Managed Lanes Network Development Strategy – Phase I

Managed Lane Separation Treatment

MARICOPA ASSOCIATION OF GOVERNMENTS

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1.0 BACKGROUND

The Maricopa Association of Governments (MAG) is working in cooperation with the Arizona Department of Transportation (ADOT), Federal Highway Administration (FHWA), and other regional partner agencies to explore the regional managed lanes system, including determining future needs for High-Occupancy Vehicle (HOV) system expansion and the potential for introducing enhanced lane management techniques such as value pricing in the form of High-Occupancy Toll (HOT) lanes, and active traffic management. The outcome of this effort will be a MAG Managed Lanes Network Development Strategy – Phase I Report that will guide future planning and investment in HOV and Managed Lanes facilities in the region.

The purpose of the MAG Managed Lanes Network Development Strategy – Phase I study is to examine the existing and planned freeways in the region to identify where managed lanes strategies, policies or actions could improve overall system efficiency. For those corridors where such strategies or policies are considered most promising, the study will then provide an action plan that establishes the framework for subsequent phases to further define the network concept including establishing a preliminary concept of operations and design concept, develop corridor specific concepts including preliminary design and environmental clearance, and complete implementation including business rules, market grade traffic and revenue forecasts, construction and operations.

To support the evaluation of the managed lanes network in the MAG region, a series of technical "white papers" have been developed to examine the relevant issues by drawing upon the substantial and growing research and experience on managed lanes around the nation. These white papers will assess the pros and cons associated with each relevant issue to better enable the regional partners to reach conclusions on the feasibility and specific technical aspects of managed lanes for the Phoenix area.

1.1. Purpose and Methodology

The purpose of this white paper is to summarize policies, procedures, considerations and best practices related to lane separation for priced managed lane facilities. Currently, the Phoenix-area HOV lanes are separated from the adjacent general purpose lane by a painted stripe or buffer only. There are a range of issues that need to be considered as they pertain to the use of painted separation (either as a buffer or a stripe) for priced managed lanes. This white paper briefly investigates these issues with the intent of informing policy decisions for a managed lanes system in the greater Phoenix area.

1.2. Maricopa County HOV Lane Existing Lane Separation

Arizona's experience with HOV lanes began with construction commencing in 1983, and completion of the first operational facility on I-10 in 1988. The lanes were (and continue to be) constructed with a continuous line and/or buffer separation design. The lane separation may be as narrow as a continuous single stripe, or extend almost to 14 ft in width, as shown in Figure 1-1.

Figure 1-1 Sample Lane Separation Treatments on Phoenix-area HOV Lanes

There are three types of access to the HOV lanes in the Phoenix area, based upon the location within the corridors. These access conditions correspond with differential lane separation.

The first pertains to the mainline HOV lanes. In this condition, ADOT maintains a line or buffer separated condition, and permits access at all points. Vehicles may cross the painted buffer, regardless of the width of the buffer at that point, provided such a movement otherwise conforms to moving vehicle guidance and safety requirements.

The remaining two access conditions pertain to direct-access to the HOV lanes from other facilities. Freeway-to-freeway direct connectors provide dedicated HOV access ramps, typically located in the median. The direct connectors allow major freeway-to-freeway movement between HOV lanes without weaving. Direct access ramps (DAR) provide dedicated connections from intersecting arterial streets to the HOV lanes. As with direct connectors, DAR's eliminate weaving between HOV lanes and exit / entrance ramps from these arterials. In the MAG region, these direct-access provisions are collectively referred to as Direct HOV (DHOV) ramps. In both cases, these ramps are constructed with concrete barriers to separate the movements and provide a safe condition to the HOV lane (Figure 1-2).

Figure 1-2 Sample HOV Direct Connectors/Direct Access Ramps in the Phoenix-area

2.0 LANE SEPARATION CONSIDERATIONS

2.1. Lane Separation Options

Three different approaches for separating managed lanes from adjacent general purpose lanes are evaluated in this white paper.

- Painted line / buffer separation (as found on HOV lanes in the Phoenix area and throughout California, and priced managed lanes facilities including I-15 in Salt Lake City and SR-167 in Seattle)
- Traffic channelizer separation (as found on SR-91 in Orange County, California, I-10 in Houston, and I-95 in Miami)
- Barrier separation (as found on I-15 in San Diego and I-25 in Denver)

For purposes of comparison, access is assumed to be restricted for each comparable design, and access frequency is the same. This is an important assumption, as some contemporary managed lanes have adopted continual or near-continual access design for recently implemented facilities (Minneapolis, Salt Lake City) or are considering it (San Francisco/Oakland, Seattle) for implementing new facilities. Furthermore, in a parallel white paper, emphasis is placed on issues surrounding a continuation of Phoenix's continuous access HOV policy for managed lanes. However, for the purpose of comparability across the lane separation options, limited access has been assumed as this approach encompasses the widest array of lane separation techniques.

2.1.1. Painted Line / Buffer Separation

All HOV lanes in Arizona currently exhibit this approach of employing pavement markings to communicate the HOV lane(s) next to adjacent general purpose traffic lanes. Solid single or double white (with chevrons) pavement markings are standard in Arizona. The 2009 Manual on Uniform Traffic Control Devices (MUTCD) updated the pavement markings guidance as they pertain to Line and Buffer Separated managed lanes (including both HOV lanes and priced managed lanes). The guidance is as follows:

- Prohibited access segments consist of double-solid white lines on either side of the buffer and chevron markings if the buffer is wider than 4 feet.

- Discouraged access segments consist of two solid white lines. The MUTCD is silent on the desired width of the discouraged-access segment.

- Permitted (open) access segments should consist of either single or double wide broken lines without buffer.

All three conditions are shown in Figure 2-1 and Figure 2-2 below, followed by examples of line and buffer separation on existing priced managed lane facilities (Figure 2-3).

