STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

TRAFFIC OPERATIONS POLICY DIRECTIVE

TR-0011 (REV 08/2009)

ROBERT COPP, DIVISION CHIEF (Signature)	NUMBER 11-02	PAGE 1 OF 12
SUBJECT: Updated Managed Lane Design	DATE ISSUED 3/23/2011	EFFECTIVE DATE 4/7/2011

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DOES THIS DIRECTIVE AFFECT OR SUPERSEDE ANOTHER DOCUMENT? ☒YES ☐NO	IF YES, DESCRIBE High Occupancy Vehicle Guidelines for Planning, Design, and Operations
WILL THIS DIRECTIVE BE INCORPORATED IN THE CALIFORNIA MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES (CA MUTCD) ☒YES ☐NO	IF YES, DESCRIBE Chapters on preferential lane signing and pavement markings to be included in the next edition of the CA MUTCD

DIRECTIVE

In California, managed lanes include high occupancy vehicle (HOV) lanes, high occupancy/toll (HOT) lanes, and express toll lanes. The latter two are referred to generally as "Express Lanes".

The California Department of Transportation (Department) "2003 High Occupancy Vehicle Guidelines for Planning, Design, and Operations" (HOV Guidelines) and the content of this Policy Directive (Directive) shall be applied during the planning and development of freeway managed lane projects, including conversions of existing managed lanes to incorporate tolling or utilize continuous access. It shall be considered during the planning and development of all other freeway improvement projects (e.g. pavement rehabilitation projects) and during the course of traffic investigations that are addressing operational and safety performance deficiencies.

For ongoing projects, changes to the project design pursuant to this Directive shall be determined by the project manager and project engineer in consultation with the Headquarters' Traffic Operations Liaison (Traffic Liaison) and the district HOV program coordinator. The decision to implement the requirements of this directive will be based on the potential benefits and impacts to the project scope, cost and schedule. **The consultation and recommendations shall be documented in the form of a memorandum for the project files with the signature of the Traffic Liaison indicating concurrence.**

Retrofitting of existing facilities will not be required unless physical conditions for that facility change, such as a change in access type or an HOV-Express Lane conversion.

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The technical content of this Directive represents best engineering practices and requirements that will be incorporated into the next edition of the HOV Guidelines. This Directive also incorporates material from the most recent (2009) edition of the federal Manual on Uniform Traffic Control Devices (federal MUTCD). This material will be incorporated into the next edition of the CA MUTCD.

The following principles are expected to guide decision-making on the development and/or operations of managed lanes:

- Employ a systems management approach; managed lane strategies can affect the performance of the entire freeway system. The focus should not just be on the operation of the managed lane and its mobility benefits.
- Balance system performance and overarching goals, including safety, mobility, delivery, stewardship, and customer service when selecting and analyzing project alternatives and key features.
- Consider increasing occupancy requirements if HOV lanes are experiencing severe congestion.
- Consider planning for two managed lanes in each direction of travel if analysis determines it to be practical and beneficial.
- Consider implementing congestion pricing to utilize the full capacity of under-utilized HOV lanes if analysis determines it to be practical and beneficial.
- Ensure uniformity and consistency in the appearance of facilities within a region as much as possible; unique conditions and situations may require unconventional treatment(s).
- Ensure enforcement considerations are taken into account. Consult the California Highway Patrol (CHP) during project development.
- Consult with the Traffic Liaison to ensure that emerging best practices and recent "lessons learned" from collision analysis and research are fully considered and implemented.

MANAGED LANES ACCESS

Managed lanes in California utilize either:

- Limited-access designs (via physical barriers or barrier striping within a buffer space) which may include intermediate access openings.
- Continuous-access designs (contiguous/non-separated).

When planning managed lanes, consideration should be given to both access types. 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 facility. See Attachment 2 for a summary of design, cost and performance considerations for the two types of access designs. Various research and engineering studies on managed lane facilities have found that the highway features that can have the greatest affect on performance, including safety and throughput, are:

- The 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).

For additional information and reference material, see the Background section of this Directive and Attachment 1.

