Office of Operations

21st Century Operations Using 21st Century Technology

Considerations for High Occupancy Vehicle (HOV) Lane to High Occupancy Toll (HOT) Lane Conversions Guidebook

U.S. Department of Transportation

Federal Highway Administration

June 2007

Considerations for High Occupancy Vehicle (HOV) to High Occupancy Toll (HOT) Lanes Conversions Guidebook

Prepared for the

HOV Pooled-Fund Study
and the
U.S. Department of Transportation
Federal Highway Administration

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The intent of this study is to explore the planning, design, and ongoing operation and maintenance of HOT facilities and to provide lessons learned and applicable technical guidance that will assist the state and local transportation planners and designers in determining the conditions where HOV conversion to HOT lanes is feasible. The study reviewed a broad range of operational HOT facilities from having been operational many years to recently being opened. The study reviewed the activities of each in the planning, design, implementation and operations with special attention given to institutional, design, and operational challenges.

The guidebook provides a summary of the best practices and lessons learned from those HOT facilities currently in operation. The result is "Best Practices Top 20" list that evolved as each of the facilities learned or re-learned what other HOT facilities had previously learned. The result was a re-occurring list of "to do"s and what "not to do" to minimize issues during the HOV to HOT transition process.</td></tr>
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Metric Conversion Chart

SI* (Modern Metric) Conversion Factors

	Approximate Conversions to SI Units					Approximate Conversions from SI Units				
	Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
Length	in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
	ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
	yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
	mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
Area	in^2	square inches	645.2	square millimeters	mm^2	mm^2	square millimeters	0.0016	square inches	in^2
	ft^2	square feet	0.093	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
	yd^2	square yards	0.836	square meters	m^2	m^2	square meters	1.195	square yards	yd^2
	ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
	mi^2	square miles	2.59	square kilometers	km^2	km^2	square kilometers	0.386	square miles	mi^2
Volume	fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
	gal	gallons	3.785	liters	l	l	liters	0.264	gallons	gal
	ft^3	cubic feet	0.028	cubic meters	m^3	m^3	cubic meters	35.71	cubic feet	ft3
	yd^3	cubic yards	0.765	cubic meters	m^3	m^3	cubic meters	1.307	cubic yards	yd3
Mass	oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
	lb	pounds	0.454	kilograms	kg	kg	kilograms	2.202	pounds	lb
	T	short tons (2,000 lbs)	0.907	megagrams	Mg	Mg	megagrams	1.103	short tons (2,000 lbs)	T
Temperature (Exact)	°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8 C + 32	Fahrenheit temperature	°F
Illumination	fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
	fl	foot-lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-lamberts	fl
Force and Pressure or Stress	lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
	psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be done to comply with Section 4 of ASTM E380.

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Chapter 1. Introduction and Overview

Traffic congestion on U.S. highways serving our largest metropolitan regions have reached unprecedented levels despite our heroic but, ultimately, failed efforts to build more highways in response to the nation's insatiable demand for travel.[1] With the benefit of several decades' worth of hindsight, the U.S. transportation policy community has pledged a renewed commitment to attacking the urban transportation problem through a combination of demand and system management strategies focused on managing our existing transportation supply more effectively and efficiently.

Some of these ideas have been around for as long as the automobile itself. A major cornerstone of transportation system management (TSM) is the High Occupancy Vehicle (HOV) lane, which was first popularized in the U.S. during World War II as part a national fuel rationing program. Highway agencies and toll authorities across the U.S. operate over 2,500 HOV lane miles, with approximately 2,500 more HOV lane-miles planned over the next thirty years.

