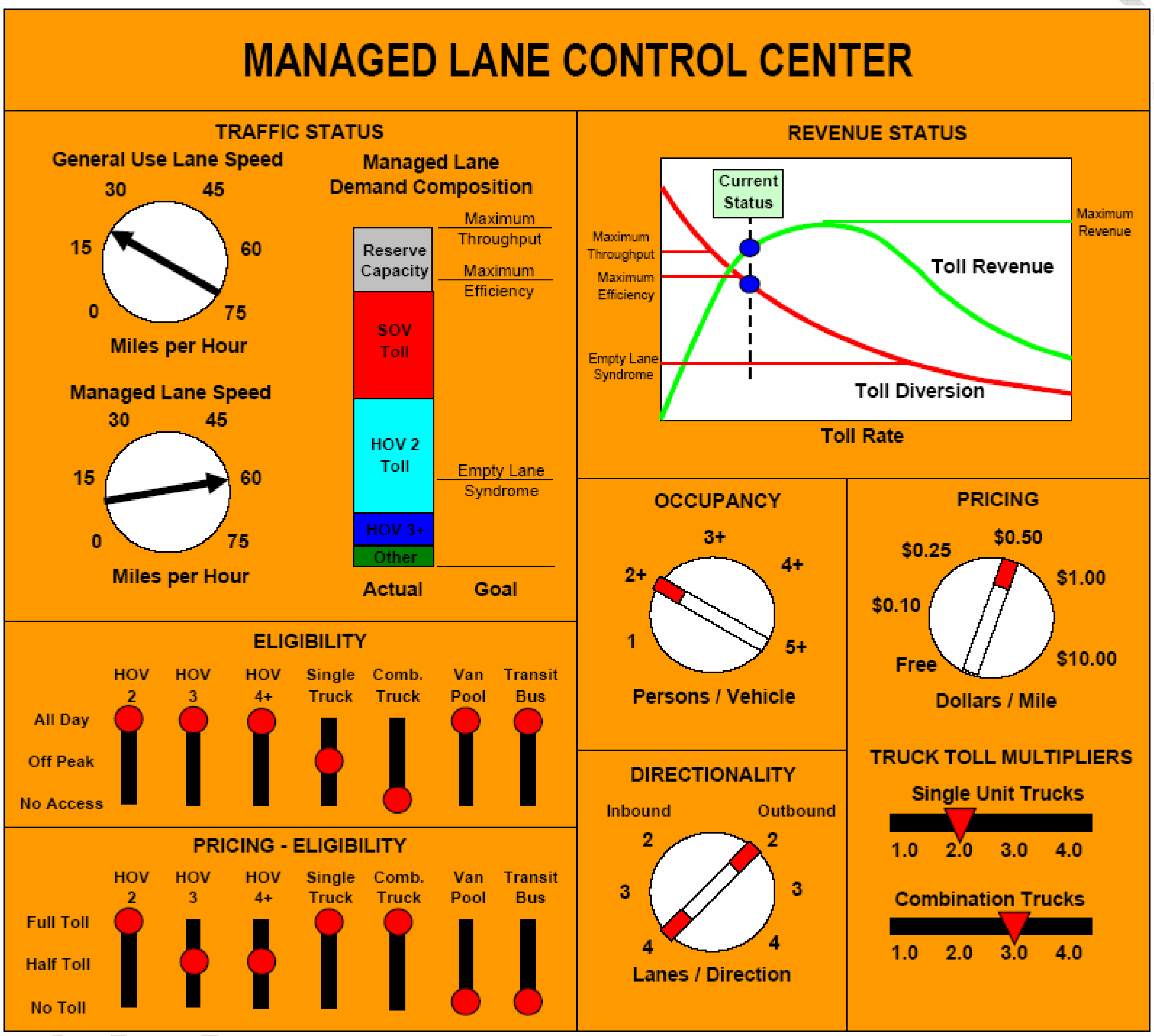
Technical White Paper

Active Transportation Management Strategies using MANAGED LANES

Introduction to Strategies and Techniques



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Preface

Population and employment growth in metro areas such as Dallas/ Fort Worth continues to increase demand on urban transportation networks. As growth continues, transportation infrastructure – which has not kept up with traffic growth in the past – must be managed more effectively to accommodate growing traffic demands. The economic consequences of unreliable transportation performance will accentuate the need to find solutions. The current political climate and constraints in transportation infrastructure funding have placed added pressure on states and local agencies to provide new transportation demand management strategies in their respective regions. Managed lanes provide an effective means to restore mobility and reliability by providing an "escape valve" for eligible users along candidate corridors.

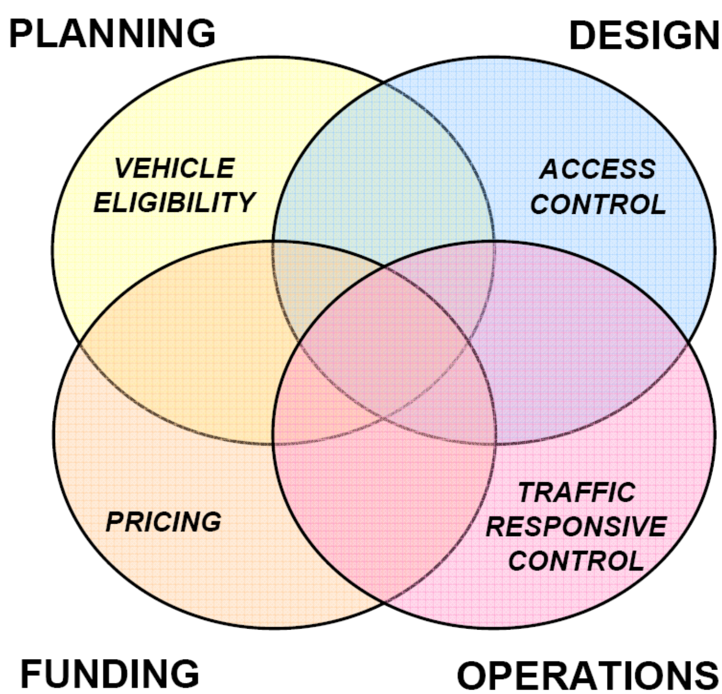
This white paper was developed during the IH-30 Tom Landry Highway Preliminary Level 2 Managed Lane Toll Feasibility Study for the Dallas District of Texas Department of Transportation (TXDOT) and the Texas Turnpike Authority (TTA). It introduces the concept of managed lanes as a flexible tool for managing corridor operations and describes the conditions under which different strategies may be better suited. The paper provides a description of the main concepts and objectives related to managed lane implementation with further elaboration and detailed descriptions provided as an appendix.

The Concept of Managed Lanes

Freeway systems are the crucial backbone of nearly every urban area's transportation system. Growing travel demand continues to strain these systems to the practical limits of performance. Since options for additional capacity are limited, existing facilities must be managed more effectively and there is a general realization that communities cannot build themselves out of congestion. Latent demand in most moderate to hyper-congested corridors is significant in that any new capacity quickly reaches its full utilization. The managed lane concept creates and preserves a portion of the highway capacity to act as a potential "escape value" for users needing a reliable transportation alternative. These facilities are geared to the traveling public that is urgently in need of a reliable trip, and most of whom may be occasional/infrequent users. The concept of managed lanes therefore is focused on providing a safe, convenient, reliable transportation alternative for eligible users in order to meet specific performance objectives and criteria.

Managed lane objectives are achieved using a mixture of operating strategies that originate from planning, design, operations and funding considerations, as depicted in Figure 1.

Figure 1
Origins of Managed Lane Operating Strategies



Strategies from any one source can potentially prevent congestion in the managed lanes and depend on the transportation characteristics of the corridor in question. Most corridors, however, require that a combination of strategies be implemented to fully optimize lane capacity utilization and generate revenues to build, operate and maintain transportation infrastructure where needed.

Vehicle eligibility strategies are a product of planning and congestion management practices, while access control strategies are developed through the design process. The traffic responsive control strategies include elements of traffic management practices, and pricing strategies originate from the need for new transportation infrastructure funding sources. All four elements in different combinations can be used to optimize multiple objectives such as lane utilization, funding, throughput, and system operation reliability. Typically, pricing strategies combined with eligibility strategies play an important and flexible role in managing the demand along a facility.

The "control center" depiction in Figure 2 on the following page provides a simplified sense of the flexible package of managed lane operating strategies that can be used to meet different transportation objectives. The flexibility and diversity provide many different combinations that, depending on the traffic demand conditions, can achieve the same give optimal objective.

The top of the control panel contains status displays that measure the corridor and managed lane performance in real time, including toll revenue generation status. Switches and knobs below the status displays illustrate how some strategies provide "discrete control" using thresholds (such as vehicle occupancy), while others provide "continuous control" over a range of settings (such as toll rates). Discrete controls have a large scale impact on traffic operations while the continuous controls provide the flexibility to "fine tune" performance towards optimal levels.

