Managed Lanes Network Development Strategy – Phase I

Managed Lane Access Treatment

MARICOPA ASSOCIATION OF GOVERNMENTS

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TABLE OF CONTENTS

1.0 Background 1

1.1. Purpose and Methodology 1

1.2. Maricopa County HOV Lane Existing Access Treatment 1

2.0 Access Considerations 3

2.1. National Trends 3

2.2. Experience of Other Communities 4

2.3. Findings Pertinent to the Phoenix Area 9

2.4. Access Policy Options 9

3.0 Issues Influencing Continuous Access 11

3.1. Operational Performance 11

3.1.1. Driver Interaction 11

3.1.2. Operational Safety 12

3.1.3. Speed Differential 13

3.1.4. Consistency of Practice 13

3.1.5. Ability to Manage HOT Lane Operations 13

3.1.6. Pricing Strategy 14

3.2. Design Needs 14

3.3. Tolling and Enforcement System Needs 15

3.4. Enforcement Needs and Preferences 17

4.0 Conclusions 18

List of Figures and Tables

Figure 1-1 Sample Lane Separation Treatments on Phoenix-area HOV Lanes 2

Figure 1-2 Sample DHOV Ramps in the Phoenix-area 2

Figure 2-1 Sample Transition and Weave Lanes 6

Figure 2-2 Sample Near-Continuous Access Managed Lanes 7

Figure 2-3 Typical Managed Lanes Merge and Weave Lane Options for Limited Access Facilities 8

Table 2-1 Access Applications in Use on Priced Managed Lanes 5

Table 2-2 Policy Options for Managed Lane Access Treatments 10

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 access treatment for managed lane facilities. There are a range of issues that need to be considered as they pertain to the Phoenix-area's existing continuous access treatment for the region's HOV 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 Access Treatment

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 1-1-1.

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.

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

The remaining two 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, thus positively affecting operations across all lanes of travel at these interchanges. 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, the construction of these access ramps may be costly, but the operational benefits can be significant at key locations (Figure 1-2).

Figure 1-2 Sample DHOV Ramps in the Phoenix-area

2.0 ACCESS CONSIDERATIONS

2.1. National Trends

The state-of-the-practice in priced managed lanes originally focused on projects that were physically separated from adjacent lanes and employed a single location for electronic toll collection, such as I-15 in San Diego and SR-91 in Orange County, CA. Since 2005, Minneapolis, Seattle, Salt Lake City, and San Jose areas have implemented priced managed lanes that track customers via electronic transponders at multiple locations and employ toll zones without physical separation. Initially, access for these projects had been restricted to designated locations, often referred to as ingress/egress zones. Most of these zones have allowed both ingress and egress movements, while some encourage only one type of movement. This was the case for I-394 (Minneapolis), I-680 (San Jose), and SR-167 (Seattle). However, over the past two years, I-35W (Minneapolis) and I-15 (Salt Lake City) have operated priced managed lanes with extended ingress / egress locations. Although not entirely continuous access, I-35W approaches such a facility with seventy percent of its lane mileage unrestricted by access.

As priced managed lane studies around the country looked at access and lane separation treatments, which go hand-in-hand with one another, few have been able to provide all of the prescribed design features requested by partnering agencies at access points between managed and general purpose lanes. In particular, despite recommendation for safety and operational efficiency, designing for separate ingress and egress movements at defined access zones has not been found to be uniformly feasible from a design or cost perspective. For many networks where managed lanes are considered, the only economically feasible means for moving individual corridor projects forward are limited to three primary options, each of which has its own advantages and disadvantages:

- Not implementing priced managed lanes. This reduces the ability to manage travel demand, degrades system performance and eliminates the potential for revenue generation. New traffic bottlenecks may be created where managed lanes terminate and traffic is forced to merge back into existing lanes.

- Implementing priced managed lanes without any access for long distances. This eliminates access to congestion-free travel for potential users in the affected zones and may create equity concerns.

- Allowing continuous access between priced managed lanes and adjacent general purpose lanes. This is the current practice for HOV lanes in the Phoenix area. Adopting continuous access design creates a need for investment in tolling and toll enforcement systems infrastructure to a greater extent than limited access design.

Each of these access options, even if applied in isolated segments, exhibits distinct advantages and drawbacks.

The greatest benefits from a priced managed lane network, in terms of both performance and revenue generation, occur when an uninterrupted system is afforded. If discontinuities occur in the system, traffic bottlenecks may be created where managed lanes traffic is forced to merge back into the general purpose lanes. Where a managed lane reverts to an HOV lane, single occupant vehicles are forced to exit back into the general purpose lanes also potentially creating a bottleneck.