Figure 2-1 Controlled Access Buffer-Separated Lane Markings (2009 FHWA MUTCD)

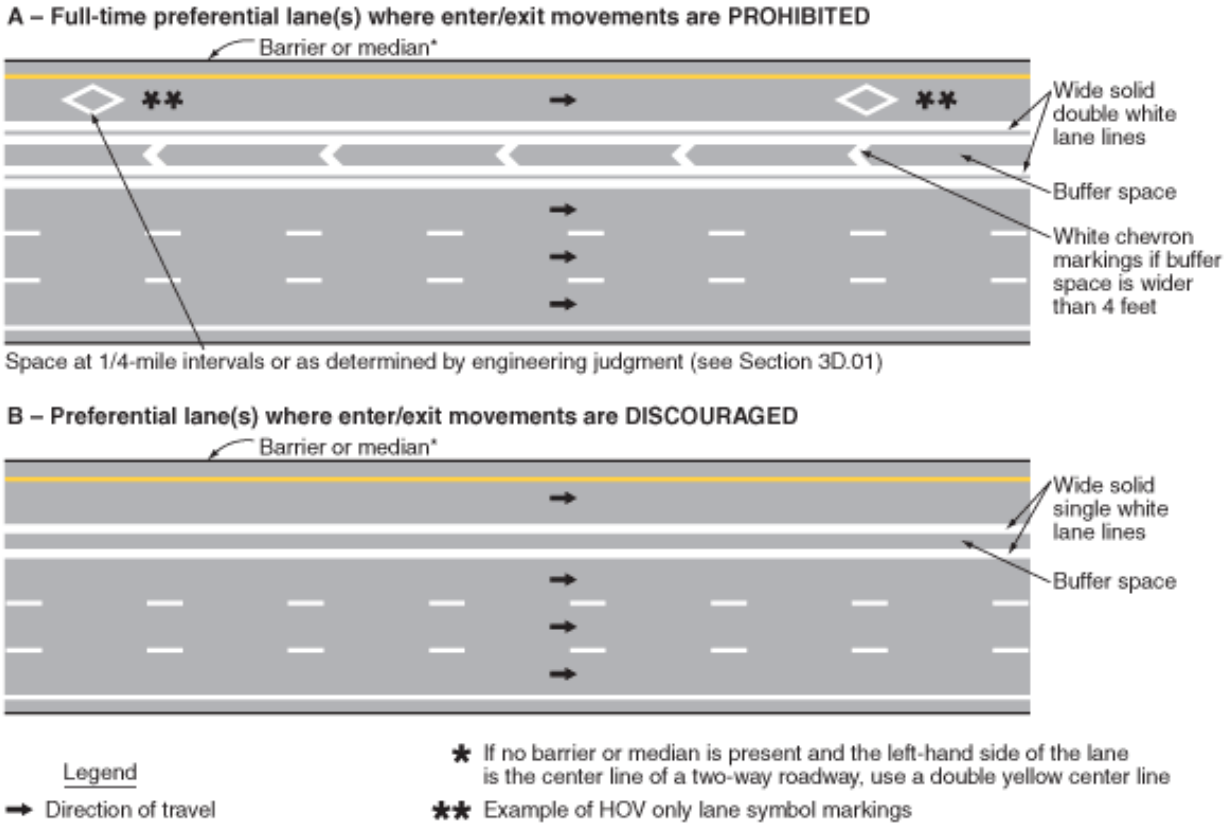


Figure 2-2 Open Access Buffer-Separated Lane Markings (2009 FHWA MUTCD)

