Managed Lanes Network Development Strategy – Phase I

Managed Lane Pricing and Tolling Methods

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Revision History

Revision	Date	Description	Submitted by
1.0	12/22/2011	Initial draft for internal review	DHU
1.1	12/27/2011	Draft for client review	DJH
2.0	03/02/2012	Final submittal with client comments	DJH

TABLE OF CONTENTS

1.0 Background 1

1.1. Purpose and Objectives 1

1.2. Defining a Pricing Approach 2

2.0 Parameters for Developing Pricing Options 4

2.1. Performance Objectives 4

2.1.1. Optimize Corridor and Managed Lane Throughput 4

2.1.2. Maintain Managed Lane Travel Time and Speed Targets 6

2.1.3. Optimize Revenue Generation 6

2.2. Pricing Variability 7

2.2.1. Flat Fee 7

2.2.2. Variable Pricing 7

2.3. Pricing Interval or Basis 9

2.3.1. Per Mile Pricing 10

2.3.2. Per Segment Pricing 10

2.3.3. Per Facility Pricing 11

2.3.4. System Pricing 12

2.4. Price Differentiation 12

2.5. Constraints Upon Pricing 14

2.6. Interaction with Active Traffic Management 15

3.0 Implications of the Pricing Approach 17

3.1. Traffic Management 17

3.2. Customer's Response to Pricing 19

3.3. Objectives of Pricing 22

3.4. Pricing System 25

4.0 Pricing Policy Options 28

4.1. Pricing System 28

4.2. Pricing Interval 28

5.0 References 30

List of Figures

Figure 2-1 Speed-Flow Relationship for Northbound I-110 General-Purpose Lanes South of Slauson Avenue, Los Angeles (May 2008).....5
Figure 2-2 SR-91 Express Lanes Static Toll Schedule 8
Figure 2-3 Segmental Toll Rate Regulatory Signs for Managed Lanes (MUTCD 2009).11
Figure 2-4 Example Switchable Transponders.....13
Figure 2-5 Example Online Carpool Registration Interfaces 14
Figure 2-4 Active Traffic Management on I-35 W in Minneapolis.....16
Figure 3-1 HOV Lane Lifecycle 18
Figure 3-3 System and Demand Management Strategies Effects on Traveler Choice 20
Figure 3-4 Estimated Toll Rate by Available Capacity 22

List of Tables

Table 3-1 Mean Value of Travel Time Savings ($/hr).....21
Table 3-2 Carpool Pricing Policies on Priced Managed Lanes.....26
Table 4-1 Pricing System Approach Options.....28
Table 4-2 Pricing Interval Options.....29

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 Objectives

Maintaining performance on the Phoenix-area HOV lanes is critical towards supporting the transit and rideshare goals for the region. Potential conversion of freeway HOV facilities to priced managed lanes would likely result in additional vehicular volumes being introduced to these facilities. In order to preserve and enhance the performance benefits of the managed lanes, careful consideration must be given to the pricing system used to manage the demand created by these new customers. The inclusion of pricing promises a real-time monitoring and response capability for managed lane operations; however, the pricing approach must be sufficiently robust to account for variations in markets, geospatial access, and demand.

Although these concerns certainly exist within any given priced managed lane corridor, they are compounded when applied across a managed lane network. For example, differential pricing mechanisms between corridors may contribute to driver uncertainty and confusion, but may also be necessary given the individualized requirements of the corridors. It should also be recognized that the pricing approach may have consequences upon public acceptance, with differing levels of acceptance and

opposition from different user groups. Fairness of the pricing mechanism may be perceived differently, depending upon various equity considerations (e.g., income, how pricing is applied, travel mode, etc.).

There are four potential objectives for developing a pricing concept for the Phoenix region:

- Simplicity. To be most effective, consumers must respond rationally to pricing signals. As such, the system, as presented, must be easy to understand and use by the traveling public. This does not imply that the components of the pricing system are necessarily simplistic, as complexity is inherent in pricing algorithms and business rules. Rather, this means that the price signals sent to and received by the customer are easy to understand.

- Effectiveness. The pricing approach should include optimization of person and goods throughput, vehicular speeds, travel time performance, revenue generation to support operation and capital improvements, and providing priority for transit. However, there are secondary objectives that the pricing program should not be blind to. These may include the management of bottleneck bypasses, corridor-wide operations, and equity considerations.

- Flexibility. The optimal pricing system will be sufficiently robust for varying scales of implementation on the network. As priced facilities may include small initial applications of new capacity and HOV-to-HOT conversions, the eventual system may also include multiple lane facilities. Ideally, the pricing system should be able to accommodate all degrees of implementation.

- Integration. Managed lane corridors may eventually have multiple operational treatments applied, including ramp metering, dynamic lane assignment, active traffic management, and other strategies. The pricing system should integrate with these efforts to the best extent possible.

The primary objective of this white paper is to examine these issues, develop policy options for pricing, and identify impacts and implications of managed lane pricing.

1.2. Defining a Pricing Approach

Phoenix's HOV lane system currently permits certain vehicle types during specified periods of the day (morning and afternoon peak periods), wherein other vehicle types are restricted from the lanes. The current system has approximately 375 lane miles, with more under development. Existing permitted users include carpools with two or more occupants, vanpools, motorcycles, and buses.

For the implementation and operation of priced managed lanes, additional permission would be granted to single- and/or low-occupancy vehicles (SOV/LOV) – depending upon either HOV 2+ or HOV 3+ definition for the corridor – that do not meet the prevailing occupancy requirements and carry an active transponder/account, or otherwise meet established criteria for paying tolls. Nationally, initial priced managed lane applications involved existing HOV facilities with demonstrable underutilization.

However, more recent proposals have examined the potential of implementing priced managed lanes in more constrained conditions, including in conjunction with increasing the occupancy requirement where overutilization is degrading the performance of the HOV facilities, or as a means of providing higher returns on investment from the provision of new capacity. Priced managed lanes are promoted as a means of responding to both overutilization and underutilization of HOV lanes. As evidenced by the operational facilities nationally, priced managed lane concepts have proven to be an effective way of managing the capacity in HOV lanes without degrading travel time advantages. Furthermore, recent financing packages assembled for priced managed lane facilities on I-635/Lyndon B. Johnson Freeway in Dallas, I-595/Port Everglades Expressway in Ft. Lauderdale, and I-495/Capital Beltway in Fairfax County, Virginia have shown the possibility of using priced managed lanes as a means of enhancing financial resources to construct new capacity.

HOT lanes, by definition, imply maintenance of HOV operations. Conversely, priced managed lanes that are built without an initial HOV designation carry no such implication. The first (and to date, only) toll lane implemented with no explicit HOV benefit is on SR-91 in Orange County, CA, which was originally developed as a privately built and operated express toll lane (ETL) corridor. However, upon the facility's acquisition by the Orange County Transportation Authority (OCTA) in 2003, the SR-91 Express Lanes operating policy has been adjusted to provided toll-free use by HOV 3+ users during most time periods, and only requiring a 50% toll payment by these users during times of heaviest congestion (currently only Thursdays and Friday PM peak periods in the eastbound direction). Express toll lane concepts that require all users to pay a toll are more attractive than HOT lanes for those transportation agencies driven by enhancing sources of revenue, demand-driven management of express lane facilities, fairness by being mode-neutral, and/or ease of enforcement.

MAG is currently investigating the implementation of priced managed lanes from a variety of perspectives, and the implications from a pricing perspective between HOT lanes and other forms of priced managed lanes are further explored here. The identification of a pricing structure for the priced managed lanes is necessary in order to provide guidance and policy regarding the implementation of the system.

2.0 PARAMETERS FOR DEVELOPING PRICING OPTIONS

This section identifies the options and parameters that inform the pricing approach for a priced managed lane network.

2.1. Performance Objectives

Performance metrics serve as the basis for understanding the performance of a managed lane network in terms of achieving regional objectives; setting system policies including prices, eligibility, and access; and adapting the operational and pricing parameters over time. Although there may be commonalities and linkages between performance measures, it is important to recognize that emphasis on particular measures may shift with different operating conditions. For example, a highly congested segment within a lightly congested corridor may have different performance measures based upon these segments. Additionally, the performance measures are not mutually exclusive, and have significant overlap with one another. As such, the application of performance objectives should be weighted as appropriate.

Ideally, a comprehensive priced managed lane performance analysis would examine the contribution of managed lanes to differing operational conditions, land uses within treatment corridors, and recurring/non-recurring traffic congestion situations. However, the performance measures used by implementing agencies are limited by the capabilities of data collection systems, modeling and evaluation tools. Typically, performance objectives for priced managed lanes focus upon traditional system measures, as the benefits to the system (reflected in aggregate metrics) are more directly relevant to prospective managed lane policy direction for congestion relief. Conversely, individual benefits from priced managed lanes (such as individual travel time savings and reliability) are inherently understood by users, but may not reflect the regional choice for a priced managed lanes strategy.