The presence of HOV lanes is an important inducement for ridesharing, which reduces vehicle trips and, in turn, lowers traffic congestion. In addition, HOV lanes – by moving high occupancy vehicles – can carry more passengers per hour than general purpose highway lanes. Today, many HOV facilities do in fact outperform adjacent general purpose highway lanes in terms of person throughput, especially during peak hours of service. By themselves, however, the extent to which HOV lanes induce new ridesharing beyond pre-existing levels is debatable and varies from region to region. Trip chaining, particularly family-related trip movements, and other factors (e.g. the scarcity of potential carpool matches) may dis-incentivize new HOV formation regardless of the presence of viable HOV express options. When new carpool formation is low, HOV lanes may go underutilized and do not meet expectations about congestion relief benefits.

Over the past decade, the commercialization of new technologies has created new opportunities to manage highways using age-old economic principles. The application of these innovative concepts have demonstrated unequivocally that congested highways can be managed more effectively and expand user choices. These applications come in a variety of names – managed lanes, high occupancy toll (HOT) lanes, Express Lanes, and smart roads. Together, they represent a growing body of evidence suggesting that efficient and effective management of existing highway assets is both achievable and sustainable.

I-15 Express Lanes in San Diego, CA

The primary purpose of this document is to provide technical guidance and recommended practices on an increasingly popular highway system enhancement opportunity: the conversion of HOV lanes to HOT lane. The guidebook is based on industry best practices with special consideration given to

1 Small, K., C. Winston, J. Yan, March 16, 2006, "Differentiated Road Pricing, Express Lanes, and carpools: Exploiting Heterogeneous Preferences in Policy Design" applicable pricing techniques, planning, cost estimation and operational requirements, including the application of supporting Intelligent Transportation System (ITS) technologies.

1.1. What are High Occupancy Toll (HOT) Lanes?

The Federal Highway Administration (FHWA) defines managed lanes as highway facilities, or a set of lanes, in which operational strategies are implemented and managed (in real time) in response to changing conditions. Managed lanes are distinguished from other traditional forms of lane management strategies in that they are proactively implemented, managed, and may involve using more than one operational strategy.[2]

The HOT lanes concept is a managed lane that combines HOV with pricing strategies to improve facility operations. Unlike HOV lanes, HOT lanes allow single occupant vehicles (SOV) to gain access to HOT lanes if they choose to pay the applicable toll. To maintain the "improved facility operations" and the service benefits of a HOT lane, HOT lanes may employ some or all operational strategies.

Operational Strategies

- Restrict HOT lane ingress and egress to specifically designated and marked locations to / from the general purpose lanes
- Limit vehicle eligibility
- Use a variable time-of-day pricing structure to manage demand and congestion.

1.1.1. HOT Lane Characteristics and Applications

Although HOT lane operational and policy parameters may vary from facility to facility, they share several common characteristics with respect to system design, physical configuration, operations and technology. FHWA's "Guide for HOT Lane Development" identifies several major characteristics of HOT lanes:

- HOT lanes typically are limited-access; normally barrier-separated highway lanes that provide free or reduced cost access to qualifying HOVs, and also provide access to other paying vehicles not meeting passenger occupancy requirements. (***Note:*** The geometric limitations of the existing HOV facility are the primary reason HOV to HOT lane implementations are not barrier separated from the general purpose lanes. Instead striping or plastic delineators are generally used as a buffer.)
- By using price and occupancy restrictions to manage the number of vehicles traveling on them, HOT lanes maintain volumes consistent with uncongested levels of service even during peak travel periods.

Barrier – separate reversible flow facility

- Most HOT lanes are created within existing general-purpose highway facilities and offer potential users the choice of using general-purpose lanes or paying for premium conditions on the HOT lanes.

2 *"A Guide for HOT Lane Development", U.S. Department of Transportation, Federal Highway Administration*

- HOT lanes utilize sophisticated electronic toll collection (ETC) and traffic information systems that also make variable, real-time toll pricing of non-HOV vehicles possible. Information on price levels and travel conditions is normally communicated to motorists via variable message signs (VMS), providing potential users with the facts they need in order to decide whether or not to utilize the HOT lanes or the parallel general-purpose lanes that may be congested during peak periods.