Managed lanes may also utilize drop ramps to and from local streets and direct connectors to and from managed lanes on other freeways. These provide system connectivity with the least potential for adverse performance impacts by allowing traffic to directly exit or enter the managed lanes without weaving across adjacent general-purpose lanes. Drop ramps and direct connectors should be considered where substantial congestion in the general-purpose lanes exists or is expected and there is a significant local demand for access to or from the managed lanes. Refer to Sections 3.7 and 3.8 of the HOV Guidelines for more information.

MANAGED LANES ENGINEERING STUDY REQUIREMENTS

Section 149 of the Streets and Highways Code requires that competent engineering estimates be made of the effects of a managed lane on safety, congestion, and highway capacity prior to constructing such lanes. **A traffic study shall be performed for all managed lane projects. This study shall be composed of an operational analysis and a safety analysis.** This traffic study replaces the "HOV Report" located in Appendix B of the HOV Guidelines. The objective of the study is to determine if, and to what extent, the design of the managed lane will meet the performance thresholds and guidance provided in this Directive, as well as any other thresholds the district or project sponsor may establish. **For new projects, the traffic study shall be conducted as early as reasonable during project development.** Ideally the study is conducted during development of the project initiation document (PID) to confidently establish an accurate cost, scope and schedule for the project. Alternatively, a more general assessment or technical evaluation may be adequate during the PID phase in order to:

- Identify potential performance problems for further study.

- Identify the scope of (and resources need for) a formal traffic study to be performed at the start of the Project Approval and Environmental Document phase.

The following information and assumptions shall be identified and utilized as part of the traffic study:

- **Design year peak-hour volumes for the managed lane(s), general-purpose lanes, and adjacent general-purpose ramps. The design year shall be 20 years from the date when the project is scheduled to be completed and opened to traffic as per Highway Design Manual (HDM) Index 103.2.**
- **The design year peak-hour volume of vehicles expected to use access locations.**
- **The types of vehicles expected to use the freeway facility (e.g., transit or trucks).**
- **Geometric constraints on the managed lanes and general purpose lanes, including known and expected bottlenecks and associated queues.**

The operational analysis is to be performed using a methodology that is acceptable to the district and the project sponsor. **The operational analysis shall:**

- **Evaluate the characteristics of the entire freeway facility, including both the managed lane(s) and the adjacent general purpose lanes.**
- **Include a merge/diverge analysis of any drop ramps or direct connectors that may be utilized on the managed lane.**
- **Evaluate the operational impacts of intermediate access openings on a limited-access facility.** Section 4.3 of the HOV Guidelines states that the operation of weaving sections at access openings needs to be considered. See the section on limited-access managed lanes design and performance considerations for more details.

The traffic safety analysis shall be performed by or approved by the district traffic safety office. This analysis will focus on the safety impact of the proposed improvements on operating conditions and collision potential by utilizing traffic and collision data and analytical tools and processes. This is especially important when the project proposes a change in the type of access. This safety analysis is independent of the broader safety review process that is required per HDM Index 110.8.

GENERAL MANAGED LANE DESIGN AND PERFORMANCE REQUIREMENTS

Geometric design of managed lane projects, including lane and shoulder widths, shall conform to the HDM. Deviations from the requirements of the HDM shall be evaluated and approved on a case-by-case basis in the manner prescribed in HDM Index 82.2. Section 3.10 of the HOV Guidelines provides a priority listing for reductions in cross-sectional elements for various managed lane geometric configurations. **This priority listing shall be utilized in the development of managed lane projects where reductions to cross-sectional elements are deemed necessary.**

State law mandates that HOT lanes operate at a Level of Service (LOS) of "C" or better (LOS "D" may be used if the Department and the operator agree). In addition, federal law mandates that HOT lanes and HOV lanes that are used by non-carpool decaled clean-air vehicles operate at a minimum speed of 45 miles per hour during the peak hour no less than 90 percent of the time over a 180-day period. **These performance thresholds shall be taken into consideration when designing a managed lane project.**

LIMITED ACCESS MANAGED LANES DESIGN AND PERFORMANCE REQUIREMENTS

Limited access operation can be implemented with the use of physical barriers or "barrier" striping to separate the managed lane from the adjacent general purpose lanes. A buffer space is typically provided to accommodate barrier striping and other traffic control devices or features (e.g. reflective markers or channelizing devices). The recommended buffer width is 4 ft (ft). However, this width may be reduced as outlined in the priority listing in Section 3.10 of the HOV Guidelines.

