California Department of Transportation's ("Caltrans") High-Occupancy Vehicle Guidelines as examples of high-occupancy vehicle lanes used within California. It is neither intended as, nor does it establish, a legal standard for use in other environments. The figure is for the information and guidance of the officers and employees of Caltrans. The figure is not a substitute for engineering knowledge, experience, or judgment. The examples given herein are subject to amendment as conditions and experience may warrant. Copyright 2003 California Department of Transportation, all rights reserved.

Figure 37. Bi-directional enforcement area for narrow median.

than 23 ft). The design of a pullout may also serve to provide maintenance access to toll system and ITS components.

The primary type of managed lanes rules infraction that enforcement officers confront is occupancy violations, which requires them to see inside a vehicle and to be able to count the number of occupants. Good lighting and a safe vantage point are needed to perform these enforcement functions. Enforcement areas should not be placed under bridges to ensure the safety of enforcement personnel (*54*).

Figure 38 shows a recent design applied to improve visibility over the above design and to serve primarily as an enforcement monitoring platform to observe toll compliance when free HOVs are allowed. This design allows officers to see over the median barrier and is placed so that toll beacons are visible from the raised parking area. The design also includes barrier overlap to protect law enforcement vehicles from being struck. This design must provide enough space between the barriers for a vehicle to maneuver in and out and for the officer to enter and exit the vehicle.

Pullouts—Refuge

On corridors with narrow lanes and corridors where part-time shoulder use is permitted (i.e., where essentially the full roadway width is used as travel lanes), disabled vehicles can effectively render one or more travel lanes unusable and thereby reduce the effectiveness of the managed lanes. In these situations, provision needs to be made for disabled vehicles to be removed from the travel lanes.

Figure 39 illustrates an emergency refuge area (ERA) in England, and Figure 40 shows an approach to an emergency refuge area from the perspective of the driver. Along the M42 motorway in England, ERAs are located approximately every 500 m and include emergency roadside telephones. The telephones are accessible to wheelchair users, located behind safety fencing, and feature text messaging and eight different languages of verbal assistance (*77*).

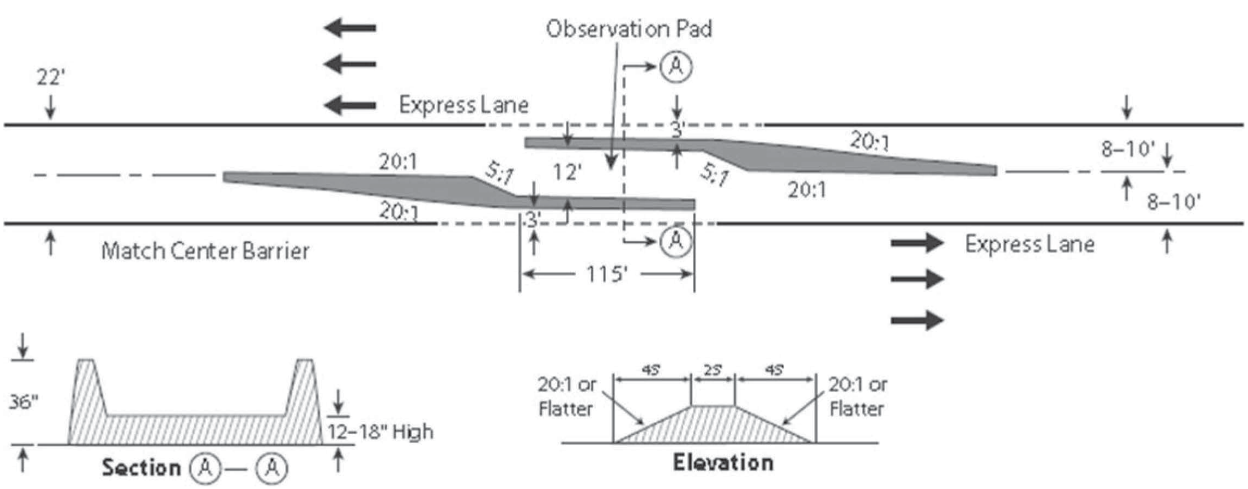
Pullouts for enforcement are more common than refuge pullouts at many existing facilities because vehicle eligibility enforcement is a key feature in HOV and HOT facilities, though pullouts have been used as early as the 1970s (see Figure 41). However, provision for disabled vehicles should be considered when sufficient shoulder width cannot be provided continuously along the length of the corridor.

Pullouts may also be provided on exit ramps if right-of-way is unavailable within the freeway corridor, but ramp pullouts are less useful for refuge purposes because the greatest need may be for vehicles that cannot travel to the next ramp but still need to be removed from the travel lane.

Geometric requirements for refuge pullouts have similarities to enforcement pullouts in that they need to be wide enough to store the disabled vehicle and still allow drivers or service providers to walk around the vehicle and assess its needs. Refuge pullouts also need to have sufficient length to allow storage of at least two vehicles (e.g., the disabled vehicle and a service vehicle or tow truck) in their full width plus accommodation to allow proper acceleration and deceleration for vehicles using the pullouts. With regard to the design of ERAs in England (*77*), the entrance taper is 82 ft (25 m), the parking length is 98 ft (30 m), and the exit taper is 148 ft (45 m).

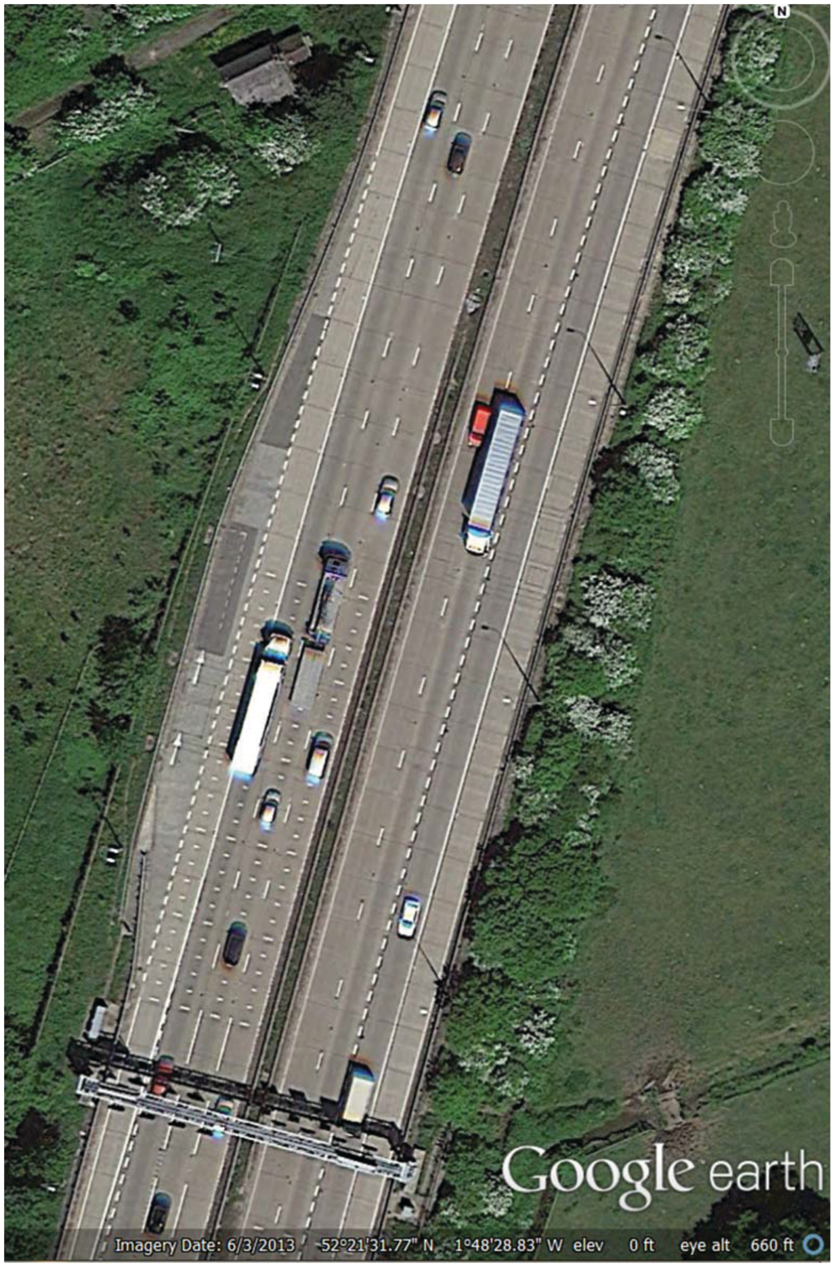
Issues Unique to HOV Lane Conversion into HOT Lane

As needs change over time, an HOV lane operator may determine that a different kind of managed lane facility is preferable and convert that HOV lane into a facility that is more suitable. This section provides guidance on issues that



Source: Adapted from Caltrans project plan sheet.

Figure 38. Enforcement monitoring area with elevated platform for improved visibility.



Source: Google Earth™.

Figure 39. Example of emergency refuge area with hard shoulder in England.

are unique to converting an existing HOV lane into a HOT lane. Some of the guidelines described herein may also be applicable for conversions to other types of managed lanes, but the designer should use strategies most appropriate for the specific type of managed lane being considered.

General Design Considerations

When pricing is added to HOV lanes, many other operational changes may also occur that are reflected in design changes, for example:

- Changing signing and pavement markings.
- Changing or restricting access, and adding weave lanes or other means of accommodating changes in demand.
- Enhancing design treatments that help enforcement.
- Modifying utilities—providing power to tolling equipment and telecommunications to the back office.
- Reconfiguring project limits and transitions/termini.
- Providing maintenance access.

When this is the case, trade-offs need to be assessed on an individual basis. Illustrations of key elements in the design of

Source: Beverly Kuhn.

Figure 40. Driver's view of approach to emergency refuge area in England.

a HOT lane are provided in Figure 42 as an example and are discussed in the following sections.

Accommodating Toll Collection in Existing Cross Section

For an HOV facility that is being converted to a HOT facility, the appropriate elements needed for toll collection must be installed along the corridor. As with the consideration of additional travel lanes, the cross section must be sufficient to accommodate substructure and superstructure including system hardware without infringing on the travel lanes or increasing the potential for crashes. In particular, the design should accommodate the potential for both toll readers and cameras, which are increasingly located on the same gantry assembly. The horizontal clearance, especially in the median for median-located facilities, should be such that anticipated users can drive past gantries without deviating from the travel way; similarly, the vertical clearance must be generous enough that the truck or bus traffic will be able to safely pass underneath gantries or other toll collection hardware. Additional post-mounted and/or overhead signs associated with toll collection must be similarly accommodated. Many projects are moving toward multiple toll zones employing multiple readers. The gantry assembly for a toll reader may be as simple as a traffic signal mast arm that protrudes over the managed lane and leftmost general-purpose lane to capture and differentiate between tolled and non-tolled traffic carrying transponders, as shown in Figure 43.

Source: Chuck Fuhs.

Figure 41. Refuge pullout as part of interim design on Banfield Freeway in Oregon.

For a HOT facility that is converted from a single-lane HOV facility, some agencies provide a toll beacon mounted on the back side of the toll gantry to help enforcement personnel determine who has not been charged and who has paid (Figure 44).

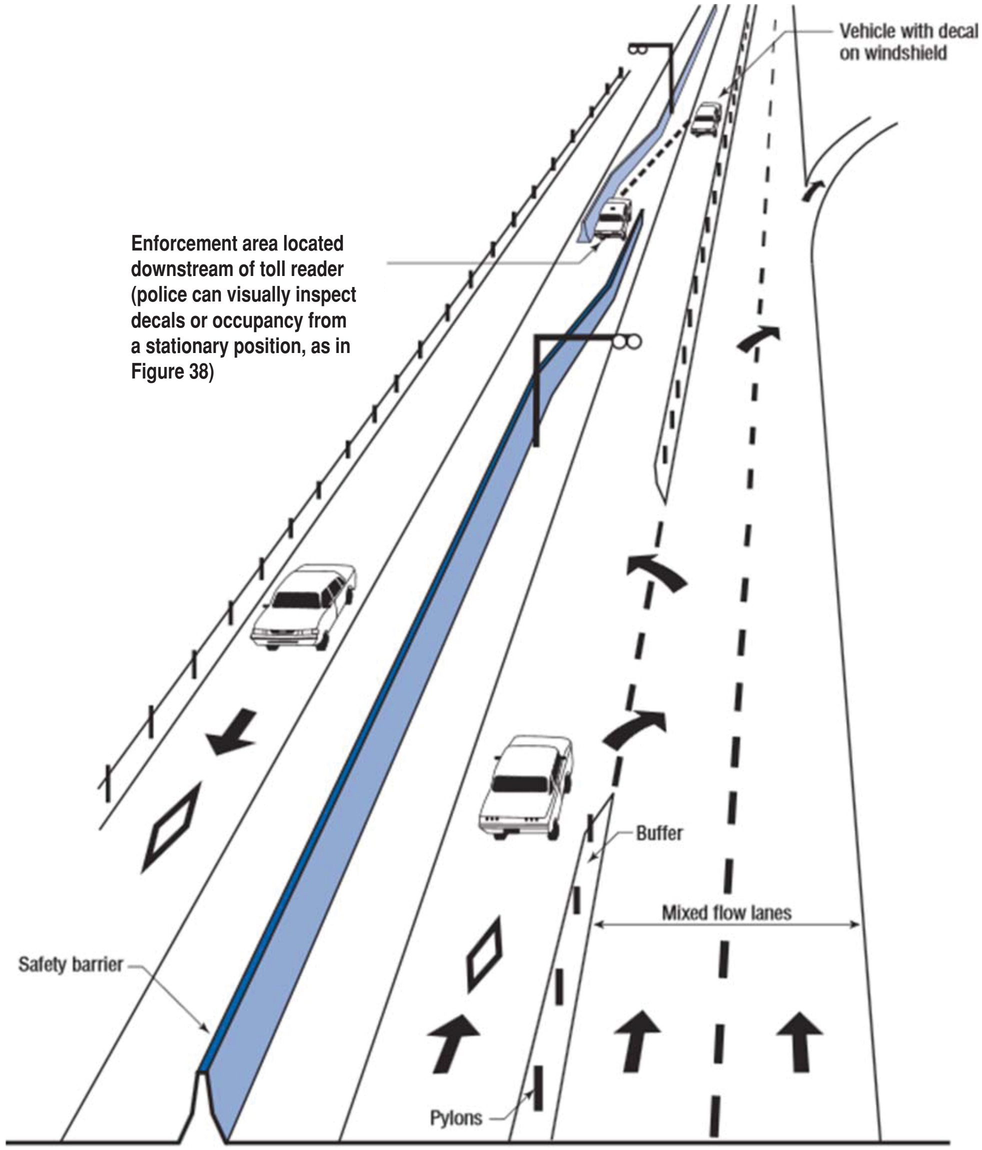
A few projects employ separate self-declaration lanes for accomplishing this, using short sections with an additional lane that provides enough width for HOVs and tolled vehicles to separate as they pass under a gantry. An observation booth or enforcement area is typically located next to the declaration lanes so enforcement personnel can observe who is declaring themselves as a non-tolled vehicle and report offenders to downstream enforcement personnel (see Figure 45). Inserting declaration lanes, along with their lane addition and lane drop tapers, requires additional width in what is otherwise a more typical cross section. This may be accomplished through additional paved width or through restriping the lanes to use part of the adjacent shoulder or buffer; as with other lane-width decisions, trade-offs will have to be considered to determine the best treatment for a particular facility.

Accommodating Enforcement in Existing Cross Section

More details on enforcement treatments were discussed previously in this chapter, but provision for enforcement is at least as important with tolled facilities as with HOV facilities. The cross section must be of sufficient width to allow for enforcement officers to complete their duties.

Access Control and Separation

If additional lanes are not required, the conversion of an existing general-purpose lane to an HOV or HOT lane is less complicated. The pavement is already in place, and it is likely that little or no additional widening or right-of-way acquisition will be necessary. However, in order to maintain premium traffic service levels and discourage toll violations, HOT lanes gen-

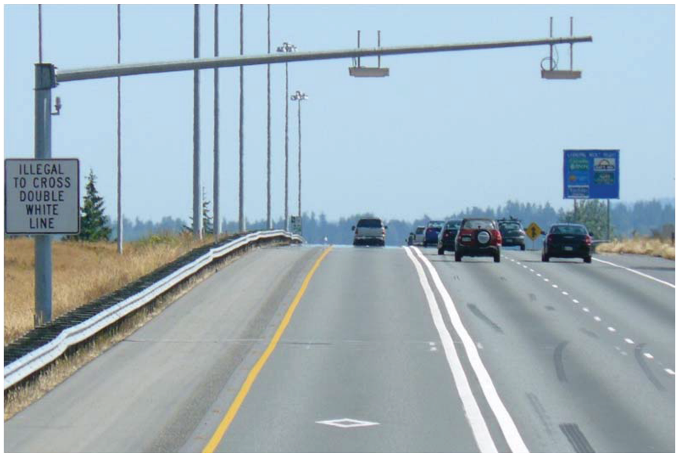


Source: Adapted from Perez and Sciara (*78*), Figure 10. This material is based upon work by the Federal Highway Administration. Any opinions, findings, conclusions, or recommendations, and translations thereof, expressed in the FHWA publication are those of that publication's authors and do not necessarily reflect the views of the Federal Highway Administration.

Figure 42. Key elements in a cross section of a HOT lane.

erally require access control. Physical barriers are preferred for permanent HOT lane installations because they provide better access control and are more effective at reducing violations and maintaining premium traffic service. Since there are often high speed differentials between general-purpose lanes and managed lanes, physical barriers also help maintain safety by preventing potential violators from crossing the buffer into the managed lanes and disrupting traffic flows (*78*). Implementing a HOT lane conversion on a non-barrier-separated facility may be more difficult—issues related to weaving, safety, enforcement, toll zones, and toll rates are all more complicated with buffer- or non-separated HOV lanes. Specific issues in a buffer- or non-separated HOT lane project will depend on the configuration of the existing HOV lane. Tolling will complicate issues since it pertains to specific traffic movement and behavior related to a driver's positioning for advantage in a facility without barriers (such as weaving to avoid a toll, or entering and exiting the lane frequently to reduce toll charges). If the proposed HOT lane project is in a region that is new to the HOT concept, it could be advisable to pilot the concept on an existing HOV facility that is barrier separated (*79*). Additional details about separation of managed lanes were provided previously in this chapter.

Similar to HOV lanes, there are two general approaches to providing access to other types of managed lanes: restricted at-grade access and grade-separated access. If the new facility will require a different type of access than currently exists on



Source: Chuck Fuhs.

Figure 43. Toll reader gantry on SR-167 in Seattle, Washington.

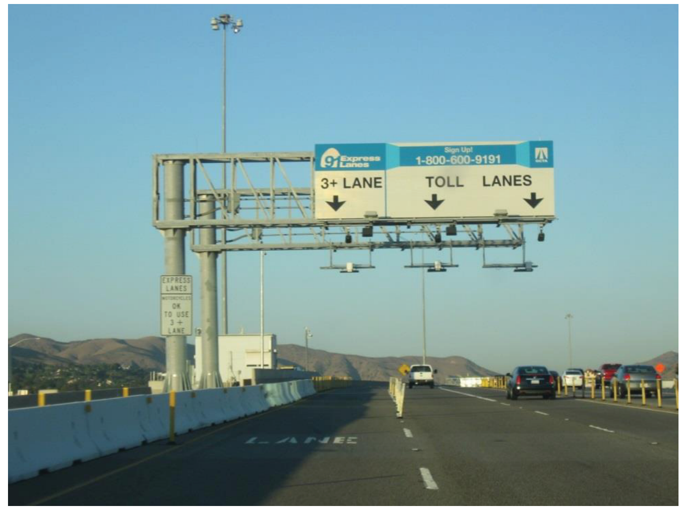
the HOV lanes, the design will have to accommodate both the new ramps and the connections to them. In particular, if a facility changes from at-grade access to grade-separated access, the design must have sufficient cross section to include the transitions and speed-change lanes associated with the new grade-separated ramps.

Access Considerations

Access into and out of a managed lane facility is one of the more critical elements in the design of the facility. Drivers must be able to make their way safely into and out of the facility in order to derive any usefulness from the facility. This section contains discussion on some of the considerations related to the design of managed lane access.

Source: Chuck Fuhs.

Figure 44. Toll beacons located on back side of gantry on I-15 in San Diego, California.



Source: Chuck Fuhs.

Figure 45. Toll declaration lanes at an electronic toll location on SR-91 in Orange County, California.

Consideration of Limited Access Versus Continuous Access

Unless a facility is designed to allow access at only the beginning and end, provision for intermediate access is typically provided. This is accomplished through either continuous access (in which eligible vehicles may enter the facility at any location along the facility) or a limited- or restricted-access approach (in which selected locations are designated for ingress, egress, or both, usually at 3- to 5-mi spacing).

In discussing the differences between the limited and continuous access, California's *Traffic Operations Policy Directive 11-02* (*35*) states that consideration should be given to both access types when planning managed lanes. The choice of access type is based on a general evaluation of the performance and management benefits for the entire freeway as well as the capital costs of building and operating the managed lanes. A summary of design, cost, and performance considerations for the two types of access designs is provided in Table 7. The directive adds that various research and engineering studies on managed lane facilities have found that the highway features that can have the greatest effect on performance, including safety and throughput, are:

- Frequency, location, type, and design of intermediate-access openings on limited-access facilities.
- Shoulder widths.
- Traffic control and safety devices that provide positive guidance (usually related to access points and driver decision-making, such as overhead signing, striping, and lighting).

Experience with existing facilities suggests that when considering whether to use limited or continuous access on a managed lane facility, operational effects should be the high-

Table 7. Summary of design, cost, and performance considerations for limited- and continuous-access facilities.

Criterion	Limited Access	Continuous Access
Cost	• Detailed operational analysis and an iterative design process are needed for best placement of access points. • This access may require more roadway width to accommodate buffer and access opening. • Additional pavement markings and overhead signing are required. • Investment in monitoring for congestion and/or crashes due to weaving near access points may be needed.	• Lower cost is incurred for design, analysis, construction, operation, and maintenance. • Adjustments require fewer engineering resources.
Mobility, Safety, and Performance	• Access points can become initial source of unstable flow and queuing in the managed lane, which can trigger the onset of congestion among all lanes. • Left-side access openings intensify weaving in the form of concentrated flows and consecutive lane changing across all freeway lanes, which may present difficulties for all drivers during periods of congestion. • Drivers are unable to access the managed lane when desired; this could induce violation of the buffer striping, which may be unexpected by drivers in the managed lane. • Limited access is a potential strategy to restrict lane changing where demand has produced or may produce a performance deficiency. • Longer-distance trips are accommodated by discouraging short-term use of lane. • Smoother flow and higher speeds can result from limited merging. • Limited access can provide greater separation to accommodate lane closure activities in the lane or adjacent lanes. • Access to some general-purpose ramps is not as convenient.	• Users must focus on potential for vehicles to enter or exit the managed lane at any point; this may reduce speeds. • Flexibility allows last-minute lane changing to reach freeway exit ramps. • There is no concentrated weaving; lane changing occurs along entire corridor when gaps appear. • Users can readily access all general-purpose ramps. • Drivers face less complex decision making. • The facility is easily utilized during off-peak hours (for part-time facilities). • There is less separation to accommodate lane closures. • Drivers will not worry about violating barrier striping when managed lane is closed for construction, maintenance, or incidents.
Enforcement	• There is a potential for lower toll evasion and occupancy violation. • Enforcement is simpler. • Express lane toll collection is simplified due to need for fewer readers.	• Greater investment in enforcement activity, systems, and zones is needed to produce the lower violation rates expected with limited-access designs. • There is a potential for higher toll evasion and occupancy violation. • The expected cost for express lane toll collection is greater due to need for additional readers.

Note: This summary does not apply to limited-access designs in which managed lane access is provided only via direct ramps to a local or other state highway or freeway.
Source: Compiled by TTI.

est priority (*67*), and such effects should be identified through a formal operational analysis (*35*). Safety, economic, and enforcement effects are also valid considerations, but they often exist in conjunction with operations. For example, if a proposed access point or series of points causes bottlenecks or does not allow managed lane drivers to use their desired general-purpose entrance and exit ramps, then the access is not serving its purpose and the effects of other factors may not be fully appreciated. This suggests a level of analysis that looks not only at the entire corridor's travel patterns (specifically including the desired origins and destinations for managed lanes users) but also at the immediate area surrounding each proposed access point or driver decision point.

The *Highway Capacity Manual* (HCM) *2010* (*80*) contains analysis methodologies for freeway weaving segments (in Chapter 12) and freeway merge and diverge segments (in Chapter 13) to predict operational characteristics such as the rate of lane changing, average speed of weaving and non-weaving vehicles, level of service, and capacity. The HCM makes the disclaimer that a limitation of the methodologies is that it does not specifically address special lanes, such as HOV lanes, within the weaving segment without modifications by the analyst. However, the principles used in the HCM methodologies have applicability for managed lane facilities, particularly for two-sided weaving segments such as those that might be found between a general-purpose ramp and a managed lane access opening. In addition, some operators of managed lane facilities may have policy directives that specify analysis tools to be used, and those applicable policies should be considered in the planning process as well.

A Minnesota study (*81*) investigated design, operational, and safety differences between two managed lane corridors: I-394, with a restricted-access design, and I-35W, with an open-access design. The authors stated that it is difficult to compare the two design philosophies because they were devised to serve the needs of the two distinct roadways. They concluded that I-394 operated very well with the closed-access design mainly because the majority of the demand originated from three distinct service interchanges, and the remaining ramps had comparatively little demand. Conversely, the interchange density on I-35W was much higher, with entrance ramps very closely spaced and with the majority of those ramps carrying large demands of HOT-eligible vehicles. The researchers stated that it would have been very difficult to follow a closed-access design on I-35W, and their research results led them to conclude that it would have made little difference in terms of mobility and safety. Comparisons of shockwave characteristics of four access zones were highlighted, and, although the volumes at each access zone were different, the shockwave lengths observed were comparable, signaling no difference in terms of safety between the two design philosophies.

Practitioners who work with existing continuous-access facilities recognize operational benefits of open access, and open access has a simpler analysis process, which identifies potential locations for restrictions instead of justifying locations for access. Practitioners in a recent survey also indicated that based on their anecdotal feedback from drivers, those who travel on open-access facilities also prefer greater access, and their experience was that effects on safety can be minimal (*67*). However, for managed lane facilities that are revenue funded or are based on public–private partnerships, the economic effects of continuous access must be considered. If access is not controlled, there is a potential for lost revenue, which could affect a project's financial feasibility. Also, in areas with very high congestion, it may be desirable to limit access to the managed lane to prevent congestion from the general-purpose lanes affecting the operations of the managed lane, or conversely, reduce the effect of managed lane traffic weaving across all the general-purpose lanes to enter the managed lanes or exit the freeway.

It is also important to have appropriate context when making decisions on operational effects of access. Managed lane and general-purpose lane operations are intertwined, so decisions about managed lanes should not consider those lanes as if operating in a vacuum. In addition, the context of time must also be considered; an access point that operates satisfactorily on Day 1 or in Year 5 may not maintain that level of operation at the end of the expected design life, so every decision maker involved in the process needs to have the same expectation of the time horizon being considered. A managed lane access analysis should not attempt to address major freeway operational shortcomings, particularly for forecast conditions, which may overwhelm any access location selection.

Continuous access and restricted access do not have to be mutually exclusive, in that a managed lane operator does not have to choose either one or the other for the entirety of a managed lane facility. Within a given facility, restrictions on access can be applied to certain parts of the facility while continuous access is provided in other parts of the same facility. Practitioners should use the principles discussed in the following sections to determine where access restrictions should be located.

Continuous-Access Considerations

Continuous access allows eligible vehicles to enter and leave the lane at any point. No additional weave, acceleration, or deceleration lane is provided, and no specific ingress/egress locations are designated. Instead, vehicles move into and out of the managed lane at any point in the same way they would change lanes in the general-purpose lanes. The striping used to separate the general-purpose and the managed lanes, along with signing and pavement markings, should indicate that access can occur at any point. Continuous access can be applied in projects with or without buffer separation between the managed lane and the general-purpose lanes.

Recent guidance from California (*35*) on the conversion of restricted-access facilities to continuous access indicates that the conversion may be allowed if it is funded by the project sponsor requesting the change. A traffic study is required for any conversion project. If a new or conversion project is on a route where express lanes (i.e., managed lanes that utilize congestion pricing) are planned within the next 5 years, and there is an intent to operate the express lane with continuous access, the California guidance requires joint consultation among the project sponsor, the state DOT, and the state police to identify strategies to limit violations. Among the strategies to be considered in the multiagency consultation are frequent toll readers and visible manual enforcement.

Frequency of Restricted-Access Points

For facilities that do not provide continuous access, defined access points are provided at regular intervals or logical locations; restricted-access points are not intended to serve every general-purpose entrance and exit ramp. A survey of managed lane practitioners (*67*) found that spacing for access openings on existing facilities tend to be between 1 and 3 mi, though the reasons for providing access of a particular type or in a specific location vary, ranging from policy decisions to safety or operational considerations. Each agency determined which factors were most important to a given facility, and the factors chosen varied from one facility to another. Similar considerations of applicable policies and safety or performance goals must be made when planning for new or revised access points.

Chapter 10 of the AASHTO Green Book (*27*) provides guidance on spacing between freeway access points. While this is intended for general-purpose access, the principles can be applicable to managed lanes. To provide sufficient weaving length and adequate space for signing, a reasonable distance should be provided between successive ramp terminals.

Figure 10-68 of the Green Book presents recommended minimum ramp terminal spacing for four various ramp-pair combinations that are applicable to interchange classifications; the exit-entrance (EX-EN) and entrance-exit (EN-EX) combinations are particularly applicable to managed lane access. The stated minimum distance for EX-EN pairs on freeways is 500 ft. For EN-EX pairs (i.e., weaving sections) on system-to-service interchanges and service-to-service interchanges, the minimum distances are 2000 ft and 1600 ft, respectively. EN-EN and EX-EX pairs on freeways have a minimum distance of 1000 ft between successive ramp terminals. As an alternative to fixed dimensions for ramp and interchange spacing, *NCHRP Report 687* (*82*) provides performance-based guidance on ramp spacing that considers geometric design, traffic operations, signing, and safety.

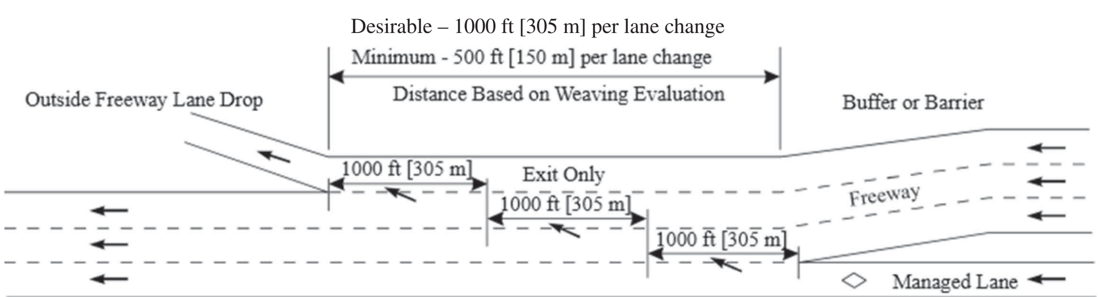
California's HOV guidelines (*53*) state that when it is operationally possible, ingress and egress locations are based on the following criteria:

- To serve every freeway-to-freeway connection.
- To serve high-volume ramps.
- To serve ramps with high numbers of carpools.
- When adjacent to park-and-ride facilities.
- When requested by transit districts.
- To assist in the modification of local commute patterns (may be at local request).
- To help balance and optimize interchange operational level of service within a local jurisdiction, within a corridor, or within a region.
- To support and encourage ridesharing programs (HOV demand/usage).

Depending on the purpose of the facility, decision makers may add to or reprioritize the criteria in this list to determine where access should be provided.

Additional guidance from California (*35*) states that existing interchange spacing is the primary consideration for determining the location of access openings. An equally important consideration is the existing and expected location of mainline operational bottlenecks and geometric constraints that produce recurrent congestion and queuing along the general-purpose lanes. Access openings should be located and designed such that they will perform at LOS C or D. They should not produce adverse impacts to managed lane and general-purpose lane performance, nor should they be placed where recurrent general-purpose lane congestion is expected. This guidance avoids the potential for undesirable conditions that result in operational and safety deficiencies. If the mainline queuing at a proposed access location is limited to a small portion of the overall peak period, then a weave-lane or merge-lane configuration might need to be evaluated and provided if it will eliminate or minimize adverse impacts.

The location of managed lane access points should avoid the creation of short weaving distances between upstream and downstream right-side ramps and left-side managed lane access. It may be difficult to find appropriate locations for managed lane access on older freeways with frequent on- and off-ramps. This is one reason that managed lanes on freeways in the San Francisco Bay Area operate with more open access, so that weaves are not constrained. Ample distance between managed lane access and general-purpose access will minimize the likelihood of congestion and related safety implications involving weaving vehicles. Recommendations for spacing between general-purpose ramps and managed lane access in previous studies and current guidelines (*4, 35, 53, 54, 59, 83, 84, 85*) have suggested that cross-facility weaving areas should provide between 400 and 1000 ft per lane change, depending on anticipated traffic volumes and other conditions. A distance of 1000 ft is the common recommendation among the more recent references, as shown in Figure 46. These distances are typically applied to passenger vehicles, so the weaving distance provided for buses should be at least as long.



Source: Adapted from Kuhn et al. (*4*).

Figure 46. Example of termination of managed lane with 1000 ft per lane change.

California guidance (*35*) mandates that the type and location of proposed access openings shall be determined by an operational analysis. It is expected that an iterative process would be used in this analysis. For example, an access opening using the simplest design and minimum lengths might be evaluated first. If the analysis supports this concept, then no further analysis of that location is necessary. Otherwise, the process would continue until an appropriate concept is identified, or all reasonable and feasible concepts are exhausted. The iterative process may require consideration of the following modifications or features (not necessarily in this order):

- Increase in weaving lengths.
- Addition of alternative types of access.
- Relocation of the access opening.
- Addition of auxiliary lanes connecting ramps on the general-purpose lanes.
- Addition of drop ramps or direct-connector (flyover) ramps.

Proposed access openings that are estimated to operate below the performance thresholds or that propose less-than-minimum lengths or spacing receive additional scrutiny. Approval will be considered when the need for the opening is justified by traffic data and the safety analysis and if traffic impact mitigation is incorporated. Approval may also require specific system monitoring to identify and correct potential performance deficiencies.

Nevada DOT (*54*) and the FHWA *Priced Managed Lane Guide* (*2*) also require or recommend, respectively, an operational analysis to determine and/or justify the location and type of access openings in a limited-access facility. Key items that should be considered in an operational analysis include level of service and avoidance of general-purpose weave turbulence such as bottlenecks near major interchanges. This guidance suggests a level of analysis that looks not only at the entire corridor but also at the immediate area surrounding each proposed access point or driver decision point.

The Nevada DOT manual (*54*) states that, generally, an access opening should be provided before and after system-to-system interchanges and other major interchanges. Nevada DOT has the following desirable minimums for frequency of access openings for different types of managed lanes:

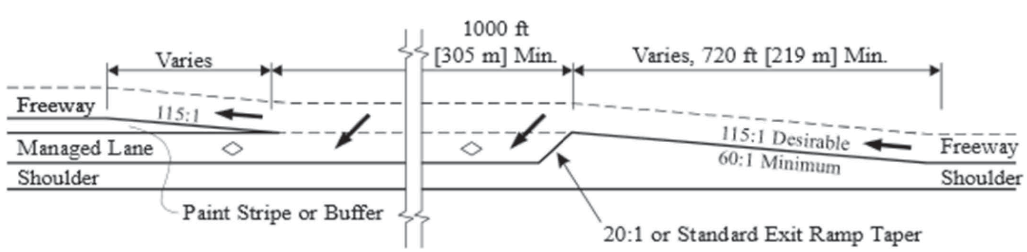
- For HOV lanes, provide a minimum of 2 mi between access openings.
- For express lanes without toll, provide a minimum of 4 mi between access openings.
- For priced managed lanes (HOT lanes, express toll lanes, etc.), provide a minimum of 2 mi between access openings.

The FHWA guide (*2*) says that, in all cases, access openings should be located and designed in a way that will not produce adverse impacts to the managed lanes and the parallel highway lanes. However, when forecast conditions are evaluated, the managed lane impacts should not attempt to address and be responsible for mitigating much larger operational issues emanating from growth in general-purpose traffic; otherwise, any near-term resolution may be difficult to reach. The locations of at-grade access openings need to be closely coordinated with highway entrance and exit ramps and allow adequate room for motorists to complete weaving movements when moving between the general-purpose and managed lanes and an entrance or exit ramp.

Treatment for Beginning a Managed Lane

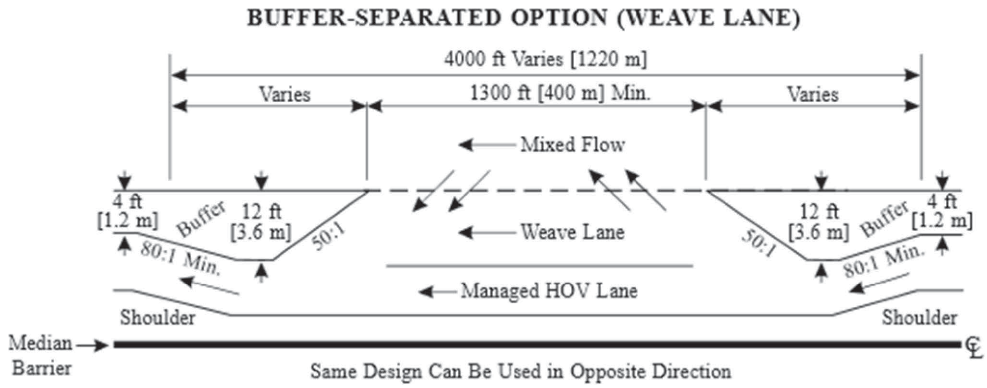
Entering a managed lane facility should require a deliberate movement. A design configuration that requires vehicles to change lanes to avoid entering the managed lane could be susceptible to violations. The only exceptions may be associated with reversible and contraflow lanes where a mixed-flow lane drop condition is common. Since a majority of managed lanes are located on the left side, next to the leftmost lane on most freeways, the beginning of these lanes should not typically change designation and cause general traffic to drive into a downstream restricted condition. It is desirable to add managed lanes to the overall roadway cross section via a left-side exit, and signing should reflect this. Figure 47 provides an example. Entrances to a managed lane facility are to be designed as lane changes to prevent motorists from entering the facility unintentionally.

The entrance point to any managed lane facility that does not have continuous access should begin no earlier than a



Source: Fitzpatrick et al. (*83*).

Figure 47. Example of entrance to a managed lane.



Source: Fitzpatrick et al. (*83*).

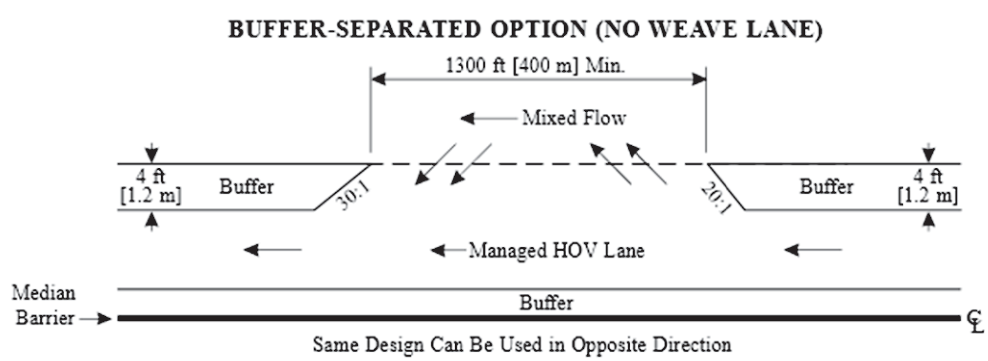
Figure 48. Example of buffer-separated intermediate weave zone access with a weave lane.

distance equivalent to 1000 ft per lane change required to enter the managed lane from the nearest entrance ramp. The design should also include accommodation for structures for advance signing upstream of the managed lane(s) and signing at or downstream of the beginning of the facility (see the section of this chapter on operational impacts on design for more information).