- HOT lanes may be created through new capacity construction, conversion of existing lanes, or converting HOV lanes to HOT lanes with additional capacity added. Since both right of way and construction funds are limited, conversion of existing HOV lanes to HOT operation is the most common approach.

Occupancy requirements on HOV facilities are usually set at HOV 2+. HOV 2+ lanes represent approximately 95 percent of all HOV lane miles operated in the United States. Nationally, most HOV lanes perform within the generally accepted range of peak performance:

- Of HOV lanes with the HOV 2+ eligibility requirement, approximately 70 percent of he nation's HOV lane miles operate with peak hour volumes between 900 and 1,500 vehicles per hour.

- Of the remaining 30 percent, 10 to 15 percent of HOV vehicles are operating with over 1,500 peak hour vehicles, and the remaining 10 to 15 percent operate at or below 900 vehicles per hour in peak hours.

Multi-lane HOV facilities that suffer chronic peak hour underutilization (below 900 vehicles per peak hour) comprise the pool of facilities most suitable for conversion to HOT lanes. HOV facilities that carry between 900 and 1,500 vehicles per peak hour generally do not offer sufficient residual capacity to sell to SOVs without risking lower level of service (LOS) than baseline peak conditions.[3] Experience has shown that raising minimum HOV access requirements to HOV+3 has had minimal effect on HOV lane performance since the number of HOV +3s is generally less than the number of HOV +2s that were using the HOV lanes. This condition may in fact result in underutilization of the HOV lanes. Additionally, with deflection of HOV +2s onto general purpose lanes, it is very likely that prevailing traffic congestion on general purpose lane will worsen.

Capacity is also influenced by factors such as facility geometry, the number of access points and the number of travel lanes. Consequently, HOT lane capacity varies from location to location. For example, a single HOT lane will have a lower managed capacity than a HOT facility with multiple lanes. Volumes on the Houston I-10 Katy Freeway QuickRide – a one lane, reversible-flow facility are kept to 1,500 vehicles/hour. However, the 91 Express Lanes provide two managed travel lanes in each direction and have been able to operate at acceptable conditions with flow rates of 1,800 vehicles/hour/lane.[4] The 91 Express Lanes expands the toll zone in each direction to three lanes designating two lanes for HOT and one lane for HOV+3 use. HOV+3 are required to mount transponders in the vehicles and are charged a reduced toll rate.

HOT Lane Performance

The emergence of HOT lane pricing techniques has been facilitated by the use of ETC. These techniques can range from flat toll to dynamic by time-of-day and offer a wide range of options for achieving greater performance. Electronic pricing, when introduced in the appropriate operational context, has been shown to offer a cost effective strategy for creating and sustaining net travel time benefits.

3 *Ibid Chapter 6*

4 *Ibid Chapter 6*

The case studies presented in Chapter 5 describe how different electronic pricing applications are used to maximize and maintain peak travel time savings.

It is important to be able to evaluate the performance of the HOT lane facility against established measures of effectiveness, and estimate travel time benefits. In Chapter 2, a more detailed discussion of system performance and user benefits associated with HOT lanes is presented.

HOT Lane Benefits

HOT lanes are intended to provide a wide variety of benefits to multiple user groups. When applied in conjunction with other management tools and sensible, targeted provision of additional lane capacity, HOT lanes have the potential to generate significant improvements in congested travel corridors.

HOT lanes can also afford a wide range of secondary benefits, including:

- New revenues that can be used to support the construction of the HOT lanes themselves or other initiatives, such as improved transit service or regional transportation initiatives;
- Traffic service improvements on congested parallel highway mainline lanes by drawing vehicles off parallel local streets and improving corridor-wide mobility;
- Performance reliability compared with general purpose lane during peak periods.
- Faster highway trips for express transit services such as bus rapid transit (BRT);
- Environmental advantages by providing opportunities to encourage carpooling, improve transit service, and move more people in fewer vehicles at faster speeds;
- Increased efficiency of managed lane facilities making them attractive in regions that might not otherwise consider them; and,
- Improving the utilization of HOV lanes and therefore eliminating potential pressure to convert under performing HOV lanes to general-purpose use.