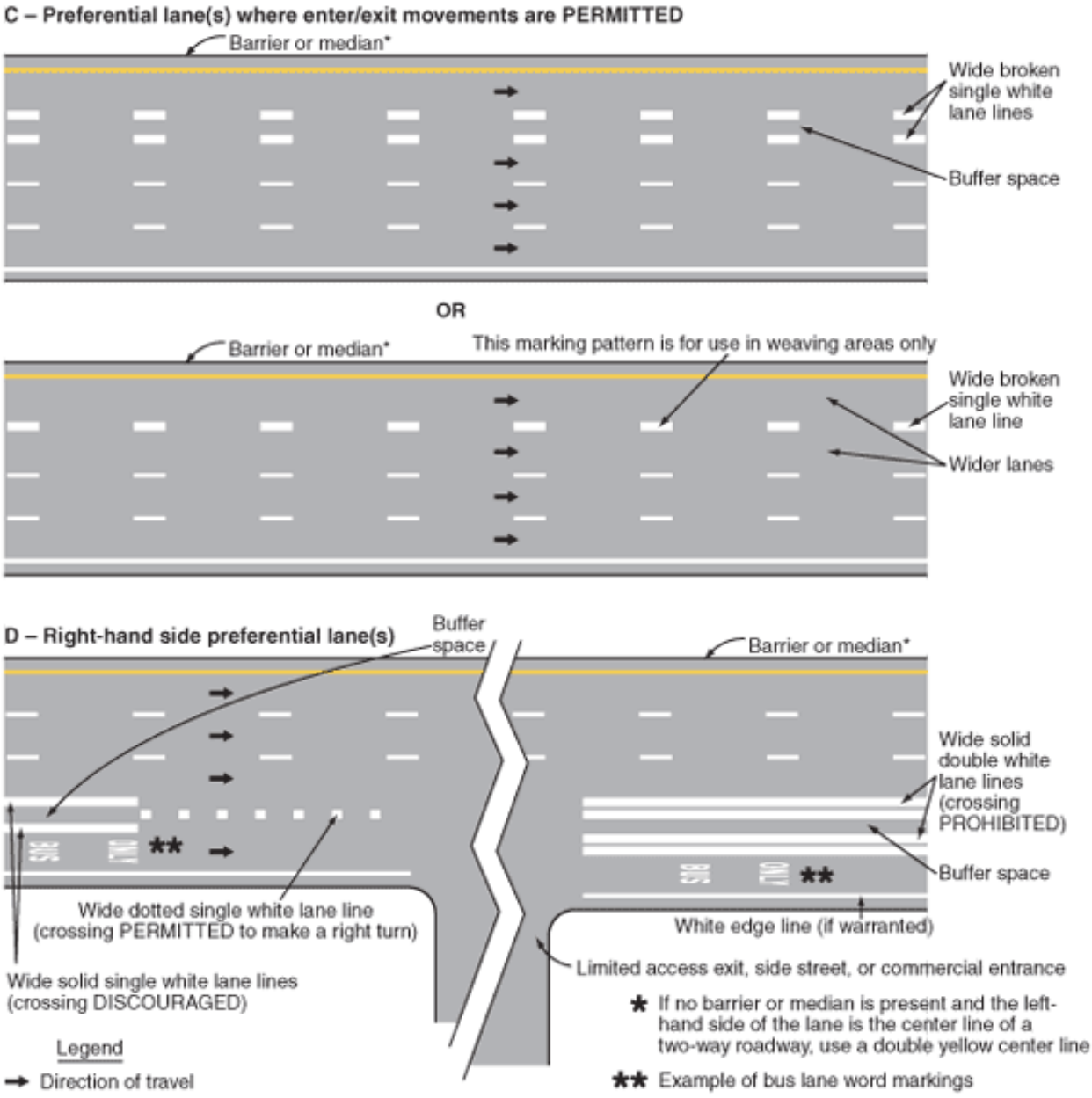


Figure 2-3 Sample Line and Buffer Separated Managed Lanes

SR-167, Seattle, Washington

I-35W, Minneapolis, Minnesota

I-680, Oakland / San Jose, California

I-85, Atlanta, Georgia

It must be noted that the current lane markings for HOV lanes in the MAG region are generally inconsistent with the recently adopted MUTCD guidance, particularly in the context of the current continuous access operating policy. The MUTCD stipulates the use of wide broken lane lines for both single line and buffer (double line) separation of continuous access managed lanes facilities. Current HOV lane markings in the MAG region consist of a single wide solid line or double wide solid line (sometime in conjunction with chevrons) to designate lane separation in a manner consistent with those recommended for "discouraged" movements in the MUTCD.

2.1.2. Traffic Channelizer Separation

To more clearly delineate managed lanes and reduce buffer crossing violations, traffic channelizers can be placed at frequent intervals in the designated buffer area. As per the 2009 MUTCD, channelizers are 42 inches in height; orange, yellow or white in color; nighttime retroreflective; and permanently affixed to the pavement with epoxy or other means. They are typically installed at a frequency of about every 12 feet, and,

centered within the striped buffer area such that installation and replacement will not adversely affect other pavement markings or pavement delineators for buffer areas.

The width of the buffer within which the channelizers are located will have a consequential effect upon friction between the managed lanes and the general purpose lanes. On I-95 in Miami and SR-91 in Orange County, the 2 to 4 foot buffer (split evenly between managed lanes and the general purpose lanes) separates traffic and preserves better speeds in the managed lanes; however, vehicles striking the channelizers or illegal buffer crossings occur occasionally, requiring roughly 1/3 of the channelizers to be replaced on an annual basis. By comparison, the 16-foot buffer on the I-10 facility in Houston (split evenly) provides substantial separation from traffic with minimal strikes or illegal crossings. In essence, the I-10 facility has adopted the footprint of a barrier separated facility, yet implemented it with channelizers and a buffer.

Examples of managed lanes utilizing channelizers are shown in Figure 2-4 below.

Figure 2-4 Sample Traffic Channelizer Separation

SR-91, Orange County, California

I-10, Houston, Texas

I-95, Miami, Florida

2.1.3. Barrier Separation

Barrier separation is preferred where managed lane operation creates oncoming traffic conditions between the managed lanes and adjacent general purpose lanes, such as contra-flow or reversible segments (this condition is neither currently present nor envisioned in the Phoenix area), or where the maximum speed differential is desired between the managed lanes and the general purpose lanes in concurrent flow applications. Barrier separation may be mounted on the pavement (precast units) or cast-in-place. Either approach requires about 2 feet of width for the barrier plus sight distance and drainage space on either side. Typically these requirements are accommodated within the 10-foot emergency breakdown shoulders for both roadways, making the total buffer area about 22 feet for many design settings. The total added width for barrier separation when compared to other approaches is about 13 feet per direction in the typical cross section. Additional width is required for access points, as barrier openings at access locations require attenuation for any barrier ends exposed to oncoming traffic.

Moveable barriers provide an additional level of long-term operational flexibility while maintaining the benefits of cast barriers. These special barriers are most useful for corridors with clearly defined peak directionality, such as that used on I-15 in San Diego, California. However, they also carry ongoing operations and maintenance costs.

Barrier separation may be applied in settings where restrictions limit the ability to provide full shoulders, as is the case on many barrier separated HOV lanes around the country. This carries an additional disadvantage of needing to obtain state and federal design exceptions for non-standard shoulder and lane widths. Logically, lower operational speeds and possible safety concerns could be anticipated in these restricted segments; however, given the limited implementation and short segments, existing research does not demonstrate sufficient evidence to confirm these impacts.

Finally, barrier separation provides managed lanes operators with greater opportunity for system experimentation without degrading operations on the general purpose lanes. Implementing agencies have recently investigated options for differential speed limits (higher speed limits in the managed lanes) and variable vehicle eligibility (truck-only lanes in off-peak periods and/or off-peak directions) for short term implementation on managed lanes facilities. Longer term, other opportunities may be available, including automated highway systems and grid-electrification for transportation energy in the lanes. In all cases, the barrier separation provides additional levels of assurance to the operator that such innovative applications will not have a detrimental effect upon overall corridor operations. Conversely, such experimentation would not be recommended with buffer separation.

Examples of barrier separation treatments are shown in Figure 2-5.

Figure 2-5 Sample Barrier Separated Managed Lanes

Fixed Barrier, I-25, Denver, Colorado

Moveable Barrier, I-15, San Diego, California

2.2. Experience of Other Communities

At present, a dozen priced managed lanes are in operation and as many more will become operational by 2015. National experience indicates that a majority of concurrent flow HOV lanes are separated by either defining lane markings or a narrow buffer. As can be seen in Table 2-1, a variety of separation treatments have been applied to the sample priced managed lanes projects. Whereas earlier managed lanes applications tended towards physical separation in the form of barriers and/or channelizers, contemporary implementations have utilized buffer and striping separation only. This may be indicative of the constrained environment or cost for new capacity in these projects, and should not be construed as an industry preference.