The implementation of pricing on the managed lane network will invariably affect the performance of the managed lanes by design. The purpose of priced managed lanes is to manage the system through price signals. These price signals will vary in multiple dimensions so as to achieve one or more of the primary performance objectives. These primary performance objectives are described below:

2.1.1. Optimize Corridor and Managed Lane Throughput

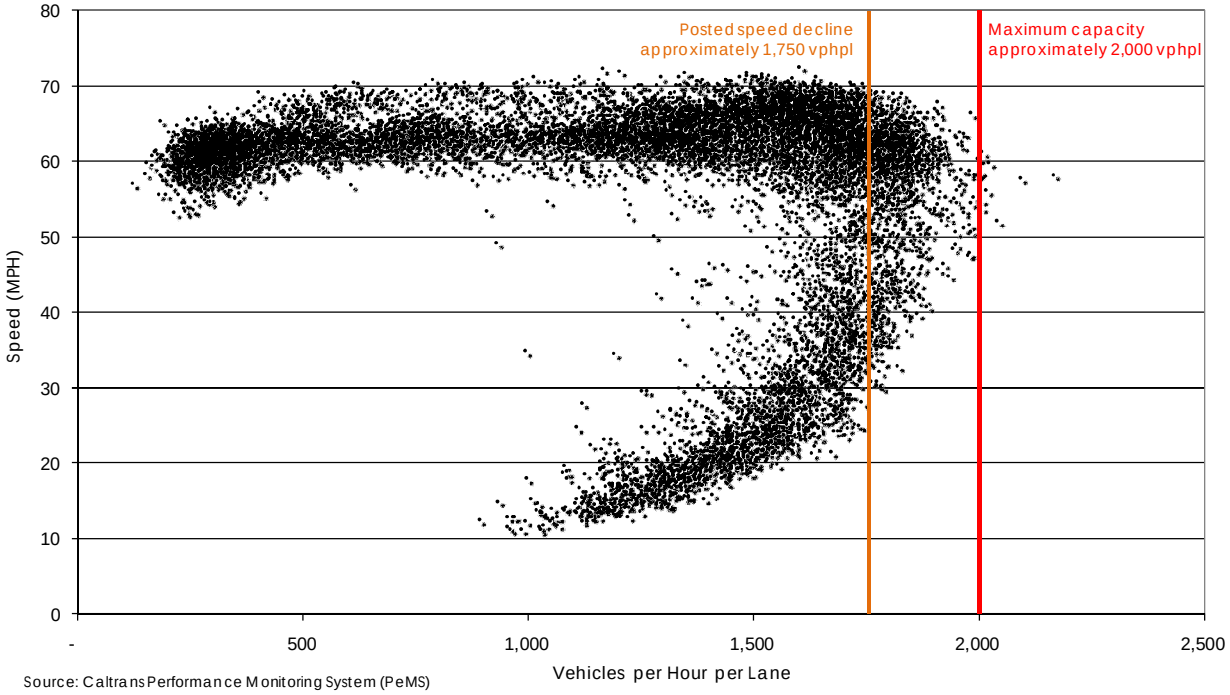
Optimizing throughput, regardless if measured by vehicular or person throughput, is an objective for overall mobility and congestion reduction. Corridor throughput refers to the number of vehicles and/or persons traversing the corridor on both transit and in private vehicles per unit of time. Increases in the number of vehicles or persons using a corridor would imply that the pricing policy on the managed lanes were effective in serving more persons across all lanes of traffic.

Pricing to optimize throughput generally implies the full utilization of the managed lanes vehicular capacity for maximum person movement. For pricing schema, a balanced approach to price setting would be oriented towards smoothing the use of the

managed lanes. Any spikes in price may create temporary imbalances, such as too many drivers accessing or avoiding the lanes at any given point in time. As these imbalances can lead to shockwaves that traverse upstream, the pricing system should aim to smooth demand for the managed lanes to avoid peaking, even to the detriment of overall operations. As a result, a focus on overall corridor throughput may imply the managed lanes will operate at less than the posted speed limit.

Whereas throughput can be measured by an increase in the overall number of people or vehicles moving in the corridor, managed lane vehicular throughput has an identifiable capacity threshold. As illustrated in Figure 2-1, which shows the relationship between speed and traffic flow (measured in vehicle volume) for general purpose lanes on the northbound I-110/Harbor Freeway in Los Angeles, freeway travel speeds generally start to decline from posted speed limits when traffic flows reach about 1,750 vehicles per hour per lane (vphpl) on average, although the flow rate at which speeds decline from the posted speed limit can generally vary from about 1,500 vphpl to 1,900 vphpl indicating the volatile nature of the traffic flows at these levels of utilization. Furthermore, a saturated condition is reached at a flow rate of approximately 2,000 vphpl beyond which there are very few instances when higher flow rates are observed indicating the effective maximum vehicle throughput of the freeway corridor.

Figure 2-1 Speed-Flow Relationship for Northbound I-110 General-Purpose Lanes South of Slauson Avenue, Los Angeles (May 2008)



Source: Caltrans Performance Monitoring System (PeMS)

The optimization of corridor vehicle flow via pricing is intended to avoid speed breakdowns across the entire corridor that result from a loss of capacity in high demand or over-saturated conditions by balancing corridor demand across both the general purpose lanes and managed lanes. This balance is achieved by pricing the available

capacity in the managed lane to maintain maximum vehicle flow and travel speeds across the corridor. In order to increase throughput beyond the optimal vehicle flow threshold (the flow rate at which speeds start to decline below posted speed limits), managed lane policy is typically oriented towards person throughput (holding vehicular throughput static) by increasing average vehicle occupancy within the corridor, either through the expansion of transit services or incentives for higher rates of carpooling.

2.1.2. Maintain Managed Lane Travel Time and Speed Targets

The flow rate at which speeds decline from posted speeds or when saturation occurs will vary by corridor. For managed lane facilities, which are most often a single or dual lane, the threshold for speed decline is typically less than that observed for general-purpose lanes where more lanes are available; generally between 1,500 and 1,650 vehicle per lane per hour. Optimizing throughput in the managed lanes recognizes that the desired vehicle flow rates may result in managed lane travel speeds that are less than the posted speed limit. This vehicle flow rate is generally considered the optimal operating threshold and is typically based on a predefined minimum travel speed in the managed lanes (often 45 mph which is consistent with Federal statute regarding traffic operations for HOV's in a managed lane). In contrast to simply maximizing corridor throughput, this objective identifies the maximization of safe travel speeds and reduction of travel time for managed lane users as the principal measures. Travel time is strongly influenced by the speed that the vehicle is able to travel. In turn, speed will be influenced by any delays experienced due to bottlenecks or other queues caused by congestion. Price cannot easily be set to affect travel speeds in any given spot along a facility; however, it can be set to maintain an average travel time over a segment.

Maintaining average travel times as the pricing objective may mean less-than-full utilization of the managed lanes capacity throughput the corridor, as the price will be set to avoid breakdown in speeds and to anticipate unmanaged demand (e.g., HOV and other unmonitored users) in the managed lanes. As a result, the lane management is more independent from the general purpose lanes, and the performance of the general purpose lanes may be reduced relative to the objective for managed lane throughput optimization.

2.1.3. Optimize Revenue Generation

Optimizing revenue places greater reliance on the aggregate value of the volume of customers at the prevailing price than the time and conditions sensitivity that comes with the other objectives. The facility will be managed to stabilize and optimize revenue as a summation function of price for each customer. When the time savings benefits of the managed lanes are lower, demand will be more elastic or price sensitive, and the price may need to be lowered to increase revenue, just as a slight discount by retailers may encourage greater consumption, and thus, greater gross receipts. However, when the time savings are great (such as when the general purpose lanes are highly congested), customer demand will be more inelastic or price insensitive and the price can be raised with less deterrence of customers, thereby increasing revenue.

Optimizing for revenue generation is not dissimilar from optimizing for travel time and speed targets, in that it often results in less-than-full utilization of the managed lanes capacity, and correspondingly higher speeds. The price may be set at a higher rate for less vehicles, or, at a lower rate for more vehicles, all depending upon the prevailing corridor conditions that determine the demand for the express toll lanes. In practice, it is more difficult to measure the conditions that maximize revenue than optimizing throughput. Overshooting the price that maximizes revenue can result in less aggregate revenue due to a lack of paying customers and possible public opposition from corridor drivers unwilling or unable to pay to use the likely underutilized managed lane. By comparison, lowering the price can result in more revenue with more paying customers being served, and thus, potentially better conditions in the general purpose lanes. However, too low a toll and/or too many users in the managed lanes may reduce the relative time savings between the managed lanes and general purposes lanes thereby reducing the value of the time savings to paying customers, resulting in less revenue and lower managed lanes customer satisfaction due to a feeling of not getting enough value for money. Recognizing the possibility of measurement error, optimizing for revenue should err slightly on the side of under-pricing to avoid an unfavorable condition.

2.2. Pricing Variability

Multiple mechanisms exist for pricing a managed lane facility.

2.2.1. Flat Fee

Flat fee (or fixed-rate pricing) is often used on traditional toll roads, where the rate does not vary by time of day or the distance traveled. From a historical perspective, flat fee/fixed-rate pricing had the advantage of being easy to communicate and collect when toll collection required customers to carry cash and was limited to a staffed tollbooth or an automated coin machine. The advent of electronic toll collection technologies have made other pricing mechanisms more viable, including distance-based tolling, time of day variable toll rates, and dynamic variable pricing where rates adjust in real time according to prevailing conditions and predetermined business rules.

In terms of managed lanes, the first flat fee experimentation involving HOV-to-HOT conversion was the sale of a monthly subscription pass for SOV use of the I-15 Express Lanes in San Diego. This experiment lasted only one year before conversion to electronic tolling. More recently, Utah's I-15 Express Lanes operated as a flat fee subscription facility for four years before converting to electronic pricing. Overall, using flat fee pricing requires a commitment to toll rate escalation in order to preserve levels of service and recognition that the facility must be undersold in order to avoid breakdown into congestion.

2.2.2. Variable Pricing

Whereas flat rate pricing may work sufficiently well for traditional toll roads and bridges, variable pricing is well suited to priced managed lanes. In order to maximize the use of limited managed lane roadway capacity and maintain incentives for higher occupancy vehicles, most managed lanes have implemented variable pricing based

on real-time (or anticipated) demand as a primary tool in lane management. Variable pricing serves as the principal mechanism for regulating access to the managed lanes, allowing for maximization of capacity while still promoting free-flow speeds. Variable pricing for managed lanes can take one of two forms – static variable pricing or dynamic variable pricing.

2.2.2.1. Static Variable Pricing

Static variable pricing is based on a set time of day schedule and is actively used on the I-25 (Denver), SR-91 (Orange County), and I-10 (Houston) priced managed lane facilities. Under this variable pricing scheme, toll rates vary through the day following a predetermined, "static" toll schedule that is developed based on historical traffic conditions within the corridor so as to anticipate periods of highest demand and price accordingly. Figure 2-2 provides an example static variable pricing schedule as published for the SR-91 Express Lanes in Orange County. The toll schedule for SR-91 is updated every 90 days based on a review of prevailing traffic conditions in the managed lanes during the prior 90 day period.