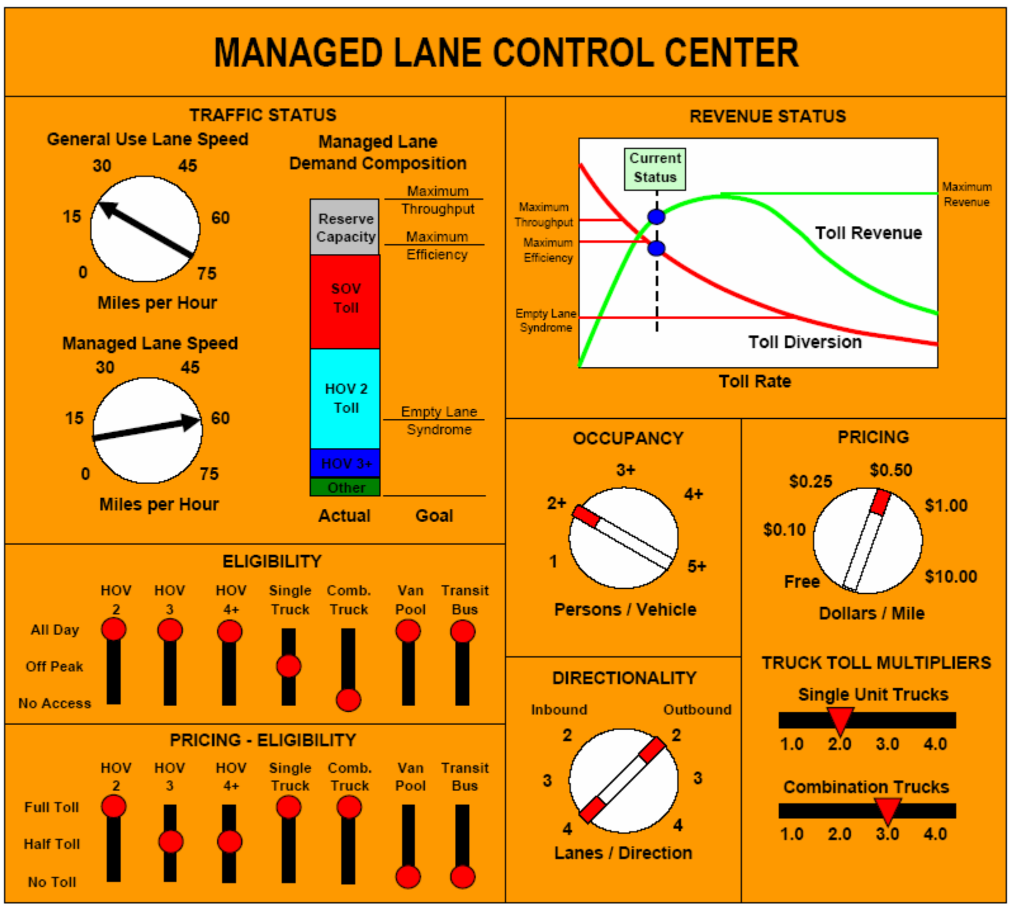
Key considerations regarding managed lane control strategies must include:

- lane management as a goal to optimize utilization of the lane,
- an understanding that changing traffic conditions and characteristics may warrant changes to the combination of operating strategies applied within individual corridors and across the different facilities,
- a degree of flexibility within the strategies to respond to changing traffic conditions that is dependent on the level of uncertainty and volatility in corridor demand and operations,
- an appreciation that any given combination of strategies will not necessarily produce optimum performance for multiple objectives at the same time, and
- the need for a monitoring and reevaluation process that periodically modifies the desired package of objectives in response to fundamental changes in corridor traffic characteristics on a long-term basis.

The level of complexity associated with managed lane implementation therefore requires flexibility and experimentation to achieve the best compromise among objectives. Monitoring of the facility also becomes a necessary function to provide advanced notice of when current objectives are no longer met due to changing traffic characteristics.

The next section describes the various objectives that are typically considered in concert with the operational strategies that can be implemented as part of a managed lane project. Appendix A contains an overview of landmark projects that played a role in the evolution of modern managed lane practice and a tabular list of existing, committed and planned managed lane facilities across the country.

Figure 2
Simplified Illustration of Flexible Control



Transportation Management Objectives

Transportation infrastructure is normally built to meet objectives that fall into three general categories: operational objectives to optimize the utilization of the managed lane facility, financial objectives to generate revenue and user objectives to improve travelers' experience on the facility. The most common objectives under each category are briefly described below with a more comprehensive description provided in Appendix B.

Operational Objectives

- ***Congestion management:*** Managed lanes can influence corridor demands by shifting the inherent distributional characteristics of the corridor and can improve mobility and reliability for eligible users needing the reliability of a congestion-free alternative.
- ***Throughput maximization***: This objective maximizes either the person or vehicle volumes of a corridor through appropriate managed lane operating strategies.
- ***Operational efficiency:*** Managed lane operating strategies that maintain high operating speeds while maximizing throughput achieve the best level of efficiency.

Financial Objectives

- ***Revenue maximization:*** This objective produces the highest total revenue the travel market can sustain through continuous optimization of toll rates in response to travel market demand and congestion levels.
- ***Revenue target:*** This objective seeks to achieve a specific level of total revenue to meet a defined cost/liability target.
- ***Economic efficiency:*** This theoretical objective sets tolls at levels equal to the marginal economic cost imposed by additional travelers on a congested transportation system. It has never been used in practice.

User Objectives

- ***Safety:*** This objective applies operating strategies that produce traffic conditions that minimize accident risk.
- ***Reliability:*** This objective maintains traffic operations at a level that minimizes the variation in travel time.
- ***Convenience:*** This objective minimizes additional effort required to take advantage of a managed lane facility.
- ***Cost Effectiveness:*** Managed lanes can reduce user costs associated with congestion. These benefits can be quantified to optimize benefits against toll costs.

The prioritization between the operational and financial objectives is highly dependent on the importance that revenue generation plays in the funding of the project. The user objectives are usually a lower priority and are addressed to the extent possible within the constraints of the selected operational and financial objectives.

Managed Lane Operating Strategies

Operating strategies for managed lanes can be defined in four distinct categories: eligibility, responsiveness, pricing, and access control. The *vehicle eligibility*, *traffic responsive control* and *pricing* strategies focus primarily on demand-side considerations. *Access control* strategies encompass facility design characteristics that are related to the supply-side considerations. In general, more restrictive and inflexible strategies require a more frequent re-evaluation as corridor travel conditions change. Strategy restrictions and simplicity, therefore, have a tendency to limit the flexibility required to manage demand over the potential range of traffic conditions. On the other hand, a comprehensive and flexible set of managed lane operating strategies will limit the frequency of such re-evaluations but may require more effort to implement.

Eligibility Strategies

The early history of managed lane implementation is dominated by application of eligibility strategies to limit traffic on the managed lanes and avoid congestion. These strategies consist of lane use restrictions based on vehicle type or person occupancy to achieve the operational objectives. The following are some examples of eligibility strategies:

- ***Vehicle Occupancy:*** This strategy restricts eligible use of managed lanes to high-occupancy vehicles (HOVs), which could include transit buses. The occupancy strategy supports person throughput and/or person efficiency objectives. The definition of minimum occupancy is used to manage the number of vehicles in the lane to remain below a targeted capacity/level of service.

- ***Vehicle Type:*** This strategy restricts eligible use of managed lanes to specific vehicle types. Restriction for transit buses in the form of a busway or restriction for trucks in the form of truck-only-lanes, provides a mechanism to managed demand for an exclusive market and can improve vehicular throughput and/or efficiency and safety.

Eligibility strategies applied alone may not provide sufficient control to optimize managed lane operations against defined objectives. For example, switching from a two-occupant to a three-occupant HOV requirement generally removes so much traffic from the managed lane that both vehicle and person throughput are reduced (this can result in the low-volume “empty lane syndrome”). Eligibility strategies can be combined with traffic responsive control and/or pricing strategies to better utilize the excess capacity that may occur.

Traffic Responsive Control Strategies

Managed lanes improve traffic flow within a transportation corridor using operational strategies dependent on prevailing traffic conditions. As traffic conditions change, managed lane strategies must also adapt accordingly. Traffic conditions that are more sporadic (thus less predictable) require greater flexibility within the operating strategies.

The following list describes different levels of "temporal control flexibility" from least to most flexible can be implemented as part of any one strategy:

- ***Fixed:*** Operating strategies do not change throughout the day in response to operational conditions. Strategies are only changed after prolonged statistics indicating poor performance of the current strategy package.
- ***Time of Day:*** Time of day operating strategies are applied during defined time intervals that are determined through periodic analysis of corridor traffic characteristics.
- ***Variable (Static):*** Operational strategy changes are triggered by defined traffic performance thresholds and implemented through specific variable set of control measures.
- ***Demand Responsive (Dynamic):*** Strategies can change continuously throughout the day in response to changing traffic conditions and are implemented through a dynamic demand responsive set of control measures.

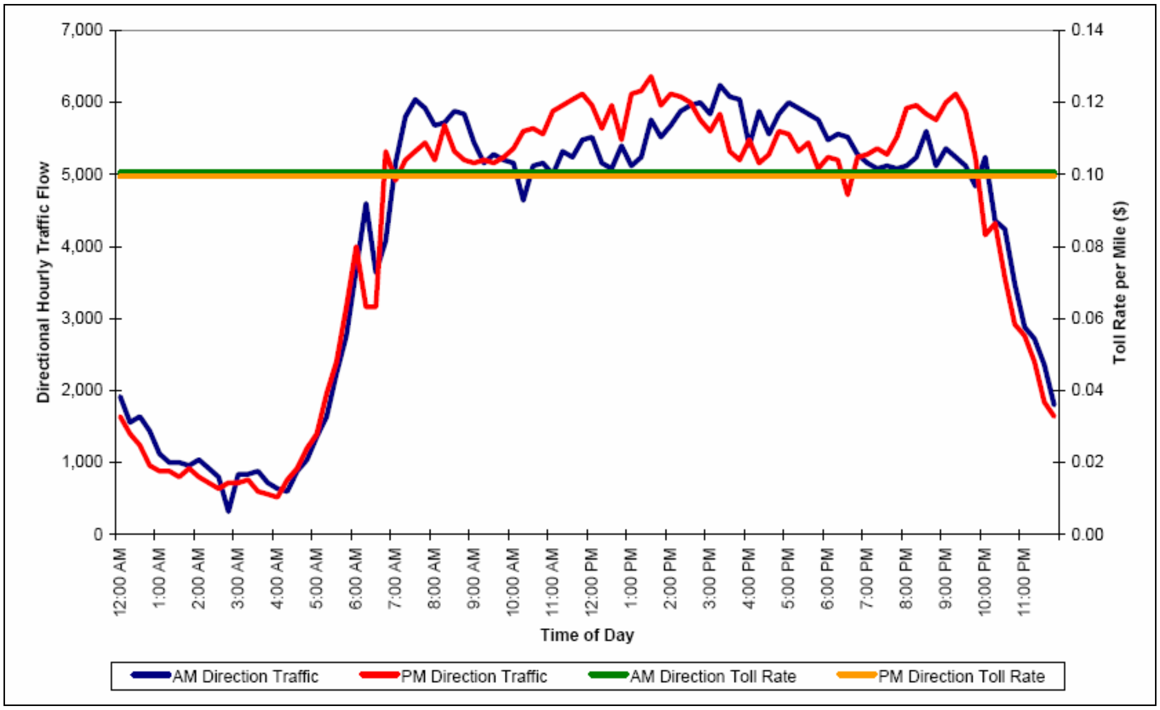
Pricing Strategies

Pricing strategies provide a flexible mechanism to fine tune traffic demand patterns to meet traffic management objectives such as throughput and/or efficiency maximization. Pricing allows for the regulation of facility demand by charging a toll and can be used in concert with eligibility strategies and/or traffic responsive control strategies. Pricing improves lane utilization by allowing non-eligible users to "buy in" to the unused capacity of the facility.