Intermediate-Access Treatments—Weave Zones and Weave Lanes

An access point at an intermediate location may accommodate both those moving into the managed lane and those leaving the managed lane. In some situations, however, only ingress or only egress may be allowed. A common design that accommodates both maneuvers is a weave lane, which is a short-distance lane added to the cross section to provide space for weaving into and out of the managed lane facility separate from the travel lanes. A schematic for a buffer-separated option with a weave lane is shown in Figure 48. A weave zone is a design that provides for weaving maneuvers into and out of the managed lane. A weave zone may or may not have a weave lane; in designs without a weave lane, the entry and exit maneuvers take place similar to lane changes between other travel lanes on the freeway. Figure 49 shows an example of a weave zone without a weave lane, which is a design that can be more easily implemented within a constrained right-of-way. However, a weave lane can be provided if it is deemed beneficial and sufficient right-of-way is available, particularly when high volumes of access maneuvers are observed or anticipated. An opening or merge area of 1300 to 2000 ft has been recommended in other guidelines (*4, 53, 54*), and a total of 4000 ft is recommended for the entire length of the access area when a weave lane is provided (*86, 83*).

Increasing the length of access points and providing weave lanes are two common treatments that are available for facilities with restricted access that have increased demand or anticipate increased demand, particularly if the facility is being considered for expansion from a single lane to multiple lanes. Providing or converting to continuous access is also an option, but each option should be considered in the context of an operational analysis to determine which treatment is best for a particular facility (or specific location within that facility).



Source: Fitzpatrick et al. (*83*).

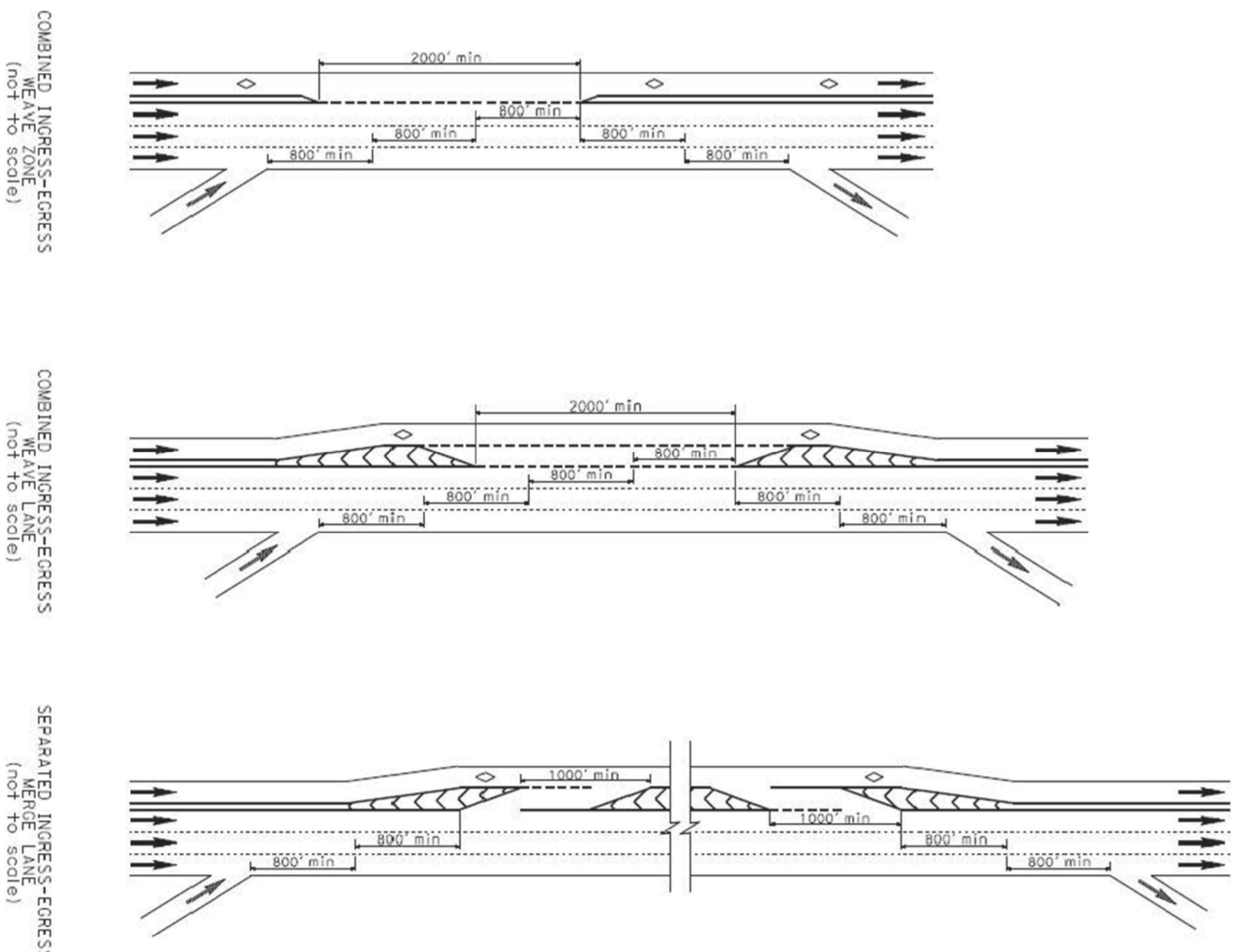
Figure 49. Example of buffer-separated intermediate weave zone access without a weave lane.

The weave zone should be longer than the minimum shown in Figures 48 and 49 if the design vehicle is a bus or if a high volume of such vehicles is anticipated. If a merge area is sufficiently long, it may be used as a passing zone for managed lane facilities with just one lane (*83*); if passing behavior is not desired, then openings longer than 2000 ft are discouraged (*83*). An illustration of California's most recent guidance (*35*) for access openings of 2000 ft in length, including dimensions for lane-change maneuvers to adjacent entrance and exit ramps, is shown in Figure 50. The first example is for a weave zone, the second is for a weave lane, and the third is for an auxiliary or merge lane, which is discussed in more detail in the next section.

Experience with the use of weave lanes in Los Angeles has highlighted the problem of general-purpose traffic using the weave lane for queue jumping where it is provided in a typically congested area. In such circumstances, the use of separated ingress and egress merge lanes should be considered to separate the two respective movements and create a break in the weave lane to discourage queue jumping.

Intermediate-Access Treatments—Auxiliary Lanes

If the buffer is sufficiently wide, managed lane access can take the form of an auxiliary speed-change lane, where a driver desiring to enter into the managed lane facility enters an at-grade ramp, travels through the buffer, and then merges into the managed lane. The same scenario would apply for a driver leaving the managed lane facility to enter the general-purpose lanes, as shown in Figure 51 and the third example in Figure 50. The design must have sufficient length for the driver to adjust speed and merge into the desired facility, and there must be sufficient spacing between ramps to accommodate weaving, similar to the design of an auxiliary lane for a freeway entrance ramp.



Source: Caltrans, © 2014, all rights reserved.

Figure 50. Access types with minimum recommended opening lengths and weaving distances.

Source: Marcus Brewer.

Figure 51. Exit from managed lane using an auxiliary lane on the Katy Freeway (I-10) in Houston, Texas.

Source: TTI.

Figure 52. Example of direct-access managed lane ramps over general-purpose lanes in Houston, Texas.

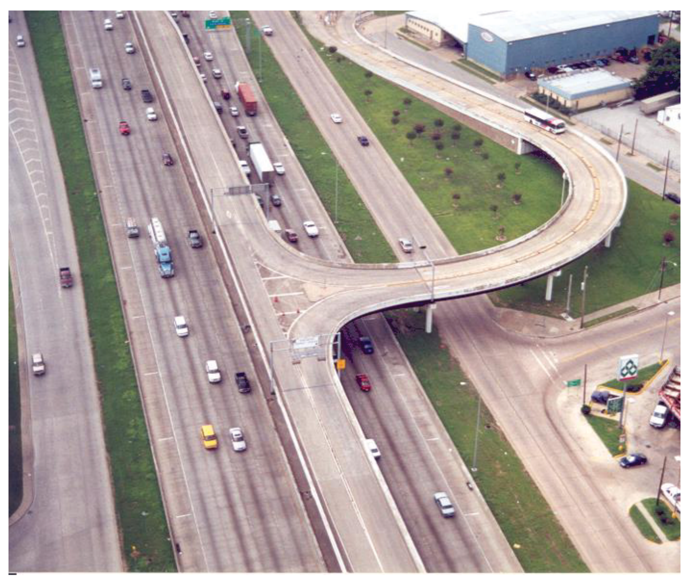
A shortcoming noted on some projects is drivers attempting to use such ramps to both enter and exit; pavement markings should clearly define whether the ramp is intended for entrance or exit, and application of pylons or concrete barriers may be necessary to prevent unintended movements.

Intermediate-Access Treatments—Direct Access

Similar to traditional freeway entrance/exit ramps, direct (grade-separated) access ramps carry managed lane traffic directly to and from major interchanges with other freeways and managed lanes, and with the street network (i.e., they require no cross-facility weaving to enter the managed lane facility). Two typical designs for direct-connect ramps are flyovers that are either directional ramps for reversible flow (Figures 52 and 53) or common bi-directional structures (Figures 54 and 55). Ramps to reversible-lane facilities are typically directional and reversible as well.

The design of a direct-connect access ramp should follow the guidance of a traditional freeway entrance/exit ramp as described in the AASHTO Green Book (*27*) and applicable state-level guidance. Design speeds are critical, similar to any high-speed ramp. Most flyovers connecting managed lanes on different freeways are designed with a 50-mph design speed or better. Most bi-directional ramps are separated by a barrier between opposing flows. In particular, the designer should ensure that there is provision for sufficient speed-change/merge/diverge length at the ramp termini, as well as provision for sufficient sight distance around the separation barrier and for attenuation at the gore area of the ramp.

Direct ramps may also be located on the left side of the facility, and this setup is more common for managed lanes than for entrance and exit ramps for general-purpose lanes. Two possible purposes for left-side ramps are to provide access from one managed lane facility to another or to provide access to transit facilities. Left-side ramps are typically discouraged for general-purpose lanes, and while they may be appropriate for certain situations in managed lanes to



Source: TTI.

Figure 53. Example of direct-access managed lane ramp to park-and-ride facility in Houston, Texas.

Source: Chuck Fuhs.

Figure 54. Ground-level view of direct-access managed lane ramp in Houston, Texas.

facilitate access, the design of the roadway must provide sufficient cross section for the lanes needed to accommodate the anticipated volumes for each movement. The ramp must be long enough to minimize the potential for queue spillback from the ramp into the managed lane, and sufficient signing must be provided in advance of and at the access point to inform drivers which direction is the mainline since the ramp is located on the left instead of the right.

Intermediate-Access Treatments—High-Volume Direct Access

For high-volume access movements, particularly between managed lane facilities, it may be appropriate to use a ramp that is equivalent to a freeway-to-freeway connector. In locations where high managed lane volumes are anticipated for connecting traffic between two managed lane facilities or with major transit or activity centers, high-speed flyover ramps are justified. For concurrent flow facilities, ramps typically share a common structure to serve both directions on a common alignment and bridge structure. Flyover ramps are designed to the same geometric and design speed conditions as any other higher-speed freeway-to-freeway connector. To connect managed lanes located to the left of general-purpose lanes, ramps are most commonly oriented to the left of the mainline managed lane roadway and connect two freeway lanes left to left, sharing a common structure (see Figure 56). Two-way flyover ramps contain barrier separation between opposing flow (see Figures 57 and 58). The cross section on the ramp is the same as a two-way barrier-separated facility.

Source: Chuck Fuhs.

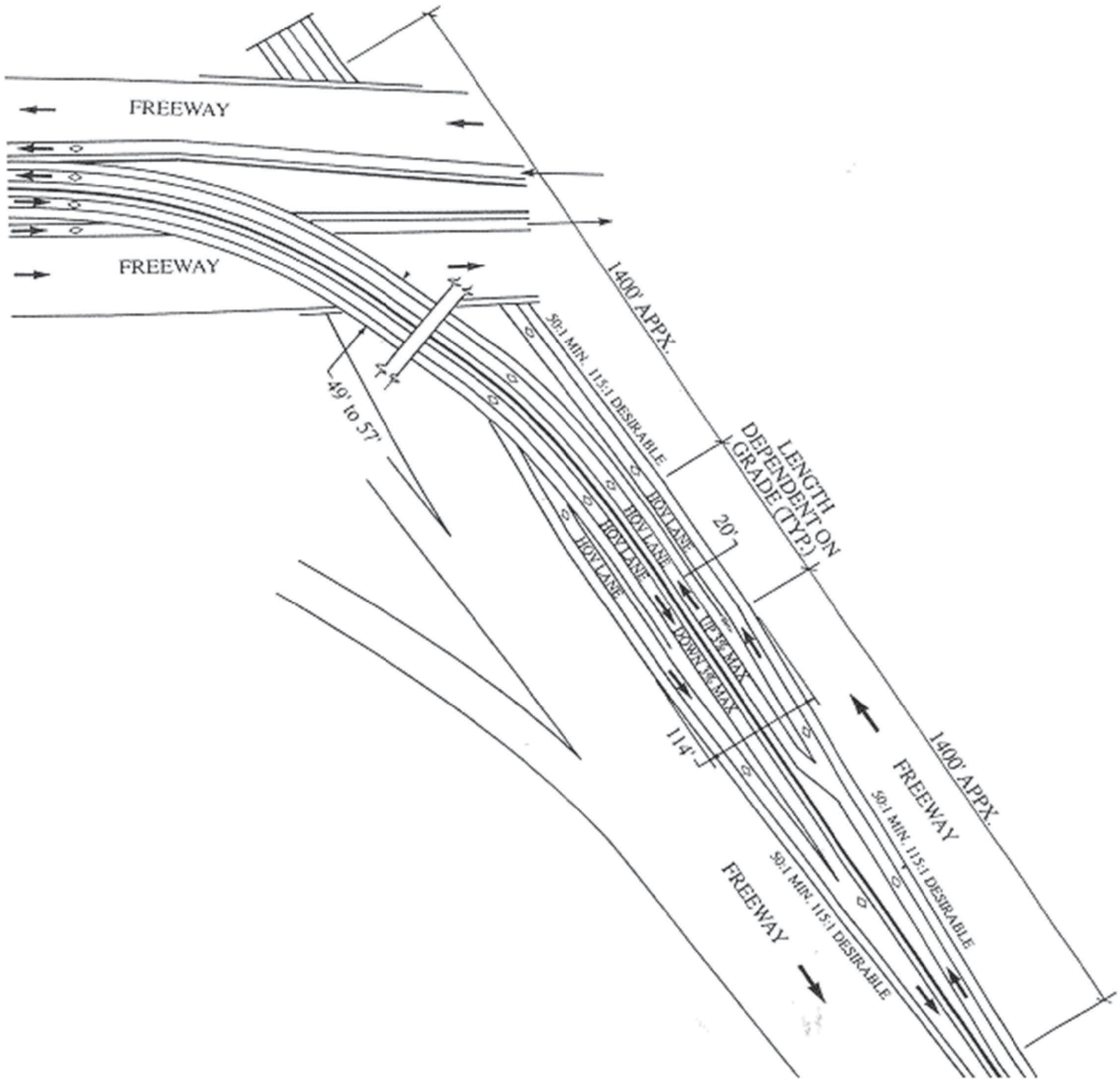
Figure 55. Example of direct-access managed lane ramp to local street in Houston, Texas.

Treatment for Ending a Managed Lane

Terminating a managed lane facility requires proper accommodation of all vehicles (both in the managed and general-purpose lanes) approaching the point of termination. Two methods are commonly used: continuing the managed lane(s) as general-purpose lane(s) or merging the managed lane(s) into the general-purpose facility. The recommended method is the former; multiple guidance documents recommend that a managed lane continue as a general-purpose lane when terminated (*4, 53, 54*). If managed lane use is high and right-of-way is constrained, the design should carry managed lane volumes into a general-purpose lane while dropping a general-purpose lane farther downstream on the right (see Figure 59). Both origin and termination treatment locations need to consider proximity to existing or planned right-side freeway ramps. Experience suggests that for single-lane treatments, providing 1000 ft of minimum lane weaving is desirable, with 500 to 800 ft being adequate in some instances. Determination of the actual weaving distance should be based on a weaving analysis. Locating a terminus should consider grade, curvature, and specific traffic conditions. Tangent locations are encouraged where good sight distance can be provided. Each design setting is unique in terms of the traffic mix, lane demand, roadway geometrics, and related factors. The termination treatment location and weave or merge section should also consider traffic impacts under differing peak and off-peak travel conditions.

If the managed lane volumes do not exceed 1000 vehicles per hour, a merge area of approximately 2500 ft in length may be acceptable, but effects on the general-purpose lanes should be checked. Also note that the merge tapers in design are desirably 115:1 with a minimum of 60:1, and diverge tapers are desirably 50:1 with a minimum of 20:1 (see Figure 60).

Some facilities will need to have an interim terminus until they are extended in a subsequent phase. Design of those termini should follow the same guidelines as for permanent



Source: Nevada DOT, Planning Division, Safety Engineering Section (*54*).

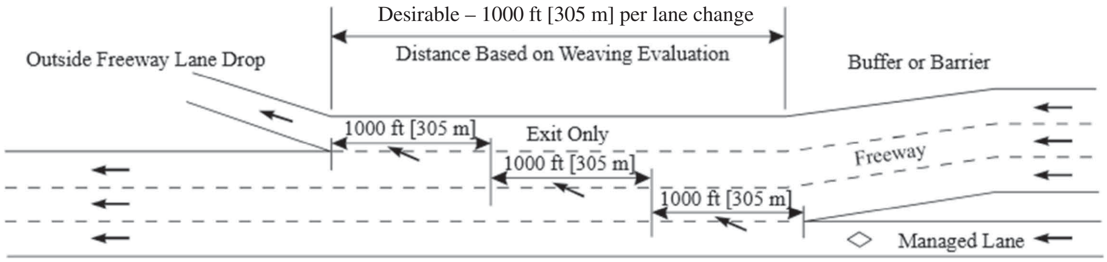
Figure 56. Example layout for a two-way flyover ramp.

Source: Nevada DOT, Planning Division, Safety Engineering Section (*54*).

Figure 57. Aerial view of two-way interchange flyover ramps.

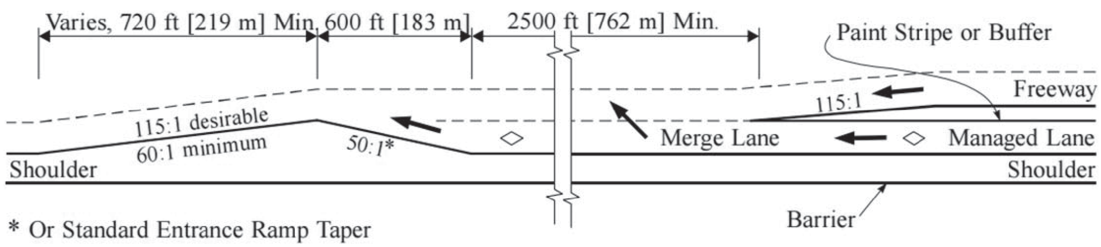
Source: Nevada DOT, Planning Division, Safety Engineering Section (*54*).

Figure 58. Two-way interchange flyover ramp.



Source: Adapted from Kuhn et al. (*4*).

Figure 59. Terminating an HOV lane as a general-purpose lane.



Source: Kuhn et al. (*4*).

Figure 60. Terminating an HOV lane into a general-purpose lane.

treatments, and the cross section of the facility must provide sufficient width to accommodate the selected treatment.

The design should also include accommodation for structures for advance signing upstream of the terminus of the facility and needed signing at or downstream of the end of the facility (see the following section on operational impacts on design for more information).

Operational Impacts on Design

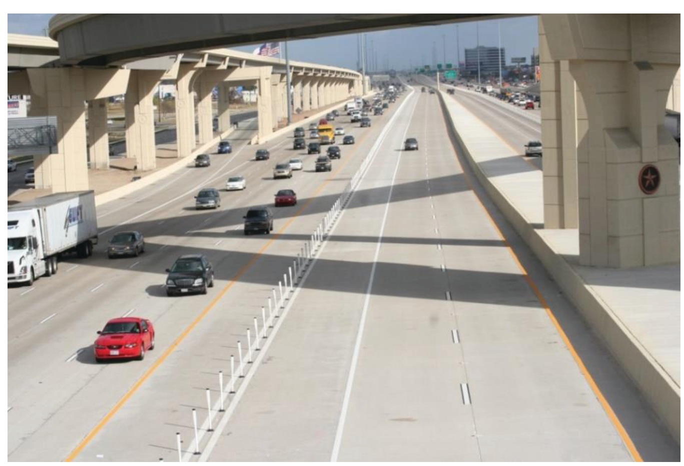
The design must allow the facility to serve the purpose for which it is intended, so certain aspects of operation must be considered in the design. This section contains guidance on selected operational issues unique to managed lane facilities that have an effect on the design of the facility.

Capacity

The geometric features of a managed lane can strongly influence capacity, as well as the pricing and operating rules. The number of lanes, type of buffer, and access design are all characteristics that impact capacity. It is important to consider these features when designing a managed lane, and a capacity analysis may be useful to examine how different design alternatives may perform. Some projects such as US-290 in Houston (see Figure 61) have specifically been designed with enough width so that a new access feature, auxiliary lane, or other capacity enhancement can be added in the future without major redesign. Such design flexibility becomes more important in highly dynamic corridors where changes in operation and demand are anticipated into the future.

Based on the research conducted for NCHRP Project 03-96, a draft version of a chapter for the *Highway Capacity Manual* provides guidance to consider how different geometric features influence capacity (*87*). The draft chapter is divided into sections that correspond to facility type, specifying these concepts:

- Continuous access.
- One- and two-lane, buffer separation.
- One- and two-lane, barrier separation.



Source: Chuck Fuhs.

Figure 61. Managed lanes with available width for future enhancements on US-290 in Houston, Texas.

In the draft chapter (*87*), speed-flow diagrams were calculated and provided for each facility type. The speed-flow diagrams for continuous-access and one-lane, buffer-separated facilities have an additional set of curves that account for congestion in the adjacent general-purpose lanes. These curves show a frictional effect. Two-lane facilities that are buffer separated and all barrier-separated facilities are not influenced by congestion in the general-purpose lanes and thus do not show any friction in the diagram.

Adjustments for cross-weaving movements were also suggested in the HCM draft chapter from NCHRP Project 03-96 (*87*). The adjustments are recommended to be applied in instances where intermittent access to the managed lanes is provided. Prior research has indicated that capacity in the general-purpose lanes is negatively correlated with the amount of cross-weaving traffic entering the managed lane and the number of lanes that have to be crossed by vehicles. Capacity can also be reduced when the managed lane access point and the freeway entrance or exit ramp are relatively close to one another.

The amount that capacity is reduced in the general-purpose lanes, due to the placement of intermediate-access segments, can be represented through a set of capacity reduction factors. The capacity reduction factors can be estimated as a function of the number of general-purpose lanes, the amount of cross-weaving flow, and the distance between the freeway on-ramp and the start of the managed lane access segment. The following equation is used to calculate a capacity reduction factor [from Table 26 in *NCHRP Web-Only Document 191* (*87*)]:

$$\mathrm{CRF}(\%) = -8.957 + 2.52 \times \ln(\mathrm{CW}) - 0.001453 \times L_{\mathrm{CW-Min}} + 0.2967 \times \mathrm{GPLs}$$

Where:

CRF = capacity reduction factor
CW = cross-weave flow measured in passenger cars per hour.
$L_{\mathrm{CW\text{-}Min}}$ = length from the gore of the freeway entrance ramp to the beginning of the managed lane access segment.
GPLs = number of general-purpose lanes, ranging from two to four lanes.

Examples of various capacity reduction factor estimates (developed using the above equation) can be found in Table 8. These estimates are derived based on common combinations of roadway geometric features and cross-weave flow conditions.

Tolling Systems

This section contains a brief discussion of selected design topics related to tolling systems. For more information on tolling systems, please refer to the section on toll collection system development, deployment, and phasing considerations in Chapter 5.

Electronic toll collection requires a decision on where the toll collection occurs, and such locations are almost always in a constrained median environment. A significant investment in gantries for signing and tolling is required, so the placement of tolling installations needs to strategically assess how the facility can be best managed with a minimum of installations. Toll installations need to be accessible for maintenance, both from the median and often from the right side where power and communication are provided. A variety of different vendors offer electronic tolling systems, but all use some form of transponders to read electronic tags in users' vehicles and/or cameras to read license plates and send bills to those without transponders.

Regardless of the choice of tolling system, the design will need to accommodate the necessary infrastructure, which typically involves large structures, such as gantries, as well as hardware such as cameras and electronic readers, roadside controllers, communications equipment, and power. The use of variable pricing on priced managed lanes requires additional

Table 8. Capacity reduction factor estimates.

	$L_{\mathrm{CW\text{-}Min}}$ (ft)	Cross-Weave Flow (vph)				
		100	200	300	400	500
4 GP Lanes	1500	1.6%	3.3%	4.5%	5.7%	6.5%
	2000	1.0%	2.2%	3.7%	4.7%	5.3%
	2500	0.2%	1.6%	3.3%	4.1%	4.7%
	$L_{\mathrm{CW\text{-}Min}}$ (ft)	Cross-Weave Flow (vph)				
		100	200	300	400	500
3 GP Lanes	1500	1.2%	3.1%	3.9%	5.5%	6.1%
	2000	0.8%	2.0%	3.5%	4.3%	4.7%
	2500	0.2%	1.4%	2.6%	4.1%	4.3%
	$L_{\mathrm{CW\text{-}Min}}$ (ft)	Cross-Weave Flow (vph)				
		100	200	300	400	500
2 GP Lanes	1500	1.0%	2.7%	3.7%	5.1%	5.3%
	2000	0.6%	2.0%	3.1%	4.3%	4.9%
	2500	0.0%	1.2%	2.2%	3.3%	4.1%

GP = general purpose.

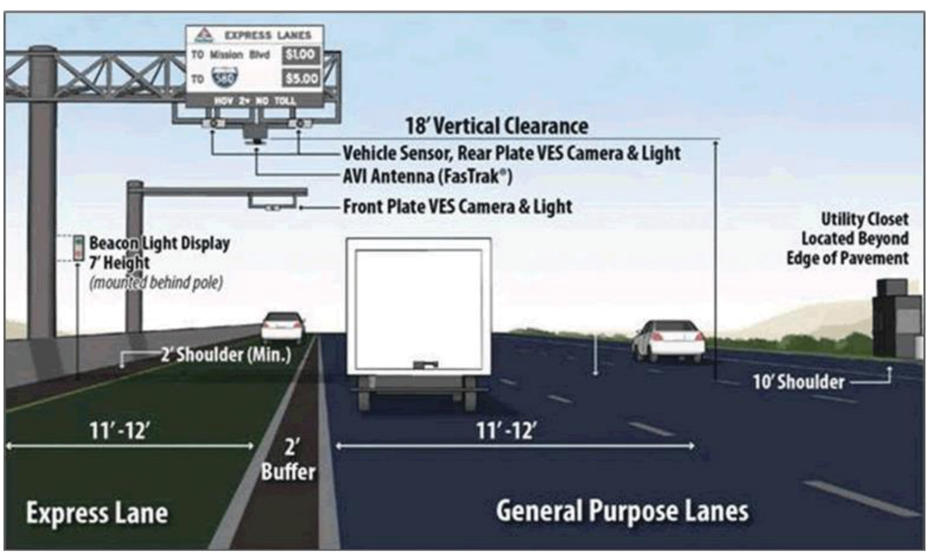
infrastructure and communications abilities to communicate the current toll to drivers. Additional discussion of appropriate infrastructure can be found in Chapter 6 in the section on toll collection system operations.

If pricing is being used to maintain a specified operational threshold, a variable toll system needs to either be based on a schedule that reflects typical peak-demand curves or be dynamic and receive real-time traffic input to calculate the toll rate. This real-time traffic information is obtained using loop detectors or other devices capable of detecting characteristics of the traffic stream in the managed lane(s), such as traffic volume and speed. Dynamic signs are commonly used to display toll rates for downstream destinations. The toll that customers see when making a choice to use or remain in the lane should not change from the time they see the rate to the time they actually enter (or remain in) the facility. The tolling system design opens a customer transaction at the first access point but does not process the completed trip transaction until the vehicle passes one or more downstream tolling gantries and the transaction is closed (*2*).

If a single-lane HOT facility has declaration lanes to separate HOVs from tolled vehicles, the cross section must have two lanes at the tolling gantry and must also provide the necessary lane addition and lane drop tapers on either side of the gantry. An alternative to this method is the use of transponder technology that enables the driver to declare status as an HOV or tolled user through the transponder or by changing the account status prior to the trip, allowing all traffic in the HOT facility to use the same lane at the gantry. In this case, enforcement usually occurs using an indicator beacon visible to law enforcement personnel on a gantry or other structure indicating the status (HOV or SOV) that the vehicle has chosen to declare.

Priced managed lane toll zones should be equipped with all necessary infrastructure to identify vehicles, initiate toll transactions, identify and photograph license plates of potential violators (or pay-by-plate/pay-by-mail customers), and inform enforcement personnel of account status through strategically placed transaction status indicator beacons or through displays inside the enforcement vehicle. In a typical toll zone configuration, a vertical post with counterbalanced cantilevered horizontal arms will serve as the toll gantry. In the dual-gantry system shown in Figure 62, a minimum vertical clearance of 18 ft is provided between the automated vehicle identification (AVI) antenna and rear-plate-facing license plate image camera on the mast arm. A transaction status indicator beacon is mounted where it can be seen by toll enforcement personnel. Many toll zones will also have a designated area for adjacent enforcement personnel monitoring. The availability and placement of these observation locations will generally be in the vicinity of the toll reader and beacons. Sufficient lighting must be present to support license plate recognition and image capture; many current camera systems include their own required lighting for either infrared or color images, but additional lighting must be provided separately if not included as part of the camera system.

Variations on the dual-gantry system shown in Figure 62 include single-gantry systems, systems that capture images of only front license plates (instead of rear plates or both), use pavement loops instead of overhead vehicle detectors, and adjust the position of the status indicator beacon if right-of-way is constrained or if there is an adjacent rail corridor.



Source: Perez et al. (*2*), Figure 6-18. This material is based upon work by the Federal Highway Administration. Any opinions, findings, conclusions, or recommendations, and translations thereof, expressed in the FHWA publication are those of that publication's author(s) and do not necessarily reflect the views of the Federal Highway Administration.

Figure 62. Example managed lane toll zone design.

All of the priced managed lane toll zone components need appropriate access for preventive maintenance and other in-field needs. To provide this access, all components should be housed collectively in hardened and protected utility cabinets with sufficient controls to prevent tampering, promote safety for maintenance personnel, and provide easy access. These cabinets should be placed a sufficient distance from the travel way, preferably beyond the clear zone, to provide safer access for maintenance and to minimize the fixed-object hazard to drivers. Sufficient conduits to the gantries are installed under the general-purpose lanes (*2*). Appropriate access to the gantries also needs to be considered for maintenance or replacement of gantry-mounted hardware and similar activities.

Figure 62 shows one example of hardware configuration. Other configurations may place utility cabinets or closets within the median where sufficient width is available; cabinets can be mounted on the gantries, or they can be installed at ground level. This median-oriented configuration allows the conduit to also be installed within the median, eliminating the need to close freeway lanes for conduit-related maintenance.

For median facilities, cantilevered signs from the median can be used to visually separate managed lane signs from others. One solution is to use separate sign structures staggered longitudinally so that each sign sequence on the left (managed) or right (general-purpose) is perceived as a separate sequence, separated laterally and longitudinally. This type of sign structure strategy can be costly, but if addressed early in the design process, proper footings can be installed. For more details on signs to be used on managed lanes, see Chapter 4.

While not strictly a geometric design consideration, the design of the pavement (e.g., driving surface and subbases) should be such that it can accommodate necessary conduits for wiring (e.g., power, communications) below the surface of the roadway. Figure 63 shows an example from Colorado (*88*) of design provisions for conduits and a structure that might be used in a facility represented in Figure 62. Considerations for maintenance of those conduits and the adjacent roadway are discussed in Chapter 6.

Enforcement Systems

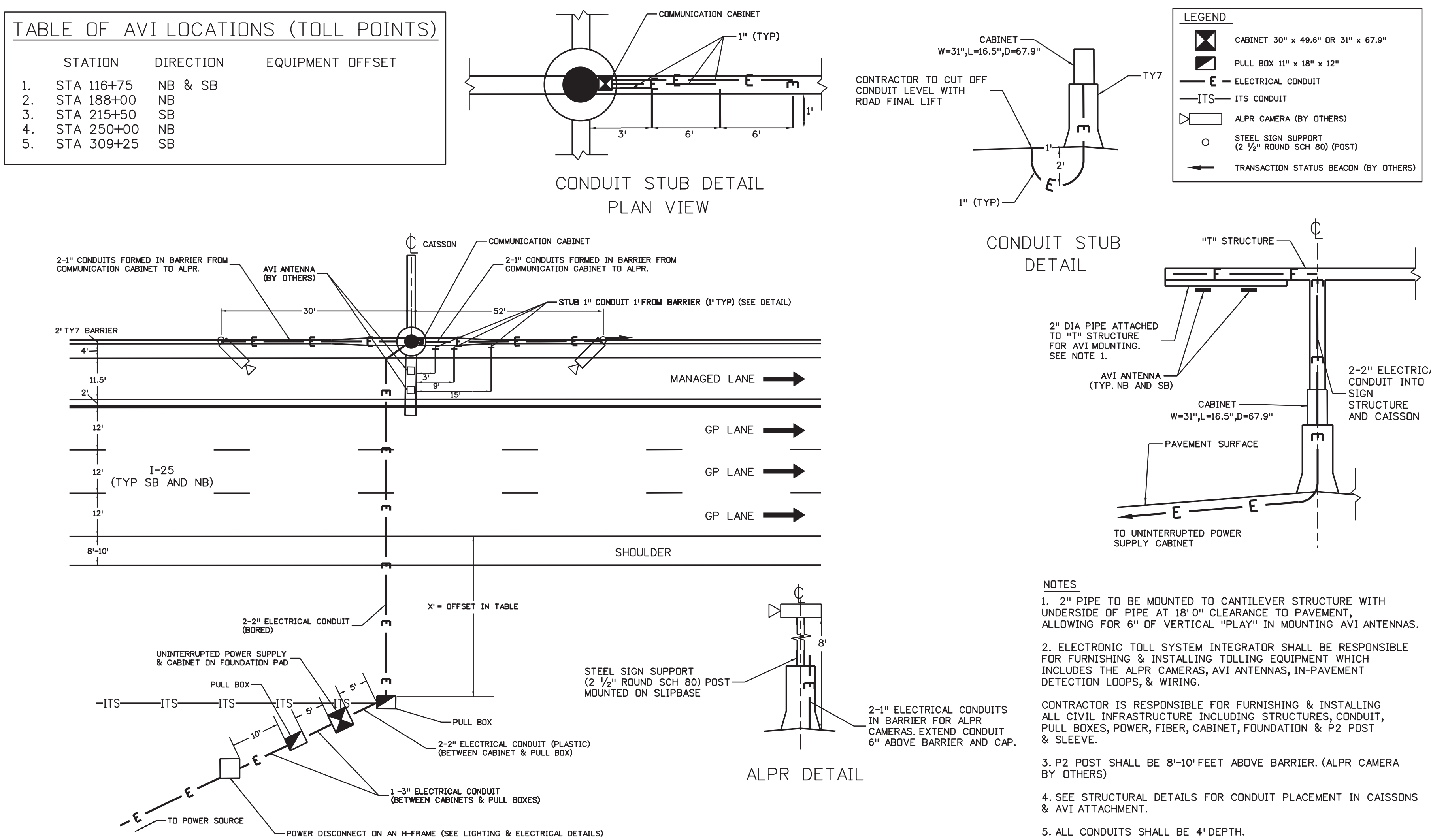
With the vehicle restrictions that are inherent to managed lane facilities, enforcement is necessary to ensure that only authorized vehicles are using the facility. Managed lane restrictions are in addition to traditional traffic violations (e.g., speeding, reckless driving) that must also be addressed. As a result, enforcement officers need accommodation to safely perform their field enforcement duties within the managed lane facility. Enforcement activities that include writing citations and interacting with drivers are more easily accommodated on facilities with full-width shoulders; however, for facilities with narrower shoulders, and for enforcement activities such as observation of vehicle eligibility or traditional traffic monitoring, additional treatments (e.g., enforcement monitoring and pullout areas) may be appropriate. Some states have developed design guidelines for those treatments, which are summarized in this section.

The California HOV guidelines (*53*) call for the following enforcement area configurations, listed in order of preference:

1. Continuous paved median 14 ft or wider in both directions for the length of the HOV facility should be built. If space is available, additional enforcement areas may be built in conjunction with the median.
2. When 14-ft continuous paved median shoulders are not possible, paved bi-directional enforcement areas spaced 2 to 3 mi apart should be built. A separation in the median barrier should be provided for motorcycle officers to patrol the HOV facility in both directions of travel.
3. Where median width is limited, some combination of 1 and 2 should be included.
4. Paved directional enforcement areas should be spaced 2 to 3 mi apart and staggered to accommodate both directions when space limitations do not allow any of the above outlined considerations.
5. Where space is limited, directional enforcement areas should be located wherever right-of-way is available.

Guidance in Washington's *Design Manual* (*55*) states that enforcement of an inside HOV lane can be done with a minimum 10-ft inside shoulder. For continuous lengths of barrier exceeding 2 mi, a 12-ft shoulder is recommended for the whole length of the barrier. For inside shoulders less than 10 ft, enforcement and observation areas should be located at 1- to 2-mi intervals or based on the recommendations of the state police; these areas can also serve as refuge areas for disabled vehicles. Washington's manual recommends observation points approximately 1300 ft before enforcement areas, though they may also be located just downstream of toll gantries within sight of the toll beacon. Observation areas can be designed to serve both patrol cars and motorcycles or motorcycles only. The designer should coordinate with the appropriate enforcement agency(ies) during the design stage to provide effective placement and utilization of the observation points. Median openings give motorcycle officers the added advantage of being able to quickly respond to emergencies in the opposing direction. The ideal observation point places the motorcycle officer at least 18 in. in the median so the officer can look down into a vehicle and see over the barrier. The enforcement area should be located on the right side for queue bypasses and downstream from the stop bar so the officer can be an effective deterrent.

While these examples are based on enforcement of HOV lanes, principles of HOV enforcement can also be applicable to other types of managed lanes. The designer must consider



Source: Colorado DOT (*88*).

Figure 63. Example design provisions for ITS and electrical conduits.

the specific needs of a particular facility when determining what elements to include in an enforcement design. Literature on this topic, as it pertains to the design implications for implementing managed lanes, can be found in the tables in the eligibility validation and enforcement sections within the operations and maintenance chapter (Chapter 6). The section of this chapter that focuses on pullouts provides more guidance on the design of enforcement areas.

Incident Management

Incident management is a critical element for consideration in design of managed lanes. Often, right-of-way considerations limit the corridor envelope, making incident management more challenging. For projects where full shoulders can be developed both inside and outside of the travel lane, incident management is similar to any other freeway setting. However, consideration should be given to incident management regardless of the cross section involved.

Incident management can be broadly divided into three major categories:

- Crash or disabled vehicle.
- Enforcement.
- Natural or man-made disaster.

A response to a crash or disabled vehicle on a managed lane is similar to a response to an incident on a general-purpose lane. If, however, the cross section is limited, it can add complexity to a response plan; several approaches are applied in the design that can be considered to account for unique characteristics of a limited cross section. These include:

- Consideration of access openings or gates in the barrier (i.e., offsets) that allow for easier response on barrier-separated lanes.
- Continuous illumination or spot illumination at access points.
- Emergency pullouts or shoulders periodically provided if continuous shoulders cannot be provided.
- Comprehensive camera surveillance to the traffic operation center.
- Parking or monitoring locations for dedicated tow services for very restricted lane designs and reversible and contraflow treatments.

To better address incidents for the entire freeway and managed lane, dynamic lane control through active traffic management can be employed to enable the managed lane to discontinue operation, if needed, to allow an incident to be resolved. In the case where a substantial amount of shoulder space was used to develop the managed lane, this design can be particularly appropriate. In essence, under conditions when there is no incident, the managed lane provides the potential capacity that the shoulder represents if used as a travel lane, meaning that the additional capacity allowed by the use of the shoulder is usually available, and, when it is not (i.e., when an incident occurs), conditions revert to what they would be without the managed lane being developed. Unless the managed lane is barrier separated, responding to a crash or other incident in the managed lane is similar to responding to an incident in the inside lane of a general-purpose facility. In this scenario, an operation is either better than or no worse than what would be experienced without the managed lane. This design creates an incentive to implement a managed lane even with a restricted cross section.