Figure 2-2 SR-91 Express Lanes Static Toll Schedule

91 Express Lanes **Toll Schedule** Effective January 1, 2012 — **Eastbound** SR-55 to Riverside Co. Line

	Sun	M	Tu	W	Th	F	Sat
Midnight	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
1:00 am	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
2:00 am	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
3:00 am	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
4:00 am	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
5:00 am	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
6:00 am	$1.30	$2.10	$2.10	$2.10	$2.10	$2.10	$1.30
7:00 am	$1.30	$2.10	$2.10	$2.10	$2.10	$2.10	$1.30
8:00 am	$1.65	$2.10	$2.10	$2.10	$2.10	$2.10	$2.10
9:00 am	$1.65	$2.10	$2.10	$2.10	$2.10	$2.10	$2.10
10:00 am	$2.55	$2.10	$2.10	$2.10	$2.10	$2.10	$2.55
11:00 am	$2.55	$2.10	$2.10	$2.10	$2.10	$2.10	$2.55
Noon	$3.05	$2.10	$2.10	$2.10	$2.10	$3.15	$3.05
1:00 pm	$3.05	$2.90	$2.90	$2.90	$3.15	$4.95	$3.05
2:00 pm	$3.05	$4.15	$4.15	$4.15	$4.25	$3.10	$3.05
3:00 pm	$2.55	$4.45	$3.70	$3.95	$4.95	$9.75	$3.05
4:00 pm	$2.55	$4.55	$6.80	$7.30	$8.95	$8.85	$3.05
5:00 pm	$2.55	$4.85	$6.25	$7.50	$8.80	$7.00	$3.05
6:00 pm	$2.55	$4.45	$3.60	$3.60	$4.40	$5.35	$2.55
7:00 pm	$2.55	$3.15	$3.15	$3.15	$4.55	$5.00	$2.10
8:00 pm	$2.55	$2.10	$2.10	$2.10	$2.90	$4.55	$2.10
9:00 pm	$2.10	$2.10	$2.10	$2.10	$2.10	$2.90	$2.10
10:00 pm	$1.30	$1.30	$1.30	$1.30	$1.30	$2.10	$1.30
11:00 pm	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30

91 Express Lanes **Toll Schedule** Effective January 1, 2012 — **Westbound** Riverside Co. Line to SR-55

	Sun	M	Tu	W	Th	F	Sat
Midnight	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
1:00 am	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
2:00 am	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
3:00 am	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
4:00 am	$1.30	$2.45	$2.45	$2.45	$2.45	$2.45	$1.30
5:00 am	$1.30	$4.00	$4.00	$4.00	$4.00	$3.85	$1.30
6:00 am	$1.30	$4.15	$4.15	$4.15	$4.15	$4.00	$1.30
7:00 am	$1.30	$4.60	$4.60	$4.60	$4.60	$4.45	$1.75
8:00 am	$1.75	$4.15	$4.15	$4.15	$4.15	$4.00	$2.10
9:00 am	$1.75	$3.30	$3.30	$3.30	$3.30	$3.30	$2.55
10:00 am	$2.55	$2.10	$2.10	$2.10	$2.10	$2.10	$2.55
11:00 am	$2.55	$2.10	$2.10	$2.10	$2.10	$2.10	$2.95
Noon	$2.55	$2.10	$2.10	$2.10	$2.10	$2.10	$2.95
1:00 pm	$2.95	$2.10	$2.10	$2.10	$2.10	$2.10	$2.95
2:00 pm	$2.95	$2.10	$2.10	$2.10	$2.10	$2.10	$2.95
3:00 pm	$2.95	$2.10	$2.10	$2.10	$2.10	$2.55	$2.95
4:00 pm	$3.10	$2.10	$2.10	$2.10	$2.10	$2.55	$3.10
5:00 pm	$3.10	$2.10	$2.10	$2.10	$2.10	$2.55	$3.10
6:00 pm	$3.10	$2.10	$2.10	$2.10	$2.10	$3.05	$2.55
7:00 pm	$2.55	$1.30	$1.30	$1.30	$1.30	$2.10	$2.10
8:00 pm	$2.55	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
9:00 pm	$2.55	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
10:00 pm	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30
11:00 pm	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30

Within a rather limited set of example cases, this structure has generally been shown to produce higher rates of net revenue over dynamically priced facilities, potentially due to lower operations and maintenance costs and greater customer predictability, although this may be a factor of the existing facilities' dual lane structure. However, to be most effective, this form of variable pricing requires both a high degree of variability by time of day and day of the week and a system for altering toll rates over time. One lesson learned from prior experience with SR-91 has been that a biannual schedule for toll rate reassessment and change may be insufficient for adapting to market changes, as the facility was slow to react to the market downturn in 2008-2009.

2.2.2.2. Dynamic Variable Pricing

Dynamic variable pricing utilizes a variable tolling structure whereby the toll rate is calculated and adjusted in near real-time based on the actual prevailing traffic conditions in the managed lanes (and sometimes in combination with the adjacent general purpose lanes). Dynamic pricing has emerged as the standard practice for multiple-segment priced managed lane facilities, including those in operation on I-15 (San Diego), I-95 (Miami), I-680 (San Jose), I-394 (Minneapolis) and I-35W (Minneapolis). The first two examples are dual lane treatments; the latter three examples offer only one lane of travel in each direction. A single lane design is particularly amenable to dynamic pricing because it is fully constrained by the slowest moving vehicle and therefore the potential for higher fluctuation in throughput necessitates the more active demand management system that dynamic pricing provides.

Among the existing dynamic priced facilities, evidence has been mixed regarding net revenue. San Diego and Minneapolis have each struggled with meeting operations and maintenance (O&M) obligations at certain times with their dynamically priced facilities. Dynamic pricing often carries higher levels of toll operation expenditures, including reliance on real-time traffic monitoring. Furthermore, the toll rate is more finely tuned compared to static variable pricing (which to some extent must anticipate a worst case condition by time of day) due to the ability of a dynamic pricing system to respond in near real-time to variability in use, which in turn can effectively reduce revenue generation. That said, the most significant demonstrable corridor wide improvements in overall performance have been witnessed in Miami on the dynamically priced I-95 Express.

2.3. Pricing Interval or Basis

An important aspect of pricing is providing the potential customer clear indication in advance of entering a managed lane what the current price is, and assurance that the price indicated is indeed what is charged. Managed lanes customers require advance pricing information at decision points located far enough upstream in a means that is easily understood and permits an informed decision to use the lane or not. Due to the size and complexities of a managed lanes network, communication may need to be provided through a variety of means and customized to the extent possible. The need to communicate price signals to customers is significantly limited by the spatially-based interval of the pricing scheme. For any selected basis by which to price the system, there are two implications – one to the system (behind the scenes),

and the other to customer understanding. It should be noted that these can be mutually exclusive to one another. For example, MAG may opt to calculate tolls on a per-mile basis, but communicate it to the customer as a segment-based price.

There are four primary interval options for the calculation of tolls.

2.3.1. Per Mile Pricing

This scheme calculates toll rates on a per-mile basis. From a system perspective, per-mile rates comprise the standard calculation for toll revenue, and offer ease of benchmarking to other toll facilities. Furthermore, a per-mile basis may allow for detailed application of variable rates by mile, localizing congestion effects for maximum system efficiency.

For customers, a per-mile fee is easy to communicate but difficult to understand, as it requires customers to both know the mileage distance to their destinations as well as conduct the mathematical calculation while driving. Although future technology may make such a calculation easy within the vehicle navigation system or on a smartphone application, this capability is readily available today. Furthermore, sensitivity may be distorted by certain values which may have a different psychological effect than other values. Finally, per-mile pricing may create an incentive for weaving, as customers try to only use the managed lanes for congested sections (thereby minimizing cost on uncongested sections).

Although tolls are typically calculated on a per mile basis for all existing and proposed dynamically priced managed lane facilities, there are currently no facilities that display toll rate information to the customer on a per mile basis.

2.3.2. Per Segment Pricing

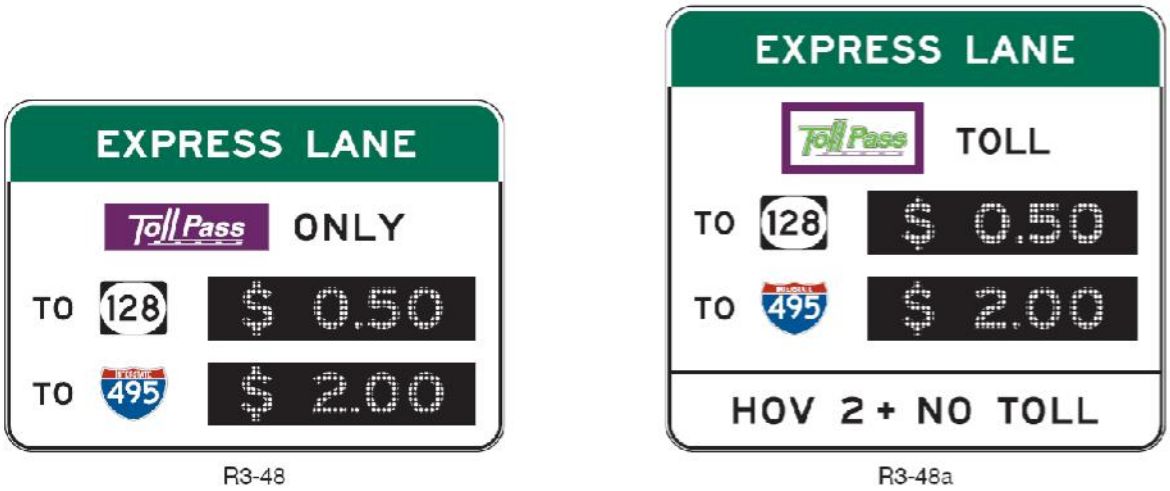
Segments may be defined in different ways – between each managed lane ingress and egress, by freeway ingress and egress points, by minimum or maximum distance thresholds, to an important or major decision point, or to a common destination. From the system perspective, segmental pricing permits isolation of congested segments for intensity of management by pricing, and allow for prices to vary by segment. Furthermore, segments may have different objectives from one another. A segment in a highly congested corridor section may be managed for performance objectives whereas a segment in a lightly and/or infrequently congested area may be managed for revenue generation.