The following section illustrates some temporal pricing strategies that can be implemented to suit defined 24-hour corridor traffic flow patterns. The patterns are charted in 15-minute increments (left vertical axis) to illustrate the level of variability in traffic flow in each direction of travel. Each chart also provides an illustration of how toll rates may be varied (right vertical axis) in response to changing traffic flow rates.

Fixed/Set Pricing: Under this pricing strategy, toll rates are fixed for all users and all times of the day. A toll rate sensitivity study is typically conducted to determine a suitable fixed toll rate that is high enough to maintain a target traffic demand level. This pricing mechanism is best suited for facilities with stable traffic volumes throughout the day with no distinct high peaking characteristics and when demand management is not a significant issue as shown in Figure 3.

Figure 3
Traffic Flow Pattern – Fixed Toll Rates



Fixed/Peak Pricing: Under this pricing strategy, higher fixed toll rates are used in the heavy volume direction during the peak, with a lower rate used during the off peak periods. Peak period pricing can encourage peak shifting of some traffic as a result of discounted rates during off peak periods, which could increase the overall throughput of the facility. This strategy is most effective where traffic patterns exhibit a consistently stable, high-volume peak period and stable, lower volumes during all other periods as shown in Figure 4.

Scheduled/Preset Pricing: Under this pricing strategy, the toll rates are set to account for the defined changes in traffic demand along the corridor. The exact segmentation of the periods is determined by the traffic characteristics and can include peak, shoulders and off-peak periods. Like the fixed/peak strategy, this can encourage better utilization of capacity during off peak periods. This strategy is most effective when traffic patterns are stable within more than two different levels, and/or there are consistent and stable day-to-day fluctuations as shown in Figure 5. A four-tiered variable pricing strategy is illustrated in the figure.

Figure 4
Traffic Flow Pattern – Fixed Peak/Off Peak Toll Rates

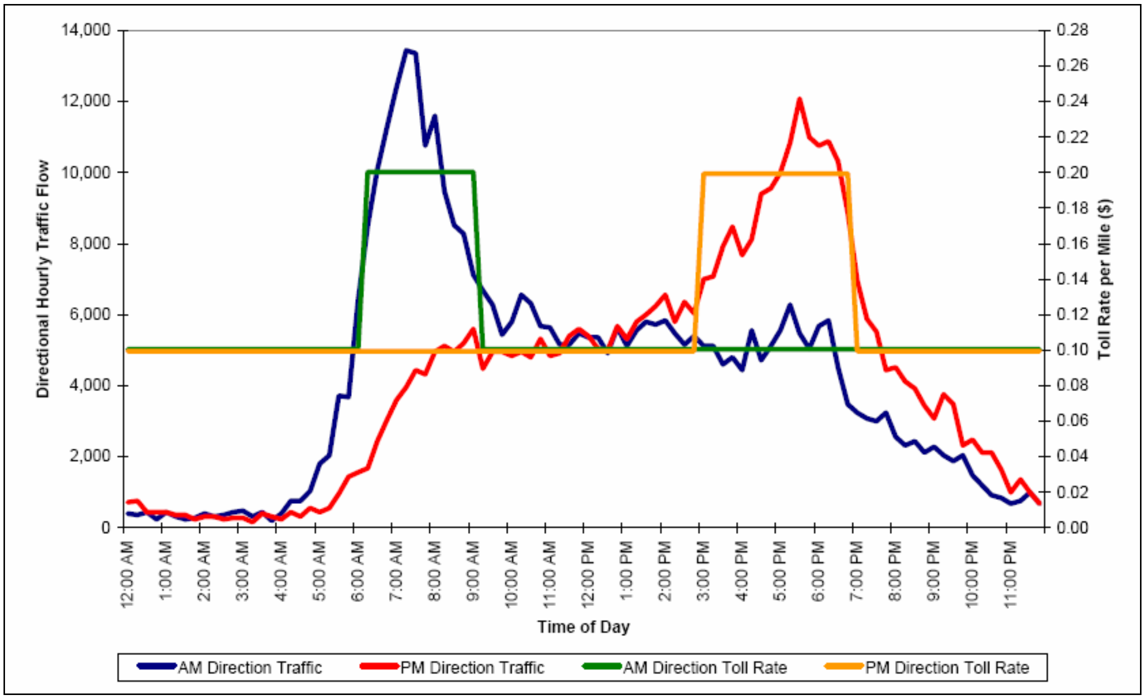
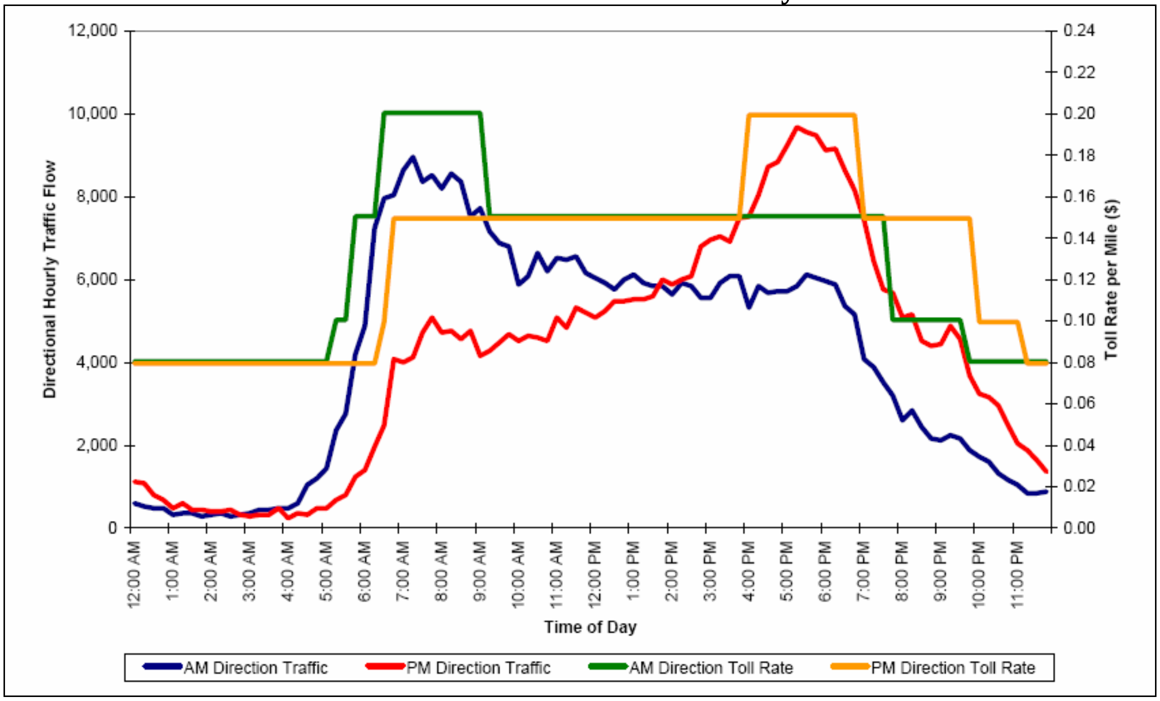
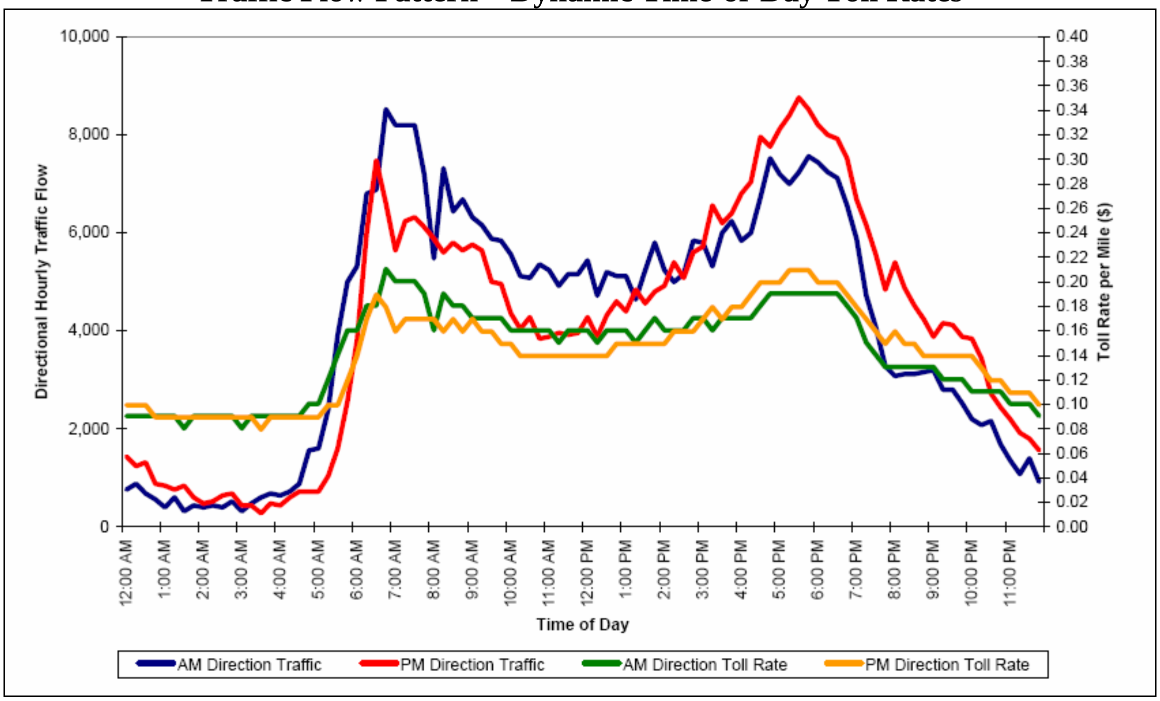


Figure 5
Traffic Flow Pattern – Preset Time-of-Day Toll Rates



Dynamic Pricing: Under this pricing strategy, toll rates are dynamically linked to traffic performance based on traffic conditions monitored in real time. Toll rates can vary at intervals of 3 to 15 minutes, and can be set to whatever level is necessary to achieve defined objectives. This pricing strategy is most effective in conditions where the traffic volumes are extremely high, volatile and/or sporadic, thus requiring constant toll rate adjustments to ensure performance objectives are met. This strategy is best suited for corridors that continuously experience reliability problems and are prone to high incidents and/or special event traffic as shown in Figure 6. The dynamic nature of this pricing strategy makes it the most capable of managing traffic demands to achieve throughput and/or efficiency objectives.