Dynamic lane-use control may be possible in the general-purpose lanes. In this way, the facility operator can close the affected general-purpose lane(s) and open the managed lane(s) to all traffic. It should also be noted that the type of barrier or buffer plays a role in the effectiveness of this strategy. If a fixed barrier (e.g., a concrete barrier) is used, access to the managed lane to provide incident response can be an issue that is not present with buffer or pylon separation. This factor should be taken into account when selecting the separation treatment and design.

Enforcement should also be considered in incident management. The business rules for the facility will need to address enforcement decisions. For instance, if only specialized vehicles such as buses or emergency vehicles are allowed to travel with no charge and all other vehicles are charged the same toll regardless of occupancy or vehicle type, enforcement is very simple and can be handled primarily through video enforcement coupled with double-white-line or other barrier-crossing violations enforced in the same way as other traffic violations. If discounts or non-tolled usage based on vehicle type or vehicle occupancy are offered, enforcement becomes more complex, often substantially more complex. In these cases, an enforcement area to allow officers to pull over suspected violators will likely need to be developed at periodic locations in the corridor. These areas should be designed to the extent possible to take advantage of areas where additional right-of-way may be available or easily obtained. Guidance on design of enforcement areas was provided earlier in this chapter.

Managed lanes can provide a significant improvement to a corridor's ability to handle emergency operations. Potential scenarios should be developed in advance, and operating strategies should then be developed, as discussed in Chapter 6, Operations and Maintenance. As an example, in a coastal area subject to tropical storms, both sides of an expressway may be devoted to general evacuation in one direction under contraflow operation. However, in these cases, it is necessary to provide emergency personnel with a route into the affected area during the evacuation to respond to problems that can develop. In these situations, the managed lane may be able to operate in the opposite direction of evacuation flow to allow responders to enter the evacuation area.

Incident strategies will be based on the needs of the facility and the community the facility serves. Specific strategies and procedures will need to be developed that take into account the incidents that could occur on a particular corridor.

Drainage and Hydraulic Needs

Drainage considerations for managed lanes are similar, if not identical, to drainage considerations for freeways in general. For managed lanes located to the left of general-purpose lanes, drainage is a particular consideration if the opposing directions of travel are separated by a median barrier. In those conditions, the shoulder should also be designed to handle gutter spread and drainage. In many guidelines, that shoulder width is a minimum of 4 ft, and guidelines are also typically provided for the design and spacing of the drainage inlets, but there is a wide variety of practices in use by agencies across the country, and drainage preferences in one jurisdiction may not be acceptable in another. The designer must take into account the drainage design requirements in effect in the jurisdiction (e.g., a state DOT, county, or city) that apply to a particular managed lane facility.

CHAPTER 4

Traffic Control Devices

Overview

Traffic control devices (TCDs) are an integral part of an overall communication plan to promote user understanding of routing and operations of managed lanes. This chapter provides guidance on how to find relevant sections of the *Manual on Uniform Traffic Control Devices* for application to managed lanes. The chapter also discusses challenges unique to managed lanes regarding selection and placement of signs, pavement markings, and related TCDs. As managed lane designs and operations continue to evolve, TCD plans must depend on the general principles put forth in the MUTCD to provide good signing for both familiar and non-familiar users.

Defining Traffic Control Devices

The MUTCD is approved by the Federal Highway Administrator as the national standard for TCDs on any street or highway open to public travel (*1*). Each state then adopts the federal manual, adds state-specific supplements, or creates its own state manual patterned after the federal version. A list of state MUTCD supplements can be found on the FHWA MUTCD website (*89*). The federal MUTCD website also includes information on interim approvals, interpretations, and revisions. Users of the MUTCD should check the website frequently for updated information. At the time of writing this document, the 2009 MUTCD was in force with the next planned major update to be completed in 2016. The 2009 MUTCD was the first manual to address TCDs for priced managed lanes. This version also reorganized and consolidated past sections on preferential lanes including HOV and bus-only lanes. The MUTCD is referenced extensively throughout this chapter, and the 2009 edition with revisions (*1*) is the version from which the guidelines and standards are drawn. Relevant interim approvals and official interpretations since 2009 are also included in this chapter.

Along with the MUTCD, the federal standard highway signs and markings publication, which includes detailed design information, is available. The layouts for the new signs introduced in the 2009 MUTCD are included in the 2012 supplement to the 2004 edition of *Standard Highway Signs* (*90*).

Another resource that may assist with making general decisions on signs and markings is the *Traffic Control Device Handbook,* Second Edition (*91*); however, the document does not contain specific information regarding managed lanes.

The MUTCD defines a traffic control device as:

> Signs, signals, markings, and other devices used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, pedestrian facility, bikeway, or private road open to public travel by authority of a public agency or official having jurisdiction.

The MUTCD applies to toll roads under the jurisdiction of public agencies or mobility authorities or public–private partnerships. These facilities, including managed lanes, are considered public highways by the MUTCD.

Terms for Toll Collection Methods

Electronic toll collection (ETC) in the MUTCD definitions includes transponders, license plate capture systems that bill a registered user, and license plate capture systems that bill the registered vehicle owner by mail [see FHWA (*1*), p. 13, Definition 59]. As payment systems continue to evolve, these definitions may change. At the time the 2009 MUTCD was being written, license plate capture systems were just entering the marketplace as acceptable forms of payment for vehicles not preregistered in the system. Because of this, the guidance on whether so-called pay-by-mail systems qualify as *registered* ETC accounts is not clear in the MUTCD. In the definition of ETC, pay-by-mail systems are included, but the use of the phrase “registered ETC accounts” elsewhere in the manual may cause confusion. A subsequent MUTCD interpretation request resulted in an official ruling from FHWA regarding such pay-by-mail systems (issued November 2013). This ruling indicated systems that employ license plate capture systems for non-registered users are described in Section 2F.13 of the MUTCD concerning conventional toll roads and that these provisions apply to managed lanes as well. The official ruling included a typical layout drawing for such payment systems for managed lanes (*92*).

Terms for Channelizing Devices

A wide variety of other traffic control devices, ranging from overhead lane controls to gates for reversible and contraflow lanes, can be found in practice and are found in a variety of guidance treatises including the MUTCD. Some devices may be proprietary or customized for specific operations, such as movable barrier treatments for contraflow lanes. In such cases, the devices may not be commonly found in current guidance.

Pylons used to separate managed lane operations from general-purpose traffic are not specifically addressed in the MUTCD. The word "pylon" was first used in managed lane parlance in the 1970s on contraflow lanes in New York City, Marin County, and Houston. Pylon appears in the Texas *Managed Lanes Handbook* (*4*), while California uses channelizers in its state MUTCD (*75*), and Florida uses express lane markers in its state handbook (*72*). The California MUTCD 2014 edition defines channelizers as "flexible retroreflective devices for installation within the roadway to discourage road users from crossing a line or area of the roadway. Unlike delineators, which indicate the roadway alignment, channelizers are intended to provide additional guidance and/or restriction to traffic by supplementing pavement markings and delineation" (*75*).

A review of the federal MUTCD reveals that the device as used with a managed lane is not specifically discussed. The term "channelizing" is a general term covering several devices (e.g., cones, tubular markers, vertical panels, drums, barricades, and longitudinal channelizing devices) that are used for numerous purposes. These include providing for smooth and gradual changes to vehicular traffic flow in conditions such as a reduction in the number of lanes, channelizing traffic away from an area, providing visual separation, or prohibiting lane changing. The temporary traffic control chapter in the 2009 MUTCD shows several examples of channelizing devices in Figure 6F-7 (*1*). The device that is similar to what is installed to separate a managed lane from a general-purpose freeway lane is labeled "tubular markers." Note that the devices shown in MUTCD Figure 6F-7 are orange and white since that chapter is concerned with work zones. Orange should not be used when there is no work zone present.

While these channelizing devices have been used with managed lanes for a long time, they are not described in the national MUTCD for that application, perhaps because they have not been considered a traffic control device but rather a design feature. Whether the device is a traffic control device or a design feature could affect the use and terminology. For example, is the device supplementing another traffic control device such as pavement markings, or is it a stand-alone device? Ultimately, it will be up to FHWA, with input from others such as the National Committee on Uniform Traffic Control Devices, to develop and/or adopt a term on a national level if this managed lane device is considered to be a traffic control device.

For this document, the term "pylon" will be used. Additional discussion on pylons is in Chapter 3 (pylon separation).

Relevant MUTCD Sections

The majority of signs and markings prescribed in the MUTCD apply to managed lane facilities. The MUTCD introductory chapter (2A) for signs contains many general principles, such as for sign spreading, that are applicable and particularly important for managed lanes facilities.

In addition to the overall guidance, the MUTCD contains an entire chapter specific to preferential and managed lanes. The MUTCD uses the term "preferential lane" as a high-level category descriptor for any highway lane that is reserved for the exclusive use of one or more specific types of vehicles or vehicles with at least a specific number of occupants. This term first appeared in the 1976 MUTCD and at that time focused on bus and carpool lanes. The specific type of vehicle in the case of managed lanes could include vehicles with the proper toll payment transponder, those preregistered in some other way, or those willing to pay a fee assessed through license plate recognition. The category of vehicles with a specified minimum number of occupants refers to traditional HOVs. A preferential lane specifies a highway lane, not an entire highway, so toll roads where all lanes are tolled at all times are excluded from this definition. MUTCD Section 2G.01 states that toll roads utilizing ETC payments are not considered preferential lanes.

The MUTCD notes that preferential lanes (Section 2G.01) can be concurrent or contraflow or be on an independent roadway on a separate right-of-way, which would include elevated roadways. These lanes may operate continuously or only at certain times of day. A preferential lane can be buffer separated (including the use of pylons, rumble strips, or other lane-separating devices in the buffer), contiguous (separated from the adjacent general-purpose lane only by pavement markings), or barrier separated.

The MUTCD uses special terminology to distinguish among the many types of preferential and managed lanes. Figure 64 diagrams the relationship among the different terms used in the manual.

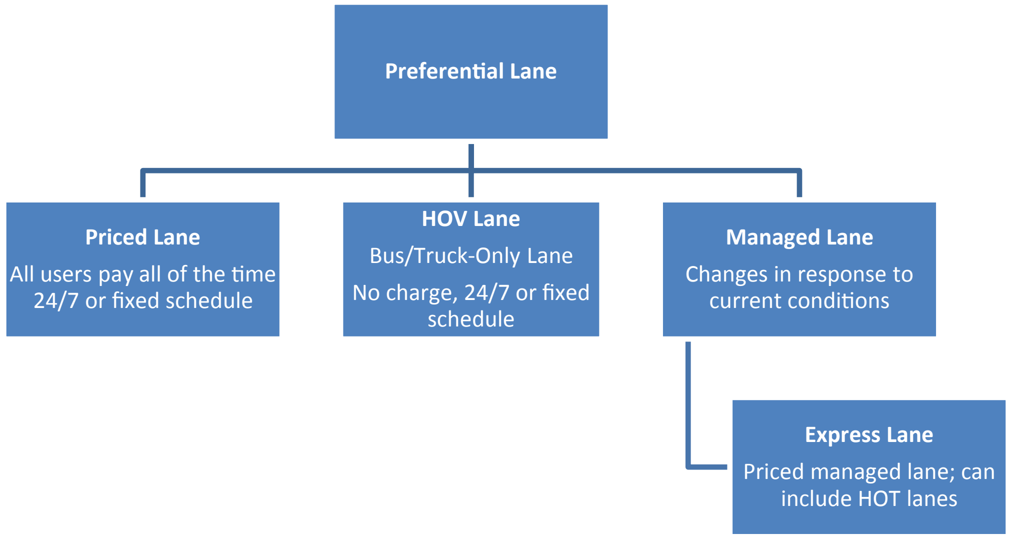


Figure 64. Relationship among different MUTCD terms.

A managed lane in the MUTCD is a type of preferential lane defined as follows:

> Managed Lane—a highway lane or set of lanes, or a highway facility, for which variable operational strategies such as direction of travel, tolling, pricing, and/or vehicle type or occupancy requirements are implemented and managed in real-time **in response to changing conditions** (emphasis added). Managed lanes are typically buffer- or barrier-separated lanes parallel to the general-purpose lanes of a highway in which access is restricted to designated locations. There are also some highways on which all lanes are managed. [FHWA (*1*), Section 1A.13, Definition 112]
>
> Managed lanes typically restrict access to designated locations only. [FHWA (*1*), Section 2G.01]

Priced managed lanes typically use open-road tolling where vehicles travel at highway speeds and pay tolls using a transponder or through license plate capture. The MUTCD provides some definitions related to open-road tolling as it relates to traditional toll roads [FHWA (*1*), Definitions 128–130, p. 17]. The definition of electronic toll collection specifically includes both transponders and optical scanning of license plates as collection methods [FHWA (*1*), Definition 59, p. 13].

The following sections of the MUTCD contain information specific to managed lanes:

- **Chapter 2F. Toll Road Signs.** This chapter includes topics related to purple background color as well as size and use of ETC pictographs. Some of the guidance on placement of regulatory and payment signs over specific lanes at toll plazas could also inform decisions about placement for managed lane approaches and payment areas.
- **Chapter 2G. Preferential and Managed Lane Signs.** This section was based on information for HOV lanes contained in older versions of the MUTCD. For this reason, some users may find it confusing when applying TCDs to newly constructed managed lane facilities not converted from existing HOV lanes. This chapter addresses regulatory, warning, and guide signs for managed lanes. Section 2G.16 contains new content specific to more modern priced managed lanes and how to adapt the HOV sign guidance to apply to priced managed lanes.
- **Chapter 3D. Markings for Preferential Lanes.** This chapter addresses lane markings as well as word and symbol pavement markings.
- **Chapter 3E. Markings for Toll Plazas.** This chapter may be useful to review for possible pavement marking applications in tolling areas for managed lanes.
- **Chapter 3H. Channelizing Devices Used for Emphasis of Pavement Marking Patterns.** This chapter includes guidance for size and color of channelizing devices, such as pylons, tubular markers, vertical panels, and lane separators.

General Sign Design Considerations

Operating agencies are allowed to use pictographs on signs to denote a particular toll payment system. A pictograph is defined as follows:

> Pictograph—a pictorial representation used to identify a governmental jurisdiction, an area of jurisdiction, a governmental agency, a military base or branch of service, a governmental-approved university or college, a **toll payment system,** or a government-approved institution. [FHWA (*1*), Section 1A.13, Definition 146]
>
> Pictographs shall be simple, dignified, and devoid of any advertising. [FHWA (*1*), p. 29]
>
> The ETC pictograph [see FHWA (*1*), Chapter 2A] shall be of a size that makes it a prominent feature of the sign legend

> as necessary for conspicuity for those road users with registered ETC accounts seeking such direction, as well as for those road users who do not have ETC accounts so that it is clear to them to avoid such direction when applicable. [FHWA (*1*), Section 2F.04, goes on to provide guidance on sizes for pictographs]

A pictograph is different than a symbol. The term "symbol" is limited to apply to only traffic control messages, for example, the use of a curved arrow on a warning sign as opposed to the word message CURVE AHEAD. Symbols must undergo human factors testing to determine adequate levels of comprehension, recognition, and legibility. Unique symbols not adopted by the MUTCD may not be used on traffic control devices, except through FHWA's official experimentation process.

> Symbol—the approved design of a pictorial representation of a specific traffic control message for signs, pavement markings, traffic control signals, or other traffic control devices, as shown in the MUTCD. [FHWA (*1*), Definition 227, p. 21]

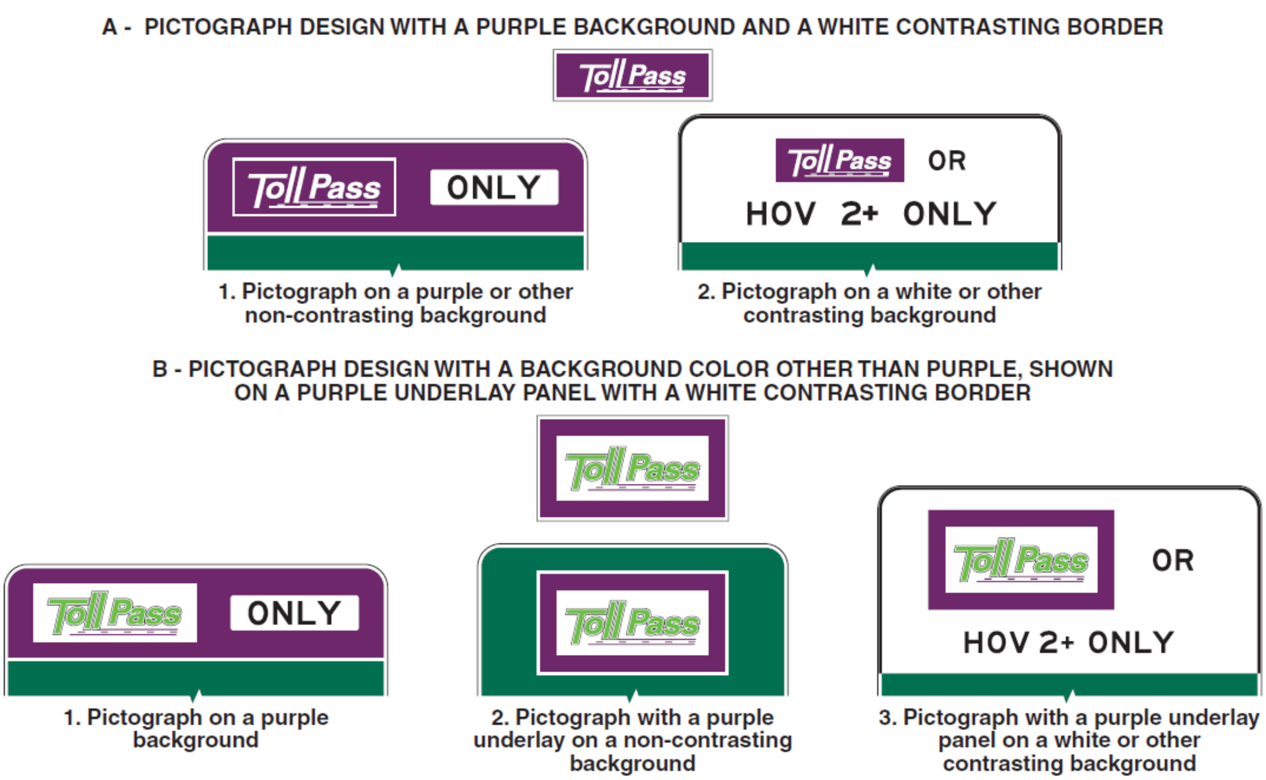
The term "logo" is often used to refer to the image, color, and letters used to identify a particular toll collection system (e.g., TxTag). The word "logo" in the MUTCD is used only on specific service signs [FHWA (*1*), Chapter 2J], such as gas, food, and lodging. In MUTCD parlance, the TxTag logo is called a pictograph (see Figure 65).

Source: TxDOT (*93*), Figure 2F-1TA.

Figure 65. Example of pictograph used in Texas for electronic toll collection.

Section 2F.13, Paragraph 11 provides a standard for the use of the pictograph on guide signs:

> If only vehicles with registered ETC accounts are allowed to use a toll highway, the guide signs for entrances to such facilities shall incorporate the pictograph adopted by the toll facility's ETC payment system and the regulatory message ONLY [see MUTCD Figures 2F-1 (reproduced as Figure 66 in this document), 2F-5, and 2F-6]. The use, size, and placement of the ETC pictograph shall comply with the provisions of Sections 2F.03 and 2F.04.



Source: FHWA (1), Figure 2F-1.

Figure 66. MUTCD examples of ETC account pictographs and use of purple backgrounds and underlay panels.

The 2009 MUTCD assigned the color purple to be used on portions of signs that include information on the required ETC payment system. No sign shall ever contain a full purple background; the purple is always used as the background color for a section of the sign, or as the background color for an underlay panel to provide contrast and emphasis for ETC pictographs. The assignment rules for purple are contained in the MUTCD toll road chapter, Section 2F.03. Because the 2009 MUTCD was unclear about ETC payment systems that use license plate capture, FHWA issued an official interpretation in 2013 that indicates that a purple background is not required for these systems (*92*).

One other section that may be relevant to managed lanes concerns the use of Internet addresses and phone numbers. Many managed lane operators like to provide enrollment information on traffic signs. These are prohibited in general in Section 2A-06 and specifically addressed for application to ETC systems in MUTCD Section 2F.18.

> Except as provided in Paragraph 16 and except for the Carpool Information (D12-2) sign [see Section 2I.11], **Internet addresses and e-mail addresses,** including domain names and uniform resource locators (URL), **shall not be displayed on any sign, supplemental plaque, sign panel** (including logo sign panels on Specific Service signs), or **changeable message sign.** [emphasis added, FHWA (*1*), p. 29]
>
> Section 2F.18 ETC Program Information Signs
> Standard:
>
> 01 Except as provided in Paragraph 2, signs that inform road users of telephone numbers, Internet addresses, including domain names and uniform resource locators (URLs), or e-mail addresses for enrolling in an ETC program of a toll facility or managed lane, obtaining an ETC transponder, and/or obtaining ETC program information shall only be installed in rest areas, parking areas, or similar roadside facilities where the signs are viewed only by pedestrians or occupants of parked vehicles.
>
> Option:
>
> 02 ETC program information signs displaying telephone numbers that have no more than four characters may be installed on roadways in locations where they will not obscure the road user's view of higher priority traffic control devices and that are removed from key decision points where the road user's view is more appropriately focused on other traffic control devices, roadway geometry, or traffic conditions, including exit and entrance ramps, intersections, toll plazas, temporary traffic control zones, and areas of limited sight distance.

One last section to highlight comes in the general design of signs section and provides some flexibility in word messages that managed lane designers may want to use:

> State and local highway agencies may develop special word message signs in situations where roadway conditions make it necessary to provide road users with additional regulatory, warning, or guidance information, such as when road users need to be notified of special regulations or warned about a situation that might not be readily apparent. Unlike colors that have not been assigned or symbols that have not been approved for signs, new word message signs may be used without the need for experimentation. [FHWA (*1*), Section 2A.06 Design of Signs, p. 29]

Guide and Regulatory Signs

The introduction to MUTCD Section 2G.16 is mandatory reading for anyone concerned with the design of signs for priced managed lanes. It makes a number of key points:

- Preferential lanes can be easily named by the type of vehicle that uses them, for example, HOVs or buses.
- It is difficult to establish a naming convention for the various types of managed lanes due to continuing evolution in operational strategies.
- Designing sign sequences for managed lanes must consider access points and the need to repeat operational information near every access point.

The MUTCD makes several distinctions concerning terminology and color for signs based on whether all vehicles traveling that road or lane are required to provide payment through ETC accounts. These standards and guidance are spread across Chapters 2F and 2G. Note that some state MUTCDs (e.g., Texas) have included additional criteria to accommodate local practice and existing regional facilities.

The MUTCD has adopted the term "express lane" to apply to priced managed lanes including those that offer discounts to HOVs. The express lane term only applies to a managed lane that has pricing as one of its operational strategies. For those facilities that only use occupancy eligibility as their management strategy, signs should designate the facility as an HOV lane and use the HOV diamond symbol [see FHWA (*1*), Section 2G.16, Paragraph 07]. The thinking behind this distinction is that the term express lane conveys that some special requirement exists such that access is limited and pricing is employed (along with occupancy restrictions on some facilities). It also distinguishes these lanes (where SOVs and HOVs are both allowed) from traditional HOV lanes where an SOV would be considered a violator.

Since signs in the managed lane may be visible to drivers in the general-purpose lanes, it is critical to distinguish the managed lane signs by the use of a header panel. Examples of header panels can be seen in Figure 66 on the top row. Sign placement can also help distinguish the signs intended for the different users. MUTCD Section 2E.11 includes helpful guidance on the number of signs at overhead installations and discusses the idea of sign spreading.

If a single sign structure supports signs for both the managed and general-purpose lanes, maximum lateral separation while maintaining position relative to the center of respective lanes is desirable. For median-oriented managed lanes, cantilevered signs over the managed lane located from the median barrier can be used to visually separate managed lane signs from others. The best solution is to use separate sign structures staggered longitudinally so that each sign sequence on the left (managed) or right (general-purpose) is perceived as a separate sequence, separated laterally and longitudinally. This type of sign structure strategy can be costly and may result in sign clutter, but if done early in the design process, proper spacing may be achieved. Appropriate structural references and standards should be consulted, such as the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals,* Sixth Edition (*94*).

Sign plans should also include all necessary warning signs, such as those indicating merging traffic (W-4 series), especially for traffic entering from the left. Curve speed advisories, advisory speeds at access points, and lane ending warnings are other examples of typical warning signs used in managed lanes.

Regulatory Signs for Priced Managed Lanes

MUTCD Section 2G.17 addresses regulatory signs for priced managed lanes. Earlier regulatory sign sections [FHWA (*1*), Sections 2G.03–2G.07] address general signing needs that apply to all types of preferential lanes. MUTCD Section 2G.17 addresses exceptions to these standards in the case of priced managed lanes.

Regulatory signs must address pricing, vehicle eligibility, hours of service, and possibly enforcement. The possibility of information overload is great with regulatory signs, especially if a complicated operational strategy is in place. Design choices concerning priority of guide signs compared to regulatory signs will need to be made. This is one area where practitioners should consider alternative methods of communication regarding operational rules rather than try to place multiple signs dense with information near access points.

With full-time priced facilities, it may be necessary to post additional signs or plaques to reinforce the message that tolls will be collected, particularly in advance of and at entrance ramps. The standards in MUTCD Chapter 2F concerning toll roads also apply to full-time priced facilities and require the posting of the word TOLL prior to the entrance before there is no opportunity to take another route [FHWA (*1*), Section 2F.13]. This MUTCD chapter further stipulates the addition of the ETC-only auxiliary sign, which is the agency's pictograph along with the word ONLY [FHWA (*1*), Section 2F.12].

The toll message can be introduced in route sign assemblies serving surface street access points, as shown in MUTCD Figure 2F-4, which illustrates a yellow plaque with the word TOLL in black letters above the route cardinal direction plaque. For freeway access points, a similar yellow sign indicating LAST EXIT BEFORE TOLL may be needed at points where a non-priced managed lane transitions to a priced managed lane [FHWA (*1*), Section 2F.10]. The sections concerning regulatory and guide signs for toll facilities [FHWA (*1*), Sections 2F.10–2F.12] should be consulted for additional information. Although these sections are intended for traditional toll facilities, the principles they contain can be applied to priced facilities.

The issue of whether or not to post NO CASH messages at access points is one that every ETC toll facility has faced. If license plate recognition tolling is implemented, however, the need for these signs may not be as great. If drivers enter the facility expecting to pay cash and later receive a video tolling bill, the billing statement can include additional educational information about regulations and obtaining a transponder. This approach could generate a few angry customers at first but would reduce the risk of driver information overload due to cluttered signs. If there are other toll facilities in the region that accept cash, the need for the NO CASH sign is greater in order to differentiate it from other facilities.

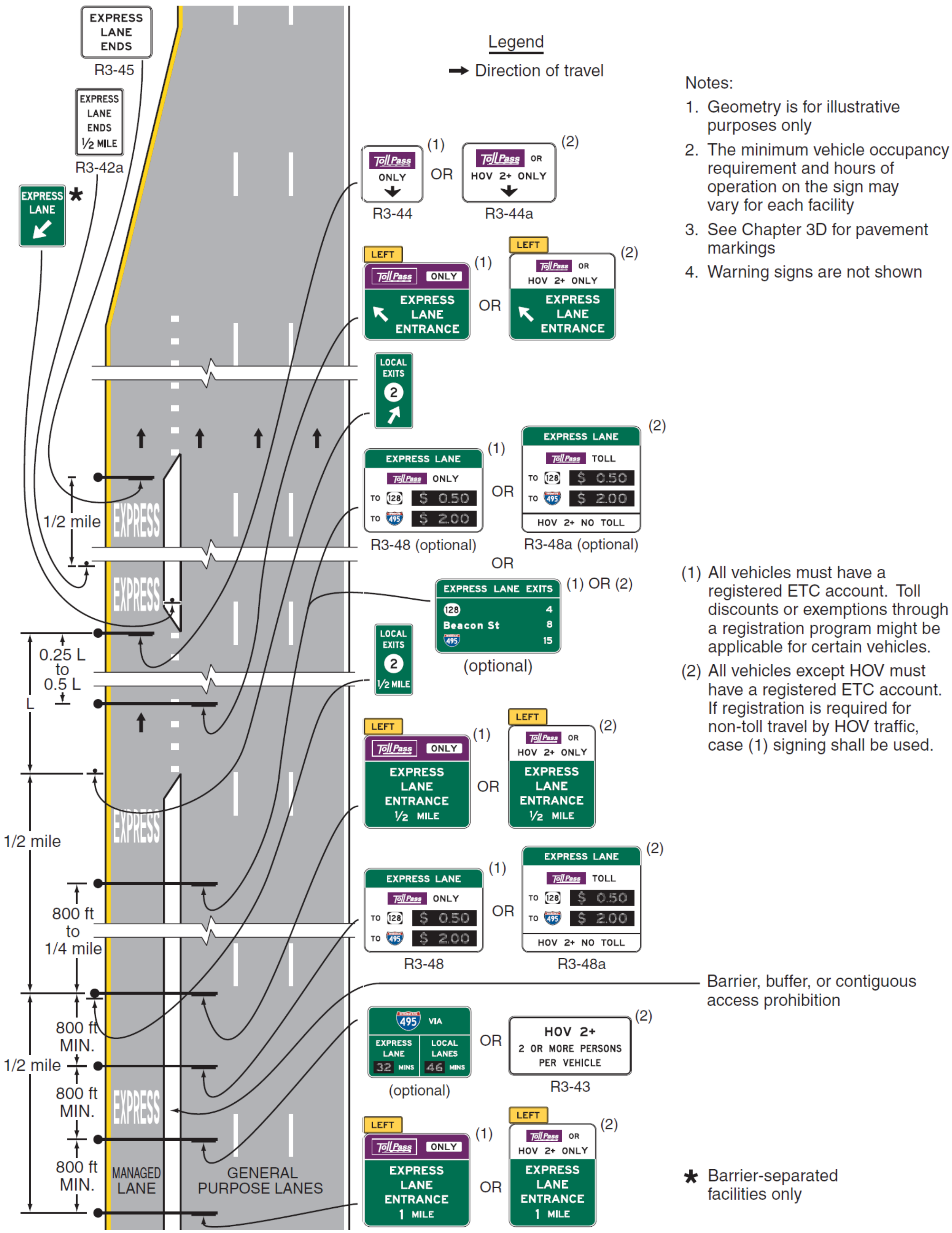
Guide Signs for Priced Managed Lanes

MUTCD Section 2G.18 contains information for guide signs for priced managed lanes. It includes several layout drawings of sign sequencing at access points to managed lanes. One example is shown in Figure 67. State DOTs and other operating agencies must adapt the guidance provided in the MUTCD for their own unique situations. WSDOT developed the typical signing plan shown in Figure 68 for a new managed lane facility opening in the Seattle area in 2015. Note that some of the signs shown in the plan do not conform to MUTCD guidance regarding maximum number of lines per sign for changeable message signs. WSDOT did follow MUTCD guidance on providing an exit destination supplemental guide sign to indicate general-purpose lane exits served by the upcoming egress points. Note that WSDOT uses the word ACCESS on the advance signs for the general-purpose lane to the managed lane rather than the word ENTRANCE used in the MUTCD examples.

Driver Information Overload and Driver Expectancy Violations

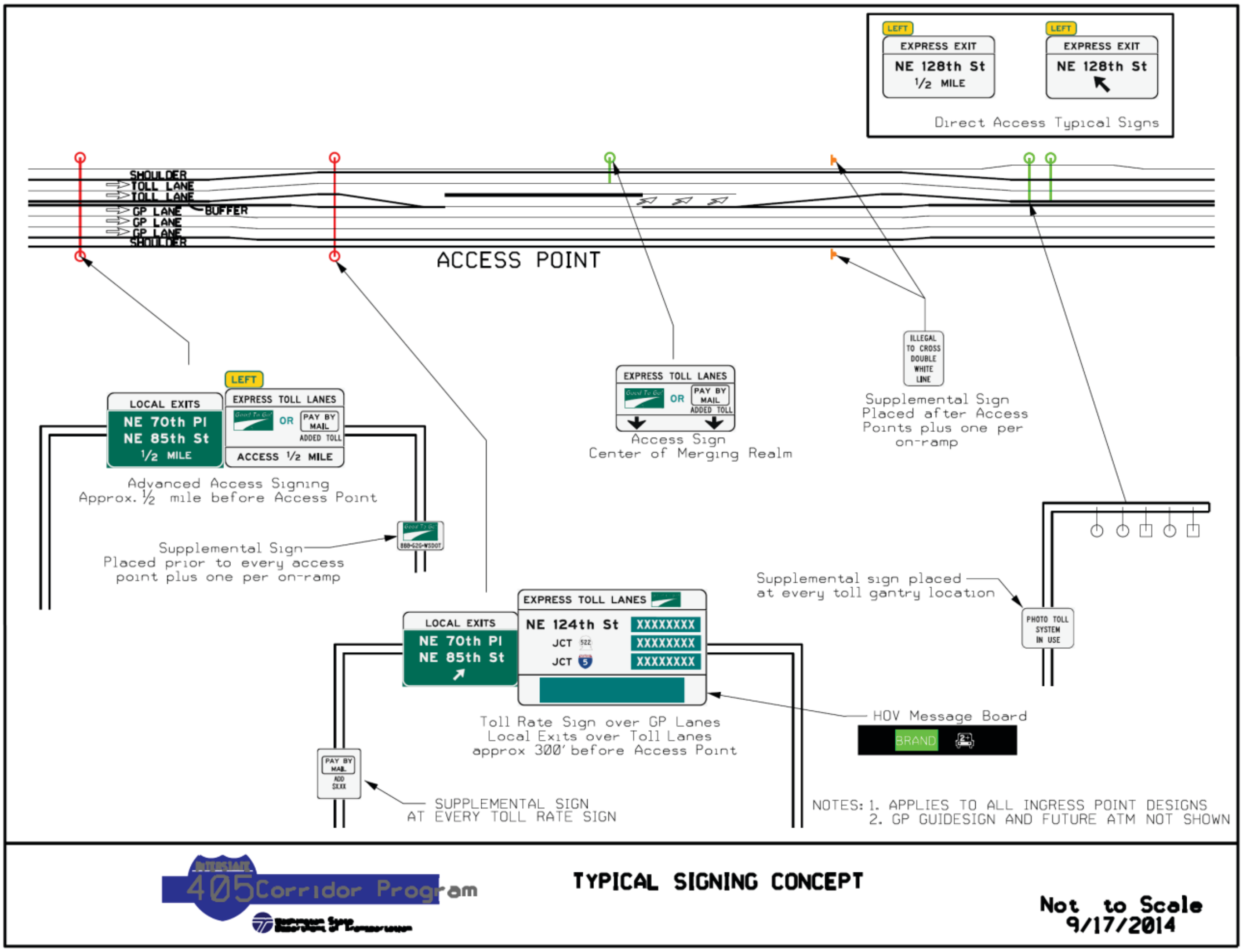
When designing sign sequences for managed lanes, it is very easy to overload the driver. The MUTCD provides some guidance on priority of signs in Section 2G.10 and more generally in Section 2A.16:

> The Preferential Lane signs should be designed and located to avoid overloading the road user. Based on the importance of the sign, regulatory signs should be given priority over guide signs. The order of priority of guide signs should be Advance Guide,



Source: FHWA (*1*), Figure 2G-24.

Figure 67. MUTCD example of signing for the intermediate entry to, egress from, and end of access-restricted priced managed lanes.



Source: Chuck Fuhs, WSDOT.

Figure 68. Typical signing layout for I-405 managed lane in Seattle.

> Preferential Lane Entrance Direction, and finally Preferential Lane Exit.
>
> Because regulatory and warning information is more critical to the road user than guidance information, regulatory and warning signing whose location is critical should be displayed rather than guide signing in cases where conflicts occur. Community wayfinding and acknowledgment guide signs should have a lower priority as to placement than other guide signs. Information of a less critical nature should be moved to less critical locations or omitted. [FHWA (*1*), Section 2A.16, Paragraph 10]

Several key issues related to sign design and installation to reduce driver information overload are addressed in MUTCD Section 2D.07 with the following guidance statement:

> Except where otherwise provided in this Manual, guide signs should be limited to no more than three lines of destinations, which include place names, route numbers, street names, and cardinal directions. Where two or more signs are included in the same overhead display, the amount of legend should be further minimized. Where appropriate, a distance message or action information, such as an exit number, NEXT RIGHT, or directional arrows, should be provided on guide signs in addition to the destinations. [FHWA (*1*), Section 2D.07, Paragraph 02]

Research has shown that one of the main reasons drivers do not use managed lanes is that they are not sure where they go (*95*). This uncertainty can be addressed in a signing plan using one or more of the following techniques:

- Supplemental guide signs before and along the route of the managed lane can be used to provide information about which exit to use to access major traffic generators and major roads and streets not directly served by the managed lanes.

- Use of an exit destination sign well in advance of the entrance point can inform potential managed lane users in the general-purpose lanes which exits are served while also notifying drivers already in the managed lane of upcoming exit points. This is illustrated in Figure 69.
- Interchange sequence signs that list the distance and destination of the next few exits can also help. An example of interchange signs can be found in MUTCD Figure 2E-31. The application guidance for these signs is found in MUTCD Section 2E.40. They are typically used in advance of and just after interchanges the entire length of a route in urban areas. If one considers an access point to or from a managed lane to be a type of interchange, then the guidance in this section is easily applied. Another way to indicate destinations served is through the use of NEXT EXIT X MILES plaques, as described in MUTCD Section 2E.35.
- Guide signs at intermediate egress points that reference local exits served by those egress points help reinforce the access plan for the managed lane for drivers in the lane and in adjacent general-purpose lanes [FHWA (*1*), Section 2G.18].
- All guide signs along the route must be consistent in their use of control cities and destination names [see FHWA (*1*), Section 2E.13]. Likewise, signs should be consistent in the use of numbered highways or the common name of a route (e.g., State Highway 67 vs. Beltline Rd.).

The overall sign sequence must consider spacing and placement to avoid further driver overload.

Drivers may also be confused about destinations served due to an imbalance in directions served at interchanges and access point:

- A managed lane is often designed to serve only one direction of travel (e.g., toward downtown) at an interchange. Where the managed lane intersects with another major freeway, it may be the case that drivers can access the intersecting freeway in only one direction. All interchange sequence and advance guide signs must indicate the cardinal direction of routes where only partial access is provided.
- Many surface street or T-ramp access points offer access in only one direction. This is particularly common near the terminus of the managed lane where a direct-access ramp may be provided for inbound traffic but outbound traffic is expected to use the exit from the general-purpose lane. This can be addressed in informational materials and with signing as space permits to indicate inbound only access.

Source: FHWA (*1*), Figure 2G-19.

Figure 69. MUTCD example of an exit destination sign for a managed lane.

As with general freeway design and signing, any roadway geometry that violates driver expectancy poses safety issues as well as decreased capacity:

- It may be the case that some access points have unexpected directions of travel or directions of turns from surface streets. For instance, in order to access a southbound managed lane, an access ramp may need to run north before turning around to reach the southbound travelway. In cases like this, additional confirmation signing may be needed on the ramp as it is heading north to assure drivers that they are on the correct ramp.
- Connector ramps from managed lanes to major interchanges may come earlier than expected and run parallel (or as a collector road) for quite a distance before turning to meet an intersecting freeway. A confirmation or pull-through sign should be provided to reassure drivers that they have taken the proper ramp.
- This is also true for at-grade access points requiring merging and crossing several lanes of traffic to reach the downstream general-purpose ramp. Supplemental advance guide signs may be needed to alert drivers to exit the managed lane well before their destination is visible.
- Left exits violate driver expectancies. All signs for access to and from the managed lanes should follow the guidance found in the general guide sign sections of the MUTCD. These include the use of a LEFT or left exit number plaque along the top of the sign [FHWA (*1*), Section 2E.31]. Note that the use of a full-width LEFT EXIT plaque at the bottom of the sign is not permitted by the MUTCD. The use of pull-through signs at left exits is also recommended to reinforce the main travelway for local-access left-hand ramps from the managed lane [see FHWA (*1*), Section 2E.12]. Left-side-oriented ramps may need to be treated with skip stripes across the gore to emphasize the mainline travel path for motorists.
- When a facility includes both at-grade access points and grade-separated ones, it is necessary to indicate direction of the exit. The geometric design should be analyzed for direction of access in terms of how a driver enters or exits at

each access point. If drivers entered the lane by changing lanes to the left, then a right-exit flyover ramp might violate their expectation of how they will exit. By listing the directions of access, the designer can highlight potential areas for confusion and provide for additional advance signing, particularly for multilane facilities.