Various HOV design guides dating from the late 1980s, including the Guide for High Occupancy Vehicle (HOV) Facilities (AASHTO, 2004), have endorsed barrier separation for high volume preferential lanes. Physical separation defined in these guides takes the form of concrete barriers on freeways, which is required for reversible lanes and highly preferred for contra-flow lanes (in the form of moveable barriers). Neither reversible nor contraflow conditions apply to the HOV concepts currently envisioned for the Phoenix area. AASHTO contends that barrier-separation is considered optional for concurrent-flow lane treatments, although limited safety data has been available to support guidance recommendations.

For facilities not incorporating barrier separation, the reasons often cited included:

- Most HOV lane treatments were retrofitted into constrained urban freeway corridors, where the ability to accommodate barrier separation would have resulted in acquisition of new right-of-way (often with community or environmental impacts) and cost prohibitive design. Managed lanes do not alter this dynamic.
- Access through barriers is seen by some police and emergency response agencies as too constraining in the event of a major incident within the managed lanes.

Table 2-1 Lane Separation Use on Priced Managed Lanes

Project	Operation	Access	Tolling	Separation	Sep Width (Ft)
SR-91 (CA)	2 lanes each direction	Single entry / exit at each end	One zone only, with HOV declaration lane	Channelizers	2 to 4
I-15 (CA)	Reversible lanes; varies 2-2 or 3-1	Limited access, with transition lane at ingress/egress	Toll zones between access locations	Barrier (moveable)	22
US-290 (TX)	1 lane reversible	Only through DARs	Fixed price, only one toll zone	Barrier	8
I-10 (TX)	2 lanes each direction	Limited access, with transition lane	Toll zones between access locations with HOV declaration lane	Channelizers	14
I-15 (UT)	1 concurrent lane each direction	Frequent (2-mile spacing) and long (3000-9000 ft) weave access zones.	Toll zones between access locations (no declaration)	Single- and double-solid line	4
I-25 (CO)	2 lanes reversible	DARs at entry / exit and 1 intermediate	One tolling zone with HOV declaration lane	Barrier	22
I-394 (MN)	1 concurrent lane in each direction; 2 reversible lanes	Frequent (1.5-mile spacing) weave; DAR's at entry / exit for reversible section	Toll zones between access locations	Double-solid line (concurrent); Barrier (reversible)	2 (line); 12 (barrier)
I-35W (MN)	1 concurrent lane in each direction	Continuous access for 70% of lane mileage	Toll zones located every 2 – 3 miles	Skip-stripe line	None
SR-167 (WA)	1 concurrent lane each direction	Frequent (2-mile spacing) weave access zones	Toll zones between access locations	Double-solid line	2
I-95 (FL)	2 lanes in each direction	DAR's at entry / exit, 2 intermediary transition ramps	One tolling zone	Channelizers	2
I-680 (CA)	1 concurrent lane (uni-direction)	Limited access, with transition lane at ingress / egress	Toll zones between access locations	Buffer	4
I-85 (GA)	1 concurrent lane each direction	Infrequent (3-mile spacing) weave access zones	Toll zones between access locations	Double-solid line	2

- Approximately 40 percent of all HOV projects operate part-time, becoming general purpose lanes in off-peak periods (as is currently the case for facilities in the Phoenix area). Many managed lanes projects also operate part-time, as established by policy. Placing these lanes behind barriers creates motorist confusion and can lead to a higher crash rate at entrance locations. Generally, practitioners pursue barriers where the preferential lane or roadway is intended to operate full time.

- Placement of barriers restricts access and the ability to easily change or alter access leading some agencies to conclude that future operational flexibility may be lost when applying barriers.

Nearly all of Phoenix's concurrent flow HOV lanes are separated by narrow designated buffers or with a single solid line. Exceptions include segments associated with DHOV treatments where barrier separation is utilized. Very few national examples of barrier-separated concurrent flow projects exist, and where found, they are generally implemented as a result of elevated ramp alignments or lanes not located in roadway medians (like the DHOV treatments in the MAG region). Isolated portions of the I-5 HOV lanes in Orange County, California, are separated by concrete barrier in an at-grade environment. This configuration comprises less than one percent of all national HOV lane mileage and less than three percent of all national concurrent-flow mileage. Besides consideration as an alternative option for proposed managed lanes on I-5 in San Diego County, no new barrier separated concurrent-flow managed lane treatments are being planned or implemented in the United States.