Limited access may be used for Express Lanes in order to designate access/tolling points and minimize toll evasions.

Access to and from a limited-access managed lane is primarily provided through at-grade access openings. At-grade access openings also referred to as at-grade ingress and egress, allow vehicles to move into the managed lane from the adjacent general-purpose lanes and vice versa. The different types of at-grade access openings (see Attachment 3) include:

- "Weave Zone": Combined ingress and egress created by short breaks in the barrier striping at carefully selected locations.
- "Weave Lane": Combined ingress and egress, which is facilitated by a weave or speed, change lane. The inclusion of a weave lane minimizes the potential for unstable flow or turbulence along the "crown" weave due to the speed differential between the managed lane and mixed flow lanes.
- "Merge Lane": Separated ingress and egress utilizing dedicated merge lanes. This design separates operational maneuvers and provides drivers with a better opportunity to adjust their speed to match that of the traffic stream into which they are merging. This further reduces the potential for unstable flow.

Any one or all three of these types of at-grade access openings may be adequate for a given location. The type of access opening used in a corridor should be consistent to better satisfy driver expectations. Site-specific operating conditions may warrant the use of a different type. Variations will typically require mitigation in the form of additional signing, enhanced pavement markings, lighting, and/or other traffic control, management, or safety systems.

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 Level of Service (LOS) "C" or "D", as per HDM Index 504.7. 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 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.

Access openings should have a minimum length of 2000 feet (ft). A minimum of 800 ft per lane change should be provided between the opening and the nearest freeway entrance or exit ramp. These lengths should also be utilized at the beginning and ending of managed lanes. These changes supersede the measurements shown in Figure 4.2 of the HOV Guidelines. A figure showing the new measurements for access openings is provided in Attachment 3.

The type and location of proposed access openings shall be determined by the operational analysis. It is expected that an iterative process would be used. 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 concepts are exhausted. The iterative process may require consideration of the following modifications or features (not necessarily in this order):

- Increased weaving lengths.
- Alternative types of access.
- A second managed lane in the vicinity of the opening.
- Relocation of the access opening.
- The addition of auxiliary lanes connecting ramps on the general purpose lanes.
- The use of drop or direct connector ramps.

Proposed access openings that are estimated to operate below the performance thresholds or use less than the minimum lengths or spacing shall be subject to the review and written concurrence of the Traffic Liaison. 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.

Lighting shall be provided for each access opening to facilitate decision making and lane changing maneuvers during hours of darkness. Deviations from this requirement shall be approved by the Traffic Liaison. Lighting will alert drivers that they are approaching left side weaving sections where lane changing and turbulence may be concentrated. Lighting should also be considered for freeway segments located between an access opening and a freeway-to-freeway interchange when the access serves that interchange. This is due to the higher weaving volumes and higher number of lane changes expected in these areas. Contact the district Electrical Design office for information on lighting requirements and assistance in the location and design of all lighting systems.

CONTINUOUS-ACCESS MANAGED LANES DESIGN AND PERFORMANCE REQUIREMENTS

Continuous-access managed lane facilities are designed to allow vehicles to enter or leave at any point. 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.

Traditionally, continuous-access facilities have only been employed in areas with shorter durations of directional congestion during peak commute traffic periods. However, continuous-access operation may be utilized whether the managed lane operates full-time or part-time. Detail M-2 in the HOV Guidelines shows an option for full-time continuous-access managed lanes.

A limited-access facility may be converted to a continuous-access facility if the conversion is funded by the project sponsor requesting the change. **A traffic study, as described in this directive, shall be required for any conversion project.**

If a new or conversion project is on a route where Express Lanes are planned within the next five years, and there is an intent to operate the Express Lane with continuous access, joint consultation shall be conducted between the project

sponsor, the Department and the CHP to identify strategies in limiting violations. Final recommendations from each entity shall be documented in the project file. Frequent toll readers, visible manual enforcement, and other innovative strategies are expected to be considered.