Special Considerations for Surface Street Access Points

MUTCD Section 2D.37 Destination Signs provides guidance on how to utilize destination names on guide signs on surface streets. The principles contained in this section may apply to certain managed lanes access points.

MUTCD Section 2D.44 Advance Street Name Signs contains helpful information about use of phrases such as NEXT RIGHT to aid wayfinding to managed lane access points from surface streets.

MUTCD Section 2D.45 Signing on Conventional Roads on Approaches to Interchanges covers signing from conventional roads approaching interchanges. Again, these principles will apply to advance managed lane signs for access points from surface streets. The use of an entrance direction sign with directional arrows allows the driver to be in the proper lane well before the turn into the managed lane. This is especially true if the managed lane entrance point is separate from the entrance to the general-purpose lanes. Examples of these types of signs applied to managed lanes can be found in MUTCD Figure 2G-18. Wherever possible, these advance signs should be placed overhead to maximize visibility. Such advance entrance and trailblazer signs can use an auxiliary plaque containing the ETC pictograph [see FHWA (*1*), Figure 2G-18].

Drivers may change their mind about using the managed lane once they see the current toll or estimated travel time. For this reason, open-access zones or paths at each access point to provide a way for drivers to avoid entering the lane after seeing the price, time, or destination sign should be provided. For surface streets, this may mean placing these signs well in advance of the entrance point and not placing them on entrance ramps where drivers have already committed to entering.

Exiting to surface streets requires adequate deceleration lane length along with an Exit Advisory Speed sign (W13-2). For many T-ramps, the intersection with the surface street is signal controlled, so a Signal Ahead sign (W3-3) may be appropriate on the T-ramp. In order to reduce weaving on the stem of the T-ramp, supplemental lane assignment signs on deceleration ramps exiting the managed lane should inform drivers which lane to be in for major traffic generators prior to the intersection.

Changeable Message Signs

A changeable message sign (CMS) is a traffic control device that is capable of displaying one or more alternative messages and can have a blank mode when no message is displayed. CMSs cannot include advertising, animation, rapid flashing, fading, dissolving, exploding, scrolling, or other dynamic elements. The MUTCD contains specific language regarding the design and operational use of CMSs (e.g., number of lines, number of characters per line, spacing, minimum character height, and width-to-height ratio) and the design of CMS messages (e.g., length and units of information). For brevity, these items are not discussed in detail herein, and the reader is referred to MUTCD Chapter 2L.

The colors used for the legends and backgrounds on CMSs must comply with the common static sign colors. If a black background is used, the color used for the text on a CMS should match the background color of the static sign it is displaying (e.g., white for regulatory). The MUTCD acknowledges newer full-matrix, full-color CMSs and encourages their use. However, the messages, signs, and symbols must comply with the applicable provisions for that type of message provided in the MUTCD. The message should be designed so that it is legible during normal daytime and nighttime conditions from at least 800 ft and 600 ft, respectively. When the legibility distance cannot be practically achieved or environmental conditions reduce visibility and legibility, messages composed of fewer units of information should be used and the message should be limited to a single phase.

CMSs may be used to change the speed limit for traffic or ambient conditions (see example in Figure 70) for managed

Source: Beverly Kuhn.

Figure 70. Changeable message sign near Seattle indicating current managed lane speed limit different from general-purpose lanes.

Source: Google Earth.

Figure 71. Variable occupancy messages displayed on changeable message sign over HOV lane on I-405 Express Lanes in Seattle.

lanes and general-purpose lanes. CMSs on roadways with speed limits 55 mph or higher should be visible from 0.5 mi under both day and night conditions.

CMSs are most appropriate when travel conditions change or where operational approaches are varied throughout the day, week, or in real time. A CMS may be used to supplement, substitute, or be incorporated into preferential lane regulatory signs. Figure 71 illustrates CMS messages used by WSDOT on the I-405 Express Lanes to indicate current lane occupancy requirements. These messages are incorporated into static signs to indicate current occupancy requirements or toll pricing if applicable (*96*). MUTCD Section 2G.03, Paragraphs 23–25, contain information about using CMSs to display variable occupancy regulatory information as well as open/closed lane status information.

Back-up and Fail-Safe Modes for Changeable Message Signs

When designing power and communications systems for CMSs, agencies should provide appropriate back-up and fail-safe modes. Operating procedures should specify the default occupancy and/or toll that is to be displayed on the CMS in case of power or communication failure. Providers should have a return-to-service requirement in line with the frequency at which messages typically change.

Variable Pricing and Occupancy Changeable Message Signs

CMSs displaying tolling information that varies by time of day and type of vehicle are described in the MUTCD [see FHWA (*1*), Figure 2G-21]. When locating pricing signs, the designer should consider the sufficient distance needed between the sign and the access point so as to provide drivers with ample time to make their cost–benefit decision about whether to enter the priced lane. Driver workload is high near access points due to lane changing, weaving, and speed maintenance. For this reason, pricing signs should not be placed immediately at the gore point of the access point. Pricing signs should be placed upstream so the driver has time to decide whether to enter and then has adequate time to complete the vehicle maneuvers to do so. Drivers must be able to rely on the information provided by the CMS. The designer should coordinate with the developers of the concept of operations and/or business rules for facility operation to ensure that changes to the toll charged on the facility allow drivers that have seen the previous rate displayed on the CMS to be charged the rate displayed when they were observing the sign.

Some agencies use a two-phase CMS to alternate travel time information with pricing or occupancy information. While this is technically allowed in the MUTCD, driver information overload is a concern with this practice if adequate sign spacing is not provided.

Traveler Information

CMSs can be used to provide traveler information concerning incidents in the managed lane, work zone activity, and other advisory information. CMSs on general-purpose lanes should be used to provide advanced information about managed lane conditions. Messages on general-purpose CMSs must be clear in indicating that the advisory condition exists in the managed lane, not the general-purpose lane. The MUTCD does not currently have standards or guidance as to how to accomplish this. Table 2L-1 of the MUTCD provides guidance on the structuring of multiple line messages and recommends using the first line to state the nature of the incident and the second line to indicate where the incident is occurring. Applying this principle would result in listing the name of the managed lane (e.g., express lane, HOV lane) on the second line.

Travel information CMSs located *in* the managed lane could be used to display general-purpose lane conditions prior to an egress point. These signs will be visible to general-purpose drivers, so some agencies have used the header panel from the managed lane static sign and placed it above the CMS to indicate that the sign is intended to be read by drivers in the managed lane. The MUTCD does not provide guidance on this practice.

Traveler information can also include travel time information. Many drivers will base their decision on whether to use the managed lane on their perception of the travel time savings. If properly instrumented, managed lane travel times can be estimated and incorporated into a traffic management center travel time and speed information system. MUTCD Figure 2G-20 illustrates a travel time information sign that compares times in the managed lane to the general-purpose lane. This type of sign should appear in a sequence that includes advance exit information signs (listing managed lane exit points) and pricing signs to further inform the driver of the costs and benefits of using the managed lane. Research has shown an even split in driver understanding regardless of whether the toll price sign came before or after a comparative travel time sign (*95*).

The MUTCD prohibitions on displaying phone numbers and website addresses applies to CMSs as well as static signs.

Lane-Use Control Signals

Lane-use control signals are overhead signals located over a certain lane or lanes that permit, prohibit, or indicate the impending prohibition of the use of lane(s). Lane-use control signals can be used for controlling reversible lanes in addition to indicating the open or closed status of one or more freeway lanes when any of the following situations apply:

- It is desired to close certain lanes at certain hours to facilitate the merging of traffic from a ramp or other freeway.
- An indication of a lane ending is needed, such as near the managed lane terminus.
- A lane may be temporarily blocked by a crash, breakdown, construction, or maintenance activities, or similar temporary conditions.

Shoulder-use managed lanes, in particular, benefit from lane-use control signals or larger CMSs that display open and closed status using word messages.

Display

Figure 72 presents the lane-use control signal symbols currently included in the MUTCD and their meanings. A steady downward green arrow is used to indicate a lane is open to drivers. A steady yellow X is used to alert motorists of the need to vacate the lane over which the steady yellow X is displayed. A steady red X tells motorists that the lane is closed and they should not be driving in that lane. MUTCD Section 4M.04 contains standards and guidance on lane-use control signal operation.

Each lane that may be closed must have a signal face capable of displaying the downward green arrow and red X symbols. Note that all of the symbols are steady (i.e., they do not flash). Lane-use control signals must be operated continuously, except those used only for special events or other infrequent occurrences and those on non-reversible freeway lanes, which can be darkened when not in operation.

Location

MUTCD Section 4M.03 specifies that color of the lane-use control signals must be clearly visible for 2300 ft under normal atmospheric conditions, unless otherwise physically obstructed (e.g., horizontal or vertical alignment). If the segment to be controlled is longer or physically obstructed, intermediate lane-use control signals must be located over each lane at frequent intervals. Motorists must be able to see at least one signal and preferably two along the roadway. Lane-use control signals must also be located as follows:

- In a straight line across the roadway.
- Approximately at right angles to the roadway alignment.
- Approximately over the center of the lane controlled.

Reversible and Contraflow Lane Traffic Control Devices

Little national or practitioner guidance is specifically provided for reversible and contraflow lanes because there are so few applications, and the application often needs to be customized to each setting and design. General TCD guidance is summarized in this section for features that are considered most critical to each design.

Reversible Lanes

Operations on reversible lanes typically function inbound in the morning and outbound in the afternoon, and as such, the facility functions in one direction or the other during most hours of the day and night. These lanes employ gates, channelized access treatments, and other traffic control devices to help prevent potential wrong-way movements, which represent the greatest safety need. While some customized TCD

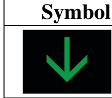
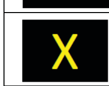
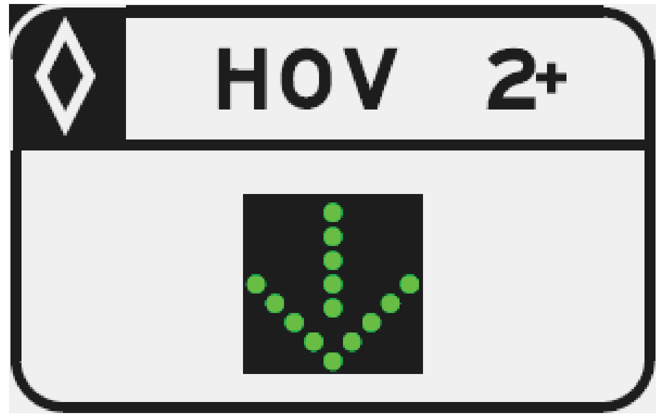
Symbol	Name	Meaning
	Steady Downward Green Arrow	Permitted to drive in the lane
	Steady Yellow X	Prepare to vacate the lane
	Steady Red X	Not permitted to use the lane

Figure 72. Summary of 2009 MUTCD lane-use control signals.

concepts are applied, most employ the following devices at channelized high-speed ramps with general-purpose lanes:

- Railroad gate arms of varying length to block off the ramp transition to the gore point. Placement is every 50 to 60 ft and usually involves a series of 4 to 10 gates depending on the length of the ramp taper (see Figure 73).
- Crash attenuation devices at the ramp gore, usually in front of a concrete barrier.
- Lane control or CMS to indicate the ramp is open or closed (see Figure 74).
- Breakaway gate (in open or closed position). A vehicle-arresting device is used to stop a vehicle that goes through the breakaway gate. The screen is often automated and lowered into position only when the ramp is closed. A typical installation is shown in Figure 75.
- Similar series of railroad-type gate arms inside the reversible lane to channelize managed lane traffic away from the closed gate and out the other side.

Fewer of these vehicle-arresting devices are employed at low-speed intermediate-access ramps from a surface street or transit support facility. The minimum device complement at these locations may include advance CMS signing, lane control or CMS lane status at the entrance, and a gate that is closed. Traffic cones are sometimes used in advance of the gate to reinforce status. Figure 76 shows the reversible lane entrance/exit on I-35E in Dallas.



Source: FHWA (*1*), Figure 2G-1.

Figure 74. Lane control at reversible lane entrance.

Most projects are at least semi-automated, allowing the transition from one direction to the other to be accomplished remotely from a traffic operation center or off-site location. Confirmation of proper transition of gate closures and changes in traffic control devices using live video feeds can be useful, and almost all projects employ some modest on-site presence to verify there are no stalled vehicles in the facility prior to opening and TCDs are properly engaged for the requisite operation period.

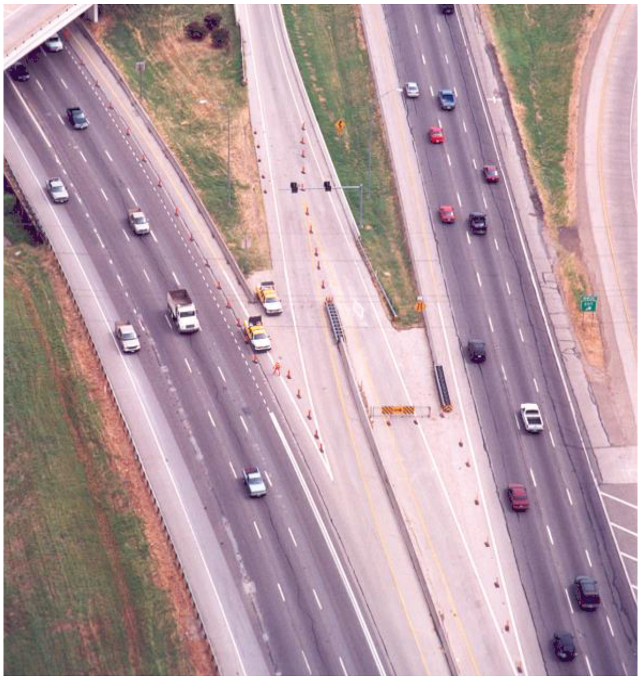
Optional traffic control devices along a reversible lane may include lane controls to reinforce the direction of travel and post information about operational status of downstream exits.

Source: Chuck Fuhs.

Figure 73. Transitional gate arms.

Source: Chuck Fuhs.

Figure 75. Tower vehicle-arresting device in place when the managed lane is closed.



Source: TTI.

Figure 76. Reversible lane entrance/exit on I-35E in Dallas.

Contraflow Lanes

As noted in the glossary, contraflow lanes borrow an off-peak direction lane on a controlled-access roadway and operate it in the peak direction during high-demand periods typically coinciding with the morning and afternoon peak hours. Contraflow lanes require a full complement of on-site operational staffing to safely separate the lane, usually employing either a movable barrier or pylons placed into pre-drilled holes in the pavement. Either approach means that the level of automation and sophistication associated with placement of traffic control devices needs to first and foremost protect motorists and deployment personnel. Therefore, setup procedures when closing the lane must travel with the flow of traffic, protecting deployment personnel from their rear and reversing when traffic control devices are removed. Figure 77 shows a typical deployment for a movable barrier, and Figure 78 illustrates a typical deployment for pylons.

The most important aspect of contraflow design from a TCD standpoint is the crossovers that allow traffic to enter and exit the borrowed lane on each end (see example in Figure 79). Crossovers involve various forms of gating, movable barrier alignments, advance signing, and often supplementary traffic cones to channelize traffic into or away from the crossover, depending on the operating condition. All forms need to consider breakaway design features in case they are struck by a motorist.

Source: Chuck Fuhs.

Figure 77. Deployment of contraflow lanes by movable barrier.

The crossover needs to include the same advance signing found for any other type of managed lane, plus the posted lane status through CMS elements in the sign.

Pavement Markings

MUTCD Chapter 3D provides information on markings for preferential lanes. Several considerations address managed lane pavement markings and may not be evident on reading the referenced sections. Since managed lanes, by their very operational nature, create a speed differential between themselves and adjacent lanes, separation markings need extraordinary attention. Markings installed need to be bold

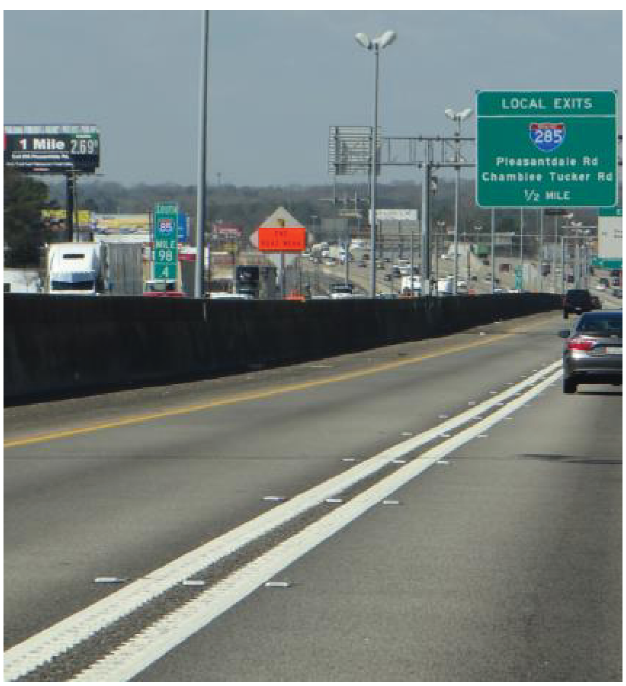
Source: Chuck Fuhs.

Figure 78. Deployment of contraflow lanes by pylons.

Source: Chuck Fuhs.

Figure 79. Typical median crossover on a contraflow lane on I-30 in Dallas.

and may need to consider strategies such as rumble treatment that discourage motorists from crossing the marking if the lane is access restricted (see Figure 80 for example). MUTCD Section 3A.06 provides basic definitions of double lines, solid lines, broken lines, etc., that should be considered when designing preferential lane markings.



Source: Chris Swenson.

Figure 80. Double white wide lane lines separating managed lanes and general-purpose lanes on I-285 near Atlanta.

Word and Symbol Markings

Words and symbols can be powerful communication tools to reinforce to drivers that they are about to enter a managed lane and to provide confirmation en route that they remain in the lane. Pavement markings with words and symbols are considered supplementary to signs. Words and symbols may also be desirable in declaration lanes in tolling zones where vehicles separate based on occupancy while passing under a tolling gantry.

MUTCD Section 3D.01 dictates the standards for color and placement of preferential lane word and symbol markings, noting that all markings shall be white and shall be positioned laterally in the center of the preferential lane.

For contiguous buffer-separated lanes, an additional standard calls for the lane to be marked with one or more of the following symbol or word markings for the preferential lane use specified:

- HOV lane—diamond-shaped symbol.
- Toll lane—word marking indicating ETC account only, such as E-Z PASS ONLY (e.g., MUTCD Section 3D.01).
- Bus-only lane—word marking BUS ONLY.
- Other type of preferential lane—word marking appropriate to the restriction.

For facilities that use more than one operational strategy, the symbol or word marking for each use shall be installed. This means that for managed lanes that function as HOV lanes and toll lanes, both the HOV diamond and the ETC account word (e.g., E-Z PASS ONLY) should appear in the lane in sequence.

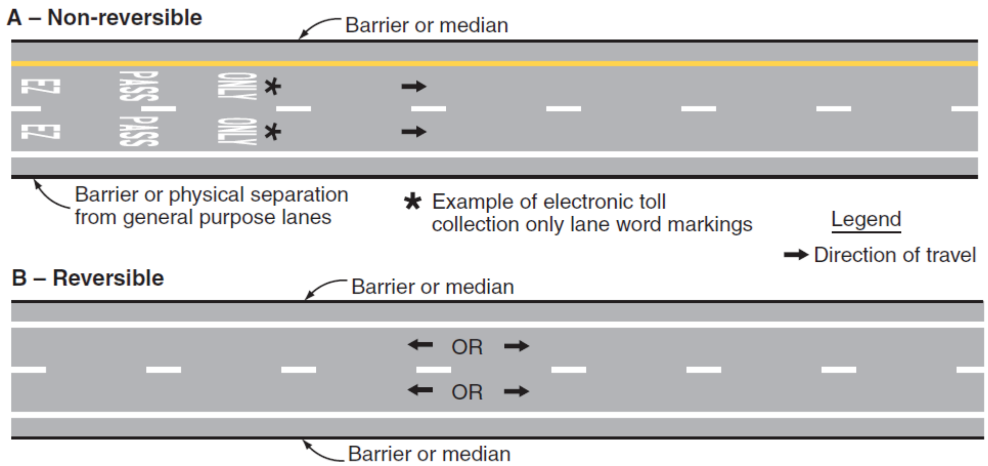
MUTCD Section 3D.01 provides guidance and support statements regarding the spacing of the markings, recommending engineering judgment that considers the prevailing speed and other factors such as sight distance. It also advises that preferential lane markings should be placed at strategic locations such as major decision points and should be visible to approaching traffic from all applicable lanes.

MUTCD Chapter 3E contains information about markings at toll plazas that may also be considered when marking tolling zones within managed lanes.

Separation from Main Lanes

Longitudinal markings serve two purposes for managed lane facilities: to indicate when ingress and egress are allowed and to provide demarcation of the travel lane. Regardless of whether the managed lane is separated from the general-purpose lane by barrier or buffer, pavement markings are a key component of the TCD plan.

Reversible facilities have unique pavement marking needs because the typical application of yellow markings on the



Source: FHWA (*1*), Figure 3D-1.

Figure 81. MUTCD markings for barrier-separated preferential lanes.

left to indicate opposing traffic depends on the direction of travel. MUTCD Figure 3D-1 is reproduced here as Figure 81 and illustrates the basic lane line color applications for reversible and non-reversible facilities.

Separation for concurrent lane treatments takes the form of either a single wider-than-typical pavement marking or a delineated buffer employing typically two parallel markings. The width of the buffer varies, and some are much wider and incorporate pylons or other channelizers to separate traffic flows. Buffers may include gore markings (Figure 82A), but this treatment can be more complicated to maintain. Maintaining marking presence also deserves more attention than typical in order to define the space for the faster-moving lanes.

For buffer-separated preferential lanes located on the left-hand side, a normal solid yellow lane is on the left-hand edge, while one of the following is on the right-hand edge:

- Where crossing of the buffer is prohibited: a wide solid double white line along both edges of the buffer space (see Figure 82A).
- Where crossing the buffer is allowed but discouraged: a wide solid single white line along both edges of the buffer space (see Figure 82B). WSDOT implemented the single white line on SR-167 to allow continuous access to the managed lane, after initially operating the lane with designated access points. An image used in the public information concerning the change is shown in Figure 83.
- Where crossing the buffer space is permitted, such as at ingress/egress areas: a wide broken single white line along both edges of the buffer space, or a wide broken white lane line within the buffer space (see Figure 82C).

The prohibited and discouraged movements shown in Section C of Figure 82 (which is an exact reproduction of Figure 3D-2 from the MUTCD) conflict with an earlier section of the MUTCD. In MUTCD Section 3B.04, there is a standard that states the following: "Where crossing the lane line markings is prohibited, the lane line markings shall consist of a solid double white line." This inconsistency should be corrected in future editions of the MUTCD.

The 2009 MUTCD also provides guidance regarding right-hand-side, buffer-separated preferential lanes and contiguous preferential lanes, which are typically found on surface streets for bus or taxi lanes.

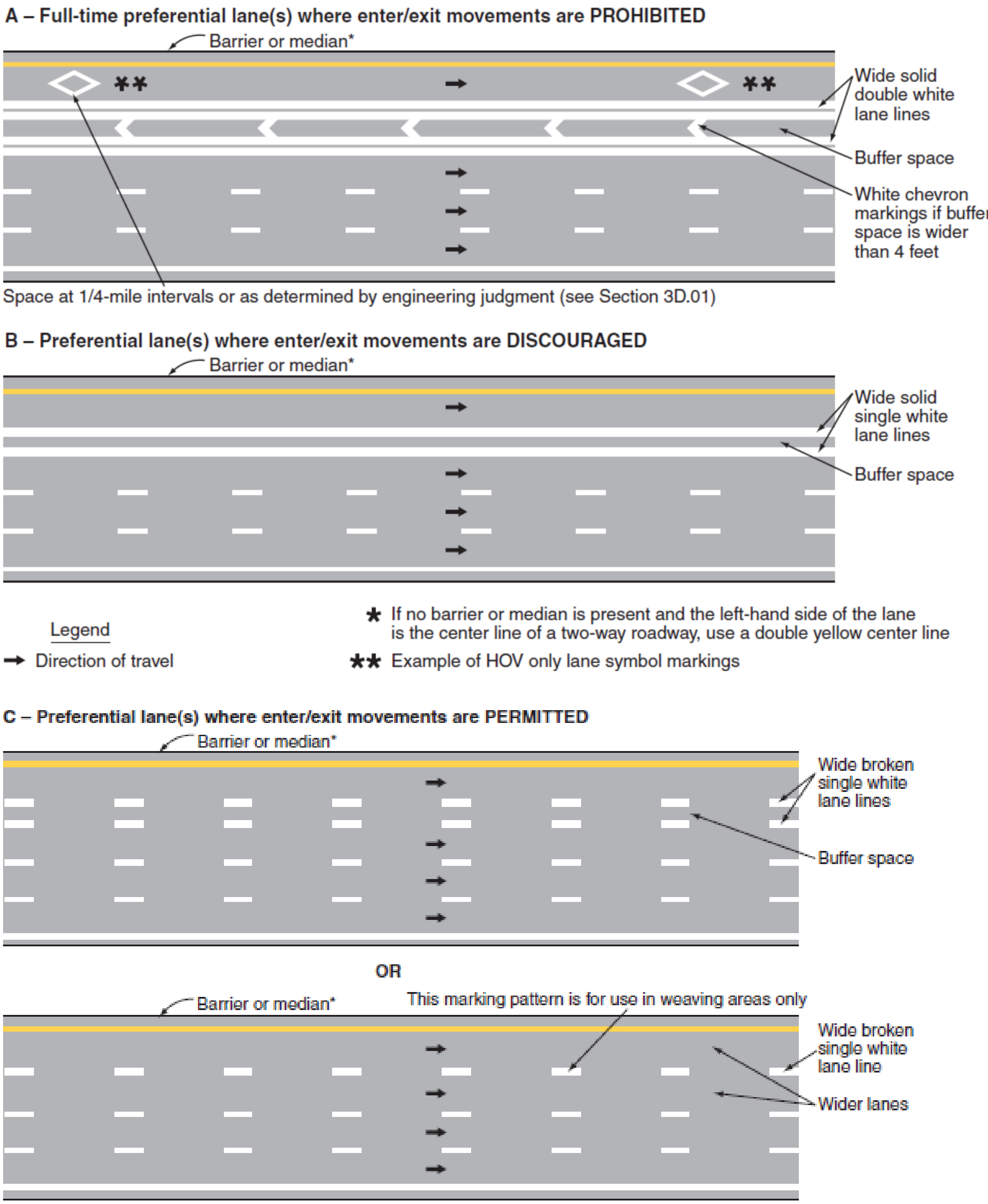
Access Points

The MUTCD does not discuss pavement markings for an access point specifically beyond indicating a broken line where lane changes are permitted. In typical layout drawings in the guide signing sections, the MUTCD does provide examples of pavement markings. For example, MUTCD Figure 2G-9 provides an example of signing for an intermediate entry to a barrier- or buffer-separated HOV lane. Within this graphic is an illustration of gore pavement markings for lane channelization.

ETC Areas on a Managed Lane

At tolling zones, pavement markings typically do not vary if the toll reader and cameras are mounted overhead and all users are required to have ETC accounts. If a facility utilizes declaration areas near electronic tolling gantries where drivers are segregated by vehicle type (e.g., HOV vs. SOV), appropriate word markings may be used as described previously. In addition, solid double white lines that separate different managed lane user types may channelize movements into the various lanes and prohibit lane changes on approach to the tolling zone.

Lane markings may delineate buffers with the use of pylons or other channelizing devices to enhance lane placement to improve toll and camera reads for some electronic tolling systems (see Figure 84).

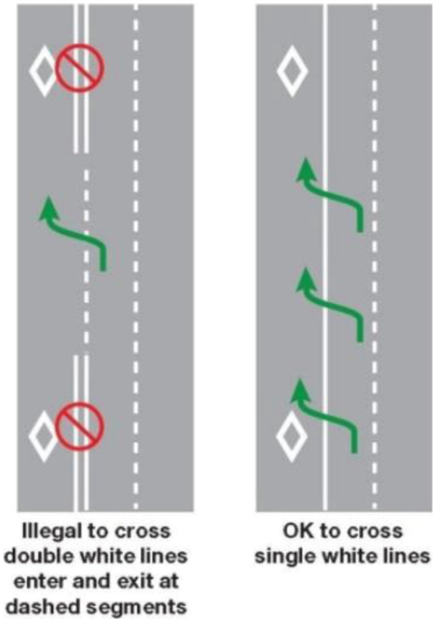


Source: FHWA (*1*), Figure 3D-2.

Figure 82. MUTCD markings for buffer-separated preferential lanes.

Managed Lane Bypasses at a Toll Plaza

Managed lanes are sometimes applied as peak-hour bypasses at toll plazas commonly leading to bridges or tunnels. Lanes approaching a toll plaza may be operated as HOV- or bus-only lanes or may be open to other vehicles with certain registered ETC accounts. When such a lane is provided, word markings and longitudinal markings are to be used on the approach to the point where the lanes diverge [FHWA (*1*), Section 3E.01]. These white lane markings may be supplemented by purple markings if the conditions for the use of purple apply. The bypass is to be accompanied by appropriate channelizing devices that are discussed in MUTCD Section 3H.01 (see Figure 85). This separation should begin on the approach to the mainline toll plaza at approximately the point where the vehicle speeds in the adjacent cash lanes drop below 30 mph during off-peak periods and should extend downstream beyond the toll plaza approximately to the point



Source: WSDOT (*97*).

Figure 83. Public education image from WSDOT regarding change from designated access areas to continuous access on SR-167.

Source: Google Earth.

Figure 84. Pavement markings at HOV declaration lane area on I-10 Katy Tollway in Houston, Texas.

Source: Mark Burris (*98*).

Figure 85. HOV bypass lanes at San Francisco–Oakland Bay Bridge.

where the vehicles departing the toll plaza in the adjacent cash lanes have accelerated to 30 mph.

Other Methods of Disseminating Information

Traffic control devices should not be the only method of explaining operations, routing, and payment to drivers. Other information sources such as media coverage, websites, advertising, and bill inserts should be used to explain these operations in detail. Some projects such as I-85 in Atlanta and I-10 and I-110 in Los Angeles have provided driving simulation videos via their websites to encourage potential customers to become familiar with the benefits and the look and feel of the facility beforehand, during the first months of operation, and thereafter for new customers. Minnesota DOT did an exemplary job of working with local media and community groups to educate the public leading up to the opening of its managed lanes (*99*). The local newspaper ran a series of short educational pieces in its transportation column in the months leading up to the opening.

Of course, there will always be out-of-town and uninformed local drivers. Focus group research has shown that if drivers feel they do not understand or do not qualify for an unfamiliar facility, they are reluctant to enter and use it (*100*).

Installation and Maintenance Considerations

While the installation of traffic control devices will vary by degree of complexity, most are often the last features of the design to be implemented. For new construction where capacity is added to a roadway, the only unique installation challenges relate to keeping unfamiliar motorists off the managed lanes until all traffic control devices are installed and the project is formally opened. This usually entails the employment of construction barrels, temporary barriers, or other means to prevent motorist confusion. Design of the traffic control devices needs to consider both the life-cycle needs and likelihood for repair and replacement. Most signing and pavement marking applications will represent a maintenance need that mirrors the roadway as a whole. However, CMS and toll-related devices, particularly the communication of business rules and pricing, may require rapid response to equipment failure, perhaps necessitating lane closure. To the extent possible, redundancies should be considered to limit the need for lane closure. For example, multiple CMSs could provide the same information upstream and at an entrance. Multiple tolling readers within a given toll zone may protect integrity of the operation without the need for frequent maintenance closures.

The installation of traffic control devices poses unique challenges, particularly if they are being augmented onto an existing managed lane operation. The most common augmentation is the addition of pricing to an HOV lane. Often, such conversions involve more than merely implementing toll gantries and supplemental signing. Business rules may simultaneously require restriction of access, changes in hours of operation, and modifications of who is and is not charged to use the facility. These changes typically represent a wholesale reconfiguration and replacement of most traffic control devices on the prior roadway, and often the life cycle of prior devices has already been served. Updating traffic control devices to current standards and retroreflectivity is an added benefit when such major operational changes occur. Implementing these changes can be challenging and subject the existing motorists to confusion. For example, a project in Miami restriped an HOV lane and shoulders to accommodate two-directional managed lanes, and then over a weekend added pylons to physically separate the two lanes from other general-purpose lanes. Motorists the following Monday responded to this change by driving into the lanes, backing up, crossing through the pylons and generally creating such erratic movements that a rash of crashes resulted. The prior operation had allowed unimpeded access into and out of the lane; the modified operation restricted access. Inadequate public service announcements, driver education, project marketing, and installation procedures were blamed (*101*). This and similar experiences suggest a strategic roll-out of such changes is critical to acclimate motorists to the new managed lane operations. This roll-out will need to involve the sponsoring and operating agencies and installers working together to best preserve operation integrity and motorist safety.

Trade-offs in Constrained Design Settings

While the best TCD design follows guidance found in the MUTCD latest edition, many managed lane design settings are extremely constrained, with limited opportunities to place sign structures without encroaching on the travelway. Some signing and pavement marking practices have been employed for these constrained settings on a project or statewide basis. Guidance for application of selected practices can be found in some state guidance treatises. Following are examples included in the Caltrans *HOV Guidelines* (*53*):

- Median-mounted signs are placed higher than standard and/or tilted up to 43 degrees from center so that the sign will not protrude beyond the barrier footprint.
- Frequency of repeating signs (e.g., hours of operation, restrictions for buffer crossing, or minimum occupancy definition of a carpool) is altered from desired standards.
- Font size is reduced below the requisite design speed and abbreviations are applied for fixed-destination signing in order to reduce overall sign size.

Source: Chuck Fuhs.

Figure 86. Example of pavement markings at a roadside geometric impediment within a tangent section.

- The number of downstream destinations on destination signing is limited.
- Warning signs are applied to the pavement in lieu of side-mount signs.
- Barrier shapes are modified to protect the sign gantry or column.
- Lane markings are placed closer together than desired, particularly if multiple stripes delineate a designated buffer.
- Pylons or other channelizing devices are placed in a designated buffer area that is narrower than standard allowances.

Another common challenge faced by practitioners is alignment of pavement markings at a point-specific impediment that encroaches on the right or left of the travelway. These encroachments often consume much of the shoulder or lateral offset that promotes sight distance in an operation setting where speed differential requires good upstream visibility. The most common practice employed is to not deviate the lane marking around the impediment. Rather, the marking should maintain the alignment and line of sight within the travelway, as illustrated in Figures 86 and 87.

The examples are not an endorsement to apply specific treatments but show that traffic control devices will not always fit the design setting, and some latitude is needed to give motorists sufficient information to safely navigate the lane, be informed of restrictions, and be able to make informed decisions.

Additional Considerations

Appropriate traffic control devices must be considered early in the planning and design process. Access points that are too close or too far apart, unusual ramp geometries, and lengthy collector roads can all violate driver expectations and cause

Source: Chuck Fuhs.

Figure 87. Example of pavement markings at a roadside geometric impediment within a horizontal curve section.

erratic maneuvers that jeopardize safety and may also reduce the number of users. The application of additional traffic control devices often cannot correct a fundamentally bad design.

Traffic control devices must be considered alongside the development of a concept of operations as part of a broader user information system, which may include other media. The MUTCD points out that the limit to the complexity of an operational strategy may indeed be the ability to create signing plans to convey the information with adequate comprehension and without overloading the driver with excessive amounts of information.

The TCD plan for managed lanes must be considered in concert with existing (or new) static and dynamic signs and markings in the general-purpose lanes. Access treatments, lane separation, destination names, route numbers, and exit distances should be consistent across both sets of signs and preferably along a corridor or within a region.

CHAPTER 5

Implementation and Deployment

While the beginning of project implementation may occur once planning is underway, this chapter defines implementation and deployment as beginning once the project plan and environmental document are approved. Implementing a managed lane project requires a rigorous dialogue between staff involved in design, operations, and construction. Increasingly, toll collection and active traffic management systems integration requires installation and construction services from a diverse array of specialists who may be unfamiliar to traditional roadway contractors. System-level planning and coordination is key to maximizing efficiencies and ensuring integration between systems where needed. This chapter outlines the various steps toward implementing and, ultimately, opening a managed lane facility.

Design Review

Within the context of project implementation, the concept of design review incorporates principles identified in the systems engineering process. Designing and constructing managed lanes involves multiple disciplines, including software development, high-sensitivity electronic equipment and technology, as well as civil and structural engineering. The design review process ensures that the specifications for these systems are incorporated, reflect the common requirements of established systems such as the National Intelligent Transportation Systems (ITS) Architecture (a common framework for planning, defining, and integrating ITS deployments), and identify appropriate interdependencies. Furthermore, the design review process highlights issues or concerns before committing to deployment, with the allowance for changes to each subsystem.

Importance of Design Review

The development of a managed lane project involves complex systems installed by disconnected entities. For example, pavement and bridge structures in managed lanes may be constructed by the civil *contractor,* but the installation of toll collection equipment is the responsibility of the toll collection systems *integrator.* Often, these functions come together at points of demarcation in the field between the integrator and the contractor responsible for overall lane construction. For example, the contractor installs power to a common access utility panel, and then the integrator is responsible for pulling power from this utility panel to the toll collection equipment in the field. Similarly, the contractor is responsible for placing the systems utility cabinet on a concrete pad with a number of appropriate conduits, and then the integrator is responsible for pulling wire and making appropriate connections within the cabinet to the toll collection equipment. As such, it is useful within the design review process to highlight these points of demarcation and to identify any gaps or overlaps in separate contracts regarding the responsibility and fulfillment of these dependencies.

It is essential that the requirements of the systems be reflected in the final design specifications because these specifications remain the only consolidated document from which the managed lane systems are constructed. The *Priced Managed Lane Guide,* in particular, notes "priced managed lanes often require complex design solutions and the need to consider exceptions to design standards, because they are often built in constrained highway corridors with right-of-way constraints and require the installation of ETC equipment and enforcement locations" (*2*). As with most components of systems engineering, identifying challenges, risks, shortcomings, and issues early in implementation is critical to cost containment, making the design review process valuable and effective.

Configuration Management for Design Review

Within the realm of ITS, for which toll collection and managed lane systems are highly correlated, the U.S. DOT has encouraged the concept of **configuration management** for the design review process. According to the Electronics Industries Alliance/American National Standards Institute's publication on configuration management as a national standard, "Configuration management, applied over the life cycle of a system, provides visibility and control of its performance, functional, and physical attributes. Configuration management verifies that a system performs as intended, and is identified and documented in sufficient detail to support its projected life cycle" (ANSI/EIA 649-B-2011).

Within this concept, the sponsor agency has primary responsibility for tracking individual configuration items within the design plans, controlling changes from the design to accommodate field realities, and accounting for configuration items so that multiple disciplines have current access to applicable components of the design (*102*).

The configuration management process, as referenced, is designed to enhance the understanding of those disciplines affiliated with the interconnected systems (ANSI/EIA 649-B-2011). The outcome of the design review process is to advance the facility designs through increasing levels of detail, with confidence that critical points of overlap and dependency have been resolved. For managed lanes and affiliated ITS and toll collection systems, the design review is completed separately for conceptual, preliminary, and final design. The final design typically involves advanced levels of testing to ensure the system will function properly before the toll collection systems integrator procures equipment and completes the development. As such, the design review is a positive affirmative process—the system design, by default, is not deemed ready for deployment until the review affirms the readiness of the system.

The design review will permit agency and contractor staff within each review function the opportunity to propose a design change in order to enhance the effectiveness and delivery of the managed lanes system. Often, changes will be proposed to reduce costs, meet scheduling requirements, or fulfill base requirements of interconnected systems. However, changes may also be proposed to reflect new technologies or procedures that have been developed since the initial design and offer an opportunity for the implementing agency to enhance the longevity and efficiency of the system. Regardless, when a proposed change is offered, it should be accompanied by an assessment of overall impact to the system as a whole—including costs, scheduling, and other effects upon connected systems.