Limiting access for long stretches without any means of restricting such access or inadequate enforcement invites violations and erratic movements. This situation may also create an environmental justice issue where some commuters are allowed managed lane access while others in the affected zones are not.

2.2. Experience of Other Communities

At present, twelve priced managed lanes are in operation and about as many more will become operational by 2015. Table 2-1 summarizes these current projects. HOT lanes allow free use by HOVs with the requisite number of minimum persons without the need for transponders, while Express Toll Lanes (ETL) are essentially toll lanes and do not provide a pricing preference to HOVs. Current projects provide the following relevant access experience.

A wide variety of access concepts have been tested, and to date, all seem to work in a manner considered safe by local project sponsors and operators. Some projects have had to be modified to reach a condition that was considered safe. For example, the Utah DOT extended the access zones on I-15 from 1,000 to 3,000 feet, in order to reduce the impacts of weaving. Florida DOT converted the previously continuous access HOV lanes on I-95 to limited access, narrowed I-95's buffer and added channelizers in order to prevent lane changes and erratic movements. Finally, Minnesota DOT has utilized three different access concepts – reversible with barrier separation and DHOV, weave access with buffer separation, and continuous access. However, Minnesota DOT's experience with continuous access has been sufficiently positive that this is currently the preferred access design for their upcoming facilities on I-94, I-35W North, and I-35E North. It should be noted that no project has had to be closed because it could not be mitigated to meet safety concerns.

Despite Minnesota's experience, a majority of projects currently utilize some form of hard or soft barrier to separate toll operations from adjacent free lanes. In part, separation for reversible lanes in Minneapolis, Houston, San Diego and Denver was dictated by the intended operation in which concrete barriers were required to prevent wrong way movements, and this design was already present prior to augmenting the project with pricing. The project's prior design influenced access for these treatments. For example, reversible lanes typically do not have any unprotected at-grade access openings with adjacent lanes, appropriately relying on barrier channelization and DHOV access to fully control and prevent wrong way movements. These experiences are relevant to the Phoenix area only in the context of the regions existing DHOV ramps.

Table 2-1 Access Applications in Use on Priced Managed Lanes

Project	Operation	Access	Tolling	Separation
SR-91 (CA)	2 lanes each direction	HOV lane transition at entry / exit	One zone only, with declaration lane for HOV	Channelizers
I-15 (CA)	2 reversible lanes original; convertible extension to 2-2 or 3-1	Limited access, with transition lane in-between ingress / egress	Toll zones between access locations (former declaration lane not used)	Barrier
US-290 (TX)	1 lane reversible	Only through DHOV	Fixed price, only one toll zone	Barrier
I-10 (TX)	2 lanes each direction	Limited access, with transition lane in-between ingress / egress	Toll zones between access locations with declaration lanes for HOV	Channelizers
I-15 (UT)	1 concurrent lane each direction	Frequent (2-mile spacing) and long (3000-9000 ft) weave access zones. Used to be continuous access for HOV only	Toll zones between access locations (no declaration)	Single- and double-solid line
I-25 (CO)	2 lanes reversible	DHOV at entry / exit and 1 intermediate	One tolling zone with declaration lane for HOV	Barrier
I-394 (MN)	1 concurrent lane in each direction, 2 reversible lanes for 3 miles	Frequent (1.5-mile spacing) weave access zones; DHOV at entry / exit for reversible section	Toll zones between access locations	Double-solid line (concurrent); Barrier (reversible)
I-35W (MN)	1 concurrent lane in each direction	Continuous access for 70% of lane mileage	Toll zones located every 2 – 3 miles	Skip-pattern line
SR-167 (WA)	1 concurrent lane each direction	Frequent (2-mile spacing) weave access zones	Toll zones between access locations	Double-solid line
I-95 (FL)	2 lanes in each direction	HOV lane transition at entry / exit, 2 intermediary transition ramps	One tolling zone	Channelizers
I-680 (CA)	1 concurrent lane (uni-direction)	Limited access, with transition lane in-between ingress / egress	Toll zones between access locations	Buffer
I-85 (GA)	1 concurrent lane each direction	Infrequent (3-mile spacing) weave access zones	Toll zones between access locations	Double-solid line

Other selected projects from this list feature concurrent flow designs applying a single dedicated lane in each direction. They have access design and operational attributes which reflect two slightly different philosophies.