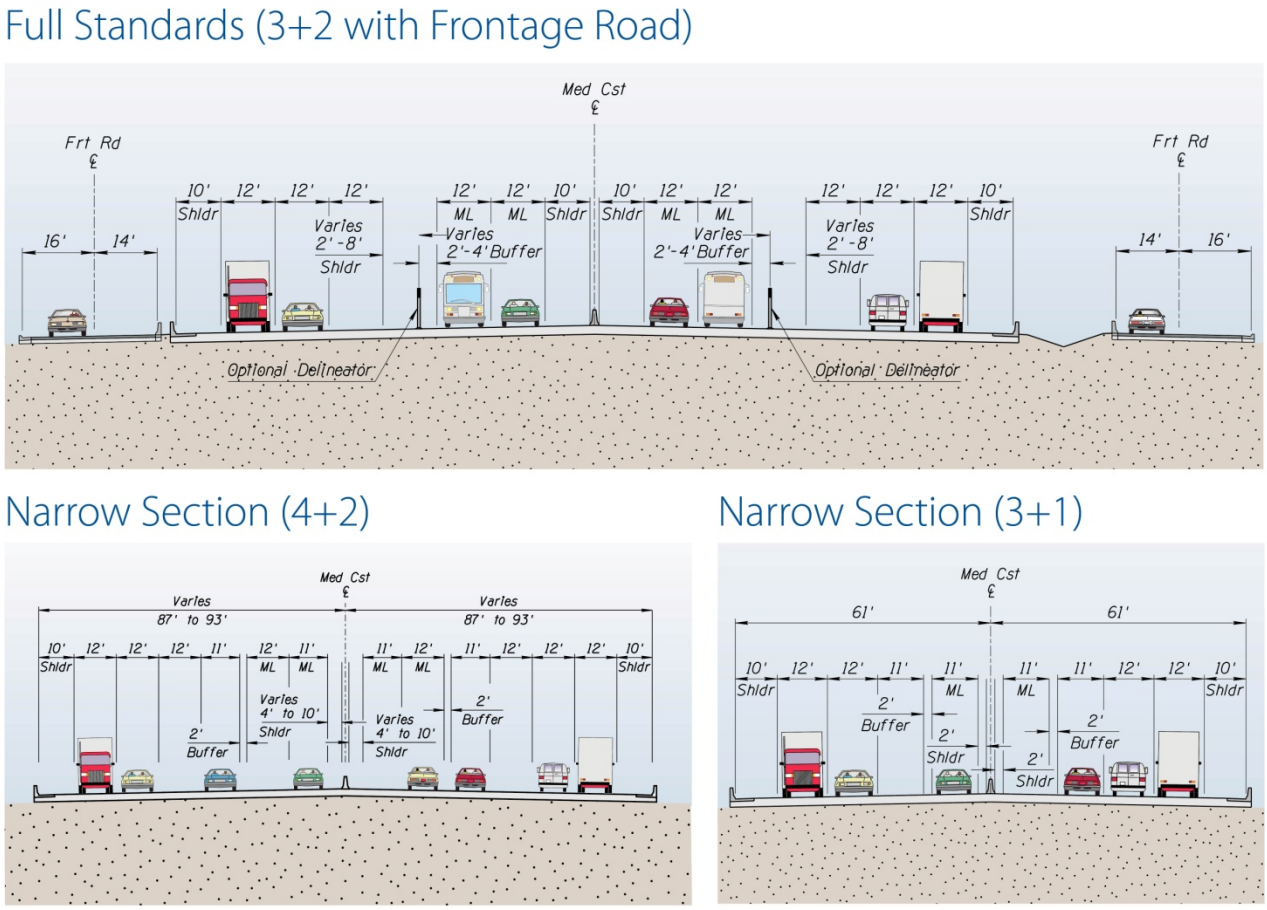
Table 2-2 Example Lane Configurations for Priced Managed Lanes

Project	Operation
I-15 San Diego	(2+2 Configuration) 10' Shoulder | Barrier | 10' Shoulder | 14' ML | 13' ML | Moveable Barrier | 13' ML | 14' ML | 10' Shoulder | Barrier | 10' Shoulder (3+1 Configuration) 10' Shoulder | Barrier | 10' Shoulder | 13' ML | Moveable Barrier | 13' ML | 14' ML | 14' ML | 10' Shoulder | Barrier | 10' Shoulder
SR 91, Orange County	2 to 4' Buffer with Channelizers | 12' ML | 12' ML | 10' Shoulder | Barrier | 10' Shoulder -| 12' ML | 12' ML | 4' Buffer with Channelizers
I-15, Salt Lake City	4' Buffer | 12' ML | 10' Shoulder | Barrier | 10' Shoulder | 12' ML | 4' Buffer
US 290, Houston	2' Shoulder | Barrier | 4' Shoulder | 12' reversible ML | 4' Shoulder | Barrier | 2' Shoulder
I-10, Houston (reconstruction)	14' Buffer with Channelizers | 12' ML | 12' ML | 10' Shoulder | Barrier | 10' Shoulder | 12' ML | 12' ML | 14' Buffer with Channelizers
I-394, Minnesota	(Reversible Configuration) Barrier | 10' Shoulder | 12' ML | 12' ML | 10' Shoulder | Barrier (Concurrent Flow Configuration) 2' Buffer | 12' ML | 10' Shoulder | Barrier | 10' Shoulder | 12' ML | 2' Buffer
I-35W, Minnesota	(Northbound direction only) 10' Shoulder | Barrier | 14' Priced Dynamic Shoulder Lane
SR 167, Seattle	2' Buffer | 12' ML | 10' Shoulder | Barrier | 10' Shoulder | 12' ML | 2' Buffer
I-95, Miami	2' Buffer with Channelizers | 12' ML | 12' ML | 4' Shoulder | Barrier | 4' Shoulder | 12' ML | 12' ML | 2' Buffer with Channelizers
I-680, Alameda County	(Southbound direction only) 4' Buffer | 12' ML | 14' Shoulder | Barrier | 14' Shoulder

*Width in feet from edge of GP lanes in one direction to edge of general purpose (GP) lanes in the other direction, inclusive of shoulders, offsets, barrier (B=2 ft.) and number of managed lanes (ML).

Figure 2-6 illustrates several typical cross sections for priced managed lanes facilities. The examples illustrated demonstrate various buffer configurations, including a full standard design that indicates option channelizers. The full standard configuration is also consistent with a barrier separated design whereby the separation barrier replaces the optional channelizers in the buffer as shown in the cross section.

Figure 2-6 Typical Managed Lanes Cross-Sections



2.3. Lane Separation Options

There are advantages and disadvantages associated with the three primary lane separation options for managed lanes facilities. For a managed lanes network in Maricopa County where HOV lanes currently operate with line / buffer separation and continuous access, there are several issues to consider when assessing whether to maintain such separation. These are summarized in Table 2-3 below.

Table 2-3 Policy Options for Managed Lane Access Treatments

Option	Pros	Cons	Experience
Barrier Separation	• Reduced toll zones • Reduces manual enforcement coverage • Speed control • Higher vehicle throughput • Variation in roadway profiles	• High cost / more right of way • Emergency access constrained • Potential loss of flexibility • Increased infrastructure maintenance	• I-15 (San Diego) • I-25 (Denver) • US-290 (Houston)
Traffic Channelizers	• Adaptation of current design • Discourages weaving / toll avoidance • Moderate cost • Higher speed differential permitted • Emergency access	• Higher maintenance cost than line / buffer • Higher manual enforcement costs • Speeds affected by adjacent general purpose traffic • Greater revenue leakage than barrier	• SR-91 (Orange County) • I-10 (Houston) • I-95 (Miami)
Buffer / Line Paint Separation	• Maintains existing design • Lowest cost • Flexibility to adapt • Emergency access provision • Diversion opportunity • May accommodate second managed lane with restriping	• Greatest revenue leakage • Highest manual enforcement costs • Lowest speed differential • Requires more frequent toll zones to reduce weaving / avoidance	• Phoenix area HOV • I-35W (Minneapolis) • I-394 (Minneapolis) • I-680 (Alameda County) • I-15 (Salt Lake City) • SR-167 (Seattle)

3.0 ISSUES INFLUENCING LANE SEPARATION

This section examines identified issues affecting the potential for different lane separation treatments on priced managed lanes.