For customers, segmental pricing is easy to understand and reduces the incentive to weave in/out of the managed lane while within a segment (which can have operationally disruptive effects). Currently, segmental pricing is used on I-10 in Houston, I-15 in San Diego, I-15 in Salt Lake City, I-394 and I-35W in Minneapolis, I-680 in San Jose, and I-95 in Miami. There can be drawbacks to segment pricing, particularly where multiple toll segments or facilities are contiguous, including the requirement of customers with multi-segment trips to continue to add their total trip cost as they proceed along the facility and a greater likelihood of weaving in-and-out of the

managed lanes as compared to facility or system pricing (although there is reduced incentive for weaving as compared to per mile pricing).

The 2009 version of the Manual of Uniform Traffic Control Devises (MUTCD) for the first time included standards for signage related to managed lanes facilities and the communications of toll rates. The MUTCD standards reflect a preference for utilizing signage that communicates toll rates by segments to potential customers, as illustrated in Figure 2-3.

Figure 2-3 Segmental Toll Rate Regulatory Signs for Managed Lanes (MUTCD 2009)



2.3.3. Per Facility Pricing

A facility, for this purpose, is defined as the initial ingress to the last egress for a managed lane along a continuous corridor (direct connections to other corridors are not considered the same facility). Given most operational managed lanes are confined to a single corridor, and some of them are barrier separated, per facility pricing is a widely established practice. Facility pricing is used exclusively on SR-91 in Orange County, I-25 in Denver and SR-167 in Seattle. Facility pricing can also be used in conjunction with per segment pricing of intermediate segments on a multiple segment facility, as is the case all of the facilities described previously under Per Segment Pricing, with the exception of I-15 in Salt Lake City which is exclusively priced by segment.

Some managed lanes, like SR 167 in Seattle, may have multiple access points but are still priced per facility. From a system perspective, facility pricing is appropriate for limited access and short distance facilities, and especially appropriate for barrier-separated pipelines. However, this pricing constrains total managed capacity on the entire facility to the lowest point along the facility. If there is a bottleneck, in order to maintain free-flow speeds, then the facility must be priced to manage volume at that capacity bottleneck.

From a customer perspective, this can be an easy system of pricing to communicate and understand. However, repeating facility price information at intermediate ingress/egress points may confuse some users into thinking that the managed lane is

segment priced, as evidenced by customer feedback on SR 167. Moreover, with multiple access points, facility pricing may create distortions in markets for the facility, as the upstream price is the same as the downstream price. This can yield geographic equity issues, such as those that emerged in Maryland for managed lane considerations in 2003, leading to significant delay in implementation.

The proposed Express Lane facilities currently under construction on I-10 and I-110 in Los Angeles will utilize a combination of per mile, segment and facility pricing, with toll rates calculated on a per mile basis, applied (and weighted) to individual tolling segments, and communicated to potential customers for the next major intermediate access point and the ultimate facility termini. This pricing approach appears to have emerged as the preference for dynamically priced managed lanes facilities.

2.3.4. System Pricing

The last form of pricing is system wide, which implies an unlimited access fee per time interval. For example, a toll of $15 may entitle a customer access to multiple express toll lanes for a two hour period. This system of pricing is untested in the United States; however, combined with a dynamic pricing scheme, this approach was implemented on the Tel Aviv Fast Lane (Israel) in January 2011. There, a monthly subscription allows customers to access both Haifa and Tel Aviv area toll lanes. From a system perspective, system pricing likely yields the lowest potential operations cost (with a registration/subscription model), but does not allow for managing localized demand. Thus, speed and travel time maintenance will be very difficult to achieve and likely lead to inefficient under-loading of the lanes.

For the customer, system pricing is very easy to understand and tracks with similar pricing of certain utilities (e.g., the typical internet connection fee is unlimited access for a set monthly subscription fee). However, it may be overly expensive for customers to use (system pricing would require access being priced for high-demand segments in the system) and inefficient (especially if price falls below use in high-demand segments).

2.4. Price Differentiation

The applicable price for access can vary for different users. Discounts or exemptions can be applied for achievement of occupancy standards (e.g., HOV 2+, HOV 3+, etc.), vehicle type (e.g., hybrids, electric vehicles (EVs), Inherently Low Emission Vehicles (ILEV's), etc.), vehicle classification (e.g., passenger vehicle, truck, etc.), or other criteria. Furthermore, pricing differentiation can be associated with the individual account. One method of responding to equity concerns is to apply toll discounts in conformity with discounted utility rates for disadvantaged households (a term called "lifeline tolling", first proposed in the San Francisco Bay Area in the mid-1990's). A similar approach has been proposed for Express Lanes in Los Angeles whereby eligible low income residents of Los Angeles County would receive discounted transponders and waived monthly maintenance fees to better enable them to meet the mandatory transponder requirement to use the facility, even as a non-toll paying HOV.

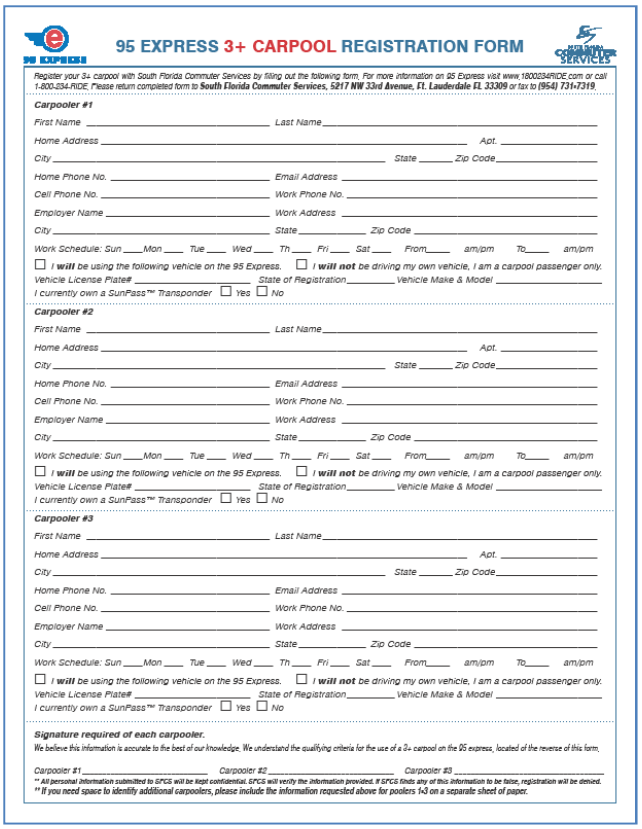
Although policy drives the application of price differentiation, technology determines the ability to actually accomplish the categorization of users. The ability to differentiate by user is dependent upon a system for segmenting users. Currently, there are two primary methods for segmentation of users.

The first involves self-declaration while in the managed lane facility. The most common means of accomplishing this is by separating traffic in toll zones – tolled vehicles in one lane and exempted (or discounted) vehicles in another lane. This system only provides for a binary application of exemptions, but does not require all users to have a transponder. Another possibility, one that is currently being explored in a few areas, is the use of switchable transponders, where users declare on the transponder device the appropriate setting for the user. This method requires HOVs or those users that meet the criteria to carry a transponder in order to receive an exemption or discount. Figure 2-4 shows an example of a switchable *FasTrak*™ transponder currently being developed for use on express lanes facilities in California.

Figure 2-4 Example Switchable Transponder

The second method involves pre-determined declaration at the user account level. This can be accomplished either by registration (either on a per-trip or permanent basis), or by the establishment of differential accounts (e.g., a non-revenue account, as is often done with toll roads for emergency vehicles and buses). Figure 2-5 shows two example online registration interfaces, including a thumbnail copy of the I-95 Express carpool registration form, and a screenshot of the I-85 Express *Peach Pass*™ Change Toll Mode mobile smart phone app.

Figure 2-5 Example Online Carpool Registration Interfaces



95 EXPRESS 3+ CARPOOL REGISTRATION FORM

Register your 3+ carpool with South Florida Commuter Services by filing out the following form. For more information on 95 Express visit www.1800234RIDE.com or call 1-800-234-RIDE. Please return completed form to **South Florida Commuter Services, 5217 NW 33rd Avenue, Ft. Lauderdale FL 33309** or fax to **(954) 731-7319**

Carpooler #1

First Name _____ Last Name _____

Home Address _____ Apt. _____

City _____ State _____ Zip Code _____

Home Phone No. _____ Email Address _____

Cell Phone No. _____ Work Phone No. _____

Employer Name _____ Work Address _____

City _____ State _____ Zip Code _____

Work Schedule: Sun ___ Mon ___ Tue ___ Wed ___ Th ___ Fri ___ Sat ___ From ___ am/pm To ___ am/pm

☐ I ***will*** be using the following vehicle on the 95 Express. ☐ I ***will not*** be driving my own vehicle, I am a carpool passenger only.

Vehicle License Plate# _____ State of Registration _____ Vehicle Make & Model _____

I currently own a SunPass™ Transponder ☐ Yes ☐ No

Carpooler #2

First Name _____ Last Name _____

Home Address _____ Apt. _____

City _____ State _____ Zip Code _____

Home Phone No. _____ Email Address _____

Cell Phone No. _____ Work Phone No. _____

Employer Name _____ Work Address _____

City _____ State _____ Zip Code _____

Work Schedule: Sun ___ Mon ___ Tue ___ Wed ___ Th ___ Fri ___ Sat ___ From ___ am/pm To ___ am/pm

☐ I ***will*** be using the following vehicle on the 95 Express. ☐ I ***will not*** be driving my own vehicle, I am a carpool passenger only.

Vehicle License Plate# _____ State of Registration _____ Vehicle Make & Model _____

I currently own a SunPass™ Transponder ☐ Yes ☐ No

Carpooler #3

First Name _____ Last Name _____

Home Address _____ Apt. _____

City _____ State _____ Zip Code _____

Home Phone No. _____ Email Address _____

Cell Phone No. _____ Work Phone No. _____

Employer Name _____ Work Address _____

City _____ State _____ Zip Code _____

Work Schedule: Sun ___ Mon ___ Tue ___ Wed ___ Th ___ Fri ___ Sat ___ From ___ am/pm To ___ am/pm

☐ I ***will*** be using the following vehicle on the 95 Express. ☐ I ***will not*** be driving my own vehicle, I am a carpool passenger only.