- ***Limited access***. Limited access designs typically feature a break in the pavement marking where access is permitted. A continuous solid pavement marking or two markings delineating a buffer area are applied. The solid stripe(s) revert to a single or dual skip-stripe where access is permitted. Neither concurrent-flow single lane projects in Minneapolis or Seattle employ transition lanes in the access zone (Figure 2-1A); however, the San Jose area I-680 managed lane does utilize transition lanes (Figure 2-1B). Weave lanes typically provide approximately 1,000 to 1,500 feet in length for weaving to occur between the managed lane and adjacent general purpose lanes. A major adjustment in driver behavior is required when an open access project is converted to a restricted access setting, based on experiences in Miami, Atlanta, and Seattle. In the case of the Seattle project, they have had to actively engage and educate prior HOV users that have been permitted unrestricted access across the solid white stripe for the past 20 years, a particularly relevant finding for Phoenix.

Figure 2-1 Sample Transition and Weave Lanes

A: SR-167 (Seattle)

B: I-680 (San Jose)

- ***Near-continuous access***. Discrete access is still applied in limited areas, but the access openings are much more frequent (averaging between 1 and 2 miles), and the length of the opening is much longer in length, approaching continuous access in operating principle. Open access points are marked by white-skip striping, while any restricted access section is noted by a double-solid, white line. The access points range from 3,000 to 9,000 feet long on I-15 in Utah (Figure 2-2A) to over 2 miles in length on I-35W in Minneapolis (Figure 2-2B), giving plenty of space for users to enter and exit the lanes regardless of the prevailing operating condition in general purpose lanes. Given the number of access points and length of access zones, about half of the project length allows continuous

access in Utah while over 70 percent of the length in Minneapolis allows access, even in toll zones.

Figure 2-2 Sample Near-Continuous Access Managed Lanes

A: I-15 (Salt Lake City)

B: I-35W (Minneapolis)

Several operational issues in common with the Phoenix area are observed. These projects exhibit high speed differentials, at least in portions of the corridor, caused by queues forming around major interchanges and lane drops. Speeds in general purpose lanes vary widely, while speeds in the managed lanes tend to be more predictable and relatively higher, with optimal operational thresholds of around 1,500 vehicles per hour seldom reached or exceeded. The ability to enter and exit anywhere along the managed lanes means that traffic is not forced to use specific designated zones, and weaving occurs as adjacent space and comparable speeds allow. Minnesota DOT even goes so far as to conduct tolling within the open access portions, under the philosophy that a) speed differential will inevitably limit toll evasion, and, b) that as the price for trip is the same across the length of the corridor, there is no incentive to avoid any given toll zone.

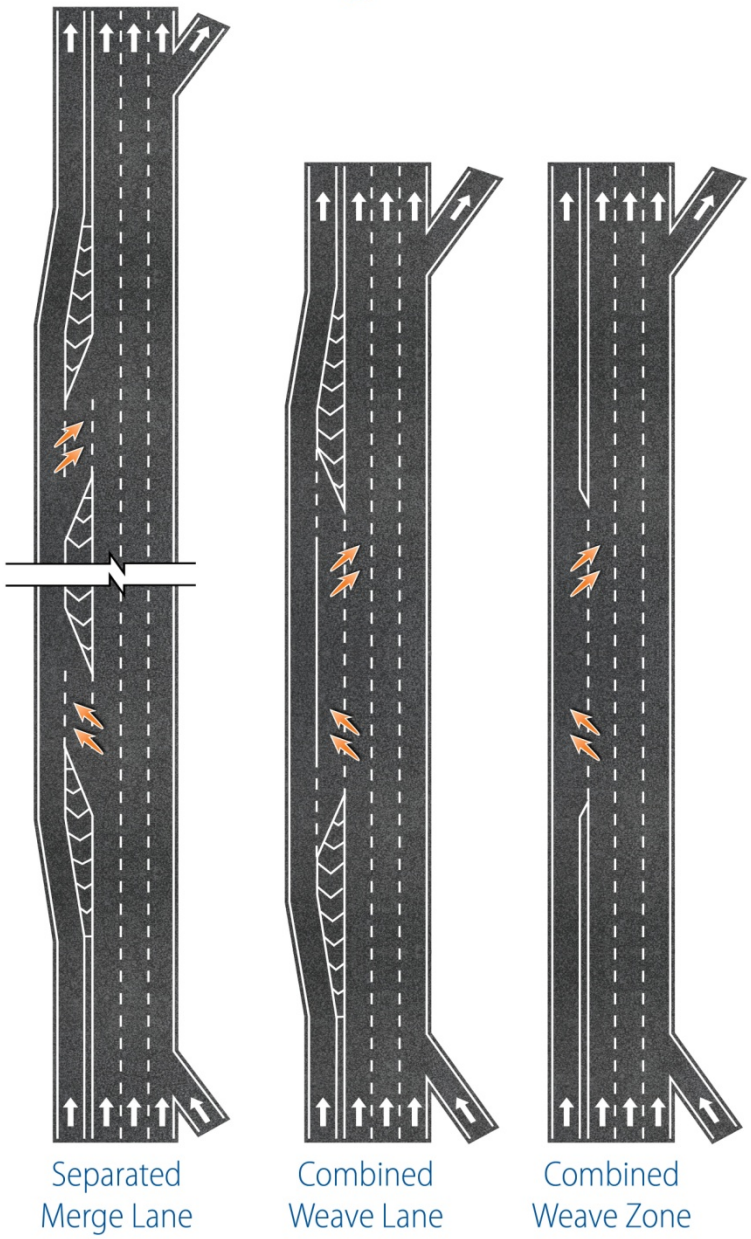
With the exception of some portions of I-35W, all concurrent flow corridors parallel the design setting found on Phoenix area freeways in the following ways. All exhibit roadway designs that are close to full standard, with modest lane width reductions over prior conditions. Full right-side breakdown shoulders are provided, and some corridors provide full median breakdown shoulders. Like Phoenix, the Minneapolis, Salt Lake City, and Seattle projects also have more limited demand periods, typically lasting no more than the peak hour in the respective peak direction.