Scheduling, Installation, Testing, and System Acceptance

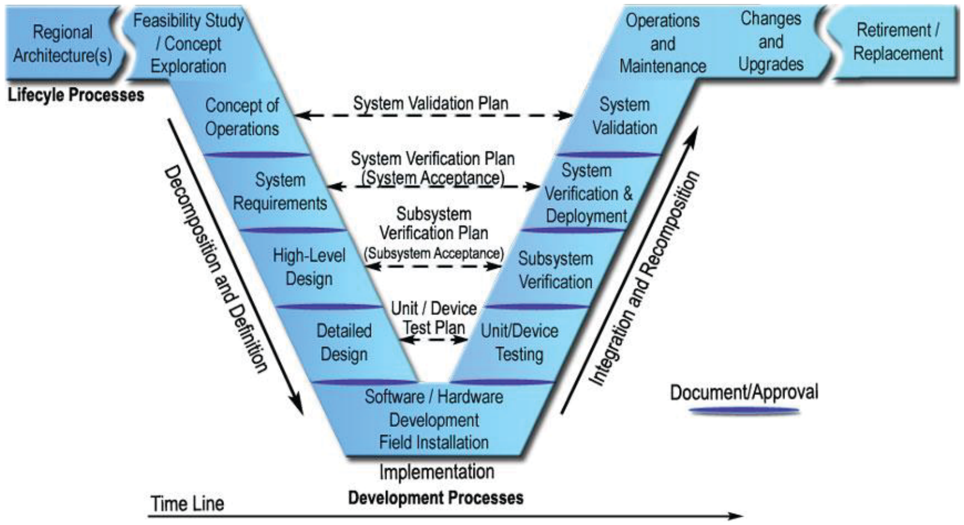
Within the context of project implementation, there are four key phases critical for success of the project: scheduling, installation, testing, and system acceptance.

- The project **schedule** defines the time frame for completion of the project and achievement of milestones, and it is used to monitor progress and denote changes that occur during design and construction. The project schedule identifies tasks, links the tasks in logical sequence, and allows for close coordination of various contractors throughout different phases of the project. The schedule defines key milestones and provides a plan through which resources can be assigned. Additionally, the schedule is used for tracking progress on individual tasks and identifying schedule risks. Installation is the culmination of the development and design phases.
- **Installation** requires close coordination between various contractors and a focus on safety for the team and for the traveling public.
- **Testing** for system implementation typically includes a series of tests to verify that project requirements are met. Testing occurs at various points in the deployment process, including environmental analysis, factory acceptance, inspections, installation, integration, and final acceptance.
- The key point of delivery is the final **system acceptance**. At final system acceptance, coming at the conclusion of the implementation stage and when the project enters revenue service and operations, the installer has provided as-built configuration documentation and drawings, training plans, licenses, and maintenance manuals. Final system acceptance typically occurs between 2 and 6 months after the system opens to revenue service, as minor adjustments to the system to respond to field service need to be worked out and officially accepted.

The installation and testing phases of a project start after final design and continue through to the operations and maintenance phases of the project. The flow of installation and testing is shown in the systems engineering V diagram (see Figure 88) from the FHWA *Systems Engineering for Intelligent Transportation Systems* handbook (*103*).

Scheduling

The **critical path method** of scheduling allows for effective management of the overall project and helps protect the project against schedule and budgetary slippage. For the schedule to be used effectively to manage a project, the schedule must be kept current with accurate status updates. Managing multiple schedules presents challenges because key milestones between various contractors and subcontractors are not always linked, and a slip in one contract does not necessarily show the impact to the other schedules. Field work often requires that changes be made in the schedule due to unexpected field conditions, weather delays, tasks taking longer than scheduled, or required rework. As such, schedule



Source: Iteris Inc. (*103*), Figure 7. This material is based upon work by the Federal Highway Administration. Any opinions, findings, conclusions, and recommendations, and translations thereof, expressed in the FHWA publication are those of that publication's author(s) and do not necessarily reflect the views of the Federal Highway Administration.

Figure 88. Systems engineering process V diagram.

dependencies should be known at the beginning of the project, such that slippages in one schedule automatically propagate to all dependent subsystems.

Installation

Prior to the start of field installation, a detailed installation plan is required. The installation plan specifies the sequence and schedule for the installation of the entire system. The installation plan typically includes a detailed schedule of activities, specific safety requirements, and contact information for staff. A description of possible phasing of deployment is also included in the installation plan. The installation must comply with applicable standards and building codes.

For a successful installation, the toll system integrator must understand the unique characteristics of the job site. These range from environmental considerations, traffic-related maintenance, specific work hours, and overall project safety requirements. When incorporating a toll system, there is usually a defined turnover process from the civil contractor to the toll system integrator to be able to install toll collection equipment. For the turnover process to be smooth, the implementing agency must have clearly defined milestones, including inspections, tests, and minimum requirements. Ideally, the civil infrastructure work on the facility would be completed prior to the transfer to the integrator, but more frequently, incremental turnover of sites requires careful coordination. Often finishing work such as striping, closing out punch list items, and removing barriers may not be done until after the turnover of the site to the integrator.

Testing

Since installation of tolling functions is substantively different from civil construction, the testing plan becomes the critical step in the integration process, and thus deserves extra attention. Testing is used to verify that the contract requirements are met. Typically, a requirements trace matrix is developed early in the project to ensure that user needs and concepts are addressed by a set of project requirements. The requirements are then used throughout the design and development phase to ensure that the system will meet the defined requirements.

The system integrator develops test plans and procedures and then completes applicable tests to demonstrate that all furnished and installed equipment, materials, subsystems, and systems function in the manner intended, and that they are in full compliance of performance standards, functional requirements, relevant industry standards, statutory regulations, and relevant codes of practice. The testing program ensures that the system functions according to the requirements and contract performance standards. The system integrator develops and conducts a comprehensive testing program, which includes testing major components and interfaces with related systems. These tests should be conducted as the system is developed, deployed, and operated to ensure compliance with the system and equipment functional requirements and performance standards. To minimize risks, the system integrator tests the performance of the system at each phase of system development, deployment, and operation. For every test, the procedures define the entry criteria, pass/fail criteria, and resolution process. Tests should be conducted by the test department or quality assurance department and not the project engineers or developers.

Typical stages of testing are as follows:

- Test plan: Plan that identifies test modules, functionality, scheduling, durations, equipment, facilities, software bug and deficiency resolution, and staff required for each stage of testing. Scheduling of each test stage should also be reflected in the project schedule.
- Unit/device test: A stand-alone test to verify that individual components meet the requirements of the project. Burn-in tests are often conducted as stand-alone tests for hardware sufficiency.
- Factory acceptance test: Subsystem verification test to demonstrate that the system components function per the design in an off-site environment in advance of field installation.
- System-to-system interfaces tests: Separate tests to demonstrate the functionality and performance of any system-to-system interfaces.
- Installation test: Testing performed for each installation to verify that the equipment has been installed and configured correctly. An installation checklist will be used to verify installation, and the installation test will verify basic functionality of the equipment.
- Commissioning test/system verification and deployment: Testing to demonstrate that the entire system, equipment, and facilities are ready for commencement of operations. Testing includes hardware, software, and equipment. Testing demonstrates aspects of system operations and services from transactions through account reconciliation.
- System acceptance testing: Final system validation testing to demonstrate that the system is fully meeting contract requirements, as well as performance requirements in operations, including a minimum number of days of actual operational testing following resolution of deficiencies (defined in the following paragraph).
- Annual system performance testing: Testing to demonstrate ongoing system reliability, service, and performance levels. As part of ongoing operations, annual system performance testing is often scheduled to begin on the anniversary date of opening for revenue collection.

A deficiency is defined as a failed test result or missing functionality when compared with the system design or functions of the system. Once resolutions to deficiencies have been identified, appropriate testing is needed to confirm that the deficiency has been corrected and that no new bugs were introduced into the system. Deficiencies can be considered for any situation that causes the following:

- Cessation of operations for any major service or operation or that results in the loss of revenue, inability to display toll rates to drivers, inability to process transactions, or inability to operate the facility.
- Impedance of operations, but not such that it causes major services or operations to cease or results in a loss of revenue.
- Hindrance to operations that is minor or administrative in nature and does not result in a loss of revenue or traffic performance.

System Acceptance

Final acceptance concludes the design and deployment phase of the project, often after the project enters the operational phase and required phasing, adjustments, and other tasks are completed before turnover. Final acceptance is deemed to have occurred when the following conditions have been met:

- Successful completion and approval of the system acceptance test.
- Delivery by the system integrator and approval of all deliverables, including as-built documentation/drawings.
- Satisfactory completion and approval of required activities and implementation items.
- Verification of requirements identified in the system requirements document.
- Satisfactory fulfillment of the system integrator's other contractual obligations.

Toll Collection System Development, Deployment, and Phasing Considerations

Toll collection system design includes the selection of off-the-shelf hardware such as cameras and computer servers and the development of custom software for the managed lane systems and the back office. The toll collection system vendor is also responsible for the integration of hardware, software, and subsystems to meet the contract requirements. The deployment of the managed lanes project is influenced by many factors, such as physical facility availability, staffing constraints, system development, legislation, funding, marketing, and stakeholder coordination. Often, a combination of factors results in the need for the project to open on a specific date or under a specific set of conditions. The earlier the final opening date is agreed upon, the easier it is to develop a deployment schedule and determine any possible phasing that is needed.

During this phase of the project, the system becomes more tangible to the traveling public; signs and gantries are installed and the final pavement striping is completed. The toll collection system is installed, with cameras, antennas, and pricing signs being the most visible features. This is the final phase to fine-tune the system, complete staff training, test the performance of the integrated system, and plan for the ribbon-cutting ceremony.

Development

The development process for toll collection systems is similar to the development of other large transportation systems. System engineering processes are used to guide the development from concept of operations, through design, installation, and testing, to final deployment (Figure 88). Some features of the toll collection system are universal to all projects; others are quite specialized for the individual project. As with any large design project, the risk is minimized by maximizing the use of proven designs and minimizing the development of new software. As an illustration of the various steps in the systems engineering process, Table 9 provides the typical methodology for software development of toll collection systems.

For most managed lane systems, the vendor modifies an existing design instead of building up an entirely new system from scratch. This allows the vendor to compress the development schedule, reduce risk, and lower the overall cost of the system. The development phase is an iterative process with multiple internal peer reviews and unit tests occurring throughout development to optimize the system.

Deployment

After the system is developed, integrated, and tested, it is ready to be deployed on site. System deployment may take several weeks to several months to complete depending on the complexity of the system and the number of toll collection sites. A deployment plan is often required to ensure a smooth transition to operations. The plan needs to address staffing, training, scheduling, testing, contractor coordination, configuration management, and any required phasing.

Deployment in the field is often complicated by other contractors working in the vicinity. The toll system integrator must cooperate fully with other contractors working on or near the facility; agencies can provide a framework for this coordination and cooperation through scheduling requirements in the contracting phase. Coordination between multiple contractors must include safety, scheduling of work, maintenance of traffic, and repair responsibility if anything is damaged during the construction. The work must be scheduled without hindering or interfering with the progress or completion of work being performed by other contractors, entities, or agencies.

Table 9. Primary tasks for the development of a toll collection system.

Task	Activities
Review Scope of Work	• Review business rules. • Review functional needs of project. • Discuss expectations with client. • Ensure compatibility with existing systems.
Develop Requirements	• List specified functional and performance requirements called out in scope of work. • List derived requirements from scope of work. • List any additional requirements from contract.
Perform Gap Analysis	• Review existing system against requirements to determine gaps. • Identify new functionality that is required. • Identify any changes that are needed to meet performance requirements.
Complete Preliminary Design	• Conduct initial high-level system design. • Determine quantity of equipment required. • Complete high-level architecture design. • Develop initial communication layout. • Produce software design.
Complete Final Design	• Finalize selection of hardware makes and models. • Finalize communication network. • Finalize power calculations and define utility requirements. • Develop interface control documents. • Conclude software design, including processes and redundancies required.
Develop Software	• Develop new software as required. • Modify existing software to meet contract requirements. • Complete unit test of code by all developers as they finish modules. • Maintain configuration management.
Integrate System	• Integrate new and upgraded software modules. • Integrate toll collection subsystems with selected hardware.
Perform Tests	• Test modules, subsystems, and fully integrated toll system.
Deploy System	• Perform on-site installation. • Test connectivity and continuity. • Configure and tune the system. • Test the system.

If the system is replacing an existing toll collection system, migrating data and transitioning to the new system need to be included in the deployment plan. Most toll collection systems use the deployment phase as an opportunity to have the system up and running for an extended period of time before going into revenue operations. Staff can be trained on the real system, sample reports can be run, and bugs can be identified and fixed prior to official testing. This phase also allows burn-in of the hardware so any defective items can be replaced prior to operation. Many issues surface when the system is operating in the real-world environment for an extended period of time. Once the system is fully deployed, tested, and accepted, it moves into the operations and maintenance phase.

Phasing

There are many different phasing considerations for deployment of large, complex toll collection systems. Some considerations may be policy driven, like when the tolls are in effect and whether they begin as fixed or dynamic tolls. Sometimes the physical infrastructure availability requires the toll system to be installed and opened in phases, and the developer may be confronted with a less than fully robust operation. These considerations need design interaction with the rest of the development team so that the system can meet functional requirements through each successive opening. Considerations need to include:

- Messages to the customer through successive changes as the project opens.
- Strategies for pricing for the near term and longer term.
- Rules for traffic safety and associated items posted on signs that may change as the project expands.
- Protocols for enforcement.
- Considerations for maintenance, such as access to field equipment.
- Considerations for design of any interim operating conditions such as access and separation treatment.
- Plans for future segments or corridors on the system, often addressed in a system-wide Concept of Operations.

Some toll collection systems choose to open with a simpler system (e.g., a single toll zone employing an off-the-shelf technology) and then add complexity (e.g., multiprotocol readers and zones) later as the need arises.

Upgrades and Expansions

Toll system technology is constantly changing and improving. New camera technology is released every year that greatly improves the capture of license plate images, and computers are faster and have more memory. Due to the MAP-21 federal legislation and its requirement for national interoperability, more facilities are upgrading their systems to correctly read transponders issued from other states and local jurisdictions. The design life for most toll systems is stated to be a minimum of 10 years, but system technology upgrades and enhancements are typically done every few years to keep the systems working at optimum performance levels. Expansions to systems are done as new facilities are opened for toll collection or existing corridors are extended. The initial design needs to be flexible in order to take into account the anticipated expansions and often short life cycles of equipment.

During the operations and maintenance phase of a project, changes to the system range from small simple changes (e.g., altering the format of a report) to significant changes of entire modules (e.g., replacement of the violation enforcement system). The standard system engineering process is for upgrades and expansions to the system. Cost–benefit analysis is typically done to determine which updates provide the most benefit for the cost and to help determine the sequence of the upgrades. Design reviews are done and a transition plan may be needed to deploy the new feature. Revised standard operating plans, training documents, maintenance manuals, and as-built plans are typically required for substantial changes. Testing is always needed for a new release of software or a hardware upgrade to ensure that the system meets the new requirements.

Often, changes are done when an extension to the existing facility is added or a new corridor is being incorporated into the system. Changes are often required to accommodate the new facilities, and additional upgrades should be incorporated in the most efficient manner.

Project Delivery

Project delivery for managed lane systems inevitably involves procurement—from planning and design through civil construction and toll integration. In delivering projects, a variety of procurement options are available to agencies looking to implement managed lanes. Many contemporary approaches to procurement involve varying aspects of partnership with private-sector entities, including integrated design and construction as well as investment risk. In particular, public–private partnership (P3) and public–public arrangements have increasingly been utilized in managed lane projects, including various facets of design, delivery, financing/funding, operation, and maintenance.

At its core, there are three separate and distinct work elements to the deployment of any managed lanes project: (a) civil construction, (b) toll system integration, and (c) tolling operations and maintenance.

These three components can be separated or combined in various forms. For example, civil construction could occur under a design–bid–build structure, design–build structure, or other delivery functions. Similarly, system integration and tolling operations and maintenance can also be combined into the civil delivery contract, resembling a P3 approach. Conversely, the toll system elements (integration and operations/maintenance) could be combined under one contract, followed by a separate design–build contract to construct the civil portions of the project.

As revealed by practitioners in the course of study, consideration should be made for scheduling the procurement of toll system integration either before or concurrent with civil procurement. The primary advantage for releasing the technical requirements for toll system integration in advance of the civil requirements is that the incorporation of toll system components can be better reflected in the overall civil construction schedule, as discussed previously. For example, in California, the toll system integration procurement precedes the civil procurement by a few months.

Importance of Project Delivery

Initial managed lane projects in the United States were procured by individual state or regional agencies to implement a discrete facility on one corridor or corridor segment. With the exception of SR-91 in Orange County, California, and I-495 in Northern Virginia, the facilities in operation by the end of 2013 involved utilization of pre-existing HOV lanes, which is common for retrofit settings. Between 2013 and 2015, however, many more facilities were constructed in corridors lacking pre-existing HOV lanes, such as the North Tarrant Express, DFW Connector, and Loop 375 Express Lanes in Texas; US-36 and I-70 in Colorado; I-95 in Maryland; and I-595 in Fort Lauderdale.

The HOV conversions permitted the implementing agency to procure only those deployment components required for converting the HOV lanes into variable priced managed lanes. This limited exposure to risk yielded a preference toward traditional procurement methods. However, over the last decade, two new models for delivering managed lanes, especially those with new construction, emerged nationally. The first—the use of public–public arrangements to implement a priced managed lane that spans multiple public entities—creates opportunities to spread risk between agencies but also adds layers of decision-making complication. Some of these arrangements are informal; others became formalized through multi- and interagency agreements, or, in states such as California, joint powers authorities were created by public–public arrangements to facilitate implementation across multiple jurisdictional boundaries.

The second model involves an increasing use of P3 to embark upon large, mega-scale projects (i.e., typically valued at $300 million or more) affecting a range of transportation improvements that could not be afforded through traditional procurement methods. This tendency toward P3 also exists on smaller projects. In 2011, Los Angeles County Metropolitan Transportation Authority employed the design–build–operate–maintain method for delivering the I-10 and I-110 express lanes in Los Angeles County, and, in 2013, the Colorado High Performance Transportation Enterprise used both a design–build contract and a design–build–finance–operate–maintain contract for delivering the US-36 managed lanes. Research from the Second Strategic Highway Research Program indicated that "the average construction value of over $1.6 billion . . . represents a marked departure from earlier P3 activity" (*104*).

Project Delivery Options

Project delivery was discussed briefly in Chapter 2 because agencies will begin to look at different options for delivering priced managed lanes from an early point. Delivery options within the implementation and deployment phase will differ significantly, and planning-level decisions may warrant reconsideration as the project procurement begins, with different delivery options for various components. For example, an agency may wish to use a traditional design–bid–build procurement for civil construction, but a design–build–operate–maintain delivery for toll systems. This delineation is addressed here.

There are four primary project delivery options, ranging from traditional design–bid–build, through design–build (where design and construction services are grouped into a single, fixed-price procurement) and design–build–operate–maintain, to private-sector concessions (where a private investor/operator is responsible for financing, designing, constructing, operating, and maintaining new toll highway projects). As discussed previously, these delivery options can span the various core tasks of civil construction, toll system integration, or toll system operations and maintenance.

Following are descriptions of the four primary procurement options for managed lanes:

- Design–Bid–Build (DBB). DBB is generally perceived as the standard procedure for procuring a highway project. In this process, the agency (either internally or through contracted staff) fully completes the design of a facility. Subsequent to completion of the design, the agency then awards a new construction and installation contract to one or more contractors. Upon completion, the agency has full responsibility for the operations and maintenance of the project. As the agency completes the design, it warrants the quality of the design documentation, and it is liable for remedy/mitigation if issues emerge that prevent the construction and installation contractors to complete their scope of work. As a result, the agency assumes the risks of errors or omissions within the final design documentation (*105*).

With existing HOV lanes being converted to priced managed lanes, design–bid–build has been sufficient for most agency projects where risk and schedule are lesser considerations.

- Design–Build (DB). Whereas DBB uses separate contracts and procurements to develop a managed lane project, DB combines both design and construction functions into one fixed-fee contract (*106*). The contractor, which typically involves a joint venture for legal liability purposes, assumes the risk of design and construction for the contractual compensation. The agency, in turn, assumes the responsibility of providing definitive metrics by which the design and construction will be evaluated and accepted under the contract agreement. The responsibility of financing, operating, and maintaining remains with the agency, but the contractor assumes risk for construction cost and schedule, making this a preferred method for complex projects.

  Whereas HOV conversions to priced managed lanes are well suited to DBB, DB is increasingly attractive for new lane construction. Recent projects using DB for managed lanes include US-36 in Colorado, I-35E in Minnesota, and I-405 in Washington.
- Design–Build–Operate–Maintain (DBOM). DBOM extends the DB model to include an operations and maintenance component over the life of the contract. Although financing remains in the purview of the public agency, the fixed-fee contract reduces the risk of maintaining the system over time. According to a Second Strategic Highway Research Program report on P3, "The advantage of DBOM procurements is that by combining these services, the private partner has an incentive to use cost-saving, life-cycle costing principles to align the design of the project with long-term maintenance activities" (*104*).

  As an example, the Los Angeles I-10 and I-110 express lanes were procured using a DBOM structure.
- Design–Build–Finance–Operate–Maintain (DBFOM). DBFOM, often called a concession agreement, involves transferring the responsibility for design, construction, finance, operations, and maintenance of a managed lanes facility to a private-sector partner for a period of between 25 to 50 years. Typically, the agreement is written such that the private-sector partner has the right to collect revenue from tolls. Alternatively, the agency may elect to withhold the right to the toll revenue and instead make availability payments during the life of the concession agreement, whereby the concessionaire is compensated for design, construction, operations, and/or maintenance milestones or performance achievement. Availability payments may be used for toll facilities that may have a greater risk of revenue generation than fully private-sector concessions would allow (*104, 107*). In either case, future revenues raised by tolls and other project sources are dedicated toward the repayment of bonds and other affiliated costs, including loans from TIFIA or private activity bonds. The private partners, as a component of the concession, invest their own equity into the project. Upon financial close, the concessionaire then enters into a fixed-priced DB contract to construct the project and a separate operate–maintain contract to collect tolls and maintain the project, often with subsidiaries to the concessionaire.

  The 91 Express Lanes on SR-91 in Orange County, California, is an example of a project that was originally procured by Caltrans as a DBFOM project. It was purchased from the California Private Transportation Corporation, the concessionaire for the project, by the Orange County Transportation Authority, a regional public agency, in 2004. Additional DBFOM projects operational in 2015 that involve revenue risk to the concessionaire include the I-635 LBJ Express Lanes in Dallas, Texas; the North Tarrant Express in Ft. Worth, Texas; the US-36 Express Lanes in Colorado; and the I-95 Express Lanes in Northern Virginia. In contrast, the I-595 Express Lanes in Ft. Lauderdale, Florida do not involve revenue risk to the concessionaire because the Florida DOT has instead elected to use an availability payment structure.

Pros/Cons of Delivery Options

The advantages and disadvantages to each of the procurement methods identified in the previous section are shown in Table 10. They were adapted from the Construction Management Association of America's *An Owner's Guide to Project Delivery Methods* (*108*).

Facility Marketing

Customers of priced managed lanes will bring similar expectations to their use of the facility as they would for any service-for-cash transaction. Just as businesses have already figured out how to enhance customer experiences in ways that help their bottom lines and ensure happy customers, so too must transportation agencies implementing managed lanes. In essence, there are two phases to the outreach and marketing plan for managed lanes.

The first phase, the *education phase,* involves project information and concept education and occurs throughout the development and construction schedule. Stakeholders and the general public will want detailed information regarding the project, and the outreach program is the primary mechanism for this occurrence. The education phase is addressed more extensively in Chapter 2: Planning Considerations.

Table 10. Pros and cons of project delivery options.

Procurement	Pros	Cons
Design–Bid–Build	• Widely used in managed lanes delivery. • Most common approach to small-scale and/or minimum-risk projects. • Agency maintains control over all phases of deployment and operations.	• Longer schedule required. • Constructability issues since cost and schedule impacts are not iterative with design. • Liability for design. • Requires full funding in place. • Least-cost approach may yield higher life-cycle costs.
Design–Build	• Shorter schedule required. • Cost efficiencies due to design/construction iteration. • Single point of responsibility for design and construction.	• Less control over design. • Requires highly responsive decision making. • Greater responsibility for agency to check milestone completion thoroughly. • Less practical under joint power arrangements. • Requires full funding in place.
Design–Build–Operate–Maintain	• Same as design–build. • Additional efficiencies gained in operational sufficiency. • Lower anticipated life-cycle costs than DBB least-cost approach.	• Same as design–build. • Requires ongoing responsive decision making.
Design–Build–Finance–Operate–Maintain	• Same as design–build. • Provides alternative revenue and funding sources. • Fully transfers risk to private sector.	• No control over design. • Requires high level of specificity in functional performance requirements. • Proposal and review process is very expensive and time consuming for agency and concessionaire. • Greater political risk. • High level of expertise in financial and legal specialties is required.

Source: Adapted from Construction Management Association of America (*108*).

In the second phase, the *sales phase,* marketing of the managed lanes addresses how to be a customer of the facility. Marketing in this phase, which begins during construction and continues throughout the life of the project, involves two general themes: initial sales and repeat sales. Initial sales involve the acquisition of equipment and registration, as may be required, to be an eligible customer of the managed lanes, whereas repeat sales concerns marketing use of the facility to meet traffic management and revenue objectives.

Importance of Marketing

Public acceptance has become the primary issue determining the success of a managed lane implementation (*51*). To affect acceptance, marketing must be viewed as a vital function for informing the public about the benefits of priced managed lanes as well as how to make informed decisions on their use as a customer. Without a well-thought-out approach to public marketing of the service, the general public may view the pending implementation of a priced managed lane facility with suspicion or disdain because it is a deviation from what is known about transportation investment. Conversely, a properly executed marketing program can enable public support. Building a baseline of understanding and acceptance through these efforts may facilitate broader support for facility and network expansion, as well as yield feedback on certain components that may prove to be unpopular or particularly well regarded. When the implementation agency enters the sales phase, marketing becomes a critical tool for encouraging corridor travelers to become regular users of the managed lanes and to meet any revenue objectives that may be essential to the project's success. As described in the FHWA *Priced Managed Lane Guide,* "Carefully planned and executed public outreach will help the public to (a) understand how a proposed priced managed lanes facility would work, (b) evaluate the advantages it might offer, (c) accept and use the facility as a new travel option, and (d) encourage travelers to become customers" (*2*).

Marketing Guidance in the Sales Phase

Managed lanes may be successful in different ways—such as those measured by traffic operations metrics or revenue goals—but ultimately, the success will depend upon the agency's ability to encourage drivers to use the facility and manage customer expectations. Since priced managed lane facilities are generally located in the median of existing freeways, drivers' choice is one of lane use, not route choice; that is, their decision is whether to use the general-purpose lanes or the managed lanes. To encourage use of the managed lanes, agencies must market their use, and many agencies with operational managed lanes have engaged professional sales and marketing services in parallel with public outreach and education efforts. This approach is essential to project feasibility if the funding of the lanes is dependent upon toll revenue.

Marketing during the sales phase should address common customer-oriented concerns such as how to open an account and obtain an active transponder, how to use the managed lanes, and reasons to use them for differing trip types. These are common issues that will continue over the life of the project. However, there are additional marketing requirements, depending upon the nature of the project. In some cases, the primary marketing effort should be oriented toward encouraging drivers to use a new facility; in other cases, the marketing message may be on different ways to use an existing facility. The latter of these situations is particularly applicable for priced managed lanes that derive from previously existing HOV lanes.

For newly constructed lanes that may be dependent upon revenue for the repayment of loans and bonds, the sales effort is designed to increase the number of potential users in order to maximize the traffic management aspect of managed lanes, provide customer satisfaction for use of the lanes, and maintain a relationship with the customers. To ensure the facility is a success, planners should target the ideal number of users it will take to reach congestion management and/or revenue goals. Underlying these tactics is the need to subtly change the way the public perceives the role of pricing and thus their behavior. Marketing and communications efforts help lay the foundation for acceptance of pricing as it becomes a key method for funding and maintaining large infrastructure projects in the future (*2*).

Two references provide a comprehensive listing of potential marketing activities, strategies, and actions for managed lanes operators. The FHWA *Priced Managed Lane Guide* devotes a chapter to developing a marketing plan during the sales phase (*2*). Additionally, the FHWA Office of Operations has created a HOT lanes marketing toolkit, available online only (*49*). The latter resource provides brochures, videos, and checklists that may be used by any implementing agency.

CHAPTER 6

Operations and Maintenance

General Operations Issues

Managed lanes must rely upon a high level of operations that integrate managed lane design, policy, and technology. The operations documentation for the managed lanes describes and implements the desired characteristics, components, and requirements for the long-term function of the system and, by nature, will change over the life of the project. As such, the elements highlighted here are intended to be revisited throughout the project development.

Concept of Operations

The concept of operations (also referred to as "Con Ops") is a formal document that establishes the framework for defining the characteristics of managed lane facilities, accomplishing necessary institutional arrangements, facilitating consistency in the development of operating policies and procedures, and measuring system performance. The concept of operations effectively establishes the rules for implementing and operating managed lanes, from individual facilities to regional networks, and assists agencies in guiding policies over time.

The systems engineering approach to project development, which was initially used in the 1950s by the military, has evolved for the purpose of developing a managed lane concept of operations. Systems engineering provides the framework for an interdisciplinary process that addresses customer and stakeholder needs to achieve the highest quality and most cost-effective outcome (*109*).

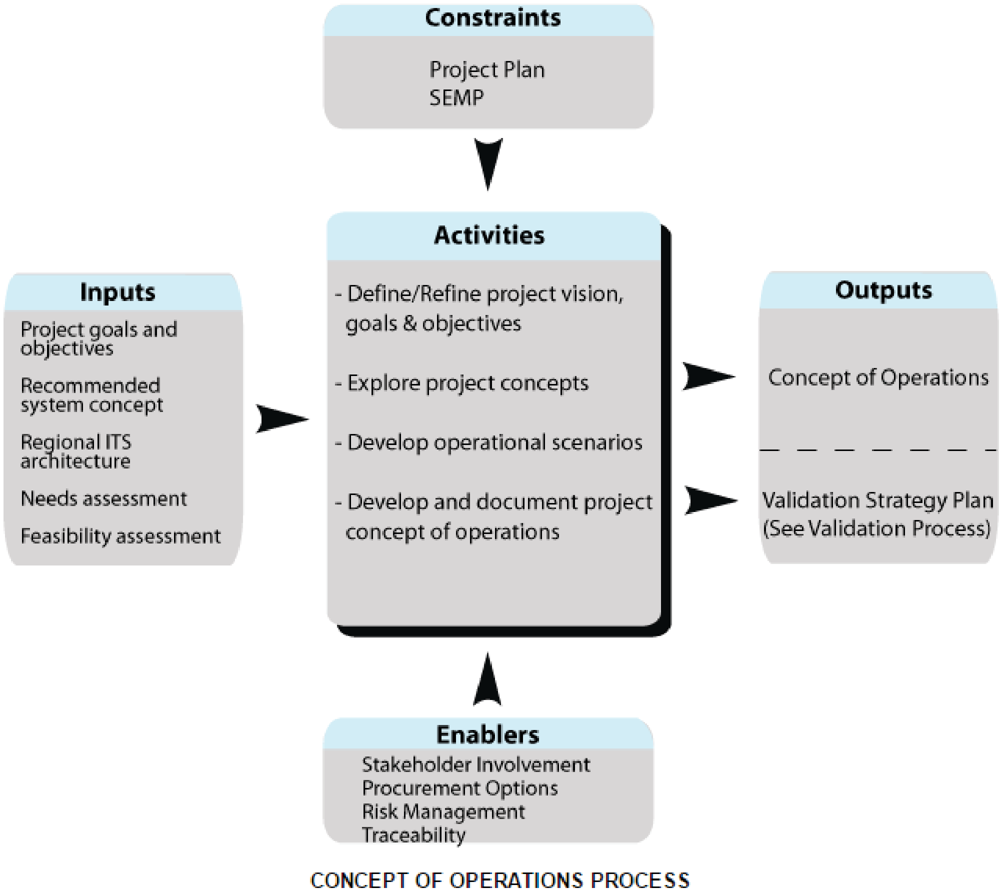
The systems engineering process has been adapted by the U.S. DOT for use with all ITS projects following the enactment of FHWA Rule/Federal Transit Administration Policy on January 8, 2001, which specifies under Section 940.11 that all ITS projects funded with the Federal Highway Trust Fund are to be based on a systems engineering analysis to ensure appropriate integration with regional ITS architecture, identify the roles and responsibilities of stakeholders, and adequately evaluate alternative system configurations and procurement options [23 Code of Federal Regulations (CFR) 940.11]. Figure 88 in Chapter 5 illustrates the systems engineering V diagram, which is representative of the project development process following the systems engineering approach. It clearly indicates the concept of operations as a fundamental element of the process to be implemented early in the project development timeline, thereby providing a foundation for subsequent analysis and design (*103*).

Building upon the synergy between ITS and managed lane projects (particularly managed lane projects integrating pricing or active traffic management), elements of the systems engineering approach are increasingly followed during project development, including the development of a concept of operations. *A Guide for HOT Lane Development* (*78*) initially identified many elements of the concept of operations as part of the organizational framework for HOT lane projects. The *Priced Managed Lane Guide* (*2*) formalized the recommendation to develop a concept of operations as part of the planning and design of managed lane facilities. Figure 89 illustrates the concept of operations process for managed lane projects.

Purpose of the Concept of Operations

The concept of operations defines various design elements and operating parameters for managed lanes building upon previously defined goals and objectives, and informs subsequent policy and business rule development. The concept of operations is one of the first documents to be produced as a result of conceptual planning—either for a managed lane facility or regional system—since the concept of operations discusses all components, including intended partnering, design, procurement, and operations.

The process for developing the concept of operations requires the engagement of decision makers and stakeholders in an interactive process to achieve concurrence on specific



SEMP = Systems Engineering Management Plan
Source: California Division, FHWA (*110*).

Figure 89. Concept of operations process.

issues and actions affecting managed lane design and operations. Furthermore, to encapsulate new information as managed lanes are planned, designed, constructed, operated, and maintained, the concept of operations is typically developed to be a living document so that the underlying framework can continually be revised and enhanced to improve the effectiveness of the facility.

Recent managed lanes provide an example of this coordination and ongoing revision. The Florida Department of Transportation prepared a facility-based concept of operations for the I-95 Express Lanes in South Florida. The initial document was developed prior to deployment of the I-95 Express Lanes in 2009. After a revision to bring the concept of operations in line with the express lanes operations manual, the concept of operations was utilized as a base-case scenario for the development of the Miami/Ft. Lauderdale Regional Concept of Operations. Consequently, the regional document includes various policies, design options, and other alternatives that are appropriate for individual corridors; however, it maintains consistency throughout the entire network. As new facilities come online or existing facilities have a revision to their operations or policies, the regional concept of operations will adapt and change. In turn, the regional concept of operations provides base guidance, planning, and design criteria for new corridors so that the planning process is efficient and effective.

The purpose of the concept of operations is to clearly delineate the roles and responsibilities of various stakeholders involved in the planning, design, construction, operations, and maintenance of managed lanes. According to U.S. DOT, an effective concept of operations addresses the who, what, where, when, why, and how questions about the project by responding to the following questions (23 CFR 940.11):

- Who—Who are the stakeholders involved with and users of the system?
- What—What are the elements and the high-level capabilities of the system?
- Where—What is the geographic and physical extent of the system?
- When—What is the sequence of activities that will be performed?

- Why—What is the problem or opportunity addressed by the system?
- How—How will the system be developed, operated, and maintained?

A concept of operations can be adapted to address individual facilities, interconnected corridors, or regional networks of managed lanes. Furthermore, the concept of operations process should be iterative to apply regional guidance during the initial development of specific managed lane facilities; establish preliminary guidance during planning and design phases of project development; and confirm final parameters for business rules, operations, and maintenance.

Regional Network Concept of Operations

A regional concept of operations addresses policy and operational concepts for regional managed lane systems rather than focusing on a specific facility or corridor. As such, a regional concept of operations can be used to establish broad parameters that guide the subsequent development of specific managed lane facilities on an integrated regional network. A regional concept of operations can also be utilized to help prioritize managed lane projects based on conceptual estimates of available funding.

The Metropolitan Transportation Commission—the MPO for the San Francisco Bay Area—was the first agency to develop a comprehensive regional concept of operations for the managed lanes in the San Francisco Bay Area. Completed in 2010, and since revised, the document has served as the basis for the deployment of the I-680 Express Lanes in Alameda County in 2010 and the SR 237/I-880 Express Lanes in Santa Clara County in 2012 (*111*).

In 2014, as mentioned previously, the Florida DOT completed the *South Florida Regional Concept for Transportation Operations* addressing the proposed managed lanes network in South Florida (*112*). In 2013, the Southern California Association of Governments initiated the Regional Express Lane Network Pre-implementation Assistance Study, which resulted in the 2015 *Regional Express Lanes Concept of Operations* for Southern California (*113*).

Review of these documents reveals that a regional concept of operations typically formalizes and documents the following topics, while continuing to provide flexibility for changes within the design and development stages:

- Regional vision and network planning.
- Regional project funding prioritization and procurement strategy.
- Operations, design, and policy guidance for regional consistency.
- Regional partnerships and agency cooperation.

Corridor/Facility Concept of Operations

The process for developing a concept of operations for a managed lanes facility should ideally be completed in two parts, with the development of an initial preliminary concept of operations and a final concept of operations.

The preliminary concept of operations should be completed early in the managed lanes facility planning process to establish preliminary guidance during the conceptual design phase of project development. In contrast, the final concept of operations should be completed near the end of the design process to apply the lessons learned and to confirm the parameters that will serve as the basis for the development of business rules, as well as the subsequent operations and maintenance of the facility.

Preliminary Concept of Operations

A preliminary concept of operations provides the opportunity to inventory all known institutional requirements to implement the facility, such as authorizing legislation or interagency agreements, ensuring consistency with long-range planning objectives, coordinating with other regional facilities, and highlighting the necessary actions to be taken by various partner agencies. As indicated in Chapter 2: Planning Considerations, the preliminary concept of operations should also identify the education and outreach program that will need to be implemented to gain feedback and support for the managed lane facility, including agency partners, elected officials, and the public. It identifies the different stakeholders that will be involved in implementing and operating the managed lanes and defines the anticipated roles that each will be expected to play, including maintenance, enforcement, and incident response. It also provides the opportunity to consolidate existing and future forecast conditions data related to the project corridor, and to establish the initial design and operational policy concept for the facility as the basis for completing the necessary environmental clearance and detailed design tasks. Finally, a preliminary concept of operations will provide a user perspective on the use of the managed lanes in order to clarify how system-level decisions translate into day-to-day use by potential customers (*2*).

The development of the preliminary concept of operations provides the initial forum to engage all of the stakeholders that will have a potential role in the development of the managed lanes facility. If the full array of potential stakeholders is engaged, then the various stakeholders can achieve concurrence on the goals of the project and the roles each of the stakeholders will play.

Traffic and Revenue Forecasting

If a revenue stream derivative from tolls generated by the managed lanes is required to fund the project, then traffic and revenue forecasting is an essential and core component of the concept of operations for the project. Chapter 2: Planning Considerations provides a more detailed examination of the traffic and revenue forecasting for managed lanes; however, this section describes its usefulness for operations considerations.

Chapter 2 defined the various levels of traffic and revenue studies, which indicate increasing levels of rigor and expertise required. Conceptual traffic and revenue forecasts, known as Level 1 studies, should be developed in conjunction with the regional concept of operations as the basis for determining potential funding availability and project prioritization. A Level 1 study can be conducted as an adjunct to planning activities, but more reliable outcomes result from specific expertise in conducting traffic and revenue studies. Preliminary traffic and revenue forecasts for a specific facility or corridor—a Level 2 study—should be developed during the preparation of the preliminary concept of operations to test policy and design concept options based on the best information available at the time. As the design for the managed lanes facility proceeds and policy actions are accomplished, final traffic and revenue forecasts should be prepared to better define the anticipated outcomes of the proposed project as the basis for establishing and managing stakeholder and public expectations, and to support the development of final tolling policy (such as minimum and maximum toll rates, etc.). These final forecasts may simply be a Level 2 study but can also be a part of a Level 3 study.

For projects utilizing multiple project financing options, including private concessions, federal loans, or private activity bonds, a complete investment-grade traffic and revenue study (a Level 3 study) will be required by investors as the basis for assessing potential funding risk. Ideally, the investment-grade traffic and revenue forecasts will be completed during the final stages (or following completion) of the project design to ensure that design features and operating policies are accurately reflected in assumptions and, likewise, necessary revenue functions are incorporated within the operations plans. A Level 3 study can only be completed by those who have the confidence of potential investors, and as such, is limited to only a few entities.