3.1. Safety

The degree of safety associated with different types of lane separation involves many factors including the mix and density of traffic in both the managed lanes and the general purpose traffic streams; specific roadway geometrics; number of access locations and their respective attributes; climate; bottleneck characteristics along the corridor; and related factors. While localized safety studies have been performed periodically on some HOV projects around the U.S., no national study has been undertaken, and no database exists from which specific causal factors associated with separation treatments could be isolated. Further, many states do not have accident forms that code crashes specific to the managed lanes, so only generalized inferences may be made to overall safety findings in this analysis. Various anecdotal observations can be drawn from prior localized safety studies, the most recent ones involving the application of restricted access settings for concurrent flow HOV lanes with buffer separation in California and Texas.

These observations include the following:

- Barrier separation is safer than non-separated alternatives, all other factors being equal. Crash rates for reversible lanes, for example, are generally lower than for concurrent buffer-separated projects. But the frequency of access, typically lower for reversible and contra-flow lanes, plays a role in this comparison.

- For concurrent barrier-separated treatments, crashes tend to be higher at the access points into the HOV lanes where attenuators are located.

- Channelizers can help to reduce crashes due to intentional buffer crossing, but do not affect crashes that otherwise occur in one of the traffic streams and go into the other. The majority of these seem to be related to excessive speed in the general purpose lanes and diverting to avoid rear-end crashes. The width of a buffer can lower this incidence. The leftmost general purpose lane is the one most affected by a higher incidence of crashes.

- Crashes for buffer separated treatments can be lower if the buffer is sufficiently wide enough to address typical diversionary movements in stopped traffic lanes. This observation suggests that a four foot buffer is better than a one or two-foot buffer, and a wider buffer may be appropriate if channelizers are applied in the center of the buffer area, but the buffer area should not be wide enough to serve as a refuge for stalled or disabled vehicles.

- For all approaches, crashes and severity of crashes are influenced by the length and location of designated access treatments and the speed and density of traffic in each traffic stream. The greater the typical speed differential and difficulty in making the weave into or out of the managed lane, the greater the

crash rate and degree of severity per incidence, based on Dallas crash data in HOV lanes. The introduction of transition lanes between the traffic streams (as discussed in the Access Treatments White Paper) can address this situation, provided queue storage is designed to accommodate demand.

- Crash rates can be higher if no inside shoulder is provided next to the managed lane, as there is less opportunity to take diversionary action to avoid stopped or slowed traffic. Similarly, a single lane setting poses greater risk to such incidents than multiple lane treatments.

Another aspect of safety is the ability to maintain the separation treatment during traffic operation. Maintenance of traffic control devices, particularly traffic channelizers, is a potential major issue since the replacement of these devices will occur at a much greater frequency than signing or pavement marking maintenance due to the susceptibility to displacement or damage of the available products. Experience on SR-91 and other facilities using channelizers suggest that an annual replacement (or more often) of individual channelizers may be required. In 2010, OCTA budgeted for replacement of two-thirds of all channelizers each year at a cost of $45 each. The ability to replace channelizers typically requires closing one active lane on one or both sides of the buffer area. This activity, which may be slated for weekend or nighttime hours, still exposes maintenance workers to a greater degree of hazard than would be prevalent for other separation treatments. The level of maintenance and safety exposure may be similar for any type of channelizer treatment, whether they be individually placed or installed on a mountable curb. However, the time required for replacement may vary and be more favorable for one product than another.

3.2. Traffic and HOT Lane Operations

The operational benefits and throughput associated with managed lanes vary by the type of physical separation and the number of lanes. Simply put, a single lane's operational capacity is regulated by the slowest moving vehicle in a stream, while a multiple lane treatment can allow for different vehicle performance and thus, support a higher traffic density. The Highway Capacity Manual provides a basis for this characteristic between capacities associated with a single directional lane on a highway and a freeway providing multiple directional lanes.

Operational experience of managed lanes is largely based on a single lane setting, since more than 85 percent of all projects fit this design condition. Operational audits of various systems provide a good indication of the level of throughput that can be anticipated for single and multiple lane designs and an approximate level of throughput associated with each.

The typical goal of a managed lane is to provide travel time savings and travel time reliability to eligible vehicles. Requirements must be established at an operating level that will sustain benefits to the largest number of users without creating too much demand to make the lane congested. The maximum threshold should be Level-of-Service (LOS) D or better, based on the vehicle mix. In most cases this value is assumed to be about 1,600 to 1,800 vehicles/hour/lane for a high-design, multiple lane facility.