MANAGED LANES STRIPING AND PAVEMENT MARKINGS REQUIREMENTS

When physical barriers are used to limit access, the facility shall be striped in accordance with Section 3B.23 of the CA MUTCD.

When barrier striping is used to limit access, the facility shall be striped in accordance with the requirements of Chapter 5 of the HOV Guidelines. Paint, rather than thermoplastic, should be used. The 2009 edition of the federal MUTCD requires the use of parallel wide solid white stripes on limited access managed lanes to prohibit and restrict lane changing. The Department is in the process of adopting this standard, pending an amendment to the California Vehicle Code. Using paint for the barrier striping will allow for easier conversion to the federal standard once it is adopted.

Continuous-access facilities shall be striped in accordance with the requirements of Section 3B.23 of the CA MUTCD. The 2009 edition of the federal MUTCD provides several different options for continuous access striping. The Department is performing engineering studies that will lead toward the selection and adoption of one of these options.

The diamond symbol pavement marking shall only be used on HOV lanes. An "HOV LANE" pavement marking shall be used on HOV lanes; the "CAR POOL LANE" pavement marking shall not be utilized. For other types of managed lanes, the appropriate pavement marking, such as "BUSES ONLY", "FASTRAK ONLY" (when all users must have an electronic toll collection transponder) or "FASTRAK OR HOV ONLY" (when only vehicles not meeting the occupancy requirement must have a transponder), shall be used. Markings should be placed along the managed lane as shown in Chapter 5 of the HOV Guidelines.

Deviations from these requirements shall require the concurrence of the Traffic Liaison. The Traffic Liaison should be consulted prior to finalizing striping plans for a managed lane in order to receive the latest guidance and direction.

MANAGED LANE SIGNING REQUIREMENTS

Overhead advance guide signs shall be provided at least 0.5 mile prior to the beginning of limited-access HOV facilities. Overhead guide signs shall be provided at the beginning of and at subsequent at-grade access openings to limited-access HOV facilities. These signs shall conform to the E8-3 and E8-2 signs shown in Figures 2G-5 and 2G-6 of the 2009 edition of the federal MUTCD. An overhead advanced guide sign may also be used in advance of at-grade access openings. **The R87-1(CA) overhead sign shall be placed at the beginning of the buffer or barrier separation.** These requirements amend the figures shown in Details M-1 and M-4 of the HOV Guidelines. The additional guide signs and the adjustment of the regulatory signs are expected to help facilitate driver decision making by more clearly identifying access openings, especially for drivers who are eligible to use the HOV lane and have just entered the freeway.

The R86(CA), R86-2(CA) or R86-3(CA) and R93-2(CA) signs shall be repeated as a package at half-mile intervals along the length of a facility and shall be placed just downstream of where drop ramps or direct connectors merge into the facility. This requirement amends the figures shown in Details M-1 through M-4 of the HOV Guidelines.

Signing for managed lanes that utilize pricing (Express Lanes) should comply with Sections 2G.16 through 2G.18 of the 2009 edition of the federal MUTCD until the adoption of the next edition of the CA MUTCD.

Deviations from these requirements shall require the concurrence of the Traffic Liaison. The Traffic Liaison should be consulted prior to finalizing signing plans for any managed lane in order to receive the latest guidance and direction.

MANAGED LANE ENFORCEMENT REQUIREMENTS

Enforcement strategies and features shall be considered during the planning, design, and operational phases of all managed lane projects. Enforcement of managed lanes is important to maintain flow, safety, and system management capabilities. Violators could impact flow rates and impact the ability of the operating agency to manage accordingly. With any access type, enforcement requires some investment and strategy for zones, systems, and personnel. Due to the personnel cost and traffic impacts of comprehensive manual enforcement, automated enforcement technology may be used once it is demonstrated to have an acceptable degree of accuracy. Until then, occupancy verification requires manual observation, which can be complex given tinted windows and obscured viewing into vehicles.

Section 6.4 of the HOV Guidelines provides guidance for enforcement area configurations utilizing the median shoulder. **Median shoulder enforcement areas shall only be used when the managed lanes are separated from the general purpose lanes by a physical barrier (such as vertical pylons or a concrete wall).** CHP policy only allows enforcement stops in the median shoulder under these conditions.