Vehicle License Plate# _____ State of Registration _____ Vehicle Make & Model _____

I currently own a SunPass™ Transponder ☐ Yes ☐ No

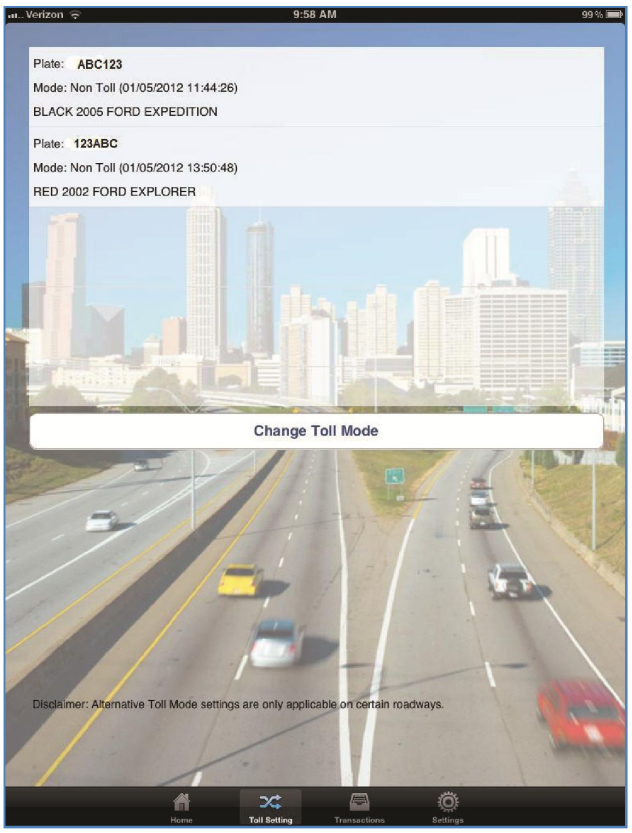
Signature required of each carpooler.

We believe this information is accurate to the best of our knowledge. We understand the qualifying criteria for the use of a 3+ carpool on the 95 express, located of the reverse of this form.

Carpooler #1 _____ Carpooler #2 _____ Carpooler #3 _____

** All personal information submitted to SFCS will be kept confidential. SFCS will verify the information provided. If SFCS finds any of this information to be false, registration will be denied.

** If you need space to identify additional carpoolers, please include the information requested above for poolers 1-3 on a separate sheet of paper.



2.5. Constraints Upon Pricing

As mentioned in various points above, the optimal pricing of a managed lane may be constrained by a variety of factors. These factors can prevent an econometric determination of price for the managed lanes. The primary constraints upon optimal pricing can be summarized as either geometric or policy.

Geometric issues include bottlenecks and access design. For bottlenecks, segment capacity may be limited to maximum throughput at the bottleneck itself. As such, the segment (or facility) is priced for the capacity at the bottleneck. The implication is that the facility cannot fully load with paying vehicles, provided the performance is maintained for the facility through the bottleneck. Managed lanes with such a capacity constraint, such as I-25 entering vehicles from Downtown Denver, do not achieve optimal pricing. Furthermore, access design and termini treatment can negatively affect optimal pricing. Vehicles entering and exiting a facility often do so at less-than-full speed. This weaving effect can create a shockwave in the managed lanes, depressing the total throughput capacity.

Policy desires may also have a negative effect on optimal pricing. The establishment of minimum and maximum rates is often perceived by decision makers as necessary to achieve public acceptance for managed lanes. However, in certain conditions, demand-driven prices may exceed the maximum rates, leading to either flow

breakdown in the managed lanes or necessitating closing the lane to LOVs as priced customers. As is the case in any imbalance between demand and price, speeds may decrease and volumes exceed capacities in these conditions. Conversely, a requisite minimum toll may be too high exceeding the prevailing value of time savings of potential customers leaving the managed lane facility underutilized despite latent demand being present. This imbalance could create negative perceptions regarding the underutilization of the managed lanes and could result in the loss of potential toll revenues.

Policy governors on net changes in dynamic pricing (affecting how price may escalate in terms of demand spikes) may affect price. If an algorithm does not have price smoothing, then price may fluctuate too severely within a short period of time, as occurred on I-394 (Minneapolis) in the first year of implementation. Conversely, if the price is not allowed to increase rapidly, demand for the managed lane may exceed capacity resulting in congested conditions before the toll can be increased sufficiently to address the imbalance.

2.6. Interaction with Active Traffic Management

One new element in priced managed lanes is the inclusion of Active Traffic Management (ATM). ATM improves safety and reliability across all lanes of traffic. In particular, speed harmonization may help delay the onset of congestion. As a result, the ATM system may have a relationship with the managed lanes in terms of the optimal pricing.

In the U.S., ATM is included whenever managed lanes are to be implemented using shoulder pavement. Presuming the desirability of left-side managed lanes (due to speed differentials and desire to avoid interchange conflicts), there are two likely demonstrations of managed lanes with ATM. The first involves dynamic lane assignment, as is currently performed on I-66 in Northern Virginia. In this case, during active hours, the general purpose lanes are shifted to the outside shoulder, while the leftmost general purpose lane becomes an HOV lane. Lane control signals and other signage control this condition. For priced managed lanes, such an implementation requires the phasing of pricing implementation. The process would be to first shift the lane, and then allow toll vehicles into the newly created managed lane.

The second scenario involves a dedicated shoulder lane assignment, as is currently done on I-35W (Minneapolis). In this case, the left shoulder becomes an active lane of traffic in operational periods (reverting to refuge in the off-peak). Although ATM is deployed to manage the shoulder, the operations of the priced managed lane resemble that of a typical buffer or line separated managed lane. It should be noted that ATM is also used on I-35W for segments not utilizing a dynamic shoulder; these segments are primarily open access.

Figure 2-4 Active Traffic Management on I-35 W in Minneapolis

Photograph source: MNDOT

3.0 IMPLICATIONS OF THE PRICING APPROACH

3.1. Traffic Management

As the Phoenix-area HOV network is examined for conversion to priced managed lanes, the policy objectives indicate this should be done without detriment to carpool and transit market share. However, this determination is based upon the current ability of the HOV network to actively manage demand. Some regional HOV lanes are already congested at certain times of the day under the HOV 2+ eligibility criterion. Without pricing, maintaining travel time savings in these HOV lanes would require an increase in vehicle occupancy requirements (from HOV 2+ to HOV 3+) with commensurate impacts to general purpose lanes when as much as 85 percent of the current HOVs with only two-occupants are removed, with many moving back into the general purpose lanes. This phenomenon was most notably witnessed during the recent opening of managed lanes on I-85 in Atlanta, where the impact of the shift in HOV 2 traffic from the HOV lanes to the general purpose lanes following conversion to a managed lane was underestimated, and the managed lanes dynamic tolling algorithm was not sensitive enough to be able to adequately respond to balance demand between the lanes. This situation, in part, led to the subsequent substantial public and political backlash against the I-85 project.

Absent a mechanism that regulates the admission of lower-occupancy vehicles into HOV lanes following a change in the minimum occupancy requirement, most regional corridors would likely have significant underutilized capacity when higher occupancy restrictions take effect, similar to the effect illustrated in Figure 3-1. In this scenario, the preservation of travel time benefits to multi-occupant vehicles takes precedence, but without new and significant HOV 3+ formation, person throughput in the HOV lane would likely take many years to reach the levels observed prior to a need to raise the occupancy criterion. By allowing LOVs to buy their way into the lanes for a fee, throughput (or related objectives) can be maximized, as shown in Figure 3-2, while maintaining toll-free benefits to the highest priority high-occupancy vehicles.

Pricing for the management of traffic on the HOV network suggests a hierarchy of users for the managed lane system is most appropriate, with transit vehicles receiving highest priority consideration, followed by multi-occupant vehicles (in order, vanpools, HOV 4+, and HOV 3), then HOV 2, and lastly single occupant users. In any situation, if the requirement to partially restrict access is present, continued access for the highest-priority users should be preserved. Specific performance thresholds may serve as "triggers" in the life cycle, so as to preserve benefits on the managed lane network to the highest priority users. In other cities, the performance thresholds have been primarily defined either as average Level of Service (San Diego), minimum speeds (Minneapolis, San Francisco, Houston), or travel times (Denver). The appropriate performance thresholds, as defined, will identify triggers in changing not only the real-time price of the lanes, but also access and eligibility for premium services. Notwithstanding other countermeasures to address breaches in the thresholds such as expanding the number of lanes or reducing access, the pricing and occupancy restriction policy should target the best approach that meets both near-term and long-term needs for the affected roadway segment.