The Primary Benefits of HOT Lanes

- They provide the driving public with a choice – premium and predictable travel conditions – on corridors where conditions would otherwise be congested, and
- They maximize the use of managed lanes – including HOV lanes – without causing traffic service to fall below desired levels.

1.2. Purpose of the High Occupancy Toll Lane Guidebook

The intended audience of this document includes states' departments of transportation (DOTs), Metropolitan Planning Organizations (MPOs), policy-making agencies, enforcement agencies and others having a role in the planning, development, management, operations, monitoring, evaluation and reporting on the performance of HOV and HOT lanes. The objective of the guidebook, which explores the planning, design, implementation and ongoing operations and maintenance of HOT lane facilities converted from existing HOV lanes, is to provide:

1. Technical guidance that will assist the state and local transportation planners in determining the conditions where conversion from HOV to HOT lanes is feasible and advisable, and

2. a comprehensive list of activities to be performed in the planning, implementation and operation of an HOT lane facility. Special attention is paid to institutional, system design and operational challenges that typically present themselves in the course of a conversion to HOT lane.

Three case studies of HOT implementations are provided in the guidebook to further illuminate key practical insights and lessons learned that would be of value to HOT planners. The case studies are based on information gathered from on-site visits and a focused interview methodology. Focused interviews were conducted with key managers at three HOT lane projects:

1. MnDOT's MnPass I-394 HOT lanes,

2. SANDAG I-15 Express and HOT lanes, and

3. CDOT's I-25 Express Lanes.

1.3. Study Approach/Methodology

The approach and methodology used in developing the Guidebook included:

- Establishing a project development framework that advances the HOT conversion project from concept to implementation;

- Employing a combination of formal interviews with recognized industry experts and selected agencies with experience in the implementation of both managed and HOT lanes;

- Conducting on-site focused interviews that inform three "case studies" of functioning HOT lanes; and,

- Conducting a literature review of current industry practices.

The research and case studies focused on all elements of project implementation, including items such as planning, design, pricing strategies, construction, operational requirements, and the integration of ITS with the HOT lane application.

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Chapter 2. High Occupancy Toll (HOT) Policy and Planning

2.1. Baseline Performance Framework for High Occupancy Vehicle Lanes

Minimum occupancy requirements for the HOV lanes should be set to avoid both underutilization and overcrowding of the HOV lanes. The primary benefit of adding an HOV lane is that total highway capacity is increased, causing preexisting HOVs to divert onto the new HOV lane and allowing Single Occupant Vehicle (SOVs) to share highway mainlines with fewer vehicles. After this initial shift in lane utilization, the resulting travel time differential between the HOV lane and highway mainline lanes could induce secondary shifts (second order changes) from SOV to HOV up to the point where service levels in the HOV lanes are impacted.

High Occupancy Vehicle (HOV) Lanes Are Intended To Meet Three Basic Objectives

1. Provide a cost-effective means of moving greater volumes of persons at higher levels of service than mainline highway lanes by reserving dedicated lanes for multi-person vehicles;
2. Promote ridesharing by setting aside reserved HOV lanes and offering travel time savings and reliability; and,
3. Reduce trip times of HOVs during congested times of day

Research on HOV lanes (Dahlgren 1995) suggests that approximately 20 percent of the existing vehicles on a three-lane highway must be HOVs for an HOV lane addition to be effective and still offer enough of a travel time savings incentive to induce ridesharing. If enough travelers shift from SOV to HOV, congestion on HOV lanes can erode the travel time differential, thereby dampening the incentive needed to promote further shifts to HOV in the long term. In cases where the pre-existing HOV share is high, HOV lanes can suffer from periodic traffic congestion during the busiest times of day. Ultimately, HOV priority treatment may contain a self-limiting threshold both in very high congestion and no congestion conditions beyond which there are limited incentives to rideshare.