Observation areas should be used on the median shoulders of facilities that do not utilize physical separation. They may be used on facilities that utilize physical separation. **The provisions in Section 6.4 of the HOV Guidelines related to the placement of median shoulder enforcement areas shall be applicable to observation areas.** Observation areas should be placed downstream of intermediate access points on limited-access facilities and downstream of drop ramps and direct connectors. The recommended dimensions for an observation area are a width of 14 ft and a length of 100 ft, preceded by a 15:1 taper and followed by a 50:1 taper.

Enforcement plans for Express Lane operations shall be developed jointly between the CHP, the Department, and the project sponsor.

DELEGATION

No new delegations of authority are created under this policy.

BACKGROUND

Managed lanes are lanes that are proactively managed in response to changing conditions and are increasingly used nationwide to deal with the increasing congestion and limited resources. The term "managed lanes" may refer to:

- HOV lanes: Buses, vans, and cars with more than one person use these lanes.
- Express Lanes: Managed lanes that utilize congestion pricing:
  - HOT lanes: An HOV lane that allows vehicles with lower occupancy to have access to the lane by paying a toll. The lanes are kept free-flowing by dynamic and congestion-based tolling, a strategy supported by the Department and the Federal Highway Administration. Tolls may change based on real-time conditions (dynamic) or according to a schedule (static).
  - Express toll lanes: Facilities in which all users are required to pay a toll, although HOVs may be offered a discount. They also utilize electronic tolling and congestion pricing. The 91 Express Toll Lanes are the only such facility in California.

Strategic goals of managed lane projects are:

- Decrease congestion duration and reduce congested locations.
- Increase person-throughput on a corridor by increasing vehicle occupancy, whether through carpooling, vanpooling or transit.
- Decrease per-person air quality impacts.
- Increase congestion avoidance choices for the public.
- Increase predictability of travel by reducing variations in delay.
- For Express Lanes, generate revenue for corridor transportation improvements that include transit and closing gaps in the managed lane network.

The type of managed lane facility utilized will be generally based on regional needs, physical and geographic setting, and unique fiscal circumstances. Due to tolling authority laws in California, Express Lanes are typically initiated by, and jointly operated with, regional transportation agencies. This relationship requires policies and standards that can be applied consistently statewide yet be flexible enough for local needs.

The Division of Traffic Operations is participating in a statewide effort to enhance California's network of managed lanes through improved performance management, partnerships, and design/operation strategies. Regional Transportation Plans contain Express Lanes as congestion management and greenhouse-gas reduction strategies. Regional partners are developing managed lanes projects for imminent use in the San Francisco Bay, Inland Empire and Los Angeles areas. The updated guidance is expected to:

- Improve the performance of managed lanes in a cost effective manner.
- Ensure a system management approach that will include all lanes.

- Mitigate the driver performance impacts resulting from the increased complexity of freeways with managed lanes.
- Provide flexibility for regional decisions.
- Provide needed compliance with federal standards.
- Provide consistent methodology statewide.

While many sections of the HOV Guidelines remain valid, some additions and revisions are needed to communicate updated knowledge and policy to internal and external partners. This Directive addresses only the most-urgently needed guidance updates. Further updates and broader topics will be updated during 2011 and 2012. This effort has been supported by the findings and recommendations of a parallel initiative (Strategic Highway Safety Program Challenge Area 5) which is focused on the impacts of our evolving and increasingly complex metropolitan freeway infrastructure and operating conditions on driver performance and safety outcomes. See Attachment 1 for a summary of this background knowledge.

This Directive is a result of the following developments.