Figure 3-1 HOV Lane Lifecycle

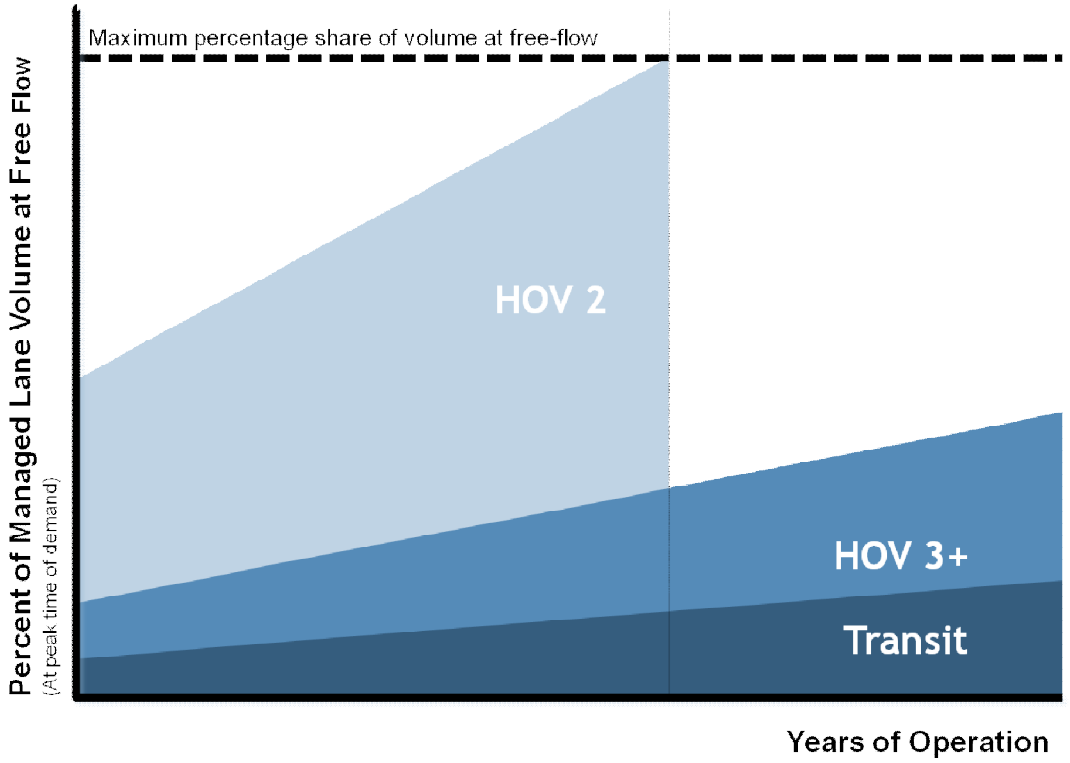
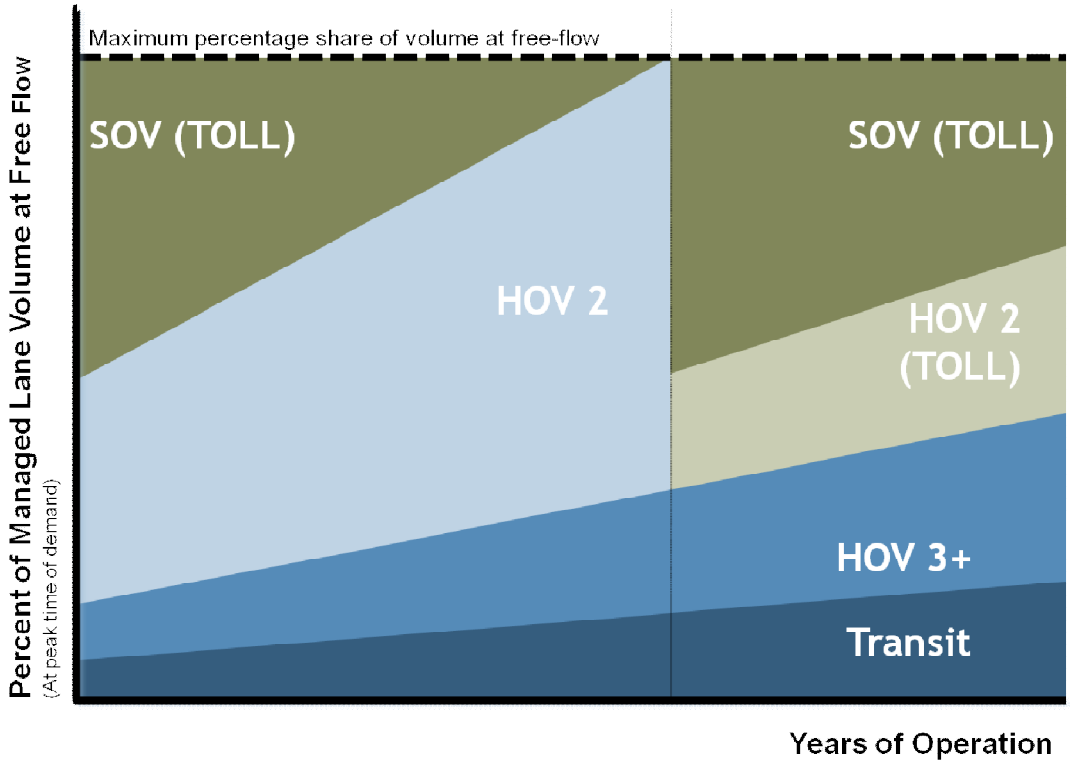


Figure 3-2 Managed Lane Lifecycle



From a thresholds perspective, managed lane capacity can be defined by a maximum allowable traffic flow rate (traffic volume measured in number of vehicles per hour per lane) or traffic density (a product of traffic flow rate divided by traffic speed measured in number of vehicles per mile). Once a managed lane capacity level is determined (based upon segment, facility, or system), tolls are set in such a way to keep the managed lane traffic at or below that level.

A number of studies have assumed the need to preserve a LOS C or better condition on the priced managed lanes to ensure that the user is gaining travel and reliability benefits or, in some cases, to meet legislative requirements (e.g., California law for the I-15 Managed lanes) or contractual obligations (e.g., full funding grant agreement for the I-25 express lanes). A 1,600 vehicles per hour (per lane) threshold may be appropriate as a default basis reflecting the optimum representation of current operating conditions on the region's most successful HOV lanes. Additionally, FHWA requires a minimum 45 mph performance threshold for HOV lanes converted to HOT lanes.

3.2. Customer's Response to Pricing

Upon the decision to conduct a trip to a set destination, a traveler faces three primary decisions between departure and arrival: choice of mode, route (if applicable), and lane (if applicable). Mode choice will inevitably determine the appropriateness of other choices. For example, if the traveler decides to drive, the traveler will need to make decisions regarding route and lanes to use while en-route. Conversely, if the traveler decides to ride transit, these decisions have, in part, been removed for that portion of the trip (recognizing that route use can be a decision factor for riding transit).

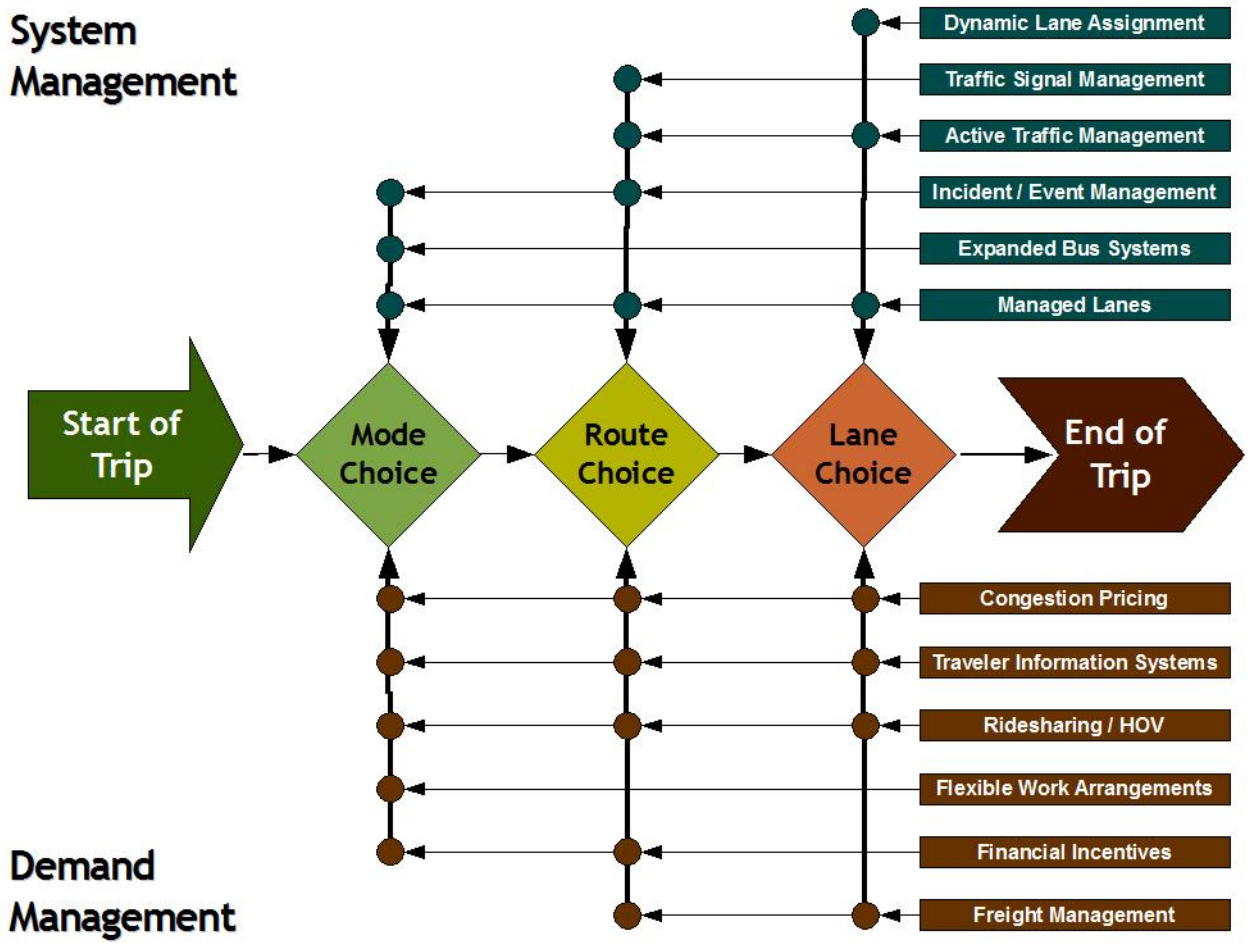
A variety of demand and system management strategies can be applied to influence these decisions for mode, route, and lane choice. As shown in Figure 3-3, congestion pricing and priced managed lanes are among the few strategies that can affect all three decision points. The question is determining how and to what extent these strategies affect the choices.

Market research of managed lanes users has repeatedly found that travel time savings and travel time reliability are the two primary factors motivating the use of priced managed lanes. Placing a monetary value on these factors is the mechanism by which congestion pricing works. However, as noted in the literature, estimating the value of travel time savings and reliability is complicated because an individual's value of time savings and reliability can vary by the moment, depending on what is happening in their lives at that time. Although some toll paying customers of priced managed lanes use these facilities on a regular basis (i.e. daily or several times per week), the majority of toll paying users of priced managed lanes only use them on an occasional basis (i.e. once a week or a couple times a month) when they most need a time savings benefit.

Regular toll paying users of managed lanes represent drivers who place a high value upon the reliability offered by the managed lanes. This valuation may be somewhat disconnected with the incidental travel time savings actually realized for any particular trip, or the perception of travel time savings and reliability may be greater than realized for this group. Occasional toll paying users of managed lanes include users who are more sensitive to realized conditions, the price of use, and the purpose of the trip.