In terms of upcoming projects to open within the next few years, a wide range of approaches are being proposed for access. Multiple lane treatments typically rely on either combined egress/ingress zones or connecting transition lanes which serve as a left-side auxiliary lane between a successive egress and ingress from and ingress to the managed lane, such as that under development for I-110 and I-10 in Los Angeles. Conversely, I-495 in Virginia and I-595 in Fort Lauderdale will exclusively employ DHOV

on their multilane facilities. None of the multiple lane concurrent designs are moving toward open, continuous access with general purpose lanes.

Figure 2-3 illustrates the typical merge and weave lane options utilized for providing access between general purpose lanes and limited access managed lane facilities. Although a combined weave zone (as illustrated on the right side of the images below) featuring a simple skip stripe is most common on existing HOV lane facilities with limited access, a combined weave lane or separated merge lane is preferable for maintaining maximum traffic flows and improved safety.

Figure 2-3 Typical Managed Lanes Merge and Weave Lane Options for Limited Access Facilities



2.3. Findings Pertinent to the Phoenix Area

The Phoenix area has an established practice as it pertains to continuous access on the HOV lane system. As such, this white paper examines the application of priced managed lanes within the existing structure, unless a compelling argument can be made for changing the mechanism of operations.

Limited access facilities with either transition lanes or exclusive reliance on DHOV is more prevalent for multi-lane or reversible treatments, where weave volumes are forecast to be high and access control must be maintained. Transition lanes are rarely found on single lane projects outside California, but this does not mean that they would not otherwise provide a benefit to the traffic stream and speed differentials involved. However, there are many locations where such transition lanes cannot be implemented due to physical constraints and cost prohibitions.

Managed lane projects in almost all cases are applying access designs customized specifically for the available conditions. If the corridor is being widened and fully reconstructed, then a majority of the desired design attributes, such as buffer separation and limited access with weave lanes, are included (e.g., I-10 in Houston, I-85 in Atlanta). Where managed lanes are retrofitted onto older freeways or tolling is placed on HOV lanes, the level of physical modification involved is generally minimized (e.g., SR-167 in Seattle). The differing design settings result in a high level of variability in how access is addressed between one corridor and urban setting, as evidenced across regions such as Los Angeles, Houston, Minnesota and Virginia.

All projects sponsors consider their selected design and operational approaches safe and enforceable. Without detailed and comparable safety studies from managed lane projects nationwide, there is no evidence of a “best” or “safest” access treatment. In some cases sponsoring agencies have modified their original designs to address identified shortcomings. These changes have included adopting restricted access when transitioning from free use to electronic dynamic pricing, lengthening access zone lengths, installing transition and weave lanes, increasing the visibility of pavement markings and channelizer installations, augmenting signing at ramps and decision points, and working with enforcement personnel to address enforcement needs more effectively.

Other locations are considering systems of managed lanes, much like that envisioned for the Phoenix area. The San Francisco Bay area, Seattle, San Diego, Minneapolis/St. Paul, Dallas/Ft. Worth, Atlanta, Houston, Miami/Ft. Lauderdale, and Charlotte have identified managed lane systems. Accordingly, system level design impacts addressing access have not been widely evaluated, nor design and operation policies adopted for any of these other areas.