Figure 6
Traffic Flow Pattern – Dynamic Time-of-Day Toll Rates



Access Control Strategies

Access control strategies are physical characteristics of managed lane facilities that determine where they can be accessed and the degree of protection provided against the friction of congestion in adjacent general purpose lanes. These physical attributes affect both demand and supply-side considerations. On the demand side, fewer access points limit the patterns of traffic that can access the facility. On the supply side, both access constraints and cross-section design characteristics affect the useable (hence reliable) capacity of the lanes. A list of physical attributes of a managed lane is included below. Appendix C contains more detailed description of these individual attributes.

- ***Type of Traffic Separation:*** Barrier, pylon, buffer or striped

- ***Number of Access Points:*** Provides a trade-off decision between cost and size/distributional characteristics of user market.
- ***Type of Access Points:*** Continuous, limited indirect, limited-direct or express (end points only)
- ***Number of Lanes per Direction:*** Multilane facilities can provide more operational flexibility with a higher revenue generation potential.
- ***Shoulder Size:*** Consideration for reliability and safety.

The most common manner in which the above access control strategies are applied to different managed lane cross-section configurations are briefly listed below with a more complete description provided in Appendix D:

- ***Dual–Divided Lanes:*** This configuration splits at least two lanes in each direction from other lanes using a physical barrier.
- ***Concurrent Flow Lanes:*** These lanes run along-side existing general purpose lanes and are separated by striping.
- ***Two-way Barrier Separated Lanes:*** These lanes are physically separated from the general purpose lanes, thus providing natural enforcement.
- ***Contra Flow Lanes:*** This configuration uses non-peak direction lanes to accommodate the peak direction traffic flow.
- ***Reversible Barrier Separated Lanes:*** These are permanent reversible lanes that do not require closure of off-peak direction travel lanes. These are best suited for traffic characteristics that exhibit large distributional splits during the peak periods.

Other Operating Strategies

Concerns regarding equitable access to managed lane facilities invariably result in experimental operating strategies to address perceived equitability issues. One recent operating strategy is referred to as the *fair and intertwined regular* (FAIR) lane strategy[1]. Under this strategy, users of non-tolled traffic lanes (with toll transponders) can accumulate credits based on the number of trips made on the general use lanes. After a defined number of such credits are accumulated, they can be exchanged for a free trip on the tolled managed lanes. (This operating strategy is conceptual and has not been implemented at this time).

Other strategies could include providing toll account subsidies to low income travelers using public transportation funding in a manner similar to mass transit fare subsidies, or making toll payments tax deductible (eligible transportation expenses) for low income travelers.

[1] "Clearing Existing Freeway Bottlenecks with Fast and Intertwined Regular Networks: Cost, Benefits and Revenues", Patrick DeCorla-Souza, Office of Transportation Policy Studies, FHWA,TRB Paper 3993, November 2003

Merging Objectives and Facility Characteristics – Identifying Suitable Management Strategies

The strategies previously discussed present a complex list of options to consider when developing a suitable strategy package for a managed lane facility. Combining strategy options is not always possible to achieve optimum performance for all objectives at the same time, primarily because the objectives counteract one another. As such, the development of a strategy package must prioritize and weight multiple objectives to achieve a balance among financial, traffic operations, and user objectives.

Where no pricing strategies are applied, managed lane strategies are limited to eligibility strategies that achieve a combination of operational and user objectives. Since eligibility strategies provide very few options to regulate traffic in the managed lanes, it can be difficult to achieve optimal performance of objectives such as throughput or efficiency.

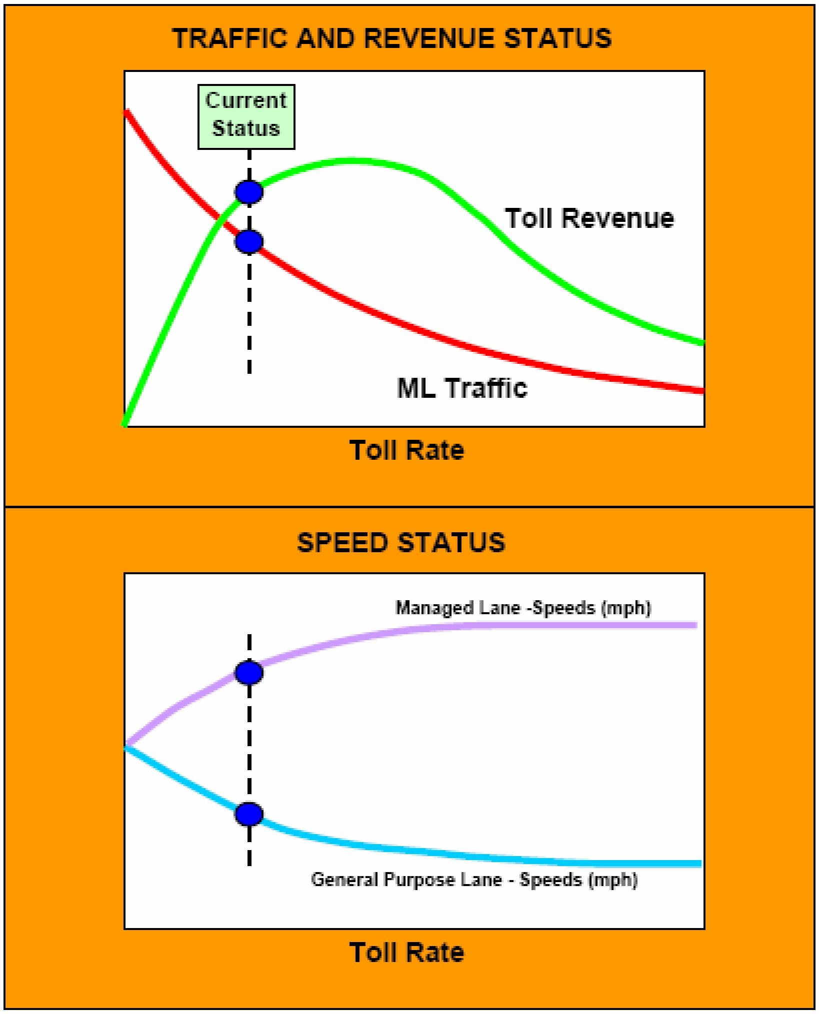
With busway and truck-only facilities, vehicle eligibility strategies are normally managed by adequately sizing the facility to handle the expected demand. If necessary, truck lanes can be managed by prohibiting trucks with a certain number of axles from using the facility.

With occupancy-based eligibility strategies, as corridor demand patterns evolve, additional strategies may be needed to facilitate optimization of throughput or efficiency. Pricing strategies add more options to manage traffic demand and potentially optimize toward specific objectives. Pricing on a per mile basis along a managed lane facility is an effective means of ensuring that users are paying fully for their use of the managed lane facility.

Pricing strategies also play their part in regulating the travel speeds between the general purpose lanes and the managed lanes themselves as depicted in Figure 7. At low toll rate levels on the managed lane, the traffic in the managed lane quickly deteriorates as a significant amount of users and latent demand access the additional managed lane capacity. Increasing the toll rates begins to divert users away from the managed lanes and back into the general purpose lanes, improves the managed lane speed at the expense of the general purpose lanes' speed. A balance between the speeds in the managed and general purpose lanes is therefore necessary under a throughput maximization objective to ensure that adequate volumes are processed through the corridor. This can generally be achieved through a weighted matrix that evaluates the overall corridors effectiveness and speed deterioration for all corridor users.

It should be noted that managed lanes typically attract a wide spectrum of infrequent users from multiple markets with different willingness-to-pay characteristics and sensitivities to congested travel times within the general purpose lanes. This wide cross-sectional market that a managed lane facility attracts has the effect of making a single pricing strategy very hard to fully quantify as to its effectiveness. Fixed pricing strategies

Figure 7
Managed Lane versus General Purpose Speeds



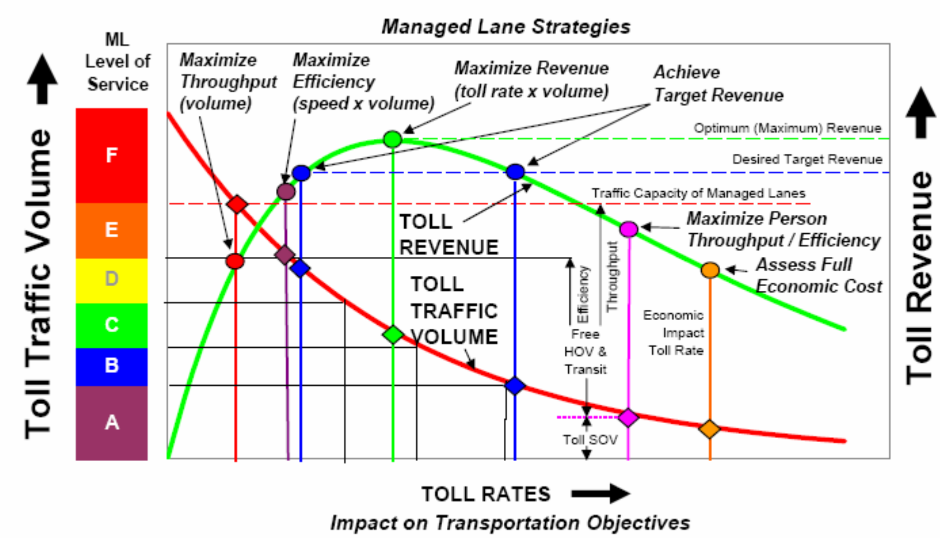
implemented along a corridor that serves multiple markets may be suitable for one chosen segment, but may not be as effective along another segment within the same corridor. This is especially critical for facilities that traverse several economic activity areas. Balancing the complexity of the pricing strategies with the length of the corridor to address these variations in market is a critical component to ensure that one segment of the managed lane does not break down to the extent that it creates a damaging ripple effect to the upstream traffic in the corridor.

The complexity with which pricing strategies interact with a managed lane facility's operational and revenue objectives is further described and shown in Figure 8.

- The red curve illustrates the *tolled traffic* (portion of potential traffic that uses the managed lane) as a function of increasing toll rate. This managed lane traffic volume decreases from the maximum potential level at the zero toll rate levels, to a minimum volume at high toll rate levels. The green curve illustrates the *total* *revenue* as a function of toll rate level and traffic demand. As the toll rate increases, less traffic uses the facility, and the level at which this reduction occurs is dependent on the income distribution of travelers in the corridor and their willingness-to-pay characteristics.