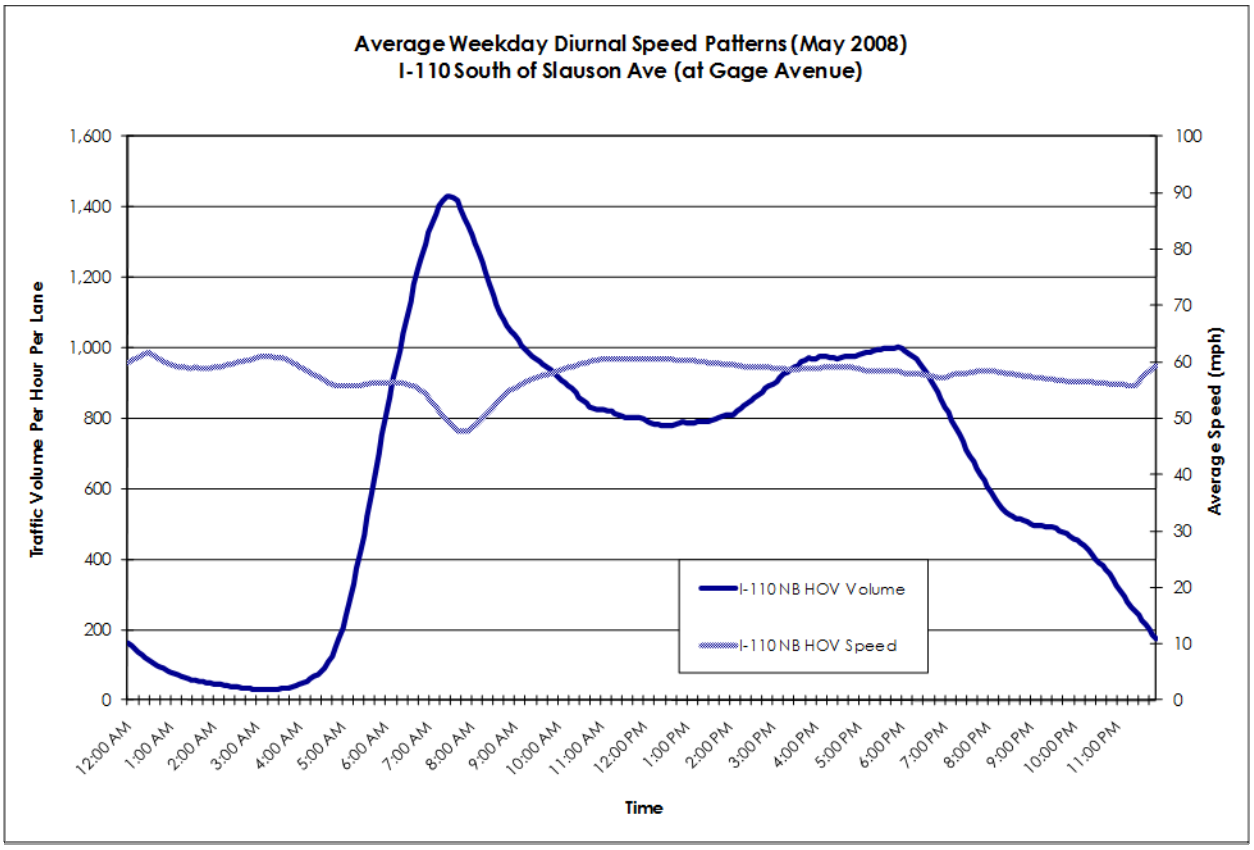
Table 3-1 presents a set of maximum thresholds for different freeway managed lane treatments for both managed demand and comparable forced flow "capacity" conditions. To provide travel benefits, the facility should apply the managed flow values.

Table 3-1 Maximum Volume Thresholds for Managed Lane Treatments

Facility Type	Maximum Managed Flow (vplph)	Maximum Capacity Forced Flow (vplph)
Barrier separated-single lane	1,600-1,650	1,800-1,850
Barrier separated-multiple lane	1,700-1,800	2,000-2,200
Barrier separated reversible-single lane	1,500	1,800-1,850
Barrier separated reversible-multiple lane	1,700-1,800	2,000 (controlled by access)
Concurrent-flow (non-separated)-single lane	1,600-1,650	1,800-1,850
Concurrent-flow (non-separated)-multiple lane	1,700-1,800	2,000
Contra-flow (single lane borrowed in off-peak direction separated by moveable barrier)	800-1,500	1,800

It should be noted that recent evaluation as part of the Los Angeles ExpressLanes project indicates that travel speeds in HOV lanes can fall below 45 mph when traffic flow rates exceed 1,400 to 1,500 vehicles per lane per hour, even on multiple lane facilities. Figure 3-1 illustrates the relationship between traffic flows and travel speeds in the HOV lanes on I-110. As can be seen in the exhibit, as flow rates exceed 1,400 during the AM peak period, corresponding travel speeds start to fall below 50 mph. This finding indicates that the maximum operational capacity in HOV lanes may be slightly below the thresholds described in Table 3-1, particularly where minimum operating speeds of 45 mph need to be preserved in accordance with existing Federal and State statutes.

Figure 3-1 Daily Traffic Flows and Speeds in the I-110 HOV Express Lanes, Los Angeles



The operation thresholds for managed lanes are approximately the same as those for HOV lanes. Ingress/egress and tolling sites can affect level of service in the same way access locations affect HOV lanes. More importantly, operational reliability and travel benefits are affected by the different design treatments, and these important attributes are not reflected in the throughput values. For example, national and local observations suggest that the observed speed differential between parallel traffic streams negatively impacts buffer and channelizer separated treatments, while barrier treatments show little speed relationship regardless of the differential. This is because motorists often drive defensively when confronted with a stopped line of traffic next to the managed lane.

The observed speed differential for buffer-separated lanes seldom exceeds 20 to 25 mph nationally. It means that regardless of the posted speed, a single-lane traffic stream in a managed lane will average about 45 mph if the adjacent lanes are averaging 20 to 25 mph, which is common in many Phoenix corridors at peak hour. These speeds will be somewhat higher for multi-lane treatments and for projects with channelizers, if these were to be implemented. On the other hand, reversible lanes like I-25 in Denver, I-15 in San Diego and US-290 in Houston exhibit virtually no reductions based on adjacent traffic conditions aside from major crash 'rubber-necking', suggesting that barrier treatments offer motorists greater confidence that an incident in adjacent lanes will not affect them.

3.3. Enforcement

Managed lanes require effective enforcement policies and programs to operate successfully. Enforcement of vehicle occupancy requirements is critical to protecting eligible vehicles' travel time savings and safety. Visible and effective enforcement promotes fairness and maintains the integrity of the facility to help gain acceptance among users and nonusers.

As more managed lanes emerge that cater to a wider array of users through pricing, enforcement is made more complicated. Among the greatest challenges in implementing a priced managed lane is determining who is a qualified carpooler; that is, who receives free or reduced pricing for travel on the facility. For priced lanes, persistent violation problems can breed disrespect for enforcement and result in a significant loss of revenue and over-utilization of the available capacity leading to degradation of the traffic flow. The consequences of unchecked violators resulting from enforcement challenges affect not only mobility but also revenue.