2.4. Access Policy Options

There are advantages and disadvantages associated with various policies for setting managed lane access treatments. For a managed lanes network in the Phoenix area where HOV lanes currently operate with continuous access, there are several issues to

consider when assessing whether to maintain such an access policy. These are summarized in Table 2-2 below.

Table 2-2 Policy Options for Managed Lane Access Treatments

Option	Pros	Cons	Experience
Direct Access	• Possible independent toll zone • Speed control • Higher vehicle throughput • Bus Rapid Transit opportunity • Eliminates friction	• High cost / more right of way • Requires accommodation on arterials / signals • Increased infrastructure maintenance	• Phoenix-area HOV lanes • I-15 (San Diego) • I-25 (Denver) • I-95 (Miami) • I-10 & I-110 (Los Angeles – under construction)
Weave / Transition	• Transition lanes may be accommodated with restriping • Reduces toll evasion from continuous access • Enables access control	• Concentrates weaves at access zones • Potential higher crash rates • Enforcement of access violations	• I-15 (Salt Lake City) • I-15 (San Diego) • I-394 (Minneapolis) • I-680 (San Jose) • SR-167 (Seattle) • I-110 (Los Angeles – under construction)
Continuous	• Maintains existing operations / design • Lowest cost • Reduces weave concentrations • Lowest crash rates • Greatest market flexibility	• Greatest potential revenue leakage • Highest manual enforcement costs • Requires more frequent toll evasion • No access control • May complicate signing • May complicate toll structure	• Phoenix area HOV lanes • I-35W (Minneapolis)

3.0 ISSUES INFLUENCING CONTINUOUS ACCESS

This section examines identified issues affecting the potential for continuous access on priced managed lanes, as a continuation of existing policy. The most frequently raised potential issues involve access safety with respect to driver interaction, impacts on operations and tolling, and enforcement in terms of the method and level that would otherwise be required. Additional cited concerns have involved the limitations on current technology and the costs associated with more frequent toll readers, cameras and back office processing to more frequently monitor traffic and collect toll transactions.

3.1. Operational Performance

When adopting continuous access, a range of factors can affect operational performance including driver interaction, safety associated with the speed differential, consistency of practice (if not all projects employ the same approach), ability to manage individual lane operations, and pricing strategy.

3.1.1. Driver Interaction

Experience in the Phoenix Area is currently founded on the knowledge that a driver can enter and exit the HOV lanes anywhere. Recent experience in August 2008 from I-95 in Miami suggests that drivers can have a difficult time adjusting quickly to a change from unrestricted to restricted access, particularly if the change is sudden, not widely communicated, and executed poorly (the initially-wide channelizer spacing made the intent ambiguous). Such difficulties in driver interaction adjustment can cause an increase in the frequency and severity of crashes, at least in the short term. On I-15 in Salt Lake City, drivers are in violation when they cross solid striped lines. Violations for this infraction may be higher than 10 percent of the observed traffic volume, per anecdotal feedback from the project operator, who also notes that operational safety does not appear to be compromised, based on observed crash incidence. The UDOT project manager does not feel that the violations are compromising operations in either parallel roadway. These limited observations suggest the following pros and cons with respect to prospects for continuous access, particularly where continuous access HOV treatments already exist.

Advantages	Disadvantages
• Driver familiarity of continuous access HOV eliminates safety concerns related to transition to continuous access managed lanes • Reduces public outreach effort required to familiarize drivers with managed lanes	• May complicate signing for driver notification of toll rates • Increases the potential for revenue leakage, and/or costs for tolling and enforcement • Reduces the ability to mitigate traffic impacts on the managed lanes in existing congested or incident “hot spot” locations

3.1.2. Operational Safety

Recent safety studies performed by the University of California at Berkeley and the Texas Transportation Institute examined crash rates for different HOV lane access features[1]. The California study, in particular, compared crash rates for restricted and unrestricted access. Results suggest a slightly lower overall rate of collisions on HOV lanes with continuous access. Some practitioners in southern California have used these data to justify moving toward continuous access HOV lanes on SR-22, SR-55 and I-215/SR-60 where movements were previously restricted. An early hypothesis is that drivers on buffer-separated lanes adopt a tunnel vision, and are less prepared for violators who cross the buffer, whereas drivers on continuous access lanes drive more defensively, knowing that a vehicle from the general purpose lane could enter at any time. No studies have been performed to date to determine if transition lanes will cause the same tunnel vision effect, versus weave lanes, which may promote defensive driving.