HOV lane performance studies typically collect peak vehicle and passenger counts for HOV lanes and highway mainline lanes and obtain average travel speed and travel time data. HOV lanes can average three to 20 times the person movement of highway mainline lanes during peak hours. If HOV lanes that carry more peak passengers than comparable highway mainline lanes and maintain peak hour volumes between 800 – 1,000 vehicles per lane per hour are determined to be an effective system management strategy.

Many HOV lanes throughout the country, under existing HOV priority allowances, achieve performance consistent with those outlined in FHWA HOV Lane Performance Guidelines. The remainder of HOV lanes currently in operation suffers from mild to severe underutilization or overcrowding or both, depending of prevailing traffic conditions. It is this subset of HOV facilities that represent the pool of potentially feasible HOT conversion projects.

2.2. Understanding the Effects of Converting an HOV Lane to HOT Lane

The conversion of an HOV lane to HOT lane results in both operational and behavioral shifts. These shifts must produce a combined positive net benefit to users in order for the conversion from HOV lane to HOT lane to be deemed worthwhile. The purpose of this section is to describe the possible behavioral effects resulting from the conversion of an HOV lane to HOT lane that should be considering in evaluating and planning.

As discussed above, the primary operational effect caused by the conversion to HOT lane is that Low Occupancy Vehicles (LOVs)[5] who now pay to use the HOT lane will gain travel time savings. Converting an HOV lane to HOT results in overall delay reduction for LOVs both for those remaining in the highway mainline lanes and those that buy into the HOT lane. Pricing optimization techniques enable the HOT lane operator to maximize travel time savings differential between HOT lane and highway mainline lanes through the day. The ability to achieve and sustain travel time savings is generally considered one of the most important operational differences between HOV lanes and HOT lanes.

The reduction in travel delay effect for LOVs is manifested in two ways:

- LOVs diverting onto the HOT lane derive a travel time savings benefit, which they gain in exchange for a toll payment.
- The initial diversion of LOVs onto the HOT lane causes a reduction in traffic volumes and traffic density, as LOVs on the highway mainline lanes share capacity with fewer vehicles.

Figure 2-1 provides a diagrammatic overview of the various effects of converting an existing HOV lane to HOT lane.

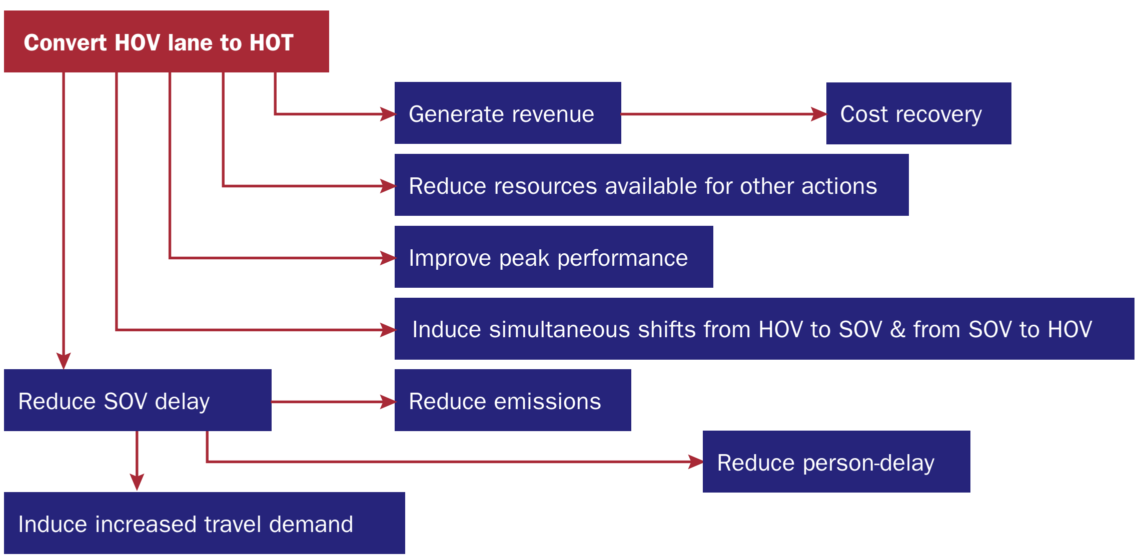

Figure 2-1: Effects From Converting to HOT lanes

5 *Low Occupancy Vehicles (LOVs) are defined here as vehicles that do not meet the HOV exemption and would be subject to the HOT lane toll*