These users are more likely to place different values of travel time savings based upon different reasons for tripmaking. Furthermore, the value of travel time savings will inherently be different between priced managed lane users and general purpose lanes.

Figure 3-3 System and Demand Management Strategies Effects on Traveler Choice



As noted by a Texas A&M University study of the I-10 Katy Managed Lanes users, urgent or out-of-the-ordinary trips are more likely to carry a substantially higher value of travel time savings over that of a typical trip (see Table 3-1). As could be expected, those running late for a meeting or appointment have a much higher value of travel time savings; what is unexpected is the large factor separating this condition from ordinary commuter travel (approaching 5.5 times greater). This response to priced managed lanes extends across all income levels, with lower income travelers often having higher average value of travel time savings than higher income travelers. The reason for this may be explained by schedule inflexibility. Regardless, the data indicates that for the purpose of estimating a customer's response to pricing on the managed lane network, consideration of the incidence of special situations within a travel market may be more important than market average income rates.

Table 3-1 Mean Value of Travel Time Savings ($/hr)

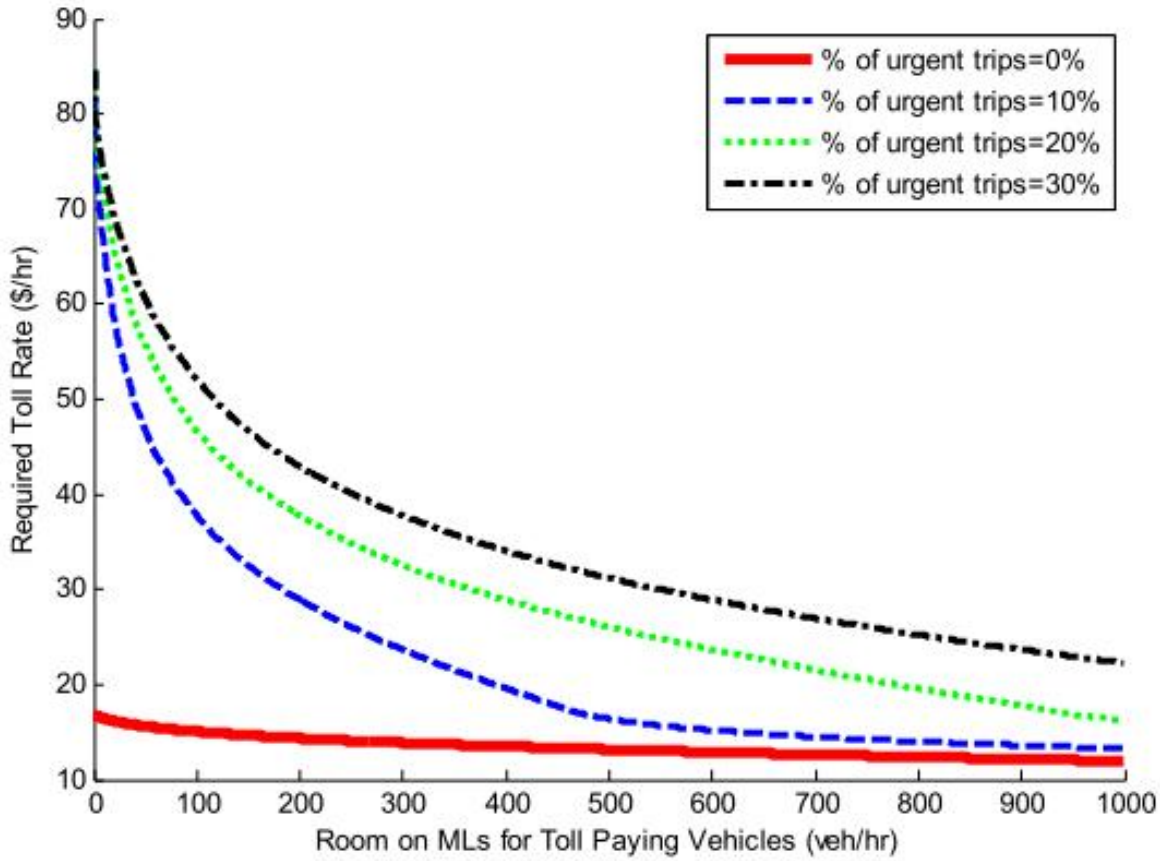
Situation	Annual Household Income		
	Less than $50,000	$50,000 - $100,000	More than $100,000
Ordinary commute	7.9	7.4	8.6
Headed to an important meeting or event	18.7	15.9	22.8
Running late for an appointment or meeting	35.2	27.9	47.5
Worried about arriving on time	25.0	21.5	30.0
Expecting potential traffic problems due to bad weather	13.9	12.2	16.0
Left late knowing the managed lanes were available for use	17.0	15.0	19.6
Need to make extra stops but still arrive on schedule	9.0	8.3	9.8

Source: Burris and Patil (2009)

As shown in Figure 3-4, assuming that all travelers are on ordinary commutes (as is commonly done on stated preference surveys and in calculating the value of time for traffic and revenue estimation) will greatly underestimate the true value of travel time savings, and as a result, the use of the managed lanes. This is important not only for revenue estimation, but also to reflect the composition of users of the facility. As those with urgent conditions have significantly higher values of travel time savings, they will comprise the initial base of users for the managed lanes, and, for whom a dynamically-priced toll will be set. Furthermore, if deciding in favor of a fixed-by-time-of-day variable toll rate or flat fee, the fees must be set with this user group in mind.

Finally, it should be noted that within the context of a managed lane network, with travelers using multiple segments on potentially separate (but connected) corridors, these effects may be amplified: the larger the network, the greater the aggregate travel time savings. Contemporary efforts to conceptually outline the pricing for connected networks in San Francisco and Houston have emphasized pricing by segment, as opposed to facility or systemwide pricing. This allows certain segments to carry higher prices than other segments. However, the anticipated detriment is potential customer confusion of the price per trip.

Figure 3-4 Estimated Toll Rate by Available Capacity



Source: Burris and Patil (2009)

3.3. Objectives of Pricing

The purpose of congestion pricing is to create market equilibrium between the effective supply of lane capacity (subject to maintaining performance objectives) and the demand for that premium trip. Congestion inherently indicates an overconsumption imbalance between supply and demand. However, identifying the appropriate supply function with which to equate demand for priced managed lanes involves an examination of pricing objectives.

A variety of factors affect the demand for trips in managed lanes, as demonstrated in the literature. These factors include:

- Density of population and activity at termini and access points along an managed lane corridor;
- Prevailing income profiles for travel markets; and
- The aforementioned trip conditions or reasons for making a trip.

Altogether, these factors affect the priced travel elasticity of demand for a managed lane trip. The price elasticity of demand varies with the price level for each potential customer. Reflecting the previous discussion on value of travel time savings in urgent

conditions, demand for such trips would tend to be fairly inelastic or insensitive to price. A toll rate of $14, for example, may be only a small deterrent for urgent trips relative to a $7 toll, as these travelers may place a very high valuation of travel time savings in this case. For other trips with less urgency and a lower value of time, the difference between $7 and $14 may result in a significant reduction in demand, suggesting that demand represented by these travelers is relatively elastic or price sensitive.

Conversely, the supply of lane capacity (measured as the direct and societal costs of providing lane space) is a fairly flat or linear curve until the lane or facility approaches its capacity limit and congestion results, where the social or network time costs borne by existing uses to provide one more vehicle space becomes excessively high — the point of flow breakdown. Given that a typical general purpose lane can carry in excess of 2,000 vehicles per lane per hour before becoming congested, the marginal "supply" cost is approximately the same whether the facility is carrying 200, 1,000, or even 1,600 vehicles per lane per hour. With the onset of congested conditions and flow breakdown as demand passes 2,000 vehicles per lane per hour, the supply curve turns sharply upward, reflecting the rapidly rising costs of adding an additional vehicle to the lane that are borne by existing travelers and society in terms of time delay, emissions, and lost productivity.

Economic efficiency is met at the price (both monetary and time costs) where the supply and demand relationships intersect: the marginal cost of travel to the individual is equal to their own costs of travel plus the marginal cost of that traveler's trip upon society reflected in the toll price. Excessive traffic demand beyond this point carries exponentially rising social costs. Although the establishment of an optimal equilibrium price is economically efficient, the ability to produce this condition through pricing is constrained by the objectives of the pricing program, manifest in tradeoffs, and the inability for all travelers to react rationally with perfect pricing information. These tradeoffs form the basis of pricing policy, and not all objectives of the program can be accomplished to the same degree.

The most apparent tradeoff is that pricing for economic efficiency — akin to throughput optimization — puts the level of demand served perilously close to the point where, in an imperfect world beset with uncertainty, an additional vehicle may enter the traffic flow, the weather may change, or an erratic driver action could trigger flow breakdown, with the result being congestion and inefficient operation. Imperfect information and the resulting uncertainty in responses by travelers necessitate setting a price higher than that required for theoretical economic efficiency. To the extent that potential pricing objectives for the managed lanes may favor revenue generation, travel time savings and/or preserving free-flow speeds over throughput optimization to maximize the use of capacity, then they involve a tradeoff from the concept of economic efficiency.

The body of research often discusses the tradeoff between pricing for revenue generation versus demand management. In the case of optimizing revenue generation, the applicable measures of effectiveness are the cumulative revenue generated by the facility (the summation across a measure of time for the price of entry for each traveler), imposition of marginal pricing (capturing higher values of travel time

savings first), and increasing vehicular throughput (in order to maximize the customer base). A revenue optimizing system may attempt to reduce exemptions and discounts, unless they serve the purpose of increasing the paying customer base, or the revenue optimization is explicitly recognized as being constrained by exemption and discount policies. By comparison, the measures of effectiveness for demand management pricing emphasize travel time and free flow speed maintenance, increased person throughput, and higher average vehicle occupancies. This system will incentivize higher occupancy vehicles so as to achieve greater corridor production (measured as carrying more people).