The Texas crash data and findings suggest that for limited access facilities, accident can tend to be clustered in the vicinity of access locations, and incident rates for ingress/egress zones are sensitive to the presence of an inside shoulder (as a refuge to avoid incoming traffic), length, location, general purpose traffic mix and observed speed differential. These findings suggest that safety may be enhanced in either approach, if underlying design and operational factors are considered, such as the provision of adequate shoulders, buffers and weave lanes.

In the absence of more definitive and comparable data from managed lane operations, there is currently no data to suggest that access needs or operational safety for an HOV user group is greatly different from a priced managed lane user group. All other factors being equal, recent experience seems to suggest that a case can be made for supporting either access approach. But greater scrutiny may be warranted for adopting restricted access in conjunction with conversion from a continuous access lane, as was the case in Miami and Seattle. Both projects were not prepared for the acclimation issues which arose, and safety can be adversely affected during this period as was particularly evidenced in the more congested corridor in Miami.

Advantages	Disadvantages
• Continuous access can have lower crash rates • Reduces the concentration of weaves at designated locations	• Eliminates ability to concentrate access at locations where it can best be accommodated

[1] *A Comparative Safety Study of Limited versus Continuous Access HOV Facilities*, Task Order 6601, University of California Berkeley Traffic Safety Center (September 18, 2007), and *Safety Evaluation of Buffer Separated HOV Lanes in Texas*, Texas Transportation Institute (November 15, 2005).

3.1.3. Speed Differential

The speed differential challenge to operating managed lanes is neither new nor unique to the Phoenix area. Any dedicated lane treatment that is not physically separated from adjacent traffic risks exposing traffic to errant driver maneuvers from either traffic stream, and loss of throughput due to the friction created by differential speeds (typically slower speeds in the general purpose lane adjacent to the managed lane. Seldom in any concurrent flow HOV lane design setting across the U.S. has a travel benefit been achieved that is greater than a 20-25 mph differential between adjacent traffic streams. The speed differential issue was addressed without the benefit of comparable safety data about twenty years ago when AASHTO first recommended narrow painted buffers. Since then, approximately 30 percent of the nation's 3,000+ HOV lane-miles have been designed with a buffer, including facilities in the Phoenix area. Many of these projects operate with continuous access by applying a double skip stripe, or a wide solid strip.

Advantages	Disadvantages
• Continuous access appears to be safety neutral (or better) • Presence of a physical buffer allows motorists to see conditions of the traffic stream ahead and react accordingly • Driver can choose the most suitable location to merge	• Does not provide ability to safely store queued vehicles between traffic streams • Reduces the ability to mitigate traffic impacts due to traffic conflict or friction in locations with unusual design characteristics affecting maneuvering ability

3.1.4. Consistency of Practice

For the most part, there is widespread consistency in HOV lane access in Phoenix. The region's adopted practice of part-time operation helped influence a parallel practice of open access, since the carpool lane needs to function like any other freeway lane outside restricted operation periods. Full-time operation does not necessarily require a change to restricted access, as evidenced in the open access HOV lanes prevalent throughout the San Francisco Bay or Seattle areas. Continuous access priced managed lanes could be similarly applied network-wide, and consistency would be maintained. But if continuous access is applied for selected locations or segments, then consistency would be compromised.

Advantages	Disadvantages
• Continuous access policy matches existing practice in Phoenix	• Differential applications in a Phoenix network may confuse infrequent users

3.1.5. Ability to Manage HOT Lane Operations

The basic tools for lane management include restricting eligibility, controlling access and applying pricing. By maintaining a continuous access environment, one of these tools is removed as a means of managing lane demand in real-time. This means that

the other tools, notably pricing, will need to play a more prominent role in preserving the appropriate level of service in the managed lane.

Advantages	Disadvantages
• Current lane management practice is maintained • Pricing is introduced to help address lane demand	• Limits ability to manage the lane through access control • Tolling structure and signage could be more complex

3.1.6. Pricing Strategy

All current managed lane projects apply a pricing strategy based on a prescribed price for a particular segment of road from a given access point to a downstream destination. Although the pricing changes in real time, it can be communicated to users based on a downstream destination. While some projects have studied the prospect of charging a "per mile" basis and communicating only this value to drivers, there is currently no operating facility that has adopted this strategy (even though the project tolling algorithm on variable priced facilities is often based on this premise). Destination-based signing could also be used with a continuous access setup. Defining limits to road segments could be difficult to communicate through signing, if drivers are able to move in and out of the HOT lanes between the driver's point of origin and final destination. Alternatively, signage could relay rates per mile; however, this strategy requires the driver to make an extra calculation of total cost per trip.