2.2.1. Shifts from HOV to LOV and from LOV to HOV

After an existing HOV lane is converted to HOT lane, the LOV toll buy-in feature will induce some additional shifts from HOV to LOV. Before the HOV lane was converted to HOT lane, all motorists who could be induced to shift to HOV presumably had already done so. Converting the HOV lane to HOT lane is unlikely to increase or even maintain existing levels of rider sharing. HOVs that are made better off by disbanding the HOV in favor of paying for HOT lane service as an LOV will shift from HOV to LOV. Likewise, some travelers will disband HOVs simply because the diversion of LOVs onto the HOT lane will cause enough highway mainline delay reduction to make HOV travel no longer worthwhile.

2.2.2. Shifts from other Routes and Times

The travel time reduction on highway mainline lanes and the presence of a HOT lane will induce some secondary behavioral shifts:

- From alternative routes to the subject highway
- From off-peak to peak, which is not less congested

With reduced delay on highway mainline lanes, LOVs that had that had previously shifted to alternative routes to save time will return to the highway via mainline lane use or HOT lane. With reduced delay on the highway, both HOVs and LOVs that had previously shifted to alternative routes to save time will return to the highway. Both groups are better off.

2.2.3. Second-order Effects and Long-Run Equilibrium

The marginal shifts from other times of day and routes, coupled with additional trips stimulated by the reduction in peak highway delay, will gradually result in increases in highway volumes, thereby offsetting some of the delay reductions caused by opening HOT lane service to toll-paying LOVs. Patterns will evolve toward a long-term equilibrium in which the relative costs and benefits of HOT lanes and highway mainline lanes are no longer sufficient to motivate further shifts from HOV to LOV. Patterns will also be stabilized to the point where additional shifts to and from other times and routes are no longer induced.

2.3. Key Planning and Policy Criteria

The purpose of this section is to describe the HOT lane project screening criteria, and identify opportunities where HOT lanes may be the most effective means of addressing a critical mobility need.

As discussed in Chapter 1, HOV lanes can be classified in terms of their average peak hour performance. HOV lanes that experience chronic underutilization (below 700 vehicles per lane per peak hour) generally comprise the pool of potential candidates' conversions to HOT lane. In these cases, the presence of an optimal toll set to maintain a minimum operating standard on the HOT lane will divert

PRE-PLANNING ISSUES/CHALLENGES

- How should HOV exemptions be modified to accommodate SOV toll buy-ins?
- What should the minimum operating standard for HOT lanes be?
- To what extent should access (ingress/egress) be limited to segregate traffic and preserve LOS performance goals on the HOT lane?
- How much are system implementation and ongoing operating costs for HOT lanes?
- What are the trade-offs between implementing a HOT lane and a toll lane with no HOV exemption?
- What legislative barriers need to be removed in order to convert an HOV lane to HOT lane?
- How should toll revenues be used?
- Who should own and operate the HOT lane?

LOVs onto the HOT lane. Underutilized HOV lanes are considered the best candidates for conversion because : a) no additional lane capacity needs to be added to the existing operating envelope, and b) the minimum vehicle occupancy requirement does not have to be adjusted.