Final Facility Concept of Operations

The final concept of operations for a managed lanes facility builds upon the prior steps in the facility planning process to consolidate the lessons learned and additional available information, resulting in a revision of the preliminary concept of operations. This document can be considered final documentation; however, operations of the managed lanes will change over time, and the concept of operations document should change with it, with revision notations offered as appropriate. As such, the final concept of operations should be revised as policy, design, or operations changes are made, effectively making it a living document.

The final concept of operations provides the opportunity to confirm the outcomes of the project planning and design process, as constructed, and to provide institutional memory regarding the various elements of the project as the basis for developing business rules that will guide operations and maintenance. This compilation incorporates the outcomes of the various technical evaluation tasks along with the findings of the agency, elected officials, and public outreach activities as reflected in the various policies and design elements agreed upon by the project stakeholders. The completion of the final concept of operations document should represent a critical milestone in the project development process to coincide with attainment of environmental clearance and completion of preliminary and/or final design.

Considerations for Toll Operations

For managed lanes with a tolling component, the use of pricing to manage traffic demand requires real-time monitoring and operations because it allows the operator to manage traffic demand with the sensitivity necessary to routinely maximize vehicular throughput. From optimized vehicular throughput on the managed lane, other objectives adopted by the operator for which traffic management is appropriate can be realized. As such, an understanding of the goals, mechanisms, and strategies for applying pricing is critical to the effective operation of managed lanes.

Pricing Performance Measures

The performance objectives of the pricing program define the operational goals that the facility is trying to achieve. These often include vehicle speed, vehicle throughput, person throughput, and travel time reliability, and may include other parameters such as carpool use, overall travel time, transit use, and transit operational speed. If revenue generation is a significant objective for the facility, revenue produced is also an appropriate operational parameter. It is also possible that facility-specific factors will lead to other performance objectives.

Defining and understanding performance objectives for the managed lanes' pricing program is essential if a cohesive and logical operating plan is to be developed for the facility. Often, these objectives may be linked to the purpose and need for the facility, as decided within the environmental process. Operational parameters, such as the toll charged, may work to achieve one objective, such as maximizing throughput, but may not be optimal for another objective, such as maximizing revenue. If operational parameters are not considered and viewed in a complete manner, achieving the best operation of the corridor may not be possible for the simple reason that "best" has not been defined in a holistic manner. Achieving the optimum performance for all operating parameters is rarely possible, and the interplay between desirable performance objectives must be understood to achieve an overall optimum result.

Multiple performance objectives can be developed for any facility, and most effects are complementary. For example, a performance objective that emphasizes person throughput will also have the effect of enhancing vehicular throughput. As a result, there are few distinct differences between the possible arrays of performance objectives. However, in limited situations, conflicts will arise and compromises between optimal and acceptable performance will need to be made.

Pricing Variability

Pricing variability pertains to the mechanism by which express lane toll rates are both set and presented to drivers on managed lane facilities. Since the first adoption of priced managed lanes on SR-91 in Orange County, California, in December 1995, the means by which toll rates are varied to both manage demand and ensure performance along the managed lanes has evolved. SR-91 utilizes a fixed schedule of toll rates that varies by the time of day. This toll schedule has changed throughout its years of operation and has maintained acceptable or better performance. In contrast, the I-15 Express Lanes in San Diego, which in 1998 was the first facility to use a dynamically set algorithm, sets the prevailing toll rate by existing traffic conditions. As more managed lane facilities have opened, the two systems of pricing have been utilized by various operators with equal levels of success. Additional implementations in the late 2000s involved hybrid toll structures using both fixed-schedule and dynamic pricing algorithms. As of 2015, multiple systems of pricing variability are in use (*114*).

Pricing may serve as the primary means of metering traffic into and out of the managed lanes. Varying toll by prevailing willingness to pay is a critical element of pricing, and all priced managed lane operators have implemented some version of it. However, the research (*114, 115*) indicates that variable pricing by either time of day or real-time traffic works equally well in managing demand, provided the operator is able to set and adjust prices based upon utilization and prevailing demand.

There are two primary forms of variable pricing in use on U.S. priced managed lanes (*114*):

- Time-of-day pricing (also called fixed variable pricing). Time-of-day pricing involves the establishment of managed lane toll rates based upon a published schedule. This system is actively used in Denver (I-25, US-36, and I-70), Orange and Riverside Counties in California (SR-91), Baltimore (I-95), El Paso (Loop 375), and Houston (I-10, US-59, I-45, and US-290). Although the toll schedule is predetermined based upon traffic conditions as collected and recorded over time, it will change over time to respond to traffic conditions in the lane. The Orange County Transportation Authority initially revised the toll schedule twice per year but has found that more frequent revision may be necessary in order to maintain performance. Furthermore, a time-of-day pricing schedule must anticipate days where traffic demand is higher than the average and set a toll accordingly. This leads to a stair-stepped pricing schedule that sits higher than the demand-set pricing. Furthermore, time-of-day pricing involves lower operations and maintenance costs because the system of pricing is not dependent upon real-time traffic measurement. Finally, toll rates need to be revisited on a regular basis and adjusted if they are not managing traffic flows as desired.
- Dynamic pricing. As compared to time-of-day variable pricing, dynamic pricing involves changing the toll rate in response to real-time traffic demand for the managed lane facility, as informed by vehicle detection technology embedded in the roadway. The dynamic pricing algorithm, which sets the toll rates, may include metrics from the adjacent general-purpose lanes, but the primary measure contributing to the establishment of the toll rates is performance within the managed lanes directly. Dynamic pricing is more commonly used on managed lanes today, including San Diego (I-15), Miami (I-95), Minneapolis (I-35W and I-394), Atlanta (I-85), and Virginia (I-495), among others.

Many characteristics can affect the pros and cons of each strategy (see Table 11). Sponsoring agencies in the Dallas–Ft. Worth region tried to reflect these different pros and cons by implementing a hybrid solution. The hybrid solution involved opening a facility with time-of-day pricing for traveler familiarity and then moving to dynamic pricing when traffic conditions warranted. In 2015, 15 managed lane projects in the United States operated under some form of dynamic pricing: 12 projects used time-of-day pricing, and 3 projects used a hybrid solution, as shown in Figure 90. Since 2015, more projects with dynamic pricing are evident as the means for applying variable pricing to manage traffic flow versus time-of-day pricing; however, both schemes continue to be adopted (*114*).

Pricing Basis

Facility pricing can be performed based on many different factors, such as follows:

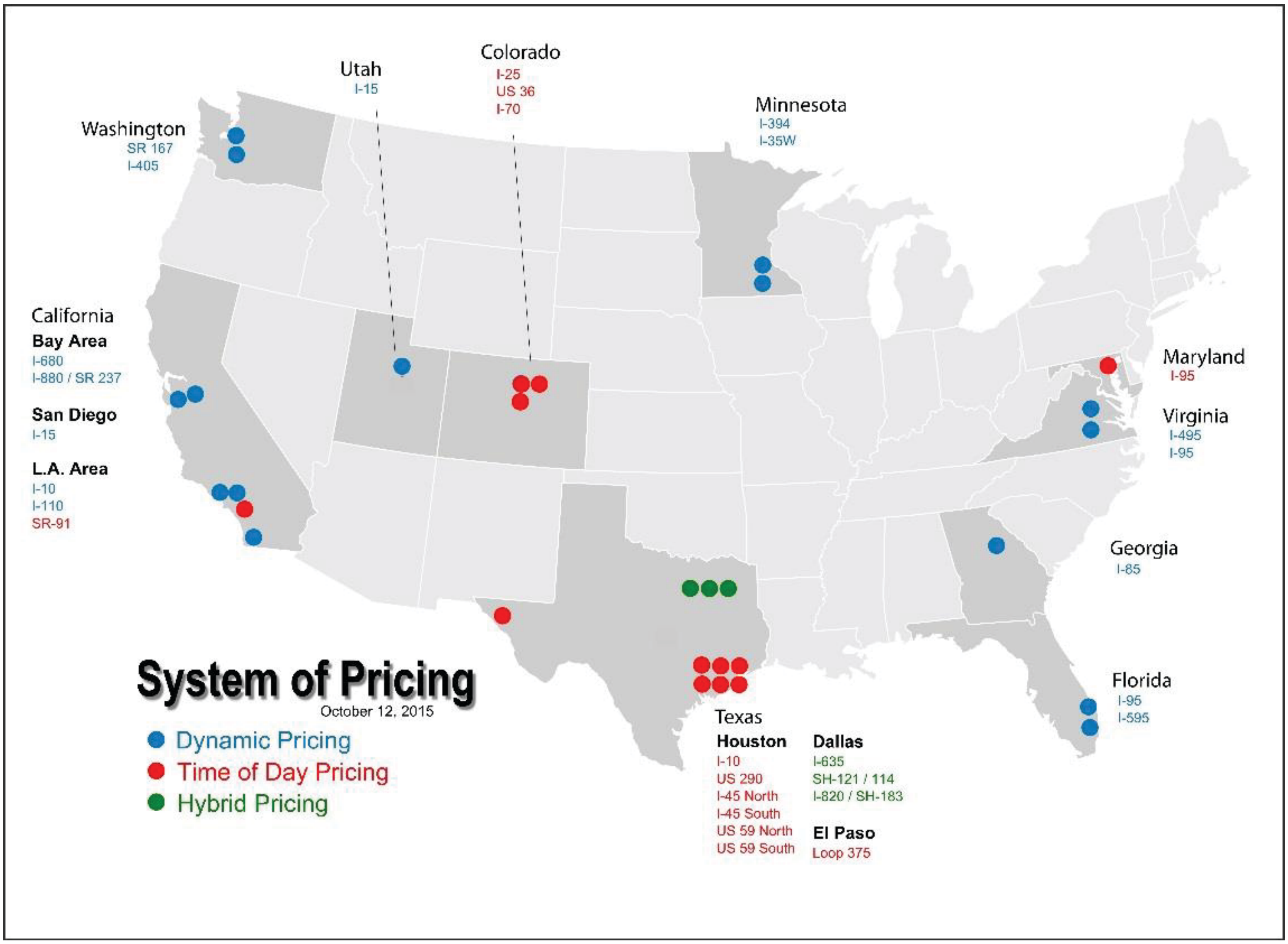
- Toll per mile.
- Toll per interval (e.g., every interchange).
- Toll per segment of the facility.
- One toll to access an entire facility.

Note that the pricing basis does not necessarily coincide with how information about the current price is passed to the driver.

Table 11. Pros and cons of pricing variability options.

Pricing	Pros	Cons
Dynamic	• Traffic responsive (responds to real-time traffic) • Ability to handle traffic spikes under special events (e.g., sports activities) • Automatic toll rate setting (no regular toll rate adjustment)	• Unpredictability • Not easy to understand for customers • Highly dependent on traffic detector systems • CMS required (must be functional) • Black box in tolling algorithms (typically proprietary property of a vendor) • Higher level of capital cost • Higher level of toll operation cost
Time of Day	• Predictability • Easy to understand (for customers) • Not dependent on traffic detector systems • CMS not necessarily required • Toll schedule crystal clear to operators (no black box) • Lower level of capital cost • Lower level of toll operation cost	• Not real-time traffic responsive (toll rates based on historical traffic conditions) • Not able to handle traffic spikes under special events • Regular toll rate adjustment required (not automatic)

Source: FHWA (*114*).



Source: WSP I Parsons Brinckerhoff.

Figure 90. Operational managed lane facilities by pricing scheme.

For example, while the facility may be priced at a moment in time at $0.21 per mile, providing the driver with a total for a given length of the road may be a clearer message. Therefore, for a 5-mi segment, $0.21 per mile may be related as a $1.05 toll to the driver.

Furthermore, the pricing basis does not inherently contain any surcharges or additional fees that may be levied on the user. For example, Colorado, Florida, and Texas permit trucks to use some of their managed lanes for an additional charge. Likewise, Washington, Colorado, and Texas charge additional fees for vehicles using a license plate invoicing mechanism of payment.

The basis for pricing can have a significant impact on how well the operations can manage traffic demand on the facility. Usually, the more refined the unit pricing basis, the better the ability to manage demand. While segment pricing can sometimes appear to the driver to be virtually identical to per-mile pricing or interval pricing, if the segment includes several entry and exit points, it may not be as sensitive to demand as a pricing mechanism that calculates the toll exactly between exit points. As the scale broadens to an entire facility, differences in demand on various segments of the facility cannot be taken into account in the pricing mechanism, and, to maintain flow on the facility, the toll will need to be set based on the area of maximum demand within the facility. This means that flow will likely be less than optimal on many facility segments, exacerbated by managed lane networks. For areas with a network of priced facilities, attempting to manage demand using pricing on the overall network becomes problematic. Establishing and understanding the pricing mechanism and its ability to manage facility demand is therefore necessary for facility operation.

Options, along with their pros and cons, are shown in Table 12.

Pricing Differentiation

Managed lanes incorporate many different operational concepts for levying fees, ranging from lanes that require all users to pay a toll to lanes that allow discounted or toll-free travel for vehicles meeting occupancy or other eligibility requirements. How this is established impacts the operation of the lane.

The ability of various types of vehicles to access the lane at discounted or toll-free rates has a significant impact on multiple issues associated with lane operation and financing. The greater the number of vehicles that are granted some type of pricing exemption, the lower the revenue produced by the lane, and the fewer vehicles that can be price managed to maintain operational goals for the facility. This has substantial impact in two areas. First, if managed lane revenues are needed for operational or capital funding, it is possible that the number of exempt vehicles could reduce revenues below acceptable levels. Second, a large number of vehicles using the lane but paying no tolls reduces the ability of the lane to meet operational goals. Depending on the number of toll-exempt vehicles, it is possible that too few vehicles will be affected by pricing, and operational goals may not be met.

Finally, lane enforcement is much more difficult if both toll collection and occupancy and/or vehicle type must be determined. Toll enforcement using readily available equipment can be performed without any in-lane enforcement. However, with current technology, occupancy enforcement requires in-lane personnel.

Options for pricing differentiation include the following:

- Requiring all vehicles to pay a toll.
- Requiring all vehicles except public and commercial transit vehicles to pay a toll. It should be noted that the FAST Act requires consistency of toll application for public and commercial buses.
- Requiring all vehicles using the lane to utilize a transponder, but offering discounted tolls to exempt vehicles (such as HOVs, low- and zero-emission vehicles).
- Allowing exempt vehicles to access the lane without toll payment and not requiring a transponder for those vehicles.

Table 12. Pros and cons of pricing basis.

Pricing Mechanism	Pros	Cons
Per-mile pricing	• Greatest ability to provide travel demand management • Most equitable assessment of use versus toll charged • Better oriented for continuous-access design	• Complicated to convey to the driver • Requires the highest level of vehicle tracking for toll assessment, which may affect public acceptance based upon privacy concerns
Per-segment pricing	• Good ability to provide travel demand management • Reasonably equitable assessment of use versus toll charged • Relatively easy to convey to the driver	• Some reduction in ability to provide travel demand management • Difficulty in communicating where segments start and end, especially difficult with continuous-access design
Facility pricing	• Easy to convey to the driver • Relatively easy to assess tolls for each vehicle	• Limited ability to provide travel demand management

Table 13. Pros and cons of pricing differentiation.

Access Mechanism	Pros	Cons
All vehicles pay	• Revenue is maximized • Enforcement is simplified • Ability to manage traffic through pricing is maximized	• Increases cost to transit vehicles • No incentive for carpooling • Requiring toll payment for emergency and service vehicles may produce political or public backlash • For conversions from HOV facilities, tolling of HOVs may not be allowed
All vehicles pay except public/ commercial transit	• Revenue is near maximum • Ability to manage traffic through pricing remains strong • Transit vehicles are easily identified in the back office, so enforcement remains simple • Cost to transit vehicles is reduced	• No incentive for carpooling • For conversions from HOV facilities, tolling of HOVs may not be allowed
Differential pricing but all vehicles must have transponder	• HOVs and other groups are incentivized with discounted tolls • Enforcement is easier when transponders are required for all vehicles • Likely will meet criteria for HOV conversion	• Potentially creates a burden for HOV vehicles to obtain a transponder • Does not allow formation of spontaneous carpools without transponders • Enforcement is complicated • Ability to manage traffic flow through pricing is significantly reduced
Some vehicles allowed to access the lane without toll payment or transponder	• HOVs of all types and other exempt vehicles are incentivized • No change in operating requirements for HOVs compared to HOV-only operation	• Enforcement is complicated • Ability to manage traffic flow through pricing is significantly reduced • Likely to have the highest violation rate of all means

The pros and cons of each of these options are shown in Table 13.

Pricing Changes

Levels of transportation demand are constantly changing, typically increasing; however, decreases can occur. For this reason, to maintain the operational goals established for the facility, pricing rates and mechanisms need to be periodically reviewed, revised, and adopted by the appropriate decision-making process. Triggers for pricing review can be as simple as a periodic schedule for review or may involve a review of facility operation, with an eye toward degradation of any project objectives. Without project review, the operation of the facility may degrade, and the existing pricing structure may not be sufficient to restore the facility to the desired operation. If pricing is not reviewed or revised over a long period of time, it is possible, if not probable, that the impacts of inflation and increasing traffic demand will result in a significant degradation of service.

Pricing reviews can be triggered by a change in facility operational parameters, such as a change in occupancy requirements for discounted tolls; a change in actual facility operation, such as a decrease in operating speed or throughput; or simply the passage of time. It should be noted that a review of facility pricing does not automatically indicate the need for a change in pricing schedule or methodology.

For a time-of-day-based operation, pricing revisions will be made to the pre-published schedule of toll pricing for the facility. It is reasonable for a review to be undertaken periodically, with 3-month intervals recommended based upon current practice. In the review, traffic speed and throughput for various times of day should be compared with optimum values. Where there is a significant difference between the observed value and the optimum value, consideration should be given to revising the pricing schedule to bring actual operation into closer alignment with optimal operation. Changes in traffic demand in response to pricing changes can take time to develop; for this reason, there should be some type of reasonable delay between the implementation of a revised pricing schedule and further changes to the pricing schedule. This length of time will vary by facility but should consider indicators of how quickly traffic stabilizes after a pricing change and any other impacts that may occur to the facility during this time, such as seasonal variations.

For dynamically priced facilities, there are other factors that need to be considered. A review should always consider any maximum pricing criteria that are placed on the algorithm. If operational parameters are consistently below optimal conditions even when the largest toll allowed is used, consideration should be given to raising the maximum allowable toll. In addition, unlike time-of-day pricing, the speed with which an algorithm reacts to changing conditions should also be evaluated. Failing conditions during times when a high

Table 14. Pros and cons of reviewing pricing changes.

Review Trigger	Pros	Cons
Change in operations	• Is sensitive to actual conditions on the facility	• Symptoms may not manifest until the problem is well developed
Passage of time	• Ensures a periodic schedule review of facility operation	• Problem may go untreated in between review intervals

toll is applied may indicate that the algorithm is not reacting quickly enough to changing conditions or is improperly balanced by its variables. In this case, the toll charge may be appropriate; however, the rate change should have been in place more quickly. Likewise, if a facility experiences low volume after tolls begin to be reduced, the algorithm may not be responding quickly enough to reductions in demand. This means that the review should consider both the amount of the toll and the rate of change in the toll compared to the rate of change in traffic demand.

Pros and cons of review triggers are listed in Table 14.

Technology Options

Toll collection technology and processes are rapidly changing, and this rapid change is likely to continue for the foreseeable future as mobile technology evolves. The rapid pace of development and replacement of technology represents challenges and benefits for managed lane operators. The problem is that technology chosen for a particular project may be quickly surpassed or, in the worst case, made obsolete.

For example, one managed lane operator utilizes a toll collection protocol that, at the time of installation, was cutting-edge technology, but today it is relatively orphaned and unused by the rest of the toll and managed lane operating community. As such, despite its current full functionality for the operator, this protocol offers the operator no benefit for toll interoperability or long-term sustainability. In 2015, the operator replaced this protocol with one used more broadly in the industry and generally regarded as a primary protocol for national interoperability. Although changing technologies can yield such unfortunate scenarios, the primary benefit to managed lane operators is that more efficient ways of collecting and processing the information necessary for toll collection are constantly being developed. Additionally, national interoperability requirements (established in U.S. federal law by MAP-21 and confirmed by the FAST Act) will require all toll operators to adhere to standards as they are developed, adopted, and enforced.

As another example, one of the main issues that an operator will need to address is whether to use a closed, proprietary standard or an open standard. While proprietary standards have been extensively used in the tolling industry, open standards such as the ISO 18000-6C transponder protocol (more commonly known as 6C) gained traction with deployment in Colorado, Georgia, Utah, Minnesota, and Washington and future deployment in California and Florida, as of 2015. This approach has the capability of increasing competition, which in turn has demonstrated a reduction in costs. In 2015, the largest 6C deployment agency has procured transponders for less than $1 per unit, which is a significant drop in price over the past few years. With deployment in California and Florida, costs are expected to decline further due to the larger installment base.

Over time, additional technologies not currently engaged in toll collection could become common. For example, connected vehicle applications, specifically those involving vehicle to infrastructure, may include toll collection as standards are developed.

For the development of a managed lane project, regardless of how technology develops, operators are well advised to select the best available technology at the latest time the decision can be made without disrupting project progress. This, along with selecting technology and platforms that are upgradeable, will likely result in the development of a good technology strategy for managed lane implementation. As many roadside systems require replacement within a 10- to 15-year time frame, the agency sponsor should monitor and evaluate new technological options for deployment when system replacement becomes necessary.

HOV Eligibility Considerations

Vehicle eligibility provides for the restriction of facility use to specific users or vehicle classifications. HOV lanes, one form of managed lane, generally require two or more occupants per vehicle (HOV2+), although a few require three or more (HOV3+), operate permit buses only, or (if on signalized roadways) allow turning movement vehicles.

Over time, the vehicle eligibility requirements to use the lane may change to reflect regional and corridor demand or to better reflect the performance objectives of the managed lane facility. Some HOV lanes needed to change their occupancy requirements over time as demand for HOV2+ facilities grew to HOV3+ in a few cases. Conversely, lane management for heavy trucks has been revised in certain areas as overall truck volume has increased. In all cases, the operation of the managed lane will change to permit other vehicles, as policy and operations require.

Operations pertaining to HOV eligibility have been addressed in *NCHRP Report 414: HOV Systems Manual*, which continues to serve as the primary guidance for such vehicle eligibility (*3*).

Ongoing Operations

Managed lanes are implemented to maintain traffic flows and the levels of performance desired on the facility. These strategies require attention to day-to-day operations in order to best extract performance from the lanes directly. Toll collection systems remain of particular interest to priced managed lanes.

Toll Collection System Operations

Toll collection systems include all software and hardware necessary to identify toll-paying vehicles, assess the correct toll, and enforce the facility to minimize toll violations. Beyond these basic elements, systems may also identify vehicle weight, number of axles, or other factors an agency wishes to identify for toll assessment.

Elements of a toll collection system often include the following:

- Transponders (for use in vehicles).
- Antennas to read the transponder.
- Readers to decode the information from antennas.
- Cameras for input to an optical character recognition system.
- Lane controllers to assimilate data from the readers and cameras.
- Protection from lightning and other weather-related events.
- Communications equipment and mechanisms to allow information from lane controllers to be forwarded to a back office.
- Back-office systems to allow proper billing for tolls as well as violation enforcement.
- Software for operating in-lane and back-office hardware.

Other equipment that may also be necessary for proper toll evaluation includes the following:

- Treadles.
- Lasers to determine vehicle type and size.
- Loop detectors or other presence-detecting devices such as cameras or microwave devices.
- Other cameras, including infrared cameras, to assist in toll collection, vehicle identification, or lane enforcement.
- Light sources, including visible light and infrared to assist in camera use.
- Enforcement provision, including parking and protection, for manual observation.
- Beacons to signal the successful completion of a transaction.

Maintenance and replacement of toll collection hardware and software will be dependent on the type of equipment involved, as well as the pace of equipment and system improvement, which has historically been rapid. This rapid improvement in equipment and systems can also affect the initial decision about what systems and equipment to deploy. Maintenance and replacement cycles for the tolling equipment and software should also be fully explored with equipment vendors, with replacement cycles often ranging from 7 to 10 years based on current practice. This allows life-cycle costs to be evaluated in the hardware and software selection process. Proper equipment selection and proper maintenance and replacement schedules are necessary to ensure the proper functioning of the toll collection system. This can be critical to revenue collections, facility enforcement, financial forecasting, and overall customer satisfaction.

Customer Service

Customer service is a necessary and vital function for toll collection. Managed lanes, like any other business that provides services, have customers. Interaction between the agency and the customer will occur often. For priced managed lanes, most interactions will be routine, such as paying tolls, opening an account, or maintaining the account. However, there will also be disputes of tolling charges and issues associated with violations. For non-priced managed lanes, customer service pertains more to assistance in forming carpools, obtaining requisite vehicle eligibility information, or other such services. Often, these functions are provided by third parties, such as transportation management associations or rideshare programs.

The ability of the agency to interact with its customers in a positive way and meet the needs of those customers will be a key factor in the overall acceptability of a managed lane. Providing an easy-to-use mechanism to interact with the agency is a key element in developing customer satisfaction. This interaction should also include outreach and marketing so that customers understand facility operation. In this way, the benefit of the facility to its various customers is maximized.

Options for direct public interaction include the following:

- Walk-in facilities include storefronts that allow face-to-face customer service. These facilities are often co-located with other sponsor agency functions, including municipal services, tolling back-office services, or rideshare services, in order to most efficiently use staff and office space. If priced, all services including toll payment, account acti-

Table 15. Pros and cons of the mechanisms for direct public interaction.

Interaction Mechanism	Pros	Cons
Walk-in facility	• Usually the best method for fully addressing a customer's needs • Usually the best method for addressing complex issues • Transponders can be directly provided to the customer	• Usually the most expensive method of customer interaction • Usually able to provide one or at best a limited number of facilities
Phone operation	• Maintains the connection with a real person • Works well in addressing complex issues • Usually less expensive than maintaining walk-in facilities • Location of the facility is not an issue	• Somewhat less effective than face-to-face communication • An alternative method for the physical delivery of transponders must be provided
Internet site	• Usually less expensive than walk-in or phone mechanisms • Usually available 24 hours a day, 7 days a week, which allows the customer to interact on his or her schedule	• Complex issues may prove difficult to resolve • An alternative method for the physical delivery of transponders must be provided
Retail-based vendor	• Provides a very convenient source for transponder sales	• Interaction is usually limited to transponder sales only

vation and maintenance, transponder sales, and violation payment should be available at the walk-in facility. It should be noted that not all managed lane facilities provide a walk-in option.

- Phone operation should be available for all managed lane facilities. The ability for the public to directly speak to a representative that is knowledgeable in facility operations, managed lane use, and account management issues is critical for proper public service. As with the walk-in facility, all services should be available via phone.
- Internet sites have become the primary and most effective method of customer interaction for business and government alike. Again, all services available from other means should also be available online.
- A growing trend in toll facilities is to use retail-based vendors for customer service—particularly transponder sales and account management. This allows customers to obtain their transponder easily, often as part of a shopping trip to a grocery store. Customers are then able to activate their transponders and create an account through any of the methods previously discussed.

The pros and cons of the mechanisms for direct public interaction are given in Table 15.

Startup/Opening Guidelines

Facility Marketing

Branding and marketing allow a managed lane to develop a sense of identity with the public while providing appropriate information to the public. Various functions for public outreach and marketing are addressed in Chapter 2: Planning Considerations and Chapter 5: Implementation and Deployment. Although the context of the marketing guidance in the previous chapters pertains to the conceptualization and development of managed lanes, the need for marketing and outreach is ongoing. New customers will continue to require guidance on how to use the managed lanes, and under what context. The FHWA *HOV Marketing Manual* (*116*) provides helpful guidance for sponsor agencies, whereas the FHWA *Priced Managed Lane Guide* (*2*) provides guidance for priced managed lane facilities.

Eligibility Validation

Vehicle eligibility is a key component of managed lanes, as is validating customers' eligibility. Vehicle eligibility is discussed in Chapter 2: Planning Considerations. For the purposes of managed lane operations, the primary challenges include articulation of current eligibility requirements to motorists and adequate enforcement to maintain vehicle eligibility as a system control.

Managed lane facilities may provide preferential access to vehicles that meet certain qualifications. Motorcycles, zero-emission vehicles, alternative fuel vehicles, vanpools, and buses have all been identified in federal law, state authorization, and sponsor agency business rules as eligible for preferential access. For example, federal law regarding managed lanes (generally codified under 23 U.S.C. 129 and 23 U.S.C. 166) allows for preferential access consideration of transit, paratransit, motorcycles, toll-paying SOVs, and designated hybrids on managed lanes operated on roadways constructed with federal funds. Furthermore, performance requirements for managed lanes authorized under 23 U.S.C. 166 require sponsor agencies to change the managed lane operation policies, including minimum occupancy, hours of operation, pricing, and exceptions, for any managed lanes that degrade beyond defined performance minimums. It is under the performance requirements that vehicle eligibility may be altered. Managed lanes authorized under 23 U.S.C. 129 have different requirements and do not provide for HOV benefits by right.

On most managed lanes, vehicle occupancy is the primary vehicle eligibility requirement. As such, validating occupancy is a key enforcement challenge. Without credible eligibility declaration and validation, the desired operation of the facility is jeopardized. In extreme instances, violation rates of greater than 50% are known to have occurred. At high violation rates, the managed lane in essence reverts to a general-purpose lane and is not capable of providing the operational benefits it is designed to provide. Occupancy enforcement remains a primarily manual process. While gantry lights and/or mobile readers for optical character recognition can be used to identify which vehicles have declared themselves to be HOVs on priced managed lanes, occupancy detection, whether automated or visually performed by an officer in the field, still requires a traffic stop to verify that occupancy requirements are not met on priced and non-priced managed lanes alike. Children in car seats, occupants in the backseat, or even reclined passengers require that validation of occupancy prior to issuance of a citation must include a traffic stop.

Automated systems of occupancy validation are showing promise; however, they do not yet meet the requirements for enforcing occupancy violations based on automated detection. Instead, many sponsor agencies have expressed interest in using automated validation systems as a support role for manual enforcement—either for identifying repeat likely violators, signaling downstream officers of potential violators, or simply aiding in occupancy counts for performance monitoring.

In a priced managed lane with discounted tolls for HOVs, the willful violation of occupancy eligibility constitutes a revenue loss, as well. On managed lanes that allow some vehicles to obtain a discounted toll trip, determination of eligibility to receive these benefits creates additional complexity in the toll collection and enforcement process. Particularly for occupancy determination, eligibility validation remains a process that is predominantly manual. This includes both a vehicle's declaration of eligibility as well as enforcement of eligibility.

Options for declaration of HOV status include switchable transponders, account status declaration, and declaration lanes.

As the name implies, **switchable transponders** allow users to declare the mode in which their vehicle is currently operating. Depending on facility requirements, this transponder can switch between HOV and non-HOV; switch between non-HOV, HOV2+, and HOV3+; or, for facilities where HOVs are not required to use a transponder, simply include an on-off switch. The first facilities to undertake this type of declaration provided patrons with a special radio wave blocking bag that prevented transponders from being read by the toll facility. Current form factors include two or three switch settings and are compatible with common transponder protocols. Recent best practices in Colorado and Washington have led to a switchable transponder that displays a different color on both sides of the transponder device to signal the current switch setting. The different color panels allow enforcement personnel to validate the number of persons in a vehicle without needing to look away from the windshield. Switchable transponders are in use in California, Colorado, Virginia, and Washington.

Account status declaration allows drivers to use common, non-switchable transponders yet still declare their occupancy status. A driver that is changing status from HOV to SOV or vice versa logs into his or her account and makes the appropriate status change. The status change can be permanent until changed again in the account or can expire after a certain period of time. Smartphone apps have also been developed to allow this change to be made. Drivers are cautioned to not change their status while the vehicle is in motion. Also, advance notice is required to allow information on the account status to be downloaded to the lane controllers. It should be noted that only accounts for which the status has changed need to be downloaded at any given time. However, facilities usually perform a complete download of the status of all accounts on a daily basis. This download is often done during periods of very low traffic. Account status declaration is in use in Atlanta and Dallas–Ft. Worth. For example, in Atlanta, enforcement officials are provided with an audible or visual alert if a license plate matches the database of registered HOV3+ users to prompt a visual inspection for vehicle occupancy compliance. Officers upload a list of occupancy violations written during a shift to the express lane back-office system.

A **declaration lane** is a lane segment within the toll zone of a managed facility that allows toll customers to enter one lane and declare themselves, and allows exempt vehicles (such as HOVs) to use another lane to declare themselves as toll-free eligible. The lanes are usually side-by-side on a facility and only extend long enough to allow the drivers to safely diverge and merge. Declaration lanes are in use in California and Houston.

Since on-site enforcement is a part of eligibility validation, the facility design should accommodate the anticipated traffic stops and account for the safety of both the officer and the vehicle occupants. The best way to allow for this need is to design and designate specific enforcement areas that provide a safe pull-off from the in-lane traffic. Additionally, providing sufficient space and protection for vehicle parking should be considered in the toll zone and/or enforcement area design, as is practiced in the Dallas–Ft. Worth region. In California,

Table 16. Pros and cons of various eligibility declaration mechanisms.

Declaration Mechanism	Pros	Cons
Switchable transponder	• Does not require communication with the agency to change status • Relatively simple to use	• Requires a costlier transponder • Transponder can inadvertently be left in the wrong mode • Changing the transponder status can be distracting to the driver
Account status declaration	• Allows the use of a very simple and inexpensive transponder	• Declaration must be made in advance of facility use • Accounts can inadvertently be left in the wrong mode • Driver may change account status while moving despite warnings to the contrary
Declaration lane	• Simple for the driver	• Requires development of additional lanes on portions of the facility, which may require right-of-way and have a significant cost

current practice has yielded the development of an enforcement monitoring template that can be incorporated within various toll system designs. More details on enforcement area design can be found in Chapter 3.

The pros and cons of various eligibility declaration mechanisms are described in Table 16.

Traffic Monitoring and Control

Traffic monitoring and control pertain to the mechanisms, systems, and operations strategies in place to ensure safe and efficient operation of the managed lanes. Modern urban transportation systems are often operated at capacity during peak periods of travel, which places demand on transportation agencies to obtain more out of the existing systems. Since the early 1960s, there has been a recognition that active monitoring and control of traffic on the highway network would improve the throughput of the system and make the network safer and more reliable. Systems used to monitor traffic include closed-circuit television (CCTV), detection, and reports from staff patrolling the system. Increasingly, third-party traffic data from probe metrics are being used. Active monitoring is typically centrally managed through traffic management centers with operators and systems that can monitor traffic at corridor, region, state, or multistate levels.

Traffic control systems include traffic signals, ramp meters, changeable message signs, gates, pavement markings, barriers, and lane designations. Managed lanes are another form of traffic control, utilizing pricing, occupancy requirements, vehicle class restrictions, and/or time-of-day restrictions to actively control traffic using the facility. Mechanisms for monitoring managed lanes include the systems used to monitor traditional facilities but also need to include enforcement mechanisms and active monitoring of individual lane users to ensure that each user meets the requirements for use of the managed lane facility.

Monitoring and control of the managed lanes are critical elements of success. The key difference between a managed lane and a general-purpose lane is that the managed lane has an expected level of performance. This means that when performance does not meet expectations, operational or design changes for the managed lane are required. General-purpose lanes have no such requirement.

Meeting the performance goal of a managed lane facility requires that the system be actively monitored and controlled so any events or disruptions can be quickly cleared. Additionally, the amount of traffic using the facility needs to be monitored and controlled to ensure that the capacity of the managed lane is not exceeded. Traffic control options include active control (pricing), access control, and occupancy control (HOV requirements).

A wide variety of technologies and strategies are available to provide traffic monitoring and control (see Table 17). Effective technologies provide the facility operator with the ability to see and track conditions. It is common to have a mix of strategies. For many managed lane facilities, the systems that monitor the managed lane are also used to monitor the adjacent general-purpose lanes. The best options provide video surveillance and a sensor network that can be monitored by facility operators to give real-time information about the status of the entire facility and its connections. The systems used for monitoring and control should archive information so that system performance can be tracked and reported.

For additional information on traffic controls and signage, see Chapter 4. Physical control of the traffic using the facility is provided by the access management strategy for the facility. Access control is discussed in the following section. Options for enforcement of managed lane requirements are covered in the enforcement section under the section on managed lane system operations.

Access Control

Access control pertains to methods used to manage a vehicle's access into or out of a managed lane. The design of managed lane access is defined by operational goals, geometric

Table 17. Traffic monitoring and control options used in managed lanes.

	System	Purpose
Monitoring	Video	Traffic management center operators can monitor performance and dispatch resources to incidents. Video is used as a key source of traveler information for users.
	Vehicle detection	Detection is necessary to actively manage the number of vehicles in a managed lane and is a key source of information for performance monitoring and reporting.
	Field reports	Derived from agency and enforcement staff, or from the public via 911 or reporting systems, field reports provide an active form of detecting incidents that affect managed lane operations.
Control	Toll systems	Pricing acts as a market-based control mechanism for how many vehicles use the facility.
	Regulatory signing and pavement marking	Regulation determines who is eligible to use the facility and where access occurs.
	Barrier and gate access control	Physical barriers control ingress and egress from the facility.
	Enforcement	Active enforcement occurs through patrols, video, and/or license plate recognition systems, and ensures compliance with the facility operations.

constraints, and capital budgets, with more detailed information available in Chapter 3. How access is managed is one of the more critical elements affecting the performance and public acceptance of a managed lane. The access strategy must have design mechanisms, control systems, and operations strategies in place to ensure safe and efficient operation of the managed lanes. In most implementations of managed lanes, access is controlled at designated locations. Access control creates a need to determine the best locations for ingress and egress into the managed lane based on factors for safety, traffic volumes, and performance. Details on access control are provided in Chapter 3. The design and management of access is critical to the overall performance of the managed lane. The access must strike a balance between allowing safe ingress and egress points and having enough access to maximize use and performance of the lane.

The access design is often determined first by a function of cost of implementation. Barrier-separated access provides the best managed lane performance potential but is also the costliest to implement. Access point locations will influence the number and type of trips that can use the managed lane. Controlling access, by definition, places controls on which trips can use the managed lane. All trips in a corridor cannot have access to the managed lane, so the developer must determine which trips are the target market for the facility and design access accordingly. In designs with at-grade access, the developer should locate access so that trips have sufficient distance to safely maneuver across general-purpose lanes of traffic and avoid providing access where such movements would create new bottlenecks.

Four main options exist for controlling access and are defined by how they separate traffic between the managed lane and the general-purpose lanes. The four options are barrier separation, buffer separation, pylon separation, and open access. These four systems of separation are also discussed in Chapter 3.

Business Rules for Managed Lanes

Business Rule Development

Business rules for managed lanes describe how the concept of operations will be implemented. Business rules cover all elements of facility operation, including day-to-day operation and operations under unusual or emergency conditions, and describe how these operations will be carried out. As such, they are more detailed than the concept of operations.

Business rules are needed to ensure fair and consistent performance in dealing with the facility's customers as well as other entities that are involved with the operation of the facility including interoperable agencies. While business rules should provide stable guidance for facility operation, they should be routinely reviewed and updated as needed.

Business rules should be developed with input from all affected agencies and stakeholders. This ensures that the business rules will be practical and fully functional internally to the agency operating the facility and as well as externally in interactions with other stakeholders including interoperable toll agencies. Cooperation between agencies in the industry is common, and using business rules from other agencies provides a reasonable starting point for development of business rules for a new agency/facility. Use of business rules from interoperable agencies may be particularly appropriate.

Typical topics addressed in business rules include the following:

- **Definitions and Acronyms.** Providing definitive statements of terms can help alleviate discrepancies and other problems when the business rules are applied by agency personnel.