Advantages	Disadvantages
• Per mile pricing could be preferred by users as they control how long they remain in the managed lane	• Per mile pricing requires extra thought on the part of drivers to calculate price for their intended trip distance • Destination pricing could confuse drivers who may anticipate entering and exiting in-between their origin and final destination • Drivers may attempt to exit at inopportune times to avoid additional per mile tolls • Potentially more confusing to communicate tolls to drivers if the application of differential or weighted pricing by segment is desired

3.2. Design Needs

Desired design treatments for managed lanes as published by AASHTO and FHWA involve restricted access, while the relative placement of access is dependent on a wide variety of site-specific factors. Challenges (near-term and longer-term) affecting desired access guidance include the following:

- *Desire for design consistency*. Phoenix area managed lane implementation will inevitably result in a wide variety of design conditions that will influence single

lane treatments and result in a variety of managed lane designs that are "best" fits within the various corridors. While consistency of design practice is desired, the challenges faced may mean some segments need consideration for different design and access approaches. Since the majority of managed lane use is typically from regular commuters who will familiarize themselves through repetitive use of the system, design consistency may not be as critical as the allowance for site-specific treatment.

- *Affordability and phasing*. Principled on design studies conducted elsewhere, some access treatments will prove to be affordable only in a longer-term time horizon, which may support consideration of interim approaches and design exceptions and programmatic phasing to address ultimate demand needs. This is not a radical departure from past HOV implementation experience, in which some desired facilities or design attributes were deferred until funding could be programmed for ultimate upgrades and improvements. In the Phoenix area this is evidenced in the manner that HOV lanes and freeway-to-freeway connectors are being implement in a phased manner as funding becomes available, most recently including the construction of HOV facilities on the SR-101 Loop/Pima Freeway and SR-202 Loop/Santan Freeway, and freeway-to-freeway connectors at the I-10/Maricopa Freeway and SR-202 Loop/Santan Freeway interchange and SR-101 Loop/Price Freeway and SR-202 Loop/Santan Freeway interchange. Continuous access or near-continuous access managed lane design may fit the role of an incremental step to a final design of limited access in some cases.

- *Design impacts due to changing demand and traffic patterns*. Other states' experience in implementing HOV lanes with designated access suggests that changing demand and traffic patterns have influenced the need to revise access features and some open access zones have been removed, relocated or lengthened. The level of flexibility afforded in the design of managed lanes will need this same accommodation. Continuous access or near-continuous access lanes may play a role in addressing this flexibility.

Continuous access managed lanes could avert the extensive studies needed to validate specific traffic patterns, locate access features, clear needed right-of-way and environmental reviews and design for the added roadway width assuming that transition lanes are required. Both the implementation timeline and costs for construction can be adversely affected if designated access features are implemented amidst a dynamic setting which can at best only forecast HOT lane demand and future traffic patterns. For these reasons, continuous access represents a reduction in design variables by not having to locate (or relocate) access points and not having to study traffic patterns or freeway access points. Continuous access is easier to design and implement versus discrete access.

3.3. Tolling and Enforcement System Needs

Electronic tolling typically involves the application of transponders in vehicles that communicate to roadside readers. Current technology applications typically require the reader to be located overhead on a gantry. Each vehicle's transponder is read as

it passes under the gantry. On the first managed lanes implemented on SR-91 in Orange County and I-15 in San Diego, a single reader location captured all vehicles because the lanes were physically separated from other traffic with no intermediate access points. Starting with the implementation of tolling on I-394 (concurrent flow lane portion) and subsequent concurrent flow managed lanes, congestion pricing is now increasingly applied in design settings with multiple ingress/egress zones on single concurrent managed lanes with no physical separation. In these settings it is easier for violators to cross into and out of the managed lane at will, compromising the ability to preserve traveler benefits based on the prevailing speed differential. Approaches to tolling managed lanes have changed over time to address these needs for frequent access and constrained environments, increasingly employing a combination of strategies which may include more frequently deployed transponder readers and cameras. However, fundamentally, ensuring compliance rests with the degree of investment of in-field police enforcement and electronic infrastructure.