- The colored pairs of diamond-shaped and circular points indicate hypothetical traffic and revenue levels under specific management objectives.

Figure 8
Managed Lane Operating Strategies versus Objectives



Impact on Transportation Objectives

ML Congestion (Speed)	Poor	Fair	Good	Best	Best	Best
ML Throughput (Volume)	Good	Best	Good	Fair	Fair	Poor
ML Efficiency (Speed x Volume)	Fair	Good	Best	Good	Fair	Poor
ML Reliability / Safety	Poor	Poor	Fair	Good	Good	Best

Impact of Managed Lane Strategies: ◆ *Tolled Traffic* ● *Toll Revenues*

- Each managed lane facility will have a maximum revenue generation point as depicted by the horizontal green dashed line and is referred to as the *revenue optimum/maximization* toll rate. This is the level of traffic volume and toll rate that meets the *maximum revenue* objective. Increasing the toll rate beyond this level yields lower toll traffic and less revenue potential.
- The vertical axes show color bands indicating the traffic operations *level of service* (LOS) under the different toll rate level conditions. Note the horizontal hypothetical red dashed line depicting the *traffic capacity* of the managed lane. If tolled traffic exceeds this capacity, the managed lane becomes congested (LOS F). This level of traffic defines the *maximum throughput* threshold beyond which the managed lane could not physically carry any additional vehicular traffic. As shown for this illustration, the *maximum revenue* toll rate yields a LOS C traffic flow scenario.

- *Maximum efficiency* of the managed lane is achieved when throughput is fairly high – less than maximum capacity – with a good level of service that yields reliable speeds. This point can be defined as the boundary between LOS D and E.
- The blue dashed horizontal line shows an example of a *target revenue* objective. It is worth noting that the target revenue can be achieved at two different toll rates. At the lower toll rate level, the managed lane traffic levels result in LOS D operations, while the higher toll rate levels results in LOS A operations (empty lane syndrome). A toll rate level selected between the two extremes would satisfy the revenue target objective and achieve a varied level of service criteria (throughput efficiency).
- Toll traffic and revenue conditions for a hypothetical *maximum person throughput* or *maximum person efficiency* are also depicted simultaneously. If a sizeable portion of managed lane capacity is allocated to eligible non-tolled users (carpools or transit), the toll rates may need to be set high enough to force the buy-in non-eligible demand down to match the limited reserve capacity of the lane. This type of operation can once again achieve two objectives. If objectives include a *target revenue*, and either *maximum person efficiency* or *throughput,* application of the higher *target revenue* toll rate could reduce tolled demand levels low enough to accommodate carpools and transit without tolls, thus achieving both objectives.
- If the *full economic cost* levels reflect the need for high toll rate levels, then the managed lanes may be underutilized (empty lane syndrome) with a LOS A traffic flow pattern on the facility.
- A series of transportation objectives and associated ratings can be developed as shown by the color-coded matrix below the graph. Note that the ratings for each scenario will vary by level of service in such a way that no level of traffic (or level of service) will necessarily produce conditions that are optimum for all four objectives. As such, a combination and trade-off must be made to prioritize the various objectives.

The structure and effects of Figure 8 are highly dependent on the characteristics of the managed lane corridor and will vary for different times of the day, travel markets, and regional locations – sometimes within the same corridor. During the extreme case, the managed lane demand may be too high thus requiring very high tolls to maintain reliable speeds and prevent congestion. At the other extreme, low toll rates may be required to improve lane utilization. Facility design can also influence strategy effects. For example, a barrier separated facility may provide more reliability and safety compared to a buffer separated facility.

Linking Strategy Packages to Managed Lane Operations

The managed lane strategies can be classified into four distinct categories related to planning, design, operations and funding and can be combined into multiple strategy packages. A combination of any one of these four main elements provides a different managed lane operating package that can be used to achieve a desired objective. The greatest and most flexible managed lane strategy would be achieved by combining all four strategies.

Spatial access control limits the entry and exit locations to the managed lanes, while temporal access control limits the times in which the lanes may be accessed by different market segments through either ramp metering or market-based pricing mechanisms. Ramp metering, however, does require resolution of more-complex traffic operational issues during the design process. The next section describes the complexity associated with the managed lane development process, that includes the evaluation of operating strategies, design and access concepts, to meet the desired objectives.

Managed Lane Implementation

The implementation of a managed lane facility requires the evaluation of a myriad of elements, as depicted in Figure 9. The process begins with an investigation /implementation phase, which leads to construction of a managed lane facility under certain initial operating strategies with the intent to meet defined primary objectives. Upon implementation of the project, an ongoing monitoring, evaluation and adjustment process is then needed to refine or modify the operating strategies as conditions deviate from the opening year conditions.

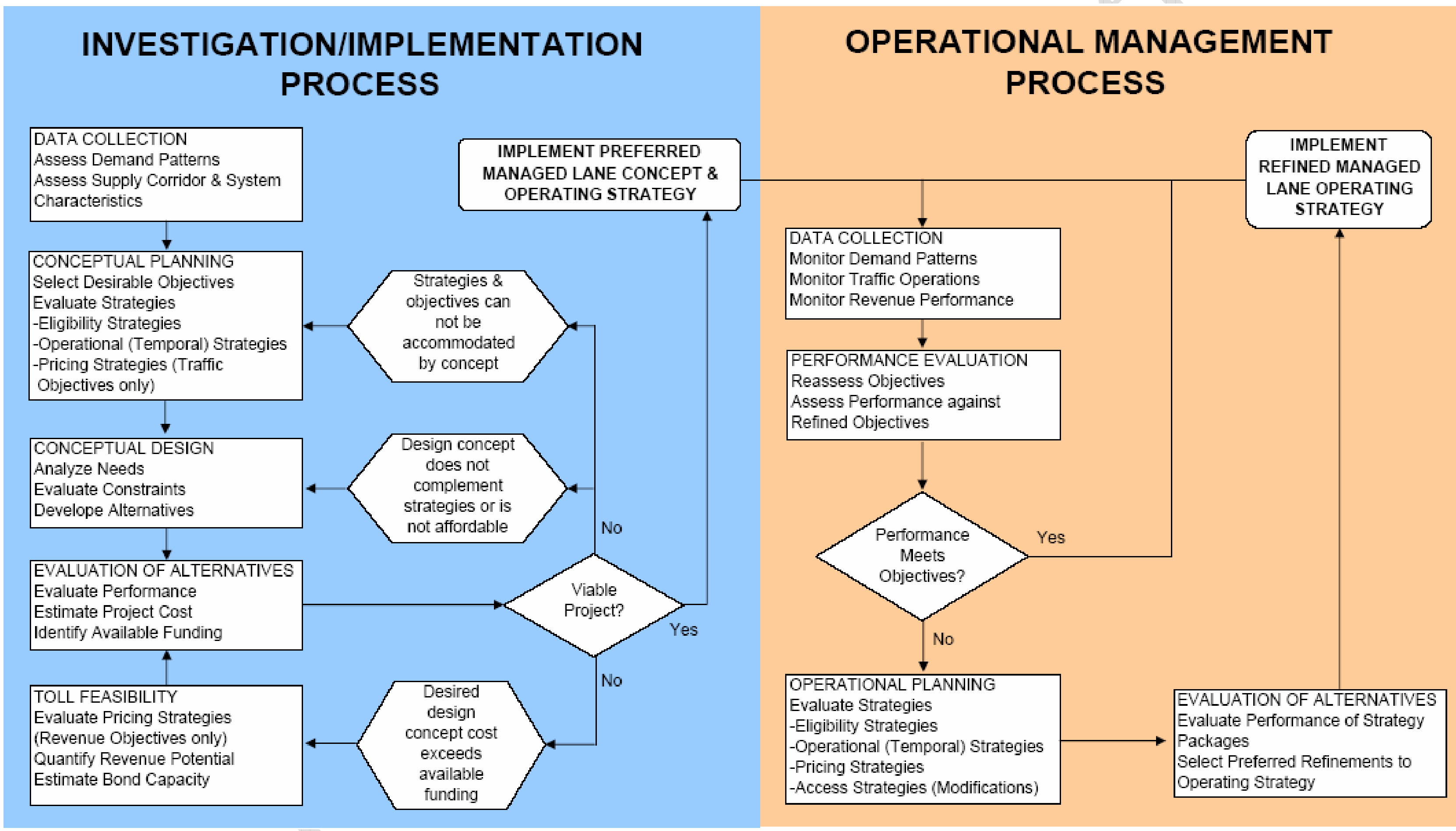
The managed lane investigation/implementation process on the left side of Figure 9 is a rational sequence of procedures and considerations required to identify candidate operating strategies, evaluate cross section design and access requirements, and assess the effectiveness of the project against specific management objectives. The process is an extension of the project implementation process that leads to a conceptual design and operating strategy for the managed lane project. When pricing strategies are incorporated, the process includes a toll feasibility evaluation process during the early stages. Financial management objectives are weighted against operational and user objectives to achieve a viable business plan that quantifies toll revenue as a funding source for use in implementing the project, and/or operating and maintaining it.

Major elements of the process include data collection, conceptual planning, conceptual design, performance evaluation and toll feasibility. Each one of the elements has an influence on the other such that a feedback loop is necessary when evaluating the suitability of the strategies to meet established objectives. The individual elements of the implementation process are briefly described below.

Data Collection

A data collection effort is generally necessary to obtain the geometric and operational information within a corridor that helps in assessing what strategy packages and design concepts would be effective to manage the travel markets that the facility will serve. Data elements needed to perform an effective analysis can be classified into three groups: characteristics of the transportation demand, characteristics of the transportation supply, and the regional highway network characteristics.

Figure 9
Managed Lane Evaluation Process Flow Chart



Conceptual Planning

Conceptual strategy planning links the corridor travel characteristics to appropriate operational strategies and design characteristics to achieve desired objectives. This process can begin with the operational and user objectives to see if a viable concept can be identified that meets defined objectives. If the objectives cannot be achieved solely using eligibility, operational and access control strategies, pricing strategies can then be accessed to gauge their effectiveness in achieving the operational and user objectives. Obviously, if the project requires additional funding sources outside of the available tax funding, revenue objectives may begin to take on a higher priority.