- Increasing congestion has led to a need to coordinate strategies, use all available freeway capacity and resources, and maximize performance of corridors.
- Research and corridor specific engineering studies concerned with performance deficiencies have expanded our understanding of the design, operational and safety features that affect managed lane and freeway system performance.
- Safety research has produced findings that supersede previously established knowledge and practices regarding managed lanes. See Attachment 1 for a summary of findings and recommendations from the 2009 report, "A Comparative Safety Study of Limited versus Continuous-Access High Occupancy Vehicle (HOV) Facilities", and the research team's collaboration with the Department's traffic safety engineering practitioners and specialists.
- Lessons have been learned from managed lane access conversion projects in southern California.
- The Department has committed to updating technical guidance and increasing statewide consistency and flexibility in managed lane operations.
- The 2009 edition of the federal MUTCD contains new managed lane signing and striping policies. There is a more stringent requirement for California to be in substantial conformance with those policies.
- There is intensifying interest in implementing Express Lanes immediately in many urban areas of the state.
- Express Lanes are relatively new to the nation and California's project development process, and as such little policy guidance exists.
- Lessons have been learned from implementation of Express Lanes in other states in the last three years.

DEFINITIONS

When used in this Traffic Operations Policy Directive, the text shall be defined as follows:

1) **Standard:** A statement of required, mandatory or specifically prohibited practice. All standards text appears in **bold** type. The verb **shall** is typically used. Standards are sometimes modified by Options.

2) Guidance: A statement of recommended, but not mandatory, practice in typical situations, with deviations allowed if engineering judgment or engineering study indicates the deviation to be appropriate. All Guidance statements text appears in underline type. The verb "should" is typically used. Guidance statements are sometime modified by Options.

3) Option: A statement of practice that is a permissive condition and carries no requirement or recommendation. Options may contain allowable modifications to a **Standard** or Guidance. All Option statements text appears in normal type. The verb "may" is typically used.

4) Support: An informational statement that does not convey any degree of mandate, recommendation, authorization, prohibition, or enforceable condition. Support statements text appears in normal type. The verbs "shall", "should", and "may" are not used in Support statements.

ATTACHMENTS

1) Summary of Background Knowledge — Page 9 of 12

2) Summary of Design, Cost and Performance Considerations for Continuous and Limited-Access Facilities — Page 11 of 12

3) Access Types with Minimum Recommended Opening Lengths and Weaving Distances — Page 12 of 12

Summary of Background Knowledge

Updating perspective on the performance of freeways with continuous-access HOV lane operation

In 2009, a University of California at Berkeley / Partners for Advanced Transit and Highways research team completed a comprehensive study of California freeways with HOV lanes. The research team compared collision data analyses for large samples of freeway facilities with continuous-access and limited-access HOV lanes. Contrary to the technical opinions presented in the current HOV Guidelines, the research team found that HOV facilities with limited access operation offer no safety advantages over those with continuous-access operation. A higher percentage of collisions were concentrated on the sample set of limited-access HOV lanes, which also had higher collision rates compared to the sample set of continuous-access HOV facilities.

The research team and the Department's traffic safety practitioners then identified the various design, operational, and safety features that affect the performance of freeways with limited access operation. The most prominent of these features include: access configurations, weaving sections (i.e. the type and length as determined by the location, spacing, and design of access openings), lighting, shoulder width, overhead signing, and pavement delineation.

Similar studies by the Texas Transportation Institute support these findings. The Department adopted a policy in 2008 that allows for the conversion of limited-access facilities to continuous access and continues to support continuous access as a HOV lane design that provides safety and throughput performance in a more cost-effective manner.

Updating design criteria for the length and location of access openings for limited-access HOV facilities

During the last several years of evaluating safety and mobility performance issues associated with HOV lane access points, substantial changes to access opening location, spacing and geometry have become clearly necessary. Bottlenecks and collision concentrations stem from the complex weaving action of vehicles at these access points, and across all freeway lanes between freeway entrances/exits and the HOV lane access points. As volumes increase, the impact of this weaving activity on freeway and driver performance becomes more intense, and eventually requires remediation through infrastructure adjustments and enhancements:

- General collision studies in California support increasing the weaving length at and between access openings beyond the current practices found in the HOV Guidelines.
- Nationally recognized research findings and products recommend longer openings and longer distances for the weaving along and between successive access openings. Prior and current national practice allows for a 1000-foot minimum access opening, and (two-sided) weaving lengths that are based on providing 500-800 ft per lane change.
- Based on the above research findings, and years of experience managing location-specific operational and safety problems, the Department's freeway operations and traffic safety engineering practitioners recommend the following changes to our standard practices:
  - increase the minimum access opening length from 1300 ft to 2000 ft, and
  - increase the "per-lane change" distance from 650 ft to 800 ft in order to avoid pushing drivers to make consecutive lane change maneuvers across the entire freeway
- Enhancements will include the expanded use of lighting, pavement delineation, and overhead signing (see next section).