- **Violation Processing.** The collection of tolls is a fundamental, mission-critical activity for managed lane operators. Enforcement of unpaid tolls is also mission critical. Because the collection of tolls is expensive and time consuming, agencies have opted to levy fines, administrative fees, and other penalties associated with collecting these debts. Having such fines and fees articulated clearly and explicitly in the business rules will provide clarity to customers, stakeholders, and the media before they become headline inducing. Additional fines or fees may be necessary for other aspects of managed lane enforcement.
- **Traffic Violation Enforcement.** In addition to toll collection, the business rules will identify the responsible agencies for enforcing traffic rules throughout the managed lanes facility. This often necessitates interagency agreements.
- **Back-Office Procedures.** The tolling back office will articulate various interactions with customers. From the establishment of accounts and any special provisions—such as discount programs, multiple vehicle accounts, nonrevenue accounts, or other special considerations—to accounting and auditing procedures, the back-office policies will be articulated in the business rules. Often, requirements for data security will be clearly stated here.
- **Interoperability.** Increasingly, the requirements for toll collection systems to be interoperable with other agencies have informed the development of refined business rules. Interoperability will affect data and transponder protocol acceptance, interagency collection and payment procedures, account management, violation processing, and methods for resolving disputes.
- **Customer Contact.** Ensuring customer satisfaction and repeat use is a mission-critical function for managed lane operators. The business rules will articulate the requirements for interfacing with customers, including customer service venues, systems, and methods for resolving disputes.
- **Equipment and Software Protocols.** Besides the specific specifications for deployed toll collection systems, the business rules will state the performance and maintenance requirements, including replacement and rehabilitation.
- **Incident Response.** The business rules will articulate the law enforcement procedures, agreements, and responsibilities for responding to incidents, inclement weather, emergencies, and other hazards in the managed lanes facility. This may include responses to toll collection, including toll suspension and/or facility closure.

Procurement/Contracting

The terms "project delivery" and "procurement" are synonymous and refer to the process of awarding and implementing contracts to design, construct, and operate transportation improvements. The range of procurement options used to implement priced managed lane projects is the same as for any transportation improvement, from the traditional design–bid–build approach that involves letting separate contracts for design and construction to those involving greater private-sector involvement and responsibility. These other options transfer increasing amounts of risk from the public to the private sector and include design–build, design–build–operate–maintain, and design–build–finance–operate–maintain. While smaller projects are normally delivered using DBB contracts, larger, more complex projects may benefit from DB or DBOM strategies, and those with revenue streams may be additionally suited to DBFOM procurement.

Options for procurement and contracting are described in detail in Chapter 5.

Managed Lane System Operations

Enforcement Systems

Managed lane enforcement can include all of the normal enforcement activities for any limited-access highway, such as speeding, reckless driving, driving under the influence, etc. However, managed lane enforcement extends beyond those and includes expanded enforcement needs such as toll collection, vehicle occupancy, and/or vehicle type. Since enforcement for routine types of violations is very similar to enforcement for those violations on general-purpose lanes, enforcement of toll collection, vehicle occupancy, and vehicle type will be emphasized here. In certain applications, commercial vehicles (such as taxis, freight, or delivery vehicles), buses, and other allowable users of the managed lanes—based upon the prevailing business rules—may have their own enforcement requirements. The principles for enforcing vehicle eligibility rules for these vehicles are the same as articulated below for toll-paying and exempt HOV users; however, additional consideration should be given to address differential speed and safety issues when managing access for these vehicles.

More information on the design of facilities to accommodate these vehicles is provided in Chapter 3.

As discussed earlier in the eligibility validation section, HOV lane enforcement has always been a significant issue with implementation of such lanes. Determination of occupancy at highway speeds is often difficult, and even when occupancy can be determined, providing areas in which enforcement stops can be made is often difficult, particularly in situations where the HOV enforcement must be done in areas with reduced shoulders or the requirement to traverse managed lane separation.

In addition to HOV enforcement on non-priced managed lanes, priced managed lanes must also deal with occupancy violations in an environment that permits SOVs (or HOV2s). Under existing operating procedures, this requires enforcement of occupancy violations to be performed manually in the managed lane itself, often under conditions that are less than ideal for the officer and the driver.

Controls are placed on managed lane use so that performance objectives are met. These usually include toll payment, occupancy requirements, and/or vehicle type requirements. Enforcement ensures that the operational parameters needed to meet the performance objectives are actually occurring in the field. Without enforcement, willful violation of the requirements can occur, and this can have a consequential impact upon not only facility performance but also revenue targets.

Regarding the enforcement of HOVs and other potentially discounted users of the managed lanes, there are multiple options for managed lane enforcement:

- Requirement for all users to carry a transponder and/or pay a toll. As the name implies, it is possible to operate a managed lane that allows only toll-paying vehicles on the facility. HOVs are still allowed; however, they must pay a toll, no different from all other vehicles. In this case, the system provides enforcement of the collection of tolls—either a toll is collected or it is not. There are no other differentiation requirements. Electronic video enforcement systems have become a mature technology for enforcing the collection of tolls in the field, with no in-lane police presence necessary. It should be noted that even in an all-vehicles-pay scenario, it is possible to allow certain vehicles to access the facility at no or a reduced charge. Transit vehicles, emergency response vehicles, or other vehicles that should be allowed access to the facility without having to pay a toll are provided with a nonrevenue transponder. In this case, the transponder is read and processed at the toll zone as any other transponder-equipped vehicle; however, its account indicates that no payment is collected by the back office. Further, vehicles of this type are usually easily identified in enforcement photos. Therefore, even if the nonrevenue transponder is not provided, it is a relatively simple matter for these vehicles to not be targeted as a toll violator.
- Declaration of occupancy with in-lane observation. Toll zone declaration of occupancy with enforcement personnel stationed at a point that vehicle occupancy can be observed, and enforcement carried out when necessary, is a common mechanism for HOV occupancy enforcement. There are three variations on this strategy, as described previously in the eligibility validation section: (a) declaration lanes, (b) switchable transponders, or (c) absence of a transponder. Regardless of the method used, a beacon is typically illuminated on top of or to the side of the gantry containing toll collection equipment (depending on the number of lanes). The beacon can be set to illuminate when the vehicle has paid a toll, or it can be set to illuminate when the vehicle has not paid a toll. When the non-toll-paying vehicle has been identified, the officer observes the vehicle to determine if the HOV occupancy requirement has been met. If the requirement appears not to have been met, a traffic stop ensues. There are many circumstances that may lead an officer to believe a violation has occurred when in fact it has not. Passengers being in the back seat of a vehicle are a common cause. If the officer verifies that the occupancy requirements for HOV were not met, a citation is issued. This method remains the most common method for HOV enforcement on managed lanes; however, it requires persistent police presence to be effective at deterring willful violations.
- Reading of mobile or fixed vehicular license plate and transponder. In Minnesota and Georgia, patrol vehicles have been equipped with readers and cameras that either allow transponders to be read by an officer in the patrol vehicle or allow license plates to be photographed and then identified through optical character recognition. The facility database is then queried to determine whether the vehicle is declared to be an HOV. For vehicles that have declared HOV status, the officer visually verifies that the HOV occupancy requirement has been met. If it does not appear to have been met, the officer proceeds with a traffic stop, and if the HOV occupancy requirement was not met, a citation is issued.

The pros and cons of various enforcement mechanisms are shown in Table 18.

Incident Management

A traffic incident is defined as any unplanned or planned event that has an impact on the optimal flow of traffic within a facility, ranging from disabled vehicles on a highway shoulder to major vehicle collisions, emergency maintenance, severe weather events, special events, and any other unplanned occurrence that can disrupt traffic flow. Traffic disruption caused by incidents results in travel time delays, losses in economic productivity, increases in vehicle fuel emissions, and overall reductions in safety.

Various events and emergencies may emerge where the transportation system on whole must be managed to a greater level than typical operations would permit. The nature of emergencies will differ from one community to another. For example, a few inches of snow in a state like Georgia can create an emergency condition, whereas such snowfall is almost a daily condition in Minnesota or Colorado and does not yield an emergency condition. However, both require their own response conditioned by local driver equipment and familiarity with snow driving. Regardless of the specific nature of the incident, collaboration and communication are vital to managing extraordinary events. Comprehensive guidance for handling such system-wide emergencies can be found in

Table 18. Pros and cons of enforcement mechanisms.

Enforcement Mechanisms	Pros	Cons
Toll-paying vehicles only	• Greatly simplifies enforcement • Revenues are maximized • Enforcement is constant	• No system-based incentive is given for HOV use • May not be allowed if an HOV conversion is involved
Declaration of occupancy with in-lane observation	• Common practice with mature technology • Depending on design, may not require tolling back-office enforcement procedures (all violators would be treated as occupancy violators)	• Enforcement in the travel lane is required • Enforcement will be periodic or costly • Occupancy identification at highway speed is difficult • Enforcement locations will become well known to regular drivers and can therefore potentially be avoided in installations that do not use barrier separation
Mobile license plate and transponder reading	• Enforcement can occur anywhere on the facility • Officer in the moving vehicle has more time to perform occupancy identification, resulting in fewer unneeded stops • Can work well without barrier separation	• Enforcement in the travel lane is required • Enforcement will be periodic or costly

NCHRP Report 777: A Guide to Regional Transportation Planning for Disasters, Emergencies, and Significant Events (*117*).

Although these system-wide events will inevitably affect the operation of managed lanes in the context of overall system management, such large-scale events are outside the scope of incident management for managed lanes in this guidance document. Instead, this guidance pertains to incidents within the managed lanes directly or within the roadway envelope in which the managed lanes reside. Without adequate response, incidents that affect managed lane operations can negatively affect public perception, system performance, or revenue collection.

Traffic incident management (TIM) is defined as the systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration of incidents and improve overall safety. An optimal TIM program is a highly specialized and coordinated approach to managing highway incidents involving a wide range of agencies and stakeholders. Success of a TIM program stems from a reduction in incident duration, a result of reducing incident detection and verification time, initiating an immediate and appropriate response, and clearing the incident as quickly as possible. An effective TIM program has been shown to increase safety, reduce delay, and improve the public perception of agency operations. TIM is not a new concept to most regions. However, due to the operational complexity of managed lanes, an enhanced or dedicated TIM program is often warranted to ensure safe and efficient operations (*118*).

Managed lane facilities are promised to operate at a higher level of service than adjacent general-purpose lanes. This is especially true of priced facilities. An effective TIM program is an essential piece in maintaining the reliability of managed lanes. Supporting agencies must be able to efficiently and effectively address incidents while preserving the integrity of the operation, revenue collection (if applicable), and a positive public perception (*12*). However, the configurations of many managed lanes can complicate TIM. Responders typically operate with limited space because many facilities do not have standard emergency breakdown shoulders and are often barrier separated from adjacent lanes. In addition, managed lane TIM resources, especially for managed lanes operated by state DOTs, may be embedded within overall freeway operations, without dedicated services or incident response performance different from any other travel lane (*53*).

Furthermore, managed lane operators have indicated that emergency responders, including police, fire, and ambulatory representatives, should be engaged very early in the design process—especially at points where decisions regarding separation and access treatment are discussed. Depending upon the emergency response and preferred handling, these representatives offer a different perspective on not only the interface with the facility but also how the design decisions may impact TIM events.

Traffic resulting from special events may resemble that of incidents; however, special events by nature are scheduled and known in advance. As a result, TIM actions and resources may be better allocated for these situations. Furthermore, the functionality of the managed lane facility may change based on the special event's traffic plan. For example, one facility under construction on I-75 in Atlanta, Georgia, has been designed to address special-event-related demand. Depending on the special event plan and its needs from the corridor, the managed lane may operate in a flood condition, in concert with the general-purpose lanes, and be operated to maximize throughput across all lanes of travel. For corridors or facilities where such events may be likely to occur, consideration in the concept of operations is critical.

Solutions and Strategies

A successful TIM program is a coordinated process consisting of multiple phases (*118*):

- Detection—The process that brings an incident to the attention of the agencies responsible for maintaining traffic flow. Technology utilized for detection typically includes CCTV cameras and incident detection algorithms optimized with real-time traffic surveillance data.
- Verification—The confirmation that an incident has occurred, determining exact location, direction of travel, and incident nature and scope. CCTV video feeds and computer-aided dispatch linkages should be shared with responding agencies to provide instant notification and real-time information to help tailor responses.
- Response—Deployment of appropriate personnel, equipment, motorist information, and traffic management. Best practices recommend use of emergency response callout lists including agency roles and contacts, freeway service patrols of congested areas to quickly detect and respond to incidents on the ground, interdisciplinary incident response teams dedicated to incident response and removal, strategically pre-positioned TIM equipment, and formal staging guidelines and training for responders. For priced facilities, collected revenues can be used to fund dedicated managed lane incident response teams.
- Site Management—Assessing the incident, establishing priorities, coordinating with appropriate agencies, and following protocols of the National Incident Management System to safely secure site and progress toward clearance.
- Clearance and Removal—Efficient removal of vehicles, wreckage, debris, spilled material, and other items from roadway to return facility to pre-incident capacity.
- Traveler Information—Dissemination of traveler information from operations center to motorists. Typical strategies include CMSs operated by the traffic management center to notify upstream drivers of the incident and possible lane closures, highway advisory radio services, 511 telephone services, and timely provision of information to media outlets.
- Traffic Management—Establishing traffic control at scene, managing roadway space, deploying appropriate personnel, and in the case of managed lanes, determining whether to route general-purpose traffic into or out of the facility to restore traffic flow.
- Planning and Evaluation—Establishing, planning, and continually evaluating the formal TIM program, which should include and confirm the identification and participation of all agencies and stakeholders, clarification of goals and objectives, development of alternative solutions and strategies, securing funding, and deployment and evaluation protocols.

An effective TIM program facilitates close coordination between agencies and dictates specific roles and responsibilities. Typical TIM agencies and roles include the following:

- Law Enforcement—Typically, first responders that assist with detection and provide first aid, emergency traffic control, and incident command.
- Fire, Rescue, and Emergency Medical Services—Responsible for emergency medical care, fire suppression, extrication, and hazardous materials response.
- Transportation Agency—Assist with detection and verification, and provide traffic management, emergency traffic control, and dissemination of traveler information. Typically organize and maintain TIM program, and act as owner/operator of managed lane.
- Towing Service—Critical partner responsible for removal of disabled vehicles and debris.
- Media—Private entity that assists in disseminating incident information to motorists.

The San Diego Association of Government's *I-15 Managed Lanes Traffic Incident Management (TIM) Plan* (*118*) included information gleaned from a best practices review pertaining to TIM. This best practices review identified traffic management practices and protocols related to dedicated resources and the use of managed lane facilities for incident traffic routing, the pros and cons of which are as follows:

- Dedicated Resources. Can ensure greater level of service and reliability within managed lanes, although uncommon due to added costs. However, managed lane strategies can include allocation of a portion of revenues toward dedicated resources.
- Managed Lane Use for Incident Traffic Routing. Allows for reduced traffic delay and can support a positive public perception, but detracts from the higher level of service intended for managed lane facilities.

Performance Monitoring and Evaluation

Performance monitoring refers to the ongoing, structured process of compiling performance data for managed lane facilities. The need for ongoing performance monitoring and the role it plays in formulating and informing adopted design practice has been frequently expressed by managed lane practitioners. Even after design decisions have been made, and this guide reflects the decisions that managed lane operators have implemented as current practice, the need for performance monitoring to inform future design decisions and refinements is critical during the planning and conceptualization process. Such a program of regular, recurring performance monitoring will help effect changes in the planning, design, and operations stages. Furthermore, these changes and refinements will continue for the life of the facility. Finally, particular attention should be placed upon continual monitoring and evaluation immediately after opening of a managed lane facility, and through the first few years of operation. Public and stakeholder attention to the facility will be more acute, with answers desired for the following questions, among others:

- How many people are using the managed lanes?
- Have the managed lanes improved traffic in the general-purpose lanes?
- If priced, what is the highest toll price?
- What is the effect on carpools?
- How much is the average toll?
- How often do account holders use the lanes?

Performance data may be collected using real-time detection equipment, regularly scheduled counts or surveys, and one-time surveys. The metrics used to track project performance should also align with the overall goals of the project as well as the level of funding available to support performance monitoring activities. Performance data should be collected prior to the opening of new managed lane facilities, with baseline data covering a 1-year period prior to opening, thereby enabling the project sponsor to document normal seasonal trends.

An optimal set of metrics will enable the project sponsor to have a clear understanding of how well the managed lane project is performing and to what extent it is meeting its various goals and objectives. Performance data should be designed, collected, and analyzed so that the project sponsor, users, and stakeholders can understand if the facility is working as planned. Performance data allow the operator to determine if changes are needed in how the system is designed or operated in order to achieve system objectives.

Given that each managed lane project is unique, performance monitoring programs should be tailored to reflect the local concerns, legislative requirements, institutional relationships, and performance monitoring precedents. The primary resource on how to conduct and evaluate performance measurement for managed lanes is *NCHRP Report 694* (*31*). Rather than prescribing particular metrics for each situation, this report provides a framework to help project sponsors identify which performance measures are likely to meet their particular needs.

Performance measurement for congestion pricing projects accomplishes four interrelated purposes:

- To ensure that the projects are functioning as efficiently as possible and to enable adjustments to operational policies if they are not.
- To quantify and validate the different benefits these facilities deliver.
- To document the application of congestion pricing as a meter on traffic demand.
- To ensure that the projects are in compliance with operational requirements placed on the facility.

Performance measures for managed lanes can be grouped into the following evaluation areas:

- Traffic performance measures describe the ability of a roadway to provide mobility. Traffic performance is the most influential measure among the five evaluation areas and is measured using traffic engineering metrics including vehicle volumes, speeds, mode share, LOS, travel times, travel time savings, travel time reliability, number of tolled and un-tolled trips, average vehicle occupancy, person throughput, and safety measures. These data are usually collected using data from automated ETC and ITS systems, as well as regularly scheduled traffic counts.
- Public perception performance measures document general awareness of the existence and intent of the priced managed lanes, as well as satisfaction with the service they provide. Commonly used public perception performance measures include satisfaction, perceived value, facility awareness, reliability, perceived time savings, and perceived safety. Because of the nature of these metrics, this information is collected through surveys of facility users and the general public.
- Facility user metrics refer to the characteristics of trip-makers who use priced managed lanes as well as the nature of the trips they make on them. Metrics could include home zip code, frequency of use, trip origin and destination, number of transponders issued, user types (transit, SOV, HOV, exempt vehicles), and demographic and socioeconomic data.
- System operations metrics provide information on the operational aspects of priced managed lanes, including system function, customer service, safety, enforcement, and finance. Common system operations performance measures include revenue, toll rates, number of violations, operating and maintenance expenditures, number of toll transactions, incidents, incident response time, and system equipment availability.
- Transit metrics describe attributes of transit services operating on priced managed lane facilities. The most frequently applied transit performance measures are travel time, on-time performance, excess wait time, and ridership.

Managed lane facilities have many performance metrics but are often developed with the overarching performance goal of the facility providing a highly reliable trip for users. As required by U.S. federal law (23 U.S.C. 166), this goal is measured by travel speeds with the target speed being 45 mph or greater 90% of the time in the managed lane. Achieving this reliability target is what attracts users to a managed lane and serves as a reason to pay a toll, form a carpool, or utilize transit in the facility.

Maintenance of Managed Lanes

While generally no different from the maintenance requirements of general freeway or HOV lane maintenance, managed lanes do require advanced maintenance of some components to sustain performance. These components comprise toll collection, intelligent transportation systems, lane separation, power, and communication infrastructure, all of which are vital for meeting operational objectives. Disruptions and failures of equipment, procedures, and functions can have a detrimental impact on safety, system capacity, and throughput, which may eliminate, negate, or compromise the benefits of the managed lanes.

Managed lane systems involve highly interdependent components and subsystems—one malfunction can impact the ability of the system to perform. In addition, many components may be difficult to access without lane closures, especially if there is a lack of shoulder space and/or worker-accessible gantry structures. Accordingly, built-in redundancy of hypercritical systems is needed in order to reduce maintenance events. Prior to installation and after opening, operators must continually analyze equipment durability, identify system design redundancies, and conduct routine preventive maintenance in order to minimize personnel exposure to traffic and frequency of maintenance activities.

Managed Lane Maintenance

There are three primary components to managed lane maintenance:

- Managed lane roadway components.
- Tolling and enforcement systems.
- Traffic control systems.

Managed Lane Roadway Components

Managed lane operators will be challenged to provide a high level of maintenance for in-lane roadway systems. Although a managed lane operator, either public or private, may be responsible for maintenance across the entire footprint of the corridor, whether the operator or the DOT has maintenance responsibility is delineated by which lane system the component is a part of. This delineation of responsibility is shown in Table 19.

Tolling and Enforcement Systems

The tolling and related enforcement systems maintenance requires specialized attention, which may be specific in nature to the technology deployed by the tolling integrator and could be located outside the managed lanes facility. For example, tolling algorithms require a significant amount of detector data across multiple lanes of traffic (managed lanes and general-purpose lanes) in order to operate effectively. Given the inability to provide maintenance during active operations, problems that emerge in the tolling detection infrastructure could result in a failure to collect tolls or to give customers sufficient information about toll prices, resulting in a loss of revenue.

Generally, the managed lanes operator will handle performance or contracting responsibilities associated with maintaining managed lane tolling, enforcement, power, and field communication systems. Dedicated staff or contractor(s) will be assigned responsibility for maintaining the tolling systems and infrastructure. In most contemporary situations, tolling and enforcement systems may be maintained by the tolling integrator, especially to the extent that any loss in equipment or procedural availability will have an impact on performance. As a result, the integrator has every interest in performing adequate preventive maintenance in order to avoid demand–response maintenance. After ramp-up, depending upon the level of risk incurred by the operator, this role may or may not be the same as the tolling integrator because a separate func-

Table 19. Primary maintenance responsibilities for lane systems.

Component	Primary Responsible Party		
	Managed Lanes	Buffer/Barrier	General-Purpose Lanes
Structures	Operator/DOT	Operator	DOT
Structural pavement	Operator/DOT	Operator/DOT	DOT
Pavement repairs	Operator	Operator	DOT
Pavement markings	Operator	Operator	DOT
Barrier	Operator/DOT	Operator/DOT	DOT
Signage (static)	Operator	Operator/DOT	DOT
Lighting	Operator	Operator/DOT	DOT
Clearing and grubbing	Operator	Operator	DOT
Sweeping/debris removal	Operator	Operator	DOT

Table 20. Primary tolling/enforcement maintenance responsibilities for managed lane systems.

Component	Primary Responsible Party		
	Managed Lanes	Buffer	General-Purpose Lanes
Signage—structure	Operator/DOT	n/a	DOT
Signage—LED panels	Operator	n/a	Operator
Pavement—enforcement zones	Operator/DOT	n/a	DOT
Lighting—toll zone	Operator	n/a	n/a
Sensors/antenna	Operator	Operator	Operator
CCTV—toll zone	Operator	Operator	Operator
Utility box	Operator	n/a	Operator
Power/telecommunications	Operator	Operator	Operator
Gantry/post	Operator	n/a	Operator
Enforcement cameras/lighting	Operator	Operator	n/a

tional group or third party may offer better performance. This delineation of responsibility is shown in Table 20.

Traffic Control / In-Field ITS

In addition to the tolling and enforcement systems, managed lanes feature virtually continuous installation of ITS technologies, including sensor loops and independent CCTV systems for traffic/incident monitoring (which may be connected to ramp metering and other traffic control systems). Of note, real-time peer-to-peer exchange of incident and traffic sensor data between regional traffic management centers, incident managers, and tolling integrators may be maintained by the operator. Otherwise, the state DOT typically maintains non-tolling-related ITS installations along the managed lane corridors.

Maintenance Program Management

Maintenance is a complex assessment of present-day impacts and future-day risk management. Maintenance and operations activities must be coordinated such that the risks of the impacts from either one or the other can be quantified.

Performance Criteria

Managed lanes maintenance goals should be articulated in terms of operational levels. Standard performance metrics include mean time between failures (a dual function of design life and preventive maintenance forestalling failure), mean time to repair (expressed as number of hours), average cost to repair, design life, and salvage value. For managed lanes, the key metrics are downtime in operational hours (critical timing during peak periods, with relaxed timing in evenings and other times of day when the project is less used), failure rates for critical components, and timeliness of response for maintenance. As detailed metrics are defined, the maintenance operator must be able to define criteria for minimum standard performance metrics. Meeting the managed lane requirements could be costly—for example, 24/7 operations may require a full-time equivalent position across the 24-hour spectrum held by multiple employees. Thus, the managed lane operator may establish critical times of response (peak periods and directions), standard times of response (daytime off-peak periods and directions), and relaxed times of response (evenings/times of low corridor volumes). Different responses can be adjusted accordingly. Public-sector options may not be well suited to handling these different staffing requirements for response, whereas private-sector arrangements may be articulated contractually.

Training

The maintenance program will include specialized training, such as on procedures for individual devices, operation and calibration of test equipment and technologies, and practices for repairing essential components of the system. This training will require refresher courses in addition to new staff training as certain components become operationally obsolete, new procedures are established, and replacement equipment installed. As a result, the toll system integrator will inevitably be involved in training staff and have a performance mandate to ensure that the system is maintainable after installation.

Acronyms

AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act of 1990
ASCE	American Society of Civil Engineers
AV	automated vehicle
AVI	automated vehicle identification
Caltrans	California Department of Transportation
CCTV	closed-circuit television
CEQA	California Environmental Quality Act
CFR	Code of Federal Regulations
CMAQ	Congestion Mitigation and Air Quality
CMS	changeable message sign
CRD	congestion reduction demonstration
CV	connected vehicle
DB	design–build
DBB	design–bid–build
DBFOM	design–build–finance–operate–maintain
DBOM	design–build–operate–maintain
DOT	department of transportation
EPA	Environmental Protection Agency
ERA	emergency refuge area
ETC	electronic toll collection
FAST	Fixing America's Surface Transportation
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GARVEE	Grant Anticipation Revenue Vehicle
GIS	geographic information system
GP	general purpose
HCM	*Highway Capacity Manual*
HOT	high-occupancy toll
HOV	high-occupancy vehicle
ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
ITS	intelligent transportation system
LOS	level of service
MPO	metropolitan planning organization

MUTCD	*Manual on Uniform Traffic Control Devices*
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NHTSA	National Highway Traffic Safety Administration
NTE	North Tarrant Express
P3	public–private partnership
PAB	private activity bond
PBPD	performance-based practical design
PEL	planning and environment linkage
RFP	request for proposals
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SOV	single-occupant vehicle
TCD	traffic control device
TCRP	Transit Cooperative Research Program
TDM	transportation demand management
TIFIA	Transportation Infrastructure Finance and Innovation Act
TIGER	Transportation Investment Generating Economic Recovery
TIM	traffic incident management
TRB	Transportation Research Board
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
UPA	urban partnership agreement
U.S.C.	United States Code
U.S. DOT	United States Department of Transportation
V2I	vehicle to infrastructure
V2V	vehicle to vehicle
VES	video enforcement system
WSDOT	Washington State Department of Transportation

Glossary

Term	Definition	Source
Acceleration	Increase in velocity per unit time; in transit, usually measured in feet per second squared (meters per second squared) or, in the United States, sometimes in miles per hour per second.	Kittelson & Associates et al. (*119*)
Access	The means of entering and exiting a designated roadway facility such as a managed lane or general-purpose lanes.	Research Team
Access, continuous	See *continuous access.*	
Accessibility	1. A measure of the ability or ease of all people to travel among various origins and destinations. 2. In transportation modeling and planning, the sum of the travel times from one zone to all other zones in a region, weighted by the relative attractiveness of the destination zones involved. 3. In traffic assignment, a measure of the relative access of an area or zone to population, employment opportunities, community services, and utilities.	Kittelson & Associates et al. (*119*)
Accessibility, persons with disabilities (full accessibility)	The extent to which facilities are free of barriers and usable by persons with disabilities, including wheelchair users.	Kittelson & Associates et al. (*119*)
Accessibility, station	A measure of the ability of all people within a defined area to get to a specific transit station.	Kittelson & Associates et al. (*119*)
Accessibility, transit	1. A measure of the availability to all people of travel to and from various origins and destinations by transit. 2. A measure of the ability of all people to get to and from the nearest transit stop or station and their actual origin or destination. 3. In common usage, often used to mean the ability of persons with disabilities to use transit.	Kittelson & Associates et al. (*119*)
Advanced traffic management system	Remotely operated traffic management system for monitoring and managing operations of a freeway system including HOV lanes and arterial streets. Major elements of the system include surveillance, communications, and controls.	Kuhn et al. (*4*)
Alignment	In transportation, the horizontal and vertical layout of a roadway, railroad, transit route, or other facility as it would appear in plan and profile. Usually described on the plans by the use of technical data, such as grades, coordinates, bearings, and horizontal and vertical curves.	Kittelson & Associates et al. (*119*)

Term	Definition	Source
Alternative fuels	Alternatives to conventional diesel fuel for urban transit buses, intended to reduce pollution. Includes methanol, propane, CNG (compressed natural gas), LNG (liquefied natural gas), hydrogen (for fuel cells), and biomass-derived fuels. All carry premium costs that trend in larger or more cost-conscious operators toward clean diesel solutions.	Kittelson & Associates et al. (*119*)
Americans with Disabilities Act of 1990 (ADA)	Federal civil rights law that ensures people with disabilities equal opportunity to fully participate in society, the ability to live independently, and the ability to be economically sufficient.	Kittelson & Associates et al. (*119*)
Arterial roadway	A signalized street that primarily serves through traffic and secondarily provides access to abutting properties; signal spacing is typically 2 mi (3 km) or less.	Kittelson & Associates et al. (*119*)
Articulated bus or articulated trolleybus	An extra-long, high-capacity bus or trolleybus that has the rear body section or sections flexibly but permanently connected to the forward section. The arrangement allows the vehicle to bend in curves and yet have no interior barrier to movement between the two parts. Typically, an articulated bus is 54–60 ft (16–18 m) long with a passenger seating capacity of 60 to 80 and a total capacity of 100 to 140.	Kittelson & Associates et al. (*119*)
Automated vehicles (AVs)	Vehicles in which some aspects of a safety-critical control function (e.g., steering, throttle, or braking) occur without direct driver input.	NHTSA (*17*)
Automatic vehicle location	The use of advanced technologies such as global positioning systems to monitor the location and movement of vehicles.	Kuhn et al. (*4*)
Auxiliary lane	A short-distance travel lane typically striped between closely spaced ramps that facilitate weaving, merging, and diverging movements.	Research Team
Availability payment	A form of compensation to private-sector concessionaires for design, construction, operations, and/or maintenance of managed lanes that are independent from project-related revenue generation.	AASHTO (*107*)
Average daily traffic	The average 24-hour volume, being the total volume during a stated period divided by the number of days in that period. Would normally be periodic daily traffic volumes over several days, not adjusted for days of the week or seasons of the year.	FHWA (*1*)
Average trip length	Passenger miles divided by unlinked passenger trips. Can be computed for pedestrian trips and vehicle trips, based on special surveys.	Kittelson & Associates et al. (*119*)
Average vehicle occupancy	The number of people divided by the number of vehicles (including buses) traveling past a specific point over a given time period.	Kuhn et al. (*4*)
Barrier	A physical separation employed between concurrent or opposing flows of traffic, often made of concrete and permanently affixed to the roadway.	Research Team
Barrier free	Containing no obstacles that would prevent use by persons with disabilities or any other person.	Research Team
Barrier-separated lane	A preferential lane or other special-purpose lane that is separated from the adjacent general-purpose lane(s) by a physical barrier.	FHWA (*1*)

Term	Definition	Source
Base period (off-peak period)	In transit, the time of day during which vehicle requirements and schedules are not influenced by peak-period passenger volume demands (e.g., between morning and afternoon peak periods). At this time, transit riding is fairly constant and usually moderate in volume when compared with peak-period travel. See also *off-peak.*	Kittelson & Associates et al. (*119*)
Beacon	Short-range roadside transceiver for communicating between vehicles and the traffic management infrastructure. Common transmission technologies include microwave and infrared.	Kittelson & Associates et al. (*119*)
Beacon (signal)	A highway traffic signal with one or more signal sections that operate in a flashing mode.	FHWA (*1*)
Benefit–cost ratio	Estimate of the anticipated dollars of discounted benefits achievable to a given outlay of discounted costs.	Kuhn et al. (*4*)
Bidirectional HOV facility	Preferential facility in which both directions of traffic flow are provided for.	Kuhn et al. (*4*)
Boarding island	1. A pedestrian refuge within the right-of-way and traffic lanes of a highway or street. It is provided at designated transit stops for the protection of passengers from traffic while they wait for and board or alight from transit vehicles; also known as a *pedestrian* or *loading island.* 2. A protected spot for the loading and unloading of passengers. It may be located within a rail transit or bus station. 3. On streetcar and light rail systems, a passenger loading platform in the middle of the street, level with the street or more usually raised to curb height, often protected with a *bollard* facing traffic.	Kittelson & Associates et al. (*119*)
Bollard	A short vertical post to prevent the unauthorized or unintended entry of vehicles into an area.	Research Team
Buffer	The pavement space between the managed lane and general-purpose lanes designated by pavement markings, typically no more than 4 ft in width.	Research Team
Buffer-separated lane	A preferential lane or other special-purpose lane that is separated from the adjacent general-purpose lane(s) by a pattern of standard longitudinal pavement markings that are wider than a normal or wide lane line marking. The buffer area might include rumble strips, textured pavement, or channelizing devices such as tubular markers or traversable curbs but does not include a physical barrier.	FHWA (*1*)
Bus	A self-propelled, rubber-tired road vehicle designed to carry a substantial number of passengers (at least 16, various legal definitions may differ slightly as to minimum capacity), commonly operated on streets and highways. A bus has enough headroom to allow passengers to stand upright after entering. Propulsion may be by internal combustion engine, electric motors, or hybrid. Smaller-capacity road transit vehicles, often without full headroom, are termed vans.	Kittelson & Associates et al. (*119*)
Bus, articulated	See *articulated bus or articulated trolleybus.*	

Term	Definition	Source
Bus, double-decker	A high-capacity bus that has two levels of seating, one over the other, connected by one or two stairways. Total bus height is usually 13–14.5 ft (4.0–4.4 m), and typical passenger seating capacity ranges from 60 to 80 people.	Kittelson & Associates et al. (*119*)
Bus bay	1. A branch from or widening of a road that permits buses to stop, without obstructing traffic, while laying over or while passengers board and alight; also known as a blister, duckout, turnout, *pullout,* pull-off, or lay-by. As reentry of the bus into the traffic stream can be difficult, many transit agencies discourage bus bay construction. 2. A specially designed or designated location at a transit stop, station, terminal, or transfer center at which a bus stops to allow passengers to board and alight; also known as a bus dock or *bus berth.* 3. A lane for parking or storing buses in a garage facility, often for maintenance purposes.	Kittelson & Associates et al. (*119*)
Bus bay, angle	A bus bay design similar to an angled parking space that requires buses to back up to exit; allows more buses to stop in a given linear space. Typically used when buses will occupy the berth for a long period of time (for example, at an intercity bus terminal).	Kittelson & Associates et al. (*119*)
Bus bay, drive-through (pull-through)	A bus bay design providing several adjacent loading islands, between which buses drive through, stop, and then exit. Allows bus stops to be located in a compact area. Sometimes used at intermodal transfer centers because all buses can wait with their front destination signs facing the direction passengers will arrive from (e.g., from a rail station exit).	Kittelson & Associates et al. (*119*)
Bus bay, linear	A bus bay design where buses stop directly behind each other; requires the bus in front to leave its bus bay before the bus behind it can exit. Often used when buses will use the bus bay only for a short time (e.g., at an on-street bus stop). Also called on-line bus stop.	Kittelson & Associates et al. (*119*)
Bus bay, sawtooth	A bus bay design where the curb is indented in a sawtooth pattern, allowing buses to enter and exit bus bays independently of other buses. Often used at transit centers.	Kittelson & Associates et al. (*119*)
Bus berth	See *bus bay.*	
Bus bulb	An extension of the sidewalk into the roadway for passenger loading without the bus pulling into the curb. Gives priority to buses and eases reentry into traffic. Often landscaped and fitted with bus shelter and other passenger amenities. Also called bus bulge, curb bulge, and curb extension.	Kittelson & Associates et al. (*119*)
Bus lane	A lane dedicated for the exclusive or primary use of buses, typically located alongside other general-purpose lanes on a controlled-access roadway or street.	Kittelson & Associates et al. (*119*)
Bus priority system	A system of traffic controls in which buses are given special treatment over general vehicular traffic (e.g., bus priority lanes, preemption of traffic signals, or adjustment of green times for buses).	Kittelson & Associates et al. (*119*)
Bus priority system, metered freeway	A means of giving buses preferential access to enter a freeway by restraining the entrance of other vehicles through the use of ramp metering; see also *freeway, metered.*	Kittelson & Associates et al. (*119*)

Term	Definition	Source
Bus rapid transit (BRT)	A bus operation that is generally characterized by operation on a separate right-of-way that permits high speeds.	Kuhn et al. (*4*)
Bus shelter	See *transit shelter.*	
Bus stop	See *stop, transit.*	
Bus transit	See *bus.*	
Busway	A roadway designed and dedicated for exclusive use by buses. May be constructed at, above, or below grade and may be located in separate rights-of-way or within highway corridors. Variations include grade-separated, at-grade, and median busways. Sometimes called a *transitway.*	Adapted from Kittelson & Associates et al. (*119*)
Bypass lane	See *queue jumper.*	
Bypass, queue	See *queue jumper.*	
Capacity, design	For highways, the maximum number of vehicles that can pass over a given section of a lane or roadway in one or both directions during a given time period under prevailing environmental (e.g., weather and light), roadway, and traffic conditions.	Kittelson & Associates et al. (*119*)
Capacity, maximum	The maximum number of persons or transit vehicles that can pass a given point in a given period of time, without regard to reliability or passenger comfort. This is a theoretical value that should not be used for planning in most cases.	Kittelson & Associates et al. (*119*)
Capacity, person	The maximum number of persons that can be carried past a given location during a given time period under specified operating conditions without unreasonable delay, hazard, or restriction. Usually measured in terms of persons per hour.	Kittelson & Associates et al. (*119*)
Carpool	An arrangement in which two or more people share the use, cost, or both of traveling in privately owned automobiles between fixed points on a regular basis; see also *vanpool.*	Kittelson & Associates et al. (*119*)
Carpool, casual	An informal carpool where commuters gather at a location to be picked up at random by motorists who do not have sufficient passengers.	Kittelson & Associates et al. (*119*)
Carpool lane	See *lane, carpool* and *lane, exclusive carpool.*	
Carrier	A person or company in the business of transporting passengers or goods.	Kittelson & Associates et al. (*119*)
Carrier, common	In urban transportation, a company or agency certified by a regulatory body to carry all passengers who fulfill the contract (e.g., pay the required fare). The service is open to the public.	Kittelson & Associates et al. (*119*)
Center platform	A passenger platform located between two tracks or guideways so that it can serve them both.	Kittelson & Associates et al. (*119*)
Central business district	Commonly referred to as downtown.	Kuhn et al. (*4*)
Change of mode	Transfer from one type of transportation vehicle to another.	Kuhn et al. (*4*)

Term	Definition	Source
Channelizer (also called pylon or delineator)	1. Plastic tube permanently employed to provide a visual barrier between concurrent traffic streams, typically located in a painted buffer area between the managed lane and general-purpose lanes. 2. Portable plastic tube inserted into the pavement into predrilled holes to delineate a contraflow lane during its operating period.	Kuhn et al. (*4*)
Commute	Regular travel between home and a fixed location (e.g., work, school). Often applied only to travel in the direction of the main flow of traffic, to distinguish from reverse commute.	Kittelson & Associates et al. (*119*)
Commute, reverse	A commute in the direction opposite to the main flow of traffic, for example, from the central city to a suburb during the morning peak. Increasingly common with growth in suburban employment. Valuable to operator because it provides additional passengers and revenue at little or no marginal cost.	Kittelson & Associates et al. (*119*)
Commute trips	Trips that are taken on a daily or regular basis to work.	Kuhn et al. (*4*)
Commuter	A person who travels regularly between home and a fixed location (e.g., work, school).	Kittelson & Associates et al. (*119*)
Concept of operations	A comprehensive description of system characteristics of a managed lanes facility, including organizational objectives, integrated systems description, and high-level description of intended operations that inform the specification of functions and design.	Research Team
Concurrent-flow lane	A preferential lane that is operated in the same direction as the adjacent general-purpose lanes, separated from the adjacent general-purpose freeway lanes by a standard lane stripe, painted buffer, or barrier.	FHWA (*1*)
Confidence level	A statement of assurance of the accuracy of a statistical statement. For instance, if it is asserted that a population parameter is indeed within the computed confidence interval at confidence level α, then the risk of error is $1-\alpha$. For example, a 95-percent confidence level has a risk of 5 percent.	Kittelson & Associates et al. (*119*)
Confidence limit	A boundary of the confidence interval, usually referred to as lower and upper confidence limits.	Kittelson & Associates et al. (*119*)
Congestion pricing	The policy of charging drivers a fee that varies with the level of traffic on a congested roadway. Designed to allocate roadway space, a scarce resource, in a more economically feasible manner. Also called congestion-relief tolling.	Kuhn et al. (*4*)
Connected vehicle	A vehicle containing an onboard unit or after-market safety device. May alternatively include a vehicle awareness device, which transmits the basic safety message but does not receive broadcasts from other devices and cannot directly support vehicle-based applications.	FHWA (*18*)
Connectivity	The ability of a public transportation network to provide service to the maximum number of origin-and-destination trip pairs through the optimal integration of routes, schedules, fare structures, information systems, and modal transfer facilities.	Kittelson & Associates et al. (*119*)