The sequential process typically used to help identify candidate strategies begins with a look at the eligibility strategies. Their effectiveness is assessed in relation to the size and composition of the eligible user groups that would be best served by the managed lanes. The operational flexibility is then evaluated to address the fluctuating and volatile nature of the identified corridor demand to determine the proper segmentation of the markets into respective time periods. Finally, pricing strategies are integrated to complement the eligibility and operational strategies. The pricing can also be used to fine tune/optimize the demand to satisfy the desired overall objectives.

Conceptual Design

The conceptual design evaluation considers the corridor's physical constraints and influence of traffic characteristics in establishing a concept for the facility. Design characteristics are briefly summarized below:

- ***Project Limits:*** The length of the managed lanes should extend through the entire length of congested operations in the general use lanes.
- ***Directionality Evaluation:*** The directionality of traffic patterns determines whether a one-way reversible facility will be more effective than a two-way facility.
- ***Access Pattern Evaluation:*** An evaluation of ramp volumes and any available origin-destination data reveals the most effective locations for managed lane access.
- ***Lane Requirements and Cross Section Design:*** Available right-of-way may dictate practical limitations to the cross section of a managed lane facility.

As part of this conceptual design, another critical factor that must be considered pertains to the communication and signage of the managed lane strategies. The level of complexity for managed lane strategies are in most cases constrained by the amount of information that can be effectively relayed to the users of the facility. Multiple price segmentations by vehicle type, eligibility and time period can very quickly become too overwhelming for the general traveling public. A simplistic and easy to understand strategy is therefore the recommended preference among existing practitioners. Drivers' abilities to interpret the signage coupled with the limited space most signs have to display the critical information to the travelers further supports the need for the implementation of a simplistic overall strategy. This is even more critical in the implementation of a long dynamically priced facility where individuals may experience several rate changes while they are traveling in the managed lane facility.

Merging of Strategies and Design Concept Options

Following the determination of effective strategies and possible design concepts, the two are merged to achieve a set of possible project implementations. Managed lane strategies provide a wide range of travel demand management options that can be made to adapt effectively to changing conditions regardless of physical or operational constraints. The flow chart at the beginning of this section illustrates a feedback process to reassess objectives, strategies and concepts based on factors other than viability (cost versus funding and revenue). The natural sequence in determining a suitable managed lane strategy for a defined corridor includes:

- Evaluate the managed lane capacity and access requirements to support desired eligibility/operations strategies.
- Evaluate the order of magnitude of costs required to provide minimal, desirable and optimal design characteristics.
- Consider the trade-off between available funding and the cost to provide different levels of design.
- Consider flexible pricing strategies to assist in maintaining defined LOS criteria under different eligibility strategies that also provides the desired revenue generation potential.
- Prioritize the objectives and implement a strategy package that is best suited to meet the established objectives.
- Provide the flexibility to restructure the strategies as the corridor characteristics evolve.

Ongoing Monitoring and Maintenance of Managed Lane Facilities

Upon implementation of the managed lane facility, a monitoring system is necessary to evaluate the effectiveness of current operating strategies and to determine when a refinement or restructuring becomes necessary. The right half of Figure 9 illustrates the typical ongoing management and maintenance process for managed lanes implementation. Key components include the monitoring of demand patterns and performance, assessing options to improve performance, refining operating strategy packages and procedures and, in some cases, refining objectives and priorities.

As travel patterns evolve, so will the need to enhance operating strategies from fixed/peak to variable, or variable to dynamic control levels. A fundamental change in demand patterns, transportation network characteristics, and/or policies may also provoke the need to refine the overall objectives and priorities applied to a managed lane facility from time to time. The advancement of technology in the implementation of toll collection systems, violation enforcement, vehicle occupancy detection, and vehicle classification systems all play a role in the degree of flexibility available for different strategy implementation. For example, by 2009, all vehicles manufactured in the U.S.

will be equipped with an identification transponder. These technologies will serve to reduce costs and expand the range of available strategies currently not available.

Appendix E contains a few lessons learned from implementation of previous managed lane projects, and discussion of two common issues associated with implementation of managed lanes and tolling policies.

Conclusions

The implementation of managed lanes has received much attention in recent year to facilitate the growing congestion problems in many urban transportation networks where right of way constraints are prohibitive to capacity expansions. This is further accentuated by the growing need for additional funding sources to provide new transportation infrastructure. The managed lane concept provides a wide range of objectives and strategies that can be used to address the ephemeral nature of traffic demand in a transportation system. The growing public acceptance of congestion as a way of life, particularly in the urban regions, is perpetuated by the realization by most that new infrastructural capacity will not fully eliminate the congestion characteristics in the transportation system. Managed lane concepts, if implemented effectively, provide an “escape valve” away from the congested system for a selected few that value and need the occasional reliable transportation network.

The flexibility embedded within the implementation of managed lanes is dictated to a large extent by the volatile nature of the traffic characteristics and the priorities placed on the key objectives to be met. Many objectives exist and can be classified into three main components: congestion management, project funding, and system operations. The optimal achievement of all possible objectives is not always possible, given that they counteract and therefore yield conflicting outcomes. The development of a set of complementary strategies must therefore create a balance that weights the various elements to provide the most suited outcomes for a given corridor.

Traffic demand typically evolves with changes to the economic, social and technological characteristics of a corridor such that a very different set of strategies and level of flexibility may be required to maintain set defined objectives over the life of a managed lane project – even if the objectives are the same in nature between two distinct corridors. A careful consideration of the markets to be served, their inherent characteristics and the future growth trends in the corridor must be evaluated and monitored to ensure that the proper strategies are selected during implementation of the managed lane. These strategies may even need to vary within the same corridor depending on the diversity of markets that the managed lane corridor serves.

Vehicle eligibility, pricing and access control strategies provide for an abundant set of potential strategies that can be used to match the many different traffic conditions and sets of objectives. The key is in allowing for the flexibility within the strategies that are made available to address the changing conditions along a studied corridor, while making them simple and easy to communicate to the traveling public. The managed lane techniques can be used to develop options within the confines of existing facilities that offer a reliable alternative for those that need it most.

APPENDIX A

Managed Lane Facilities in the United States

Though managed lanes have existed for many decades using eligibility and access control strategies alone, more flexibility has been provided with the introduction of pricing mechanism as an additional strategy. This first occurred in 1996 with the opening of the SR 91 managed lanes in California. The table below summarizes some characteristics of existing managed lane corridors that have been implemented in the United States since then.

Table A-1: Characteristics of Operating Managed Lane Corridors in the US

Facility	**SR 91**	**I-15**	**I-10/US 290**	**I-394**	**NJ Tpk.**	**I-25**
Location	Orange Co.	San Diego	Houston	Minneapolis	New Jersey	Denver
Year Started	1996	1996	1998/2000	2005	1970's	2006
Previously HOV?	No	Yes	Yes	Yes	No	Yes
Length (miles)	10	8	13.0/13.5	12.8	33	7
Through Lanes	4	2	1/1	1	12*	2
Operating Mode	HOT	HOT	HOT	HOT	Truck/HOV*	HOT
Toll Collection	Variable	Dynamic	Variable	Dynamic	Time of Day	Variable
Orientation	Two-way	Reversible	Reversible	Reversible	Two-way	Reversible
Separation	Pylon	Barrier	Barrier	Striped/Barrier	Barrier	Barrier
Primary Objective	Target Revenue	Target Revenue	Person Efficiency	Target Revenue	Safety & Convenience	Target Revenue
Secondary Objective	Person Efficiency	Person Efficiency	Revenue Generation	Improved Efficiency	Person Efficiency	Person Efficiency

* The northern section of the NJ Turnpike is a dual-divided toll road with three lanes on each of four directional roadways. Outer six lanes allow passenger cars and trucks. Inner lanes allow passenger cars with one lane designated as a tolled HOV lane during peak periods in the peak direction.

Some tangible success stories from several of these projects include:

- Commuters in Houston who use the HOT lanes save between 12 and 22 minutes on their trips, in each direction
- Approximately 23 percent of single occupant drivers of the I-15 HOT lanes in San Diego choose to pay the tolls for a faster and more reliable trip,
- After four years of operation, the increased use of the I-15 express lanes has resulted 27,200 fewer vehicles per day in the general purpose lanes,
- Surveys in San Diego indicate that a majority of both users and non-users of the I-15 HOT lanes feel this system has reduced congestion,
- Within 2 months of opening, Minneapolis reported 3,800 toll trips a day,
- In Minneapolis, the HOT lanes along I-394 have increased total corridor throughput by more than 3 percent,
- During peak periods in Orange County, the express toll lanes carry 40 percent of total corridor traffic, at speeds of 65 miles per hour,

SR 91 in Orange County, California was funded using over $100 million in private sector bonds. Though originally a HOT lane project, half tolls were imposed on two-occupant HOVs during the PM peak period to prevent congestion. The primary objectives for SR 91 are to optimize person efficiency and generate the target level of revenue required to cover bond payments and operating & maintenance costs. Managed lane facilities that allow HOVs for free achieve optimal person travel efficiency by encouraging carpooling behavior. The SR 91 operates on a variable tolling scheme that is sensitive to efficiency such that the market toll rates are charged to cover bond and O&M costs.

Person trip throughput can also be improved through mass transit initiatives that use target revenue levels to subsidize mass transit service (normally within the corridor) in addition to the normal roadway O&M costs coverage. These objectives are common to the I-15 reversible lanes in San Diego, the I-10 and US 290 lanes in Houston, the I-394 lanes in Minneapolis, and the recently converted (to HOT) I-25 reversible lanes in Denver. On the New Jersey Turnpike, a combination of truck lane restrictions and HOV designation during peak periods are used to help achieve safety, comfort, reliability, and person trip throughput efficiency. The success of these managed lane facilities has lead to several States that have implemented them to consider more, and the concept is gaining favor throughout the nation, even in places that have not traditionally included tolls in their roadway operations. Figure A-1 illustrates the location of existing and planned facilities.