While the updated criteria are substantiated, flexibility is needed when applying the criteria at the project level. The aforementioned engineering practitioners should use analytical tools, consult with the Department technical reviewers and specialists, and then exercise engineering judgment to determine the site-specific best fit. This will often be an iterative process.

Updating signing and lighting of limited-access designs

Express Lane signing is new to the industry, was just added to the 2009 edition of the federal MUTCD and in May 2010 was accepted by the California Traffic Control Devices Committee for addition to the next (2011) edition of the CA MUTCD. In addition, the Department's freeway safety team (comprised of district and headquarters traffic safety staff and the Traffic Liaisons) recommended the use of lighting along all limited-access openings. This was based on research and the collision studies performed in support of the Strategic Highway Safety Program Challenge Area 5 Action Plan. Speeds, weaving volumes and density are high and headlight glare prevail especially during the critical periods just prior to the morning peak period, and just beyond the evening peak period. Overhead lighting will mitigate the impact of adverse infrastructure and operating conditions (headlight glare, narrow shoulders, and speed differential) on HOV and Express Lane drivers attempting to execute the complex weaving maneuvers required.

A selection of references:

1. A Comparative Safety Study of Limited Versus Continuous Access High Occupancy Vehicle (HOV) Facilities, University of California at Berkeley UCB-ITS-PRR-2009-22, 2009
2. Assessment and Validations of Managed Lanes Weaving and Access Guidelines, University of Texas at Arlington, 2010, http://www.uta.edu/ce/faculty/williams/report0-5578-1.pdf
3. Managed Lane Ramp and Roadway Design Issues, Texas Transportation Institute, 2003, http://tti.tamu.edu/documents/4160-10.pdf
4. Managed Lanes - Traffic Modeling, Texas Transportation Institute, 2002, http://tti.tamu.edu/documents/4160-4.pdf

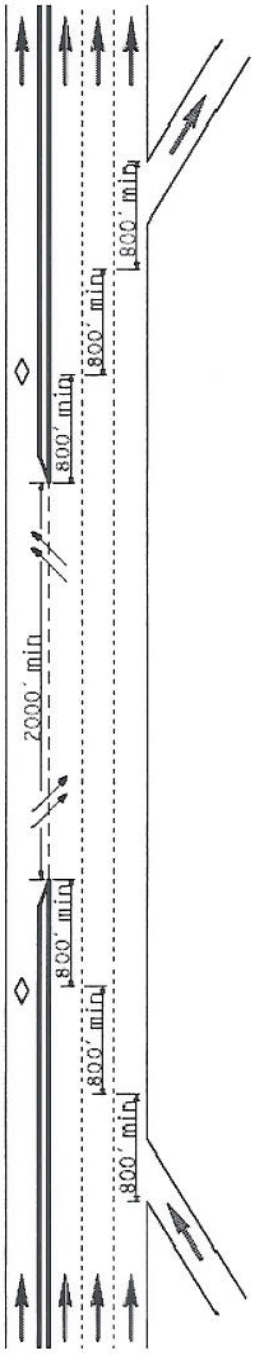
Summary of Design, Cost and Performance Considerations for Continuous and Limited-Access* Facilities

Research and engineering studies show no significant generalized differences in safety and throughput performance between limited and continuous access. The design decision will more appropriately be based on the site-specific types and patterns of traffic and the ability to manage this traffic using the access most appropriate and cost-effective for the corridor.