Term	Definition	Source
Continuous access (also called open access)	A managed lane that allows access anywhere along its length, typically separated from the general-purpose lanes of traffic by a painted stripe.	Kuhn et al. (*4*)
Contraflow	Movement in a direction opposite to the normal flow of traffic. Usually refers to flow opposite to the heavier flow of traffic. See also *commute*, *reverse.*	Kittelson & Associates et al. (*119*)
Contraflow lane	A managed lane operating in the opposite direction of the normal flow of traffic and designated for peak-direction travel; separated by pylons or moveable barrier.	Kuhn et al. (4)
Cost	Resources used to produce a product or service.	Research Team
Deadheading	Segment of a trip made by a transit vehicle not in revenue service.	Kuhn et al. (*4*)
Delay	The increased travel time experienced due to circumstances that impede a desirable movement of traffic.	Kuhn et al. (*4*)
Demand	1. The quantity (of transportation) desired. 2. In an economic sense, a schedule of the quantities (of travel) consumed at various levels of price or levels of service offered (by the transportation system).	Kittelson & Associates et al. (*119*)
Demand, effective	The number of people or vehicles prepared to travel in a given situation, at a given price.	Kittelson & Associates et al. (*119*)
Demand–response connector	Provides demand-responsive service within a defined zone that has one or more scheduled transfer points to fixed-route transit. The transfer points may be a bus stop for peak-period express or other bus service, or a rail service.	Kittelson & Associates et al. (*119*)
Demand-side policies	Aimed at reducing congestion by reducing the demand for travel, either overall or by targeted modes.	Kuhn et al. (*4*)
Design capacity	See *capacity, design.*	
Design hourly volume	The amount of traffic a transportation facility is designed to carry in 1 hour.	Kittelson & Associates et al. (*119*)
Design vehicle	A vehicle with representative weight, dimensions, and operating characteristics used to establish highway design controls for accommodating designated vehicle classes.	AASHTO (*27*)
Destination	1. The point at which a trip terminates. 2. In planning, the zone in which a trip ends.	Kittelson & Associates et al. (*119*)
Differential pricing (variable pricing)	Time-of-day pricing and tolls that vary by other factors like facility location, season, day of week, or air quality impact.	Kuhn et al. (*4*)
Direct ramp	Grade-separated managed lane ramp dedicated to the use of eligible vehicles.	Research Team
Directional split	The distribution of traffic flows on a two-way facility.	Kuhn et al. (*4*)
Dynamic pricing	Tolls that vary in response to changing congestion and demand levels, as opposed to variable pricing that follows a fixed schedule.	Research Team

Term	Definition	Source
Dynamic shoulder lanes	A strategy that enables the use of the shoulder as a travel lane—known as hard shoulder running or temporary shoulder use—based on congestion levels during peak periods and in response to incidents or other conditions as warranted during non-peak periods. In contrast to a static time-of-day schedule for using a shoulder lane, an active traffic and demand management approach continuously monitors conditions and uses real-time and anticipated congestion levels to determine the need for using a shoulder lane as a regular or special-purpose travel lane (e.g., transit only).	FHWA (*120*)
Effective operating speed	See *speed, overall trip.*	
Electronic toll collection (ETC)	A system for automated collection of tolls from moving or stopped vehicles through wireless technologies such as radio-frequency communication or optical scanning. ETC systems are classified as one of the following: (a) systems that require users to have registered toll accounts, with the use of equipment inside or outside vehicles, such as a transponder or barcode decal, that communicates with or is detected by roadside or overhead receiving equipment, or with the use of license plate optical scanning, to automatically deduct the toll from the registered user account; or (b) systems that do not require users to have registered toll accounts because vehicle license plates are optically scanned and invoices for the toll amount are sent through postal mail to the address of the vehicle owner.	FHWA (*1*)
Electronic toll collection account-only lane	Non-attended toll lane that is restricted to use by only vehicles with a registered toll payment account.	FHWA (*1*)
Enforcement	Function of maintaining the rules and regulations for a managed lane to maintain operational integrity.	Research Team
Enforcement area	Designated space on which enforcement can be performed.	Kuhn et al. (*4*)
Envelope	The width constituting a managed lane operation including the directional travel lane(s) and shoulder/buffer on each side.	Research Team
Environmental assessment	Study to determine the potential impacts on the environment from a project.	Kuhn et al. (*4*)
Environmental impact statement	Comprehensive study of all the potential impacts of a project funded with federal dollars.	Kuhn et al. (*4*)
Exclusive transit facilities	Transportation system infrastructure elements that are set aside for the use of bus transit vehicles only. Examples include some freeway ramps, queue jumpers, bus lanes, off-street bus loading or unloading areas, and guideways that are separated and fully controlled for bus transit.	Research Team
Exclusive transit lane	See *lane, exclusive transit.*	
Exclusive transitway	See *transitway.*	
Express bus service	Bus service with a limited number of stops, usually at a high speed.	Kuhn et al. (*4*)

Term	Definition	Source
Express lanes	Lanes that restrict access (e.g., I-94 Dan Ryan in Chicago) or, according to the MUTCD definition, a managed lane that employs electronic tolling in a freeway right-of-way with or without access restrictions.	Research Team
Express service	See *service, express.*	
Express toll lane or roadway	Dedicated lanes that are typically access restricted and employ electronic toll collection to manage demand.	Research Team
Expressway	A divided arterial highway for through traffic. Has full or partial control of access and generally has grade separations at major intersections.	Kittelson & Associates et al. (*119*)
Facilities, exclusive transit	See *exclusive transit facilities.*	
Factor, peak-hour	See *peak-hour factor.*	
Fees for entering	Tolls charged to vehicles entering a particular facility or an area but that do not depend on the distance traveled on the facility or in the area.	Kuhn et al. (*4*)
Fixed guideway	Transportation system composed of vehicles that can operate only on their own guideways.	Kuhn et al. (*4*)
Flyover ramp	A moderately high-speed, grade-separated ramp that connects a managed lane to another freeway, street, or transit-supporting facility.	Research Team
Forecasting	In planning, the process of determining the future conditions, magnitudes, and patterns within the urban area, such as future population, demographic characteristics, and travel demand.	Kittelson & Associates et al. (*119*)
Freeway	A high-speed divided highway with full control of access.	FHWA (*1*)
Freeway, metered	A freeway to which access is controlled by entrance ramp signals that use fixed-time signal settings or are regulated by a computerized surveillance system that monitors demand. Used to prevent or forestall the onset of freeway congestion.	Kittelson & Associates et al. (*119*)
Freight or truck lane	A facility or lane restricted to authorized truck types.	Kuhn et al. (*4*)
General-purpose lanes	Lanes on a freeway or expressway that are open to all motor vehicles.	Kuhn et al. (*4*)
Geographic information system	A computerized database management system in which geographic databases are related to one another via a common set of location coordinates. Can provide a spatial, interactive visual representation of transit operations and allow users to make queries and selections of database records based on geographic proximity and attributes such as bus stop activity levels and demographic data.	Kittelson & Associates et al. (*119*)
Global positioning system	A system that determines the real-time position of vehicles using communications with a satellite. Refers more specifically to a government-owned system of earth-orbiting satellites that transmit data to ground-based receivers and provide extremely accurate latitude/longitude ground positions.	Kittelson & Associates et al. (*119*)
Grade or gradient	Rise in elevation within a specified distance. As an example, a 1-percent grade is a 1-ft rise in elevation in 100 ft of horizontal distance, in Britain expressed as 1/100 or 1 in 100, and in Europe 10°/1000.	Kittelson & Associates et al. (*119*)

Term	Definition	Source
Grade separation	A vertical separation of intersecting facilities (road, rail, etc.) by the provision of bridge structures.	Kittelson & Associates et al. (*119*)
Guide sign	A sign that shows route designations, destinations, directions, distances, services, points of interest, or other geographical, recreational, or cultural information.	FHWA (*1*)
Headway	The time interval between the passing of the front ends of successive transit units (vehicles or trains) moving along the same lane or track (or other guideway) in the same direction, usually expressed in minutes; see also *service frequency.*	Kittelson & Associates et al. (*119*)
Headway, base	The scheduled headway between transit unit (vehicle or train) trips, between peak periods.	Kittelson & Associates et al. (*119*)
Headway, clock	The scheduled headway between transit unit (vehicle or train) trips, based on even times (i.e., 60, 30, 20, 15, 10, and 7½ minutes).	Kittelson & Associates et al. (*119*)
Headway management	A technique for managing the operation of transit units (vehicles or trains) that focuses on maintaining a certain spacing between units on the same line instead of on adhering to a timetable. For example, if units become bunched, corrective measures might include delaying the units at the rear of the bunch to provide regular headways and hence load distribution, even at the expense of reducing timetable adherence.	Kittelson & Associates et al. (*119*)
High-occupancy toll (HOT) lanes	HOV facilities that allow lower-occupancy vehicles, such as solo drivers, to use the facilities in return for toll payments, which could vary by time of day or level of congestion. May also charge lower-occupancy HOVs.	Kuhn et al. (*4*)
High-occupancy vehicle (HOV)	A motor vehicle carrying at least two or more persons, including carpools, vanpools, and buses.	FHWA (*1*)
High-occupancy-vehicle lane	See *lane, high-occupancy-vehicle.*	
High-occupancy-vehicle system	Development and operation of a coordinated approach of physical improvements such as HOV lanes, park-and-ride lots, and supporting services and policies.	Kuhn et al. (*4*)
Highway Capacity Manual	A standard reference used to calculate the capacity and quality of service of roadway facilities.	Kittelson & Associates et al. (*119*)
HOV lane management	National ITS architecture market package that manages HOV lanes by coordinating freeway ramp meters and connector signals with HOV lane usage signals. Preferential treatment is given to HOV lanes using special bypasses and reserved lanes that may vary by time of day.	Kittelson & Associates et al. (*119*)
HOV/HOT freeway-to-freeway connectors	Special freeway-to-freeway ramps restricted to HOV/HOT lane-eligible vehicles.	Kuhn et al. (*4*)
Incentive programs	Policies and techniques aimed at a specific behavior.	Kuhn et al. (*4*)
Ingress	The provision of access into a roadway.	Kuhn et al. (*4*)
Inherently low-emission vehicles	Alternatively fueled clean air vehicles. Related terms include zero-emission vehicles, ultra-low-emission vehicles, and super-ultra-low-emission vehicles powered by alternative fuels.	Kuhn et al. (*4*)

Term	Definition	Source
Integrated corridor management	The operational coordination of multiple transportation networks and cross-network connections comprising a corridor and the institutional coordination of those agencies and entities responsible for corridor mobility.	Gonzalez et al. (*121*, p. 5)
Intelligent Transportation Society of America	A non-profit, public/private scientific and educational corporation that works to advance a national program for safer, more economical, more energy efficient, and environmentally sound highway travel in the United States. Federal advisory committee used by U.S. DOT.	Kittelson & Associates et al. (*119*)
Intelligent transportation system (ITS)	The application of advanced technologies to enhance the operation and management of a transportation system.	Kuhn et al. (*4*)
Interchange	1. Facility for passenger transfers or connection between routes or modes. 2. The system of interconnecting ramps between two or more intersecting travel ways (highways, transit guideways, etc.) that are grade separated.	Kittelson & Associates et al. (*119*)
Intermediate access	The provision for access along and between the managed lane and general-purpose lanes, other than at the termini.	Research Team
Intermodal	Facility connections between transportation modes.	Kuhn et al. (*4*)
Interoperability	Ability to toll and process toll transactions and accounts from multiple operators and projects, either on a regional, statewide, or national level.	Research Team
Intersection	The point at which two or more roadways meet or cross.	Kittelson & Associates et al. (*119*)
Island, loading or pedestrian	See *loading island.*	
Island platform	See *center platform.*	
Jerk	Time rate of change of acceleration or deceleration of a vehicle, measured in ft/s^3 (m/s^3).	Research Team
Jitney	Privately owned vehicle operated on a fixed or semi-fixed schedule for a fare.	Kuhn et al. (*4*)
K Factor	In vehicle operations, the ratio of the minimum operating separation between two vehicles to the maximum emergency stopping distance. Normally greater than 1 to provide a margin of safety.	Kittelson & Associates et al. (*119*)
Kiss-and-ride	Function whereby transit riders are dropped off and picked up near a transit station.	Kuhn et al. (*4*)
Lane, bus (bus priority lane, preferential bus lane, priority bus lane)	A highway or street lane reserved primarily for buses, either all day or during specified periods. May be used by other traffic under certain circumstances, such as making a right or left turn, or by taxis, motorcycles, or carpools that meet specific requirements described in the traffic laws of the specific jurisdiction.	Kittelson & Associates et al. (*119*)
Lane, bypass	See *queue jumper.*	

Term	Definition	Source
Lane, carpool	A highway or street lane intended primarily for carpools, vanpools, and other high-occupancy vehicles, including buses, either all day or during specified periods. May be used by other traffic under certain circumstances, such as while making a right turn.	Kittelson & Associates et al. (*119*)
Lane, contraflow	A highway or street lane on which vehicles operate in a direction opposite to what would be the normal flow of traffic in that lane. Operate only during certain hours of the day, borrowing an off-peak lane for peak-direction travel. Frequently, the use of a contraflow lane is restricted to public transit and (possibly) other HOVs.	Research Team
Lane, diamond	A concurrent-flow HOV lane physically marked by diamonds painted on the pavement and often indicated by diamond-shaped signs as well. Often used synonymously with high-occupancy-vehicle lane.	Research Team
Lane, exclusive carpool	A highway or street lane reserved for carpools and vanpools.	Kittelson & Associates et al. (*119*)
Lane, exclusive transit (reserved transit lane)	A highway or street lane reserved for buses, light rail vehicles, or both.	Kittelson & Associates et al. (*119*)
Lane, high-occupancy-vehicle (HOV lane)	A highway or street lane reserved for the use of high-occupancy vehicles; see *lane, carpool.*	Kittelson & Associates et al. (*119*)
Lane, priority	A highway or street lane reserved (generally during specified hours) for one or more specified categories of vehicles, for example, buses, carpools, vanpools.	Kittelson & Associates et al. (*119*)
Lane, ramp meter bypass	A form of preferential treatment in which a bypass lane on metered freeway on-ramps is provided for the exclusive use of high-occupancy vehicles.	Kittelson & Associates et al. (*119*)
Lane, reserved transit	See *lane, exclusive transit.*	
Lane, reversible	A highway or street lane on which the direction of traffic flow can be changed to match the peak direction to use maximum roadway capacity during peak-period demands. Typically operate inbound in the morning and outbound in the afternoon, and are barrier separated.	Research Team
Lane-use control signal	A signal face displaying indications to permit, conditionally permit, or prohibit the use of the lane of a roadway or to indicate the impending prohibition of such use. Typically, the display is a green arrow, yellow arrow, and red X.	Research Team
Left shoulder	Pavement located on the left side of the managed lane travelway or general-purpose mainlanes used for enforcement and emergency stopping.	Research Team
Level of service (LOS)	1. A designated range of values for a particular service measure (e.g., “A” through “F” or “1” through “8”), based on users’ perceptions (see *quality of service*) of the aspect of transportation performance being measured. 2. The amount of transit service provided.	Kittelson & Associates et al. (*119*)
Light rail transit	Mode of transit that operates on steel rails and is powered by overhead electrical wires.	Kuhn et al. (*4*)

Term	Definition	Source
Limited access	Access management used to restrict entry to a facility based on facility congestion levels or operational condition, such as the presence of a crash or maintenance activities. Typically, access is not restricted by type of user.	Kuhn et al. (*4*)
Line haul	Portion of a commute trip that is nonstop between two points.	Kuhn et al. (*4*)
Loading island	1. A pedestrian refuge, within the right-of-way and traffic lanes of a highway or street, provided at designated transit stops for the protection of passengers from traffic while they wait for and board or alight from transit vehicles; also known as a *pedestrian* or *boarding island.* 2. A protected location for the loading and unloading of passengers. It may be located within a rail transit or bus station.	Kittelson & Associates et al. (*119*)
Local bus service	Bus routes and service characterized by frequent stops and slow operating speeds.	Kuhn et al. (*4*)
Main lane	General-purpose lane on a freeway that is open to all motor vehicles.	Kuhn et al. (*4*)
Main-lane metering	Regulation of the flow of vehicles on general-purpose lanes or on freeway-to-freeway connections through the use of traffic signals that allow vehicles to proceed at a predetermined rate.	Kuhn et al. (*4*)
Major investment study	Detailed study and assessment of the various options available for the purpose of selecting one for implementation.	Kuhn et al. (*4*)
Managed lane	A highway lane or set of lanes, or a highway facility, for which operational strategies such as managing access, restricting eligibility, or employing variable pricing are implemented and managed during peak periods and often in real time in response to changing conditions. Are typically buffer- or barrier-separated concurrent-flow lanes parallel to the general-purpose lanes of a freeway.	Research Team
Manual on Uniform Traffic Control Devices (MUTCD)	Defines the standards used by road managers nationwide to install and maintain traffic control devices on all public streets, highways, bikeways, and private roads open to public traffic. The MUTCD is published by FHWA under 23 CFR Part 655, Subpart f.	FHWA (*1*)
Median (median strip)	The portion of a divided highway that separates the opposing flows of traffic.	Research Team
Metered freeway	See *freeway, metered.*	
Metered freeway bus priority system	See *bus priority system, metered freeway.*	
Metering, ramp	See *ramp metering.*	
Mileage-based fee	The fee charged for using a vehicle based on the *vehicle miles traveled* in a jurisdiction.	Kuhn et al. (*4*)
Mobility	The ability to satisfy the demand to move a person or good.	Kittelson & Associates et al. (*119*)
Mode	Means of travel (e.g., automobile, *bus, carpool, vanpool*).	Research Team
Mode shift	The change from one means of travel to another.	Kuhn et al. (*4*)

Term	Definition	Source
Model	1. A mathematical or conceptual presentation of relationships and actions within a system. Used for analysis of the system or its evaluation under various conditions; examples include land use, economic, socioeconomic, and transportation. 2. A mathematical description of a real-life situation that uses data on past and present conditions to make a projection about the future.	Kittelson & Associates et al. (*119*)
Motor vehicle fuel tax	Pricing of gasoline and other fuels.	Kuhn et al. (*4*)
Moveable barrier	A type of concrete barrier that can be moved by a machine rather quickly (about 5–8 mph) in order to create a separated lane or reverse the operation of lanes on a freeway.	Research Team
Multimodal	Facilities serving more than one transportation mode.	Kuhn et al. (*4*)
National Committee on Uniform Traffic Control Devices (NCUTCD)	A volunteer organization that assists in developing standards, guides, and warrants for traffic control devices. NCUTCD recommends changes to the MUTCD to FHWA.	NCUTCD (*122*)
National Cooperative Highway Research Program (NCHRP)	A program established by the American Association of State Highway Officials (now American Association of State Highway and Transportation Officials) to provide a mechanism for a national coordinated program of cooperative research employing modern scientific techniques. NCHRP is administered by the Transportation Research Board.	National Academies of Sciences, Engineering, and Medicine (*123*)
National Environmental Policy Act (NEPA)	Legislation enacted in 1969 that requires that federally funded projects conduct an environmental impact statement to evaluate potential impacts.	Kuhn et al. (*4*)
Network	1. In planning, a system of links and nodes that describes a transportation system. 2. In highway engineering, the configuration of highways that constitutes the total system. 3. In transit operations, a system of transit lines or routes, usually designed for coordinated operation.	Kittelson & Associates et al. (*119*)
Non-attainment area	A geographic area in which the level of air pollution is higher than the level allowed by nationally accepted standards for one or more pollutants.	Kuhn et al. (*4*)
Off-line station	Mode transfer facility located near a managed lane but not within the freeway right-of-way. Is sometimes connected to the managed lane with a grade-separated ramp.	Research Team
Off-peak	The periods of time outside the peak periods; see also *base period.*	Kittelson & Associates et al. (*119*)
Off-peak direction	Direction of lower demand during the peak commuting period.	Kuhn et al. (*4*)
On-line station	Mode transfer facility located along a managed lane or a fixed-guideway system. (Also called in-line station in some references.)	Research Team
Open-road ETC lane	A non-attended lane that is designed to allow toll payments to be electronically collected from vehicles traveling at normal highway speeds. Typically physically separated from the toll plaza, often following the alignment of the mainline lanes, with toll plaza lanes for cash toll payments being on a different alignment after diverging from the mainline lanes or a subset thereof.	FHWA (*1*)

Term	Definition	Source
Open-road tolling	A system designed to allow ETC from vehicles traveling at normal highway speeds. Might be used on toll roads or toll facilities in conjunction with toll plazas. Also typically used on managed lanes and on toll facilities that only accept payment by ETC.	FHWA (*1*)
Open-road tolling point	The location along an open-road ETC lane at which roadside or overhead detection and receiving equipment are placed and vehicles are electronically assessed a toll.	FHWA (*1*)
Origin–destination study	Analysis of the starting and ending points or zones of people or vehicles.	Kuhn et al. (*4*)
Paratransit	Forms of transportation services that are more flexible and personalized than conventional fixed-route, fixed-schedule service but not including such exclusory services as charter bus trips. The vehicles for paratransit service are usually low- or medium-capacity highway vehicles, and the service offered is adjustable in various degrees to individual needs.	Kittelson & Associates et al. (*119*)
Park-and-pool lot	Facility where individuals can park their private vehicles and join a *carpool* or *vanpool.* Not normally served by public transportation.	Kuhn et al. (*4*)
Park-and-ride (park 'n' ride, P&R)	An access mode to transit in which patrons drive private automobiles or ride bicycles to a transit station, stop, or *carpool/vanpool* waiting area and park the vehicle in the area provided for that purpose (*park-and-ride lot, park-and-pool lot,* commuter parking lot, bicycle rack or locker). They then ride the transit system or take a carpool or vanpool to their destinations.	Kittelson & Associates et al. (*119*)
Park-and-ride lot	Facility where individuals can park their private vehicles and access public transportation.	Kuhn et al. (*4*)
Parking facility	An area, which may be enclosed or open, attended or unattended, in which automobiles may be left, with or without payment of a fee, while the occupants of the automobiles are using other facilities or services.	Kittelson & Associates et al. (*119*)
Parking management	Strategies aimed at making better use of available parking supply. Includes preferential parking or price discounts for carpools and/or short-term parkers, and disincentives for those contributing more to congestion.	Kuhn et al. (*4*)
Parking surcharges	Users who park in congested areas during the most congested periods are charged fees higher than those normally associated with the facilities they use.	Kuhn et al. (*4*)
Parking turnover	The ratio of the total number of parked vehicles accommodated during a given period in a specified area to the total number of parking spaces in that area.	Kittelson & Associates et al. (*119*)
Peak direction	Direction of higher demand during a peak commuting time.	Kuhn et al. (*4*)
Peak hour	The hour in which the maximum demand occurs on a facility.	Kuhn et al. (*4*)
Peak-hour factor (peak-hour conversion factor)	1. The ratio of the volume during the peak hour to the maximum rate of flow during a selected period within the peak hour, usually 15 or 20 minutes. 2. The ratio of the volume during the peak hour to the volume during the peak period, usually the peak 2 hours, typically 60 percent.	Kittelson & Associates et al. (*119*)

Term	Definition	Source
Peak period	Period in which traffic levels rise from normal levels to maximum levels.	Kuhn et al. (*4*)
Pedestrian	A person traveling on foot.	Kittelson & Associates et al. (*119*)
Persons with disabilities	Persons who have physical or mental impairments that substantially limit one or more major life activities. In the context of transportation, the term usually refers to people for whom the use of conventional transit facilities would be impossible or would create a hardship.	Kittelson & Associates et al. (*119*)
Pictograph	A pictorial representation used to identify a governmental jurisdiction, an area of jurisdiction, a governmental agency, a military base or branch of service, a governmental-approved university or college, a **toll payment system**, or a government-approved institution.	FHWA (*1*, Section 1A.13, Definition 146)
Platform	1. The front portion of a bus or streetcar where passengers board. 2. The waiting area next to where passengers board and alight from buses or rail transit vehicles at a transit station.	Research Team
Preferential lane	A highway lane reserved for the exclusive use of one or more specific types of vehicles or vehicles with at least a specific number of occupants.	FHWA (*1*)
Preferential parking	Incentive to encourage ridesharing. Usually located closer to the destination.	Kuhn et al. (*4*)
Price	1. A fee charged for use of a road or lane. 2. The direct costs borne by users for consuming a good or service.	Research Team
Price elasticity of demand	A measure of the sensitivity of demand for a commodity to a change in its price. It equals the percentage change in consumption of the commodity that results from a 1-percent change in its price. The greater the elasticity, the more price sensitive the demand for the commodity.	Kuhn et al. (*4*)
Pricing	1. To charge a price (or toll) for the use of a road. 2. Method used by an agency to set the price (or toll) for the use of a road.	Research Team
Priority lane	Lane providing preferential treatment to eligible users.	Research Team
Priority lane pricing	Concept of using congestion pricing on a managed lane.	Research Team
Public transit	Passenger transportation service, usually local in scope, that is available to any person who pays a prescribed fare. Operates on established schedules along designated routes or lines with specific stops and is designed to move relatively large numbers of people at one time. Examples include bus, light rail, and rapid transit.	Kittelson & Associates et al. (*119*)
Public transportation	Transportation service provided to the public on a regular basis using vehicles that transport more than one person for compensation, usually but not exclusively over a set route or routes from one fixed point to another. Routes and schedules of this service may be predetermined by the operator or may be determined through a cooperative arrangement.	Kittelson & Associates et al. (*119*)
Pullout	A short section of pavement oriented to the left or right of the managed lane travelway or mainlanes that can serve a variety of operational purposes including enforcement and emergency refuge.	Research Team
Pylon	See *channelizer.*	

Term	Definition	Source
Quality of service	The overall measured or perceived quality of transportation service from the user's or passenger's point of view, rather than from the operating agency's point of view. Defined for transit systems, route segments, and stops by level of service.	Kittelson & Associates et al. (*119*)
Queue	A line of vehicles or people waiting to be served by the system in which the rate of flow from the front of the line determines the average speed within the line. Slow-moving vehicles or people joining the rear of the queue are usually considered a part of the queue.	Kittelson & Associates et al. (*119*)
Queue bypass	A managed lane facility that provides a bypass around a queue of vehicles delayed at a ramp or mainline traffic meter or other bottleneck location.	Research Team
Queue jumper	1. A short section of exclusive or preferential lane that enables specified vehicles to bypass an automobile queue or a congested section of traffic. Often used at signal-controlled metered freeway on-ramps in congested urban areas to allow high-occupancy vehicles preference. Also known as a *bypass lane* or *queue bypass.* 2. A person who violates passenger controls.	Kittelson & Associates et al. (*119*)
Ramp control signal	A highway traffic signal installed to control the flow of traffic onto a freeway at an entrance ramp or at a freeway-to-freeway ramp connection.	FHWA (*1*)
Ramp meter	See *ramp control signal.*	
Ramp meter bypass	Preferential treatment at a ramp meter in which a lane is provided for the exclusive use of eligible vehicles such as HOVs to bypass the queue.	Kuhn et al. (*4*)
Ramp metering	Procedure used to reduce congestion by managing vehicle flow from local-access on-ramps. The entrance ramp is equipped with a traffic signal that allows vehicles to enter the freeway at predetermined intervals.	Kuhn et al. (*4*)
Rapid transit	Generic term introduced in the 1890s to denote any transit that was faster than its predecessor, most particularly for the replacement of horse cars with electric streetcars; now generally used for rail systems on exclusive right-of-way (e.g., heavy rail or metro).	Kittelson & Associates et al. (*119*)
Revenue-neutral	Pricing strategies that involve rebating some or all of the revenue generated by pricing to toll payers; raising money is not an objective of congestion pricing.	Kuhn et al. (*4*)
Reverse commute	Travel time between work/school and home in the opposite direction of the peak direction of travel.	Kuhn et al. (*4*)
Reversible lane	Facility in which the direction of traffic flow can be changed at different times of the day to match the peak direction of travel, typically inbound in the morning and outbound in the afternoon.	Research Team
Ridesharing	A mode of travel in which two or more people share a ride using a common vehicle.	Research Team
Right-of-way	1. A general term denoting land, property, or interest therein, usually in a strip, acquired for or devoted to transportation purposes. For transit, rights-of-way may be categorized by degree of their separation: fully controlled without grade crossings, also known as grade-separated, exclusive, or private right-of-way; longitudinally physically separated from other traffic (by curbs, barriers, grade separation, etc.) but with grade crossings; or surface streets with mixed traffic, although transit may have preferential treatment. 2. The precedence accorded to one vehicle or person over another.	Kittelson & Associates et al. (*119*)

Term	Definition	Source
Right shoulder	Pavement located on the right side of the managed lane travelway or general-purpose mainlanes used for enforcement and emergency stopping.	Research Team
Road pricing	An umbrella phrase that covers all charges imposed on those who use roadways. Includes such traditional revenue sources as fuel taxes and license fees as well as charges that vary with time of day, specific road used, and vehicle size and weight.	Kuhn et al. (*4*)
Separation	1. The width between a managed lane and adjacent general-purpose lane for facilities located within a freeway. 2. The physical treatment (i.e., paint stripe, barrier, channelizers, etc.) between a managed lane and general-purpose lanes.	Research Team
Service, express	Service that has fewer stops and a higher operating speed than regular service. Often used as an alternative term for limited-stop service; when agencies provide both types of service, the express service tends to have much longer sections of nonstop running.	Kittelson & Associates et al. (*119*)
Service, express bus	Bus service with a limited number of stops, either from a collector area directly to a specific destination or in a particular corridor with stops en route at major transfer points or activity centers. Usually uses freeways or busways where they are available.	Kittelson & Associates et al. (*119*)
Service frequency	The number of transit units (vehicles or trains) on a given route or line, moving in the same direction, that pass a given point within a specified interval of time, usually 1 hour; see also *headway*.	Kittelson & Associates et al. (*119*)
Signal preemption	An interruption of the normal operation of a signal in order to immediately serve a particular movement.	Kuhn et al. (*4*)
Signal priority	Technique of altering the sequence or timing of traffic signal phases using special detection in order to provide preferential treatment.	Kuhn et al. (*4*)
Simulation	1. A mathematical or conceptual presentation of traffic operational relationships and actions within a system. Used for analysis of the system or its evaluation under various conditions; an example includes traffic flow into and out of a managed lane. 2. A mathematical description of a real-life situation that uses data on past and present conditions to make a projection about future conditions.	Research Team
Slip ramp	A designated at-grade access provided between the managed lane and general-purpose lanes. May be channelized through striping or barriers, or may be an open weave zone represented as breaks in pavement markings.	Research Team
Special-use lane	Lane restricted for specific uses only.	Kuhn et al. (*4*)
Speed limit	The maximum (or minimum) speed applicable to a section of highway as established by law or regulation.	FHWA (*1*)
Speed, advisory	A recommended speed for vehicles operating on a section of highway or a specific lane based on the highway design, operating characteristics, and prevailing conditions if displayed dynamically.	FHWA (*1*)
Speed, operating	The speed at which drivers are observed operating their vehicles during free-flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed.	AASHTO (*27*)

Term	Definition	Source
Speed, overall trip (effective operating speed, cycle speed)	In transit operations, the average speed achieved per round trip, including layover and recovery time but excluding deadheading time. Calculated by individual trips, by running time periods, or for the entire schedule.	Kittelson & Associates et al. (*119*)
Speed, running	The speed at which an individual vehicle travels over a highway section.	AASHTO (*27*)
Speed–flow relationship	The relationship between the flow (volume) of units on a transportation facility and the speed of those units. As flow increases, speed tends to decrease.	Kittelson & Associates et al. (*119*)
Station	An off-street facility (typically) where passengers wait for, board, alight, or transfer between transit units (vehicles or trains). Usually provides information and a waiting area and may have boarding and alighting platforms, ticket or farecard sales, fare collection, and other related facilities; also known as a passenger station.	Kittelson & Associates et al. (*119*)
Station, accessible	A public transportation passenger facility that provides ready access, is usable, and does not have physical barriers that prohibit and/or restrict access by individuals with disabilities, including individuals who use wheelchairs.	Kittelson & Associates et al. (*119*)
Stop, far-side	A stop located immediately after an intersection.	Fitzpatrick et al. (*124*)
Stop, midblock	A stop within a block.	Fitzpatrick et al. (*124*)
Stop, near-side	A stop located immediately before an intersection.	Fitzpatrick et al. (*124*)
Stop, transit	An area where passengers wait for, board, alight, and transfer between transit units (vehicles or trains). Usually indicated by distinctive signs and by curb or pavement markings and may provide service information, shelter, seating, or any combination of these. Stops are often designated by the mode offering service, for example, bus stop or car stop.	Kittelson & Associates et al. (*119*)
Superelevation	1. In track construction, the vertical distance that the outer rail is set above the inner rail on a curve, expressed as the vertical distance of the outer rail over the inner rail or as the transverse grade percent. Permits increased operating speed on curves, cannot exceed a maximum, typically 10 percent, to allow for trains that may stop or operate at below design speed on the curve. 2. In highway construction, the banking of the roadway on a curve.	Kittelson & Associates et al. (*119*)
Support facility	A physical improvement that enhances managed lane operations, usually for a specific mode (i.e., a park-and-ride lot for transit services using a managed lane).	Kuhn et al. (*4*)
Symbol	The approved design of a pictorial representation of a specific traffic control message for signs, pavement markings, traffic control signals, or other traffic control devices.	FHWA (*1*, Definition 227, p. 21)
Throughput	The volume of vehicle or passengers passing a specific point during a predetermined period of time.	Kuhn et al. (*4*)
Time-of-day pricing	Facility tolls that vary by time of day in response to varying congestion levels. Typically, such tolls are higher during peak periods when the congestion is most severe.	Kuhn et al. (*4*)
Toll	A fee charged for use of a road or lane.	Research Team

Term	Definition	Source
Toll lane or road	A section of road where motorists are charged a usage fee that is usually collected at a specific point for a given lane or section of road.	Adapted from Kuhn et al. (*4*)
Toll zone	A defined length of lane or roadway in which a specific toll is being levied, often in real time on managed lanes based on changing traffic conditions.	Research Team
Tolling	To charge a toll (or price) for the use of a road.	Research Team
Traffic assignment	The planning and modeling process of allocating trips by different modes and to different origins and destination and routes.	Kuhn et al. (*4*)
Traffic assignment zone	The division of a study area into subunits or zones, allowing for a more detailed level of analysis.	Kuhn et al. (*4*)
Traffic control device	A sign, signal, marking, or other device used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, private road open to public travel, pedestrian facility, or shared-use path by authority of a public agency or official having jurisdiction, or, in the case of a private road open to public travel, by authority of the private owner or private official having jurisdiction.	FHWA (*1*)
Traffic volume	The number of vehicles on a roadway.	Kuhn et al. (*4*)
Transit center	Mode transfer facility serving buses or other modes such as pedestrians, kiss-and-ride patrons, rail transit, or bicyclists.	Research Team
Transit shelter	A building or other structure constructed at a transit stop. May be designated by the mode offering service, for example, bus shelter. Provides protection from the weather and may provide seating or schedule information or both for the convenience of waiting passengers.	Kittelson & Associates et al. (*119*)
Transit system, bus rapid (bus rapid transit, BRT)	An inexact term describing a bus operation providing service similar to rail transit, often at a lower cost. BRT systems are characterized by several of the following components: exclusive transitways, enhanced stations, easily identified vehicles, high-frequency all-day service, simple route structures, simplified fare collection, and ITS technologies. Integrating these components is intended to improve bus speed, reliability, and identity.	Kittelson & Associates et al. (*119*)
Transitway	A dedicated right-of-way or roadway used by transit vehicles (buses or trains).	Kittelson & Associates et al. (*119*)
Transponder	An ETC tag mounted on a windshield or license plate, built into a vehicle, or placed on the dashboard. The tag is read electronically by an electronic tolling device that automatically assesses the amount of the user fee. The transponder function may also be provided from a smartphone or other portable device through a mobile account or application.	Research Team
Transportation control measure	Series of vehicle trip-reduction measures focusing on reducing travel by single-occupancy vehicles and increasing alternative modes.	Kuhn et al. (*4*)
Transportation system management	Actions that improve the operation and coordination of transportation services and facilities.	Kuhn et al. (*4*)
Transportation/travel demand management	A variety of strategies, techniques, or incentives aimed at providing the most efficient and effective use of existing transportation services and facilities (e.g., rideshare and telecommuting promotion, managed lanes, preferential parking, road pricing, etc.).	Kuhn et al. (*4*)

Term	Definition	Source
Travel time	The length of time it takes to travel between two points.	Kuhn et al. (*4*)
Travel time reliability	The lack of variability in travel time that can be expected using different facilities.	Kuhn et al. (*4*)
Travel time savings	Time saved by using one facility instead of another (e.g., using an HOV facility rather than the general-purpose lanes).	Kuhn et al. (*4*)
Travelway	The main lane or roadway of a managed lane.	Research Team
Trip	1. A one-way movement of a person or vehicle between two points for a specific purpose; sometimes called a one-way trip to distinguish it from a round trip. 2. The movement of a transit unit (vehicle or train) in one direction from the beginning of a route to the end of it; also known as a run.	Kittelson & Associates et al. (*119*)
Trip generation rates	Number of vehicular trips to and from a development. Are used to identify the potential impacts of new projects.	Kuhn et al. (*4*)
Truck lanes	Dedicated lanes restricted or primarily dedicated to the movement of large commercial trucks.	Kuhn et al. (*4*)
User management	The types of users who can utilize a facility. HOV lanes are prime examples of user-managed facilities. Restrictions may vary by time of day or day of the week.	Kuhn et al. (*4*)
Value pricing	A system of fees or tolls paid by drivers to gain access to dedicated roadway facilities providing a superior level of service compared to the competitive free facilities. Permits anyone to access the managed lanes, and the value of the toll is used to ensure that the management goals of the facility are maintained.	Kuhn et al. (*4*)
Van	Vehicles having a typical seating capacity of 5 to 15 passengers and classified as a van by vehicle manufacturers. A modified van is a standard van that has undergone some structural changes, usually made to increase its size and particularly its height. The seating capacity of modified vans is approximately 9 to 18 passengers.	Kittelson & Associates et al. (*119*)
Vanpool	Vans and/or buses seating fewer than 25 persons operating as a voluntary commuter ridesharing arrangement, which provides transportation to a group of individuals traveling directly between their homes and their regular places of work within the same geographical area. The vans should have a seating capacity greater than seven persons, including the driver. A mass transit service operated by a public entity, or in which a public entity owns, purchases, or leases the vehicles.	Kittelson & Associates et al. (*119*)
Variable pricing	Tolls that are collected to manage demand, either dynamically in response to changing traffic conditions or in accordance with a daily schedule that reflects changing traffic conditions (in some references also called *value pricing*).	Research Team
Vehicle miles traveled	The total distance traveled in miles by all motor vehicles of a specific group in a given area at a given time.	Kuhn et al. (*4*)
Vehicle occupancy	The number of people aboard a vehicle at a given time; also known as auto or automobile occupancy when the reference is to automobile travel only.	Kittelson & Associates et al. (*119*)

Term	Definition	Source
Vehicle-to-infrastructure communications	A system designed to transmit information between vehicles and the road infrastructure to enable a variety of safety, mobility, and environmental applications.	FHWA (*18*)
Vehicle-to-vehicle communications	A system designed to transmit basic safety information between vehicles to facilitate warnings to drivers concerning impending crashes.	FHWA (*18*)
Vertical clearance	The distance between the surface of the roadway and an overhead structure that provides the basis for meeting different design vehicle requirements.	Research Team
Violation	An infraction by users against formal rules and restrictions associated with a managed lane.	Research Team
Violation rate (occupancy)	Number of vehicles that do not meet the minimum occupancy requirements on an HOV lane divided by total vehicles passing a given point or section of roadway.	Research Team
Violation rate (toll)	Number of vehicles who are subject to tolling that are not paying or are evading the toll divided by the total passing a given point or section of roadway.	Research Team
Volume	In transportation, the number of units (passengers or vehicles) that pass a point on a transportation facility during a specified interval of time, usually 1 hour.	Kittelson & Associates et al. (*119*)
Volume-to-capacity ratio	The ratio of demand flow rates to capacity for a given type of transportation facility.	Kuhn et al. (*4*)

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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