If more frequent toll readers are employed, and each reader constitutes a separate "toll" charge, each represents a transaction cost to the operator. The more tolls that are levied on a user, the higher the number of transaction costs incurred. In order to reduce transaction costs, other operators have used a single-trip toll price system. SR-167 in Seattle was one of the first such projects with frequent ingress/egress opportunities to levy a single toll on the trip the user makes

On facilities with multiple toll readers, roadside equipment collects data from the vehicle's transponder at multiple locations after which the vehicle's entrance and exit points are determined based on "trip assembly". The series of transponder reads along the lane are assembled for each reader the vehicle passes to define a "trip" for purposes of calculating a single toll transaction. This process limits the cost associated with transaction fees on the operator, and is particularly important in a continuous access environment where a user may enter and exit the managed lane at any point or various points. This application still means that frequent toll readers would be essential for such a design.

Another approach applied is cameras that perform license plate reads using optical character recognition to match license plate numbers to customer's accounts. After a license plate is observed by the camera, the plate number is matched to an account and the toll is billed directly to a registered account holder.

In principal, the application of trip assembly remains the same whether it is via transponder reads or license plate image capture, and, still begs the question of how frequent toll readers (or cameras) would need to be spaced to discourage those who deliberately choose to violate the managed lane and avoid a toll. Atlanta's managed lane system on I-85 provides half-mile spacing for toll readers, augmented by cameras. In order to hold down the costs associated with a high number of reader transactions, they only keep some readers and cameras active on any given day and periodically change which ones are active. This approach represents a balance between preserving the integrity of toll compliance and keeping operational and enforcement costs associated with toll evaders down. By comparison, Minnesota has adopted a spacing of approximately 2 miles between toll zones in its continuous access facility,

with the presumption that speed differential and a relatively low toll at any given tolling point will prevent weaving in these locations.

The tolling needs for continuous access are critical to compliance, and if the right balance between spacing frequency of toll readers and cameras can be determined, this approach would appear possible, at least for short distances, in the near-term. It appears that another evolution in technology, notably GPS-based toll collection, would enable more widespread network applications of continuous access.

3.4. Enforcement Needs and Preferences

The role of enforcement is made more complicated for managed lanes than HOV lanes because SOVs are part of the eligible traffic stream. For HOV lanes, any SOV is conspicuous based on the single driver; thus, the vehicle is easier to visually spot and pursue. Even if toll evasion is fully handled electronically, this new environment makes occupancy monitoring and apprehension more complicated. Increased challenges are placed on enforcement personnel because high-speed access limits opportunities for monitoring and apprehending violators. Over the past 30 years, no reliable automated occupancy enforcement technology has been developed, much less accepted by law enforcement agencies and traffic courts, which can positively identify the number of occupants in a carpool with reliability. This means that in-field manual enforcement presence is required in some form to manage occupancy violations.

Continuous access managed lanes design create the following enforcement challenges:

Speed differential. Enforcement officials have expressed concern about the speed differential created where continuous access allows traffic to enter and exit anywhere. At higher anticipated volumes of managed lane traffic (when compared to current HOV volumes), drivers may make maneuvers that place them at greater risk when weaving between the parallel traffic streams. More frequent readers could encourage more weaving to avoid known toll gantries, thus encouraging greater side friction than would otherwise occur for restricted access design approaches. Although many recognize that a speed differential exists now on HOV lanes, there is a perception that the effects of both higher volumes and increased weaving compound the risks to the operating environment.

Enforceability. Distinguishing who has free use, who has just paid and who has not paid can be more difficult to monitor and enforce. Unrestricted access may make it more difficult for officers to utilize such tools as beacons at designated toll gantries, since they would have to rely on some other form of portable verification.

Access violations. Since vehicles can enter and exit a managed lane at any point, officers would neither have the benefit of pavement markings that restrict traffic to designated locations, nor be able tell whether an SOV intended to enter the managed lane as a legitimate customer or making a defensive maneuver based on traffic conditions. Buffer crossings would not be an infraction they could definitively rely on in court to uphold a citation.

4.0 CONCLUSIONS

As the requirements of the Phoenix area managed lane network are developed, it is recommended that a regional tolling approach utilizing near-continuous access design and operational setting be defined to best maintain consistency with the current continuous access system in place for the region's HOV lane system while affording the operational, enforcement and toll collection benefits of restricted access in strategic location. Prevailing traffic conditions and other design, operational and cost considerations will need to be evaluated to determine the specific segments or corridors that require the application of limited access to maximize the efficiency and effectiveness of a managed lanes network.

This white paper identified several options for access. A regional preference for utilizing near-continuous access allows the region to focus subsequent efforts to identify system-based options for resolving the issues presented in Section 3. Preliminary options include the expanded use of technology and operational treatments that can positively affect compliance. Altogether, developing a near-continuous access managed lane system is possible – and desirable – but these issues must be addressed as planning and design of the managed lanes system proceeds.