The observed differences between these two systems may not be obvious or intuitive, however, and their objectives may not be mutually exclusive. Depending upon the specific market factors, the demand management price may be higher than the revenue generation price or customer volumes may be less in the revenue generation condition, for example. Another complication is that neither system of pricing captures the highest demand price of access (meaning, the highest price that each individual customer is willing to pay). At a given price for which customers are willing to pay to travel, the majority of them would have been willing to pay more, as the price is set for a customer on the margin. If the customer is willing to pay the price, it means that the benefit to the traveler is *greater than or equal to* the toll cost.

As both revenue generation and demand management attributes are incorporated within any pricing scheme, the challenge facing MAG is how to balance the effects of each objective within the pricing system. As with any management system, capabilities and limitations of the pricing system will have consequential effects on achieving the pricing objectives. Consistent application of any tolling program, let alone congestion pricing as envisioned for the managed lanes network, is important to customer understanding and as an equitable means of adopting and implementing a tolling policy. Overall, the business rules must anticipate all scenarios, and apply them consistently. Calculating the appropriate toll rate depends upon a variety of critical data. For the managed lanes, and as informed by the peer facilities, these may include:

- Balancing the needs of revenue generation and demand management within the toll algorithm;
- Establishing differential toll rates by vehicle class and occupancy
- Determining minimum toll rates for uncongested conditions, maximum toll rates for saturated conditions on general-purpose lanes, maximum toll rates for incidents on the managed lanes; and
- Determining toll rates for downstream segments from point of entry (e.g., charged the prevailing toll per segment or the “entrance toll” locked in at point of vehicle entry to system).

Variable rate schedules according to a fixed schedule have more simplified calculation of tolls, but still require balancing of objectives, differential rates by occupancy or class, and special event/incident rates.

3.4. Pricing System

Operational and system parameters affect the customer's use of the pricing system. There are multiple points of contact with the customer:

- Hours of Operation. When are the managed lanes open and accepting customers? Many HOV facilities, including those in the Phoenix area have operated only in the peak hours and/or peak direction; priced managed lanes sometimes reflect these hours of operation (such as in Minneapolis and Seattle) or operate throughout all times of day (Houston, Denver, Miami). Further discussion and detail on hours of operation is provided in the MAG Managed Lanes Hours of Operation White Paper.

- Exemptions. Exemptions and discounts can be offered by vehicle occupancy, class, or other qualifications. All *operational* priced managed lanes offer free access to at least HOV 3+, although Miami's program is sufficiently restrictive so as to minimize the total number of customers making use of this exemption, and other facilities under development in Texas do not carry an HOV exemption (see Table 3-2). In order to provide exemptions or discounts, it is necessary to determine the declaration mechanism. All but two facilities (SR-91 and I-95) are opt-out facilities (HOV declaration is accomplished by not deploying a transponder). SR-91 requires a transponder, but provides a separate HOV 3+ declaration lane in its toll zone, whereas I-95 requires registration of carpools in order to nullify tolls through back office accounting. Further discussion and detail regarding exemptions and occupancy requirements is provided in the MAG Managed Lanes Occupancy Policy White Paper.

- Communication of Price. In order to make an informed decision concerning use of the priced managed lanes, the customer must understand the price for making his or her trip. The more complicated the system of pricing (e.g., per mile pricing), the more difficult it will be for the customer to estimate the trip cost. Some facilities (Denver, Orange County) have opted for a fixed variable fee schedule, so as to allow for customer anticipation of toll rates. Other facilities rely upon in-field communication (dynamic signage, radio broadcasts) to relay dynamically changing prices.

- Lock in of Price. After communicating the price, the customer must have reliance the price will not change once he or she has committed to use of a managed lane toll segment or facility (although prices could change between segments along a multi-segment facility, if so desired, allowing the customer to exit the facility at no penalty, as is the case on I-15 in Salt Lake City). The business rules must be robust in order to allow for locking in the price while within a segment or facility.

- Overrides. In certain cases, conditions will deteriorate rapidly within the managed lane facility. In this situation, refunds or toll negation may be necessary as travel time reliability is jeopardized. Furthermore, diversion of general purpose traffic into a managed lane may also be necessary during periods of incident response.

Table 3-2 Carpool Pricing Policies on Priced Managed Lanes

Carpool Preference Combinations		HOV 3+				
		Free 24/7	Free Peak Periods Only	Free Off-Peak Periods Only	Discount Peak Period Only, Pay All Other Times	Pay 24/7
HOV 2	Free 24/7	I-15 (CA), I-110 (CA)*, I-680 (CA), I-25 (CO) , I-394 (MN), I-35W (MN) , I-15 (UT) , SR 167 (WA)				
	Free Peak Periods Only		I-10 (TX)			
	Free Off-Peak Periods Only	I-10 (CA)*, US 290 (TX)				
	Discount Peak Period Only, Pay All Other Times				I-30 (TX)*, I-635 (TX)*	
	Pay 24/7	SR-91 (CA), I-85 (GA), I-95 (FL), I-595 (FL)*, I-495 (VA)*, I-95 (VA)*				TBX (FL) Loop 1 (TX)*

* Pending facilities

The following is an example of the proposed pricing system in San Francisco as a means to illustrate how these points work in the pricing system. The toll rate is calculated on a skewed per-mile basis (e.g., 50 cents per mile), but the price communicated to the driver is rolled up into one price per segment (e.g., "$2.50 to Main Street" representing $0.50 per mile over 5 miles). Each segment may be comprised of one or more ingress-egress pairs; however, the segments should comprise a major destination (measured by exiting ramp volume, in this case, Main Street) so as to be an understandable and recognizable landmark for travelers. The total toll cost is rounded to the nearest $0.25 for ease of system and customer accounting. Finally, toll prices conveyed to the traveler may be signed as a total toll cost to the next exit, a major intermediary destination, and the final corridor destination.

In this example, the demand-prevailing per-mile toll rate will not just be reflective of current managed lane traffic demand in any given segment, but also reflective of downstream bottlenecks and other traffic conditions that may serve to meter the available capacity upstream. This skewing of the demand curve aims to reduce the effects of overloading in specific segments. The target threshold for rate setting is 1,650 vehicles per hour per lane – a general volume equivalent for Level of Service C conditions. However, a measurable performance target will also be set to ensure travel speeds of 45 miles per hour or better at all times within each segment. Additional contributing factors to the algorithm will include adjoining general purpose lane speeds and density.

Given the length, interconnectedness, and complexity of the network, pricing and behavioral instability could result without the application of some form of maximum toll, since the per-mile rates which might be needed to manage demand on certain sections of roadway could result in through-trip tolls which are so high as to discourage them. As a result, the system requires the active monitoring of pricing and behavioral characteristics, and the establishment (or adjustment) of a maximum toll rate for each segment if the performance threshold has been breached.

4.0 PRICING POLICY OPTIONS

The findings from this analysis are used to examine key issues and options for the managed lanes pricing approach in the Phoenix area.

4.1. Pricing System

Sustainable performance requires the ability to price managed lanes relative to the level of congestion with segments of each facility. This objective rules out the use of flat fee and system pricing, as these would not allow for sustaining performance across the system. Fixed-schedule variable and dynamic pricing, however, have both proven capable of providing this reliability. Options and tradeoffs are shown in Table 4-1 Pricing Table 4-1.

Table 4-1 Pricing System Approach Options

Option	Pros	Cons	Experience
Static Variable Pricing System (Fixed Toll Schedule)	• Predictability of toll charge • Generally higher rates of revenue • Permits static signage • Does not require specialized tools • Well suited for termini in arterial/grid settings	• Performance monitoring required, to ensure scheduled toll adequacy • Higher overall toll rates • Limited active management • Peak shoulder pricing performance	• I-25 (Denver) • SR-91 (Orange County) • I-10 (Houston)
Dynamic Variable Pricing System (Near Real-Time Tolling)	• Demand-based toll price • Highest level of active management • Lower overall toll rates • Automation capability	• Reduced levels of revenue • Requires dynamic signage • Potential for driver confusion/erratic response • Requires specialized tools	• I-95 (Miami) • I-15 (San Diego) • I-680 (Bay Area) • I-394/I-35W (Minneapolis) • I-85 (Atlanta)

4.2. Pricing Interval

A consistent customer experience on the managed lane system will be informed by a combination of interactions with the customer. These interactions include consistency of reliability (e.g., travel time reliability, operational status, etc.), usability (e.g., vehicle occupancy eligibility, hours of operation, toll system, roadway design, etc.), and pricing (e.g., algorithm, pricing interval, etc.). As it pertains to the pricing component of customer consistency, the recommendation is confined to applying a consistent pricing algorithm (particularly in the case of dynamic pricing) and to pricing interval. In terms

of the pricing interval, system pricing is unproven as a concept and likely unmanageable across a diverse system. The remaining options, per-mile, per-segment, and per-facility, are workable, but come with benefits and challenges (see Table 4-2). Per-segment pricing is recommended as the most effective of the options, as discrete segments are communicable to customers (via signage) and price levels can be refined for congested segments. This has the effect of leveraging many of the advantages of per-mile pricing without as many detrimental effects upon operations. Per-segment pricing can also be used in conjunction with per-facility pricing for full length trips on multi-segmented facilities, as is the case on I-15 in San Diego and proposed for I-10 and I-110 in Los Angeles.

Table 4-2 Pricing Interval Options

Option	Pros	Cons	Experience
Per Mile	• Ease of toll setting • Able to apply detailed toll rates by mile • Maximizing efficiency of toll rates per mile	• Requires extensive signage • More difficult for drivers to comprehend • Encourages weaving around high price areas • Price sensitivity distortions • Lack of predictability	• Static toll systems (bridges, roads, etc.) • Underlying toll calculation on managed lanes facilities
Per Segment	• Permits pricing isolation of congested sections • Easier for drivers to comprehend • Able to set different pricing objectives by segment • Limited intra-segment weaving	• Inter-segment weaving • Lack of predictability for downstream segments • More complex signage	• I-95 (FL) • I-394/I-35W (MN) • I-10 (TX) • I-680 (CA)
Per Facility	• Simplified price communication • Easiest for drivers to comprehend • Reduced signage • Reduced operations expenditures	• Unable to manage spot congestion • Requires pricing the bottleneck • Yields higher average toll rates than demand would otherwise require	• SR-167 (WA) • I-25 (CO) • SR-91 (CA)

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