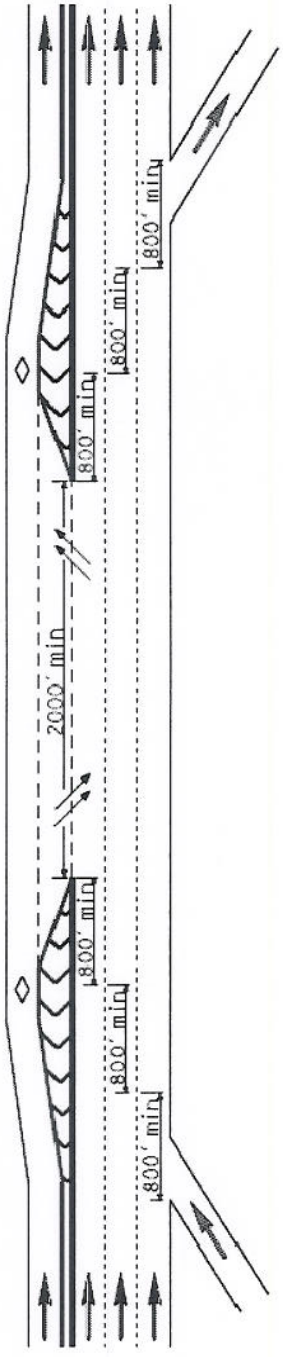
Criterion	Limited-Access	Continuous-Access
Cost	• Detailed operational analysis and an iterative design process is needed for best placement of access points • May require more roadway width to accommodate the buffer and access openings • Additional pavement markings and overhead signing are required • Investment in monitoring and adjustment of "hot spots" near access points may be needed	• Lower cost for design, analysis, construction, operation, and maintenance • Require less engineering resources to make adjustments
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 the need is greatest; this could induce violation of the barrier striping, which may be unexpected by drivers in the managed lane • Can be used to restrict lane changing where demand has produced or may produce a performance deficiency • Accommodates longer-distance trips by discouraging short-term use of lane • Smooth flow, higher speeds can result from limited merging • 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 • Allows last-minute lane changing to reach freeway exit ramps • No concentrated weaving; lane changing occurs along entire corridor when gaps appear • Users can readily access all general purpose ramps • Less complex decision-making by drivers • Easily utilized during off-peak (for part-time facilities) • 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	• Potentially lower toll evasion and occupancy violation • Ease of enforcement • Express Lane toll collection is simplified due to need for fewer readers	• Greater investment in enforcement activity, systems, and zones to produce the lower violation rates expected with limited-access designs • Potentially higher toll evasion and occupancy violation • Increased cost for Express Lane toll collection due to need for additional readers

*This summary document 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

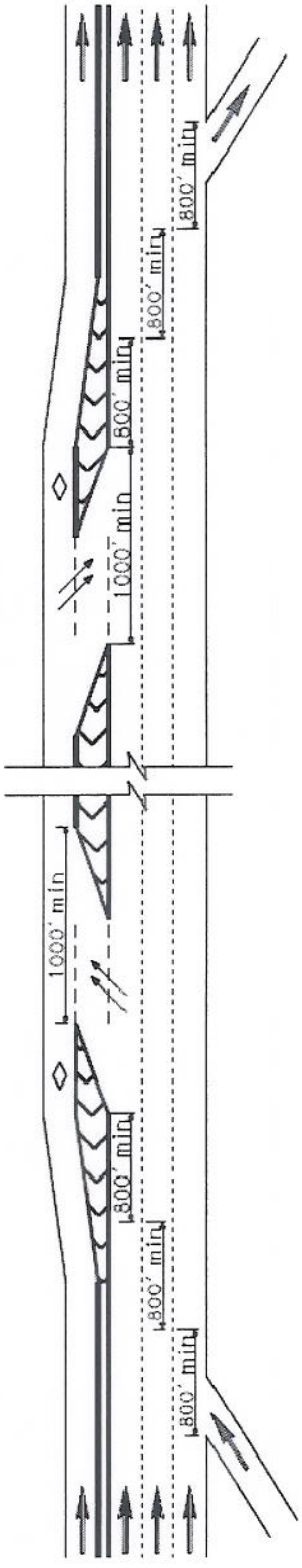
Access Types with Minimum Recommended Opening Lengths and Weaving Distances



COMBINED INGRESS-EGRESS
WEAVE ZONE
(not to scale)



COMBINED INGRESS-EGRESS
WEAVE LANE
(not to scale)



SEPARATED INGRESS-EGRESS
MERGE LANE
(not to scale)