Figure A-1: Existing and Proposed Managed Lane Facilities in the U.S

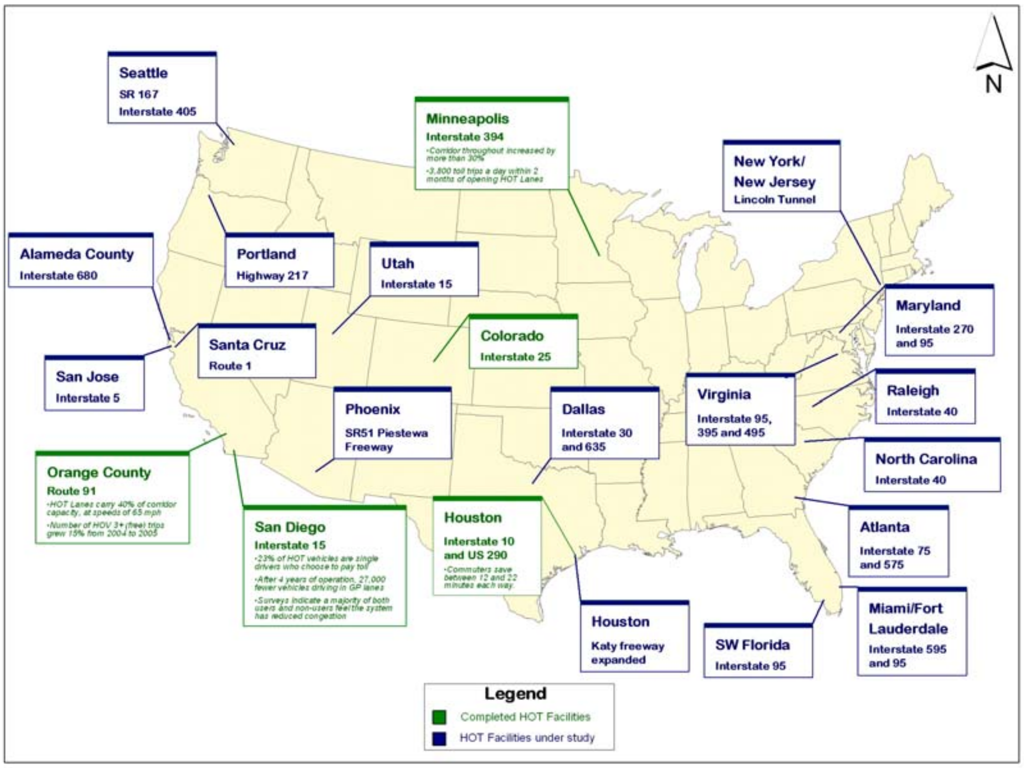


Table A-2 summarizes characteristics of managed lane corridors in operation today, under development, or under consideration. This table presents available statistics for each corridor, including primary operating objectives, operating strategies, demand and income levels, trip purposes and truck portions, and hours of operation.

Table A-2: Characteristics of U.S. Managed Lane Facilities that are Existing, Planned, or Under Evaluation

	Existing Managed Lane Facilities with Pricing Strategies				Managed Lane Facilities Under Study											
LOCATION	Orange County	San Diego	Houston	Mineapolis	Portland	Salt Lake City	San Fransisco	Santa Cruz	Dallas	Dallas	Denver	Northern Virginia	No. Virginia	Raleigh	Atlanta	New York/New Jersey
ROUTE	Route 91	Interstate 15	IH-10 & US 290	Interstate 394	Highway 217	Interstate 15	Interstate 680	Route 1	Interstate 30	LBJ - IH-635	Interstate 25	Interstate 95/395	Interstate 495	Interstate 40	Interstate 75-575	Lincoln Tunnel
OBJECTIVES																
	Provide a fast, safe and reliable commute and maintain financial viability of the lanes.	Manage traffic congestion and reduce delays on I-15 between SR 163 and SR 78 by optimizing use of freeway capacity and transportation alternatives in the corridor	Utilize available HOV capacity while preserving bus operating speed	Maximize corridor capacity and make better use of HOV lane capacity	Fund transportation improvements in the corridor	To maximize use of underutilized HOV lanes	To reduce congestion, encourage carpooling, expand express bus service and improve safety.	Reduce congestion, encourage car pools and use of alternative transportation modes to increase utilization and improve safety	Improve travel time for long distance travelers, segregate long and short distance traffic, utilize full capacity of the corridor	Relieve congestion, provide multimodal solution to regional mobility issues and support economic development	To maximize use of HOV capacity	To provide congestion free mainlines during all period of the day and raise revenue to help pay for construction	To provide congestion free mainlines during all period of the day and raise revenue to help pay for construction		To reduce single-occupancy vehicle travel, improving mobility and connectivity between activity centers and providing additional transportation choices	By providing express lane for increased bus transit service
STRATEGIES																
Pricing	$0.11-$0.85/ miles	$0.07-$0.50/miles	$0.30/mile	$0.80/mile	NA	$50 per month for SOV	Highest peak hour tolls of $0.22-$0.38/mile	NA	Dynamic pricing planned. Toll will vary from $0.05-$0.30/mile	Likely to be mileage-based dynamic pricing	$0.47/mile		$0.07 - $0.34/mile		NA	NA
Eligibility	HOV 3+ Free, SOV & HOV2+ Tolled	HOV 2+ Free, SOV Tolled, BRT Emphasis	6:45 AM to 8 AM and 5 to 6 PM HOV 3+ Free, HOV2+ Tolled,Off peak HOV2+ Free	HOV 2+ Free, SOV Tolled	NA	HOV2+ Free, SOV Tolled	HOV2+ Free	NA	HOV 3+ free with variable pricing	HOV free Sov will pay	HOV 2+, motorcycles & buses free; SOV & others tolled, HOV2+ 50% peak period discount	HOV 3+ and buses free, SOV and HOV 2+ pay variable toll rates	HOV 3+ and buses free, SOV and HOV 2+ pay		BRT / HOV and Truck-Only Lanes	Exclusive Bus Lane
Access	Buffer/pylon separation with no intermediate access	Barrier Separation with no intermediate access	Barrier separation with intermediate access	Intermediate access	NA	Intermediate access	Intermediate access	NA	Barrier separation with intermediate access	Intermediate access	No intermediate access	Intermediate access	Intermediate access		Intermediate access for both HOV and BRT stations	No intermediate access
CORRIDOR CHARACTERISTICS																
Corridor volumes	Corridor 290,000 Express lane 35,000 (2004)	Corridor 270,000 Express Lanes 30,000 (2004)	Corridor 210,000 Express Lanes 9,200 (2004)	Corridor 98,000 HOT lanes 30,000 (2004)		Corridor 290,000 Express Lanes 35,000	Corridor 188,000	Corridor 80,000-103,000	Corridor 150,000 HOV 7,200-8,000 (2005)	Corridor 270,000 (2005)	Corridor 240,000 HOV 10,000	Corridor 180,000	Corridor 225,000		Corridor 250,000 (2005)	1,700 Buses carrying 62,000 Commuters
Household Income	$132,000	$110,000	$112,000	$120,000	$76,900	$87,800	$118,000	$116,000	$111,000	$117,000	$106,000	$93,000	$130,000		$110,000	$184,000
Trip Purposes	90% HBW, 10% HBO		67% HBW, 33% HBO	78% HBW, 22% HBO	NA	NA	NA	NA	NA	NA	NA	NA	NA	90% HBW, 10% HBO	80% HBW, 20% HBO	
Truck Percentage	2-6%	5-10%					7%	3-7%	7-8%	7%		5%-15%	5%-15%		3.5%	
Type of Managed Lane	BRT/HOT Lanes	BRT/HOT Lanes	BRT/HOT Lanes	HOT Lanes	Express Toll Lanes	HOT Lanes		NA	HOT Lane			BRT/HOT Lanes	BRT/HOT Lanes		BRT/HOT Lanes	Exclusive Bus Lane
Hours of Operation	24 Hours	6 to 9 AM SB, 3 to 6:30 PM NB	5 AM-12 PM EB, 5AM-5PM WB, SAT WB 5AM-9PM, SUN EB 5AM-9PM	6 AM to 1 PM, 2 to 12 PM	NA	24 Hours	24 Hours	NA	12 AM to 1 PM EB, 3 to 10 PM WB		5 to 10 AM, 12 PM to 3 AM	6 to 9 AM NB, 3:30 to 6 PM SB	NA			Morning 6:15 AM to 10 AM
COMMENTS																
	Variable Pricing	Dynamic Pricing	Fixed Pricing		Options: 6 GP lanes (3 per direction) or 6 GP with 2 Express Lanes (1 per direction)		Opening schedule for early 2010				Toll collection began in mid-2006.					

APPENDIX B

Description of Transportation Management Objectives

Operational Objectives

- ***Congestion management:*** This objective seeks to implement strategies that reduce congestion delays and provide a faster, reliable travel alternative. The levels of acceptable congestion are defined using either level-of-service or travel speed criteria. Congestion management objectives are important in urban regions where there are prominent peaking characteristics and significant delays. Congestion reduction is also correlated with various secondary performance objectives which include reducing energy consumption and emissions. These objectives are less prominent in regional or intercity corridors. When pricing strategies are applied under this objective, dynamic control provides the most flexibility to optimize performance.
- ***Throughput maximization***: This objective applies strategies that redistribute traffic patterns (to other routes and/or other time periods) to maximize overall system throughput (persons or vehicles carried). Maximum throughput levels are normally based on a target level of demand that ensures some reserve capacity for routine traffic flow variations. This objective could encourage peak spreading by luring travelers away from the peak demand periods using time of day or dynamic traffic management strategies. This objective could also be facilitated by bridging network bottlenecks or missing roadway segments to make full use of the capacity of adjacent roadway network elements.
- ***Operational efficiency:*** For transportation systems, operational efficiency is the product of the demand volume and the operating speed. Efficiency can be measure in terms of either vehicles (vehicle miles per hour) or persons (person miles per hour). Facilities with higher efficiency deliver a larger number of trips to their destinations more quickly. Efficient facilities minimize the number of persons or vehicles "in transit," thus reducing congestion. Operational strategies that maintain high operating speeds while maximizing throughput achieve the best level of efficiency. Optimum efficiency therefore is not achieved by operating throughput levels near capacity, since travel time reliability is then compromised by small variations in traffic flow.