HOV lanes that experience chronic peak hour congestion also reflect a mismatch between existing travel demand and lane capacity, and merit some type of policy treatment to address recurring operational shortcomings. However, all congested HOV lanes are not necessarily appropriate candidates for conversion to HOT lanes. In cases where there is potential excess lane capacity and there is no operational justification for adding a second HOV lane to an existing one-lane HOV facility, conversion to a two-lane HOT facility may achieve optimal operational conditions that cannot be duplicated by a two-lane HOV lane facility.[6] (In other words, LOVs can occupy some of the otherwise under-utilized lane capacity).

Based on considerations such as those described above, the planning process should address a number of questions to determine how effectively a potential HOT conversion project addresses a current unmet transportation need. These include:

- Is there sufficient excess peak capacity to allow SOV toll buy-ins on an existing HOV lane without the need to expand lane capacity? The feasibility of a potential conversion project depends in large part to the amount of excess capacity that can be sold to SOVs. If there is abundant excess capacity on the existing HOV lane and traffic congestion on highway mainlines is moderate, it may be feasible to attract just enough SOVs onto the HOT lane through optimally priced dynamic tolling without necessitating any change in HOV toll exemption policies. In Chapter 6 Case Studies, further discussion is devoted to factors that result in a change in HOV toll exemption policies in place.

- If there isn't enough excess peak capacity in the existing HOV lane(s) to allow for SOV tolling, is there additional capacity that can be added to the existing HOV facility as part of an HOT conversion project? Many HOV lanes are only one-lane facilities with either limited or no barrier separation from highway mainline lanes. In cases where the potential market for premium HOT-lane service is large and mainline lanes suffer from severe to extreme peak congestion, it may be necessary to: 1) change the HOV exemption from HOV 2+ to HOV3+ or higher, 2) add a second HOT lane, or 3) do both.

- If changing the HOV exemption from HOV-2+ to HOV-3+ or higher is necessary, will it result in behavioral shifts that undermine the mobility improvement objective? The existing HOV eligibility status in the HOV exemption policy should be preserved in the HOT lane context whenever possible. In many instances, however, preserving the current HOV exemption may not free up enough capacity to auction to LOVs willing to pay a toll for premium HOT lane service. If the exemption is increased from HOV-2 to HOV-3+, the magnitude of HOV-2s that disband may offset any increases in carpooling motivated by the presence of tolling. Should the ultimate effect be a net reduction in HOVs and a net increase in LOVs, this may undermine one of the key objectives underlying the HOT lane concept, which is to promote trip reduction corridor-wide.

SAFETEA-LU provides operating agencies with the flexibility to allow certain vehicles not meeting the occupancy requirements, including tolled single-occupant or lower-occupant vehicles.

6 *FHWA, A Guide for HOT Lane Development, page 7.*

- Are there any unique operational and physical characteristics of the existing HOV lane facility that will require major reconfiguration? Not every HOV lane, under its current operating configuration can be readily converted to HOT without some significant physical improvements to the existing facility envelope. In addition improvements to the to limiting ingress and egress into the HOT facility, it may be necessary to modify lane configurations both at the entry and exit points of the HOT facility to minimize queuing behind bottleneck locations. The facility may also have to accommodate additional equipment including location of variable toll message signs (VTMS) and electronic toll collection equipment and supporting gantries and cabinets, and maintenance areas and enforcement envelopes.

2.3.1. Legal and Institutional Challenges

While there is growing interest in HOT lanes among local, state and federal transportation officials, there remain significant legislative and institutional barriers to widespread HOT lane implementation. Prior to the enactment of *Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)*, states were expressly prohibited from converting federal-aid highways and Interstates into toll facilities.

However, that policy was modified under *SAFETEA-LU* Pub. L. 109-59, August 10, 2005 to allow States and qualifying transportation agencies to use Federal funds for toll facility applications. Congress enabled three new exceptions, and modified one existing exception, to Title 23 of the United States Code, Section 301, which otherwise generally prohibits the imposition of tolls on facilities that use Federal funds.