To date, violation rates differ substantially across priced managed lanes – from as little as 1 to 2 percent to over 10 percent, as estimated by project operators. Extending the findings beyond priced managed lanes to all managed lanes (including HOV lanes), it should be noted that violation rates have significant variability, based upon how violations are estimated, the levels of enforcement applied in order to reduce violations, HOV operating policy, and accompanying activities and strategies which may affect the violation rate. Given these caveats on the use of the reported violation rates for these facilities, buffer separated facilities have higher violation rates than barrier separated facilities on operational facilities. Given the ease of travel across the buffer, these facilities are generally considered harder to enforce and easier for single occupant vehicles to abuse. By comparison, the presence of physical barriers prevents ingress / egress for violators upstream of enforcement locations. It should be noted, however, that of the established barrier separated facilities with low violation rates, two of the three facilities have pay-by-mail systems and/or mandatory transponders for all users. As a result of these policies, those who actually count as a "violator" is relatively low, potentially due to policy and not separation. These policies will influence how effective an enforcement system is for any priced managed lane, and as a result, makes enforcement comparisons inconclusive across different separation types.

3.4. Emergency Access

Emergency access to any managed lane treatment is critical in providing a means of quickly responding and clearing any disruptions, since preferential lane travel benefits may be jeopardized. This issue has long been a concern for reversible and contra-flow HOV lanes operated on freeways where concrete barriers are required to separate oncoming traffic conditions. On reversible lanes, permanently placed barriers separate operation, while on contra-flow lanes which borrow an off-peak direction lane for selected hours, a moveable barrier is applied. With few concurrent barrier-separated projects in operation, this issue has less frequently been raised. Managed lanes operating without barriers pose less of a problem for emergency access, as emergency vehicles can easily negotiate crossing over channelizers or a painted buffer. Therefore,

this discussion primarily is focused on emergency access for barrier-separated lane treatments.

The following criteria often frame the need for emergency access treatment:

- Event frequency: How often will disruptions likely occur based on anticipated managed lane volumes and how many of these are likely to be significant?
- Response time: What is the minimum time required to access an incident or crash site?
- Available access options: Are there other ways of accessing the managed lanes other than across the barrier, such as direct access locations?
- Roadway geometrics: What is the managed lane typical section including buffers and shoulders? Is there a means of bypassing a stalled vehicle such that emergency access is only needed to access crash sites?
- Cost: What is the level of investment appropriate for emergency access treatment?

4.0 CONCLUSIONS

There are three main approaches for separating managed lanes from adjacent general purpose lanes:

- Painted Line / Buffer Separation, as currently featured on the Phoenix area HOV system
- Traffic Channelizer Separation
- Barrier Separation

Most current managed lanes projects reflect concurrent flow lanes and are typically separated by painted buffers or traffic channelizers (e.g. Phoenix HOV lanes with pavement separation markings, and channelizers for the SR-91 Express Lanes in Orange County). Conversely, all of the current managed lane projects featuring contra-flow and reversible flow lanes are separated by concrete barrier (e.g. San Diego County's I-15 Express Lanes). Very few examples of barrier-separated concurrent flow projects exist, and where found, are generally implemented as a result of elevated ramp alignments or lanes not located in roadway medians. Besides the consideration for the proposed I-5 managed lanes in San Diego County, no new barrier separated concurrent-flow managed lane treatments are being planned or implemented in the United States.

The degree of safety associated with different types of lane separation involves many factors including the mix and density of traffic in the managed lanes facility and the general purpose lanes, specific roadway geometrics, number of access locations and their respective attributes, climate, bottleneck characteristics along the corridor and related factors. While localized safety studies have been performed periodically on some HOV projects around the U.S., no national study has been undertaken, and no database exists that could isolate specific causal factors associated with separation treatments. Further, many states do not have accident forms that code crashes specific to the HOV or managed lane, so only generalized inferences may be made to overall safety findings in this analysis. That being said, it is the consensus of the research literature that barrier separation is safer than buffer separation, all other factors being equal, but it must be emphasized that both methods of separation, buffer and barrier, are safe, approved, time tested methods of separation, for concurrent flow lane applications, by FHWA and all of the Departments of Transportation across the United States.

The other factors involved in determining the preferred type of separation for Phoenix-area managed lane system would include the differences in initial construction and maintenance costs, emergency access, managed lane operational efficiencies, deterrence to toll violations, potential right-of-way, community and environmental impacts, and finally the total present value cost for each alternative.

Table 4-1 is a summary of the prospective pros and cons of each type of separation:

Table 4-1 Summary of Lane Separation Options

Alternative	Initial Construct Cost	Annual Maintenance Cost	Emergency Access	Speed Differential	Inhibit Toll Violations	Right of Way Required
Painted Line	Lowest	Low	No Constraint	HOT Lane Speeds Reduced	Very Low	Very Low
Painted Buffer	Low	Low	No Constraint	HOT Lane Speeds Reduced	Low	Low
Traffic Channelizer	Moderate	High	Little Constraint	HOV / Managed Lanes Speeds Slightly Reduced	Moderate	Low
Barrier	Highest	Low	Constrained	HOT Lane Speeds Unencumbered	Prohibits Completely	Very High
Non-Standard Barrier	High	Low	Constrained	HOT Lane Speeds Unencumbered	Prohibits Completely	Moderate
Moveable Barrier	High	High	Constrained	HOT Lane Speeds Unencumbered	Prohibits Completely	High

For the MAG region, a continuation of the current HOV lane separation techniques is generally recommended in conjunction with the implementation of managed lanes. This approach would continue to primarily utilize a combination of painted line and painted buffer lane separation. Barrier separation would continue to be the preferred separation technique where elevated segments (including DHOV) or contraflow traffic conditions are involved.

It is recommended that ADOT begin the process of modifying the existing HOV lane marking to reflect the recently adopted provisions of the MUTCD. Specific modifications involve the use of wide broken striping to designate continuous access, as illustrated previously in Figure 2-2. Modifying lane marking to be consistent with MUTCD will be critical to ensure limited access can be clearly demarked and enforced should managed lanes implementation in the region result in the use of near-continuous or limited access treatments. Similarly, ensuring lane markings reflect MUTCD requirements will ensure managed lanes facilities in the MAG region and consistent with applications elsewhere in the nation.