Financial Objectives

- ***Revenue maximization:*** This objective sets tolls based on the public's willingness to pay for benefits such as time savings, reliability, safety, and convenience, versus other alternatives. Toll rates required to achieve this objective are normally higher than most other objectives. The distribution of economic conditions among travel markets serviced by the facility dictate the best pricing segmentation by vehicle type, time of day and eligibility. This objective is desirable when the financial aspects of the building or operating the facility are as important as other objectives. Revenue maximization is important for Comprehensive Development Agreements (CDA) and Public-Private Partnership (PPP) endeavors to cover the capital costs to build, operate and maintain the facility. Also, an assessment of maximum revenue generation quantifies the facilities full economic potential. Under traditional bonding, the full revenue generating potential of a facility gauges the level of risk investors and public policy makers are willing to take regarding toll rate increases to generate sufficient revenue to cover bond payments. Public reaction and sensitivity towards excessive toll levels may limit the ability to maximize revenue potential of transportations facilities built under both public and private funding strategies. Toll escalation policies can sometimes be employed to limit toll revenue generation in excess of what is considered reasonable. Such policies vary on a project-by-project basis and are influenced by the local and regional political climate.

- ***Revenue target:*** This objective serves to satisfy a limited financial objective associated with the managed lane facility. Typical examples include coverage of the facility's capital construction costs, coverage of operating and maintenance costs (O&M), funding facility expansion or funding other transportation programs, such as mass transit. Facilities running through established and mature corridors typically use this objective (in the urban and intercity context) to improve accessibility for multiple users in the transportation network.
- ***Economic efficiency:*** Many metropolitan regions face challenging issues associated with congested transportation networks, right–of-way and land use constraints, and air quality management. This objective aims to balance the economic externalities that exist in the network by requiring each user to pay for the marginal congestion impact that their use of the facility causes to the rest of the facility users. Tolls rates are set to price the social incremental delay imposed by managed lane users to maximize travel time savings for the corridor users. (No known toll facilities in North America have been implemented using this objective.) The economic efficiency objective is likely to produce very high toll rates that may not meet other objectives such as throughput, efficiency or revenue maximization.

<u>User Objectives</u>

- ***Safety:*** This objective highlights the need for safe transportation facilities to transport travelers and goods. Safety benefits are assessed by reviewing accident experiences on existing facilities. This objective becomes important along corridors where friction may already exist between different vehicle types such as automobiles and trucks, or between short/long distance trips where separation may reduce accident risk through less weaving and other vehicular conflicts.
- ***Reliability:*** Reliability can be a key objective for economic systems that rely on timely delivery of people or goods. Many segments of the travel market depend on a reliable transportation system for their effectiveness. For example, airport passengers require reliable airport access routes, and emergency services depend on reliable travel times to organize their effective service areas. The just-in-time

business model implemented by many manufacturing and retail services also requires a dependable transportation system to function effectively. As more industries continue to pursue just-in-time models, regions without a reliable transportation system will suffer loss of economic viability by not being able to attract such industries. A managed lane network could provide a reliable alternative for these travel markets.

- ***Convenience:*** Convenience refers to the ease in which a service is accessible. The most convenient operating strategy does not require complex user preparation that could increase the length of the trip in distance or time, increase trip preparation time, or add additional trips. Examples of convenience include:
  - payment of tolls by automated means (toll tags or video tolling) versus the need to carry specific denominations of cash, to wait for a physical transaction of payment (toll booth), or to make a separate trip to replenish an account
  - ability to use one's own vehicle rather than assembling a carpool, waiting on another carpool, or waiting for scheduled service

  Managed lanes that offer access to low occupant vehicles through payment of a toll by electronic means provide such convenience.

- ***Cost Effectiveness:*** From a user's perspective, cost effectiveness weighs the benefits of using a facility against the cost. A managed lane facility that avoids congestion produces benefits including time savings, lower vehicle operating costs, and a reduction in incidental costs associated with congestion delays. Where tolls are charged, the cost of congestion can be directly converted into revenue to build, operate and maintain facilities, thus offsetting at least a portion of the toll cost. Conversion of congestion reduction benefits into monetary terms quantifies the market value of the project from a tolling perspective.

APPENDIX C
Physical Characteristics of Managed Lanes

- ***Type of Traffic Separation:*** These include barrier and buffer separation. Barrier separation consists of physical barriers that prohibit crossing. Buffers consist of transition areas where vehicles can enter or exit managed lanes along their entire length, or in designated lane-changing areas. Barrier separation improves the capacity per managed lane by reducing access friction. Barrier separated facilities perform more reliably when incidents occur in adjacent general use lanes.

- ***Number of Access Points:*** Configurations that limit points of access reduce potential traffic demand by making it infeasible for certain travel patterns to use the lanes. This is an important trade-off consideration, since lack of access could prevent most from using the managed lane. The physical design of the managed lanes and associated access points must be considered carefully in light of dominant travel patterns in the corridor. Access to desirable locations ensures better utilization.

- ***Type of Access Points:*** Managed lane access types fall into four major categories. The categories are presented in order from most to least access.
  - <u>Continuous Access/Egress:</u> Vehicles may cross a striped buffer to enter or exit the managed lanes anywhere along their length.
  - <u>Limited Indirect Access/Egress:</u> Using physical barriers or striping, access to the managed lanes is limited to certain long segments of their length. Managed lane users must weave across general use traffic lanes to reach local highway ramps.
  - <u>Limited Direct Access/Egress:</u> Exclusive ramps are used to either connect the managed lanes directly to crossing roadways, or to cross general use lanes to adjacent roadways, thus avoiding weaving.
  - <u>No Intermediate Access/Egress:</u> The only point to access the facility is at the beginning. The only point to egress is at the end.

- ***Number of Lanes per Direction:*** Facilities with two or more lanes per direction have considerably more operational flexibility than those with only one lane in each direction. Also, under pricing strategies, multilane managed lanes have considerably more revenue generation potential due to the added capacity.

- ***Shoulder Size:*** The presence of a useable shoulder (minimum 8 foot width) on a managed lane can affect safety and reliability. Shoulders provide space for evasive maneuvers in the event of a conflict, enforcement patrols, and provide space to keep disabled vehicles from blocking the managed lanes.

APPENDIX D

Description of Managed Lane Cross Sections

- ***Dual–Divided Lanes:*** This configuration splits at least two lanes in each direction from other lanes using a physical barrier. Dual-divided facilities can be used to segment traffic by eligibility strategies. For example, the inner lanes may allow only trucks, while the outer lanes are used for passenger cars. This configuration makes sense when the portion of truck traffic is stable and large enough to warrant a separation. For corridors with a moderate amount of truck traffic, the dual-divided lanes could be managed to allow passenger cars on both inner and outer roadways while restricting trucks to the outer roadway.

- ***Concurrent Flow Lanes:*** These lanes run along side existing general purpose lanes. Typically they are the inside lane of an existing facility, separated by a striped buffer or paint stripping. This configuration is suited to short corridors where traffic volumes are not excessively heavy and where traffic enforcement can be maintained along the length of the facility. This configuration is often necessary where right of way is insufficient to provide separate shoulders and access ramps to a more desirable barrier separated managed lane facility. Most previous HOV lane facilities had been implemented in this manner.

- ***Two-way Barrier Separated Lanes:*** These lanes are physically separated from the general purpose lanes, thus providing natural enforcement. This configuration is suited for longer corridors where long-distance trips are more prominent. The configuration typically has few access and egress points and allows longer distance travelers to bypass local congestion in the general purpose lanes. There are two types of access designs that can be implemented as part of this configuration. The first consists of direct connectors, or “fly-over” ramps that connect the managed lanes to other facilities including adequate transition zones for merging traffic. The second option involves use of slip ramps. Under this design, at-grade entry and exit points are established along the corridor with either transition zones or auxiliary lanes between the general purpose and managed lanes. With slip ramps, managed lane traffic must weave across general use lanes to reach local interchange ramps.

- ***Contra Flow Lanes:*** The contra flow configuration uses non-peak direction lanes to accommodate the peak direction traffic flow. Opposing lanes are reversed to increase capacity for peak direction traffic. This configuration is best suited for corridors with highly directional peak traffic flows such that non-peak directional capacity is underutilized. Movable barriers or removable pylons are commonly used to separate the reversible lanes for peak direction travel during peak periods. The main disadvantage to contra flow lanes is that geometric constraints often limit their operating speed below the ideal 65 miles per hour.

- ***Reversible Barrier Separated Lanes:*** Reversible barrier separated lanes are permanent reversible lanes that do not require closure of off-peak direction travel lanes. Since the lanes are barrier separated, higher operating speeds can be maintained, and access control and enforcement are aided by barrier separation.

APPENDIX E

Managed Lane Experiences and Issues

Lessons Learned

The following discussion items summarize lessons learned from managed lane planning and implementation efforts, and considerations for setting managed lane policies.

- Managed lanes patronage is geared more toward a very diverse cross-section classification of the overall traveling public that typically uses the facility on an infrequent basis. This creates a situation in which a very larger percentage of the overall corridor demand may use the managed lane facility 10 percent of the time for trips that require the added reliability and accessibility.
- A public outreach effort is a necessary element of early managed lane implementation in any metropolitan area. The outreach should not be construed as a "public input" process since successful traffic management requires that system operators have significant flexibility to control these facilities to meet desired objectives. However, the outreach process can help gauge sensitivities to various operating strategies and objectives, and help determine the content of a more focused public information effort to gain public support.
- A complex management strategy is far more difficult to maintain than a simple one. Furthermore, special rules, exceptions and conditions only lead to more of the same, and ultimately reduce public confidence while increasing confusion. Wherever possible, strategies and objectives should be simple and well defined.
- Since economic, traffic and congestion conditions change over time, managed lane operating strategies need to be reviewed and revised periodically, especially if some objectives are no longer relevant. More frequent re-evaluation is also required if too many policy-related restrictions are placed on the range of operating strategies such that objectives can not be met.
- Barrier separated managed lanes provide more revenue generation potential than concurrent flow lanes since they can be operated at a higher flow rate and operating speed, and are less vulnerable to incident-related congestion in the general use lanes.
- Multilane (including dual divided) managed lane facilities provide more operational flexibility than a single managed lane in each direction.
- Most corridors already have too large a portion of 2-occupant vehicles to allow this occupancy category to use a single managed lane for free. In many cases, HOV 2+ volumes are high enough to consume all the capacity of a single managed lane. In order to retain sufficient capacity for toll revenue generation, the HOV 2+ category should be tolled on single lane facilities. Managed lane configurations that provide at least two lanes in the peak direction could have sufficient capacity to share free HOV 2+ with tolled SOVs.
- In most cases, tolled managed lanes are unlikely to produce sufficient revenue to fully pay for all aspects of their implementation. This is especially true if various

user groups are allowed to use the lanes for free (such as HOT lane projects). Under these conditions, it still may be possible to achieve a target level of revenue to fund a significant portion of the project costs and the managed lane operations and maintenance.