Through the applicable program States and qualifying transportation agencies may, with the execution of a toll agreement under Section 129 (a)(3), use Federal-aid funds for either the construction of or improvements to a toll facility or to the approach to a toll facility; or, for the reconstruction or conversion of a free highway, bridge or tunnel previously constructed with Federal-aid funds to a toll facility thus enabling conversion of HOV lanes to HOT lanes.

Specifically related to the conversion of HOV to HOT lanes, Section 1121 of SAFETEA-LU replaces Section 102(a) of Title 23 of the United States Code (23 U.S.C.) with a new Section 166 that clarifies some aspects of the operation of HOV facilities and provides more exceptions to the vehicle occupancy requirements for HOV facilities. It also authorizes states to create HOT lanes and allows states to charge tolls to vehicles that do not meet the established occupancy requirements to use an HOV lane if the state establishes a program that addresses the selection of certified vehicles and procedures for enforcing the restrictions. Tolls under this section may be charged on both Interstate and non-Interstate facilities. There is no limit on the number of projects or the number of states that can participate.

2.3.2. Building Support for HOT Lanes

Perhaps the biggest barrier to wider HOT lane implementation is public opposition. Recent experience demonstrates that HOT conversion projects are feasible from an operational and technological standpoint. With the mainstreaming of HOT lanes on the state and federal level, the public become increasingly familiar with the HOT lane concept, and the benefits these facilities offer in terms of congestion relief. Today, they are not as controversial as they once were. However, HOT lane conversion projects – because they include a tolling component – often raise spirited opposition based on equity and fairness concerns. Yet HOT lanes still provide access for HOV users as well as providing both HOV and non-HOV users with an option, or another travel choice.

Key Stakeholder Outreach Actions

- **Anticipate** opposition early.
- **Arrange** focus groups to determine local issues and strategic opportunities to address specific concerns.
- **Develop** program objectives that address and mitigate social equity concerns.
- **Gain** consensus from key influential civic and community gatekeepers.
- **Enlist** advocacy from a respected local official who will serve as project champion.
- **Manage** expectations by establishing reasonable and achievable project objectives.
- **Deliver** the project on-time and on-budget.

With the increased federal support for tolling initiatives, states and metropolitan regions throughout the country have looked closely at their highway assets for opportunities to improve mobility via facility-specific electronic tolling or ‘smart road’ applications. In states like California, Texas, Utah, Minnesota, Colorado and Washington, HOT lanes have been folded into statewide and regional transportation management plans that place increasing emphasis on system management objectives.

Over the past decade, public acceptance of electronic tolling applications on urban highways has increased, with the maturation of landmark projects like the 91 Express Lanes in Orange County, CA and the I-15 Express Lanes in San Diego, CA. Today, these facilities are commonly accepted by the public as critical elements of the region’s transportation system.

A common thread in every successful HOT conversion project is the execution of a coordinated effort to convey the justification for and benefits of the project and address public concerns about the implementation and ongoing operation of the project. It is important to note that the success of an HOT lane implementation should be measured by public acceptance as well as the ability to provide added capacity, and potentially additional revenues to support enhanced maintenance support and regional mobility objective. Public consensus for the planned project requires strong public involvement program throughout the life of the project, especially from the early planning stages.

Public Outreach Strategies

Project sponsors that manage inclusive, responsive and effective outreach to stakeholders establish their own legitimacy and the legitimacy of the technical analyses, decision-making, and public processes that support project implementation.[7] Establishing transportation taskforces and technical committees consisting of business, community members, and elected officials is a proven key to

7 Perez, B.G., and G. Sciara. “A Guide for HOT LANE DEVELOPMENT”, Federal Highway Administration Report FHWA-OP-03-009, Washington, DC, 2003 successful implementation for managed lane projects. For example, the QuickRide Program in Houston over individuals participated in 14 public meetings which helped bring forward issues such as access points and directional flow. In addition, having a strong public champion is a critical element in lending credibility to the outreach process and influencing key decision makers who may initially oppose HOT conversion projects without a clear understanding of potential project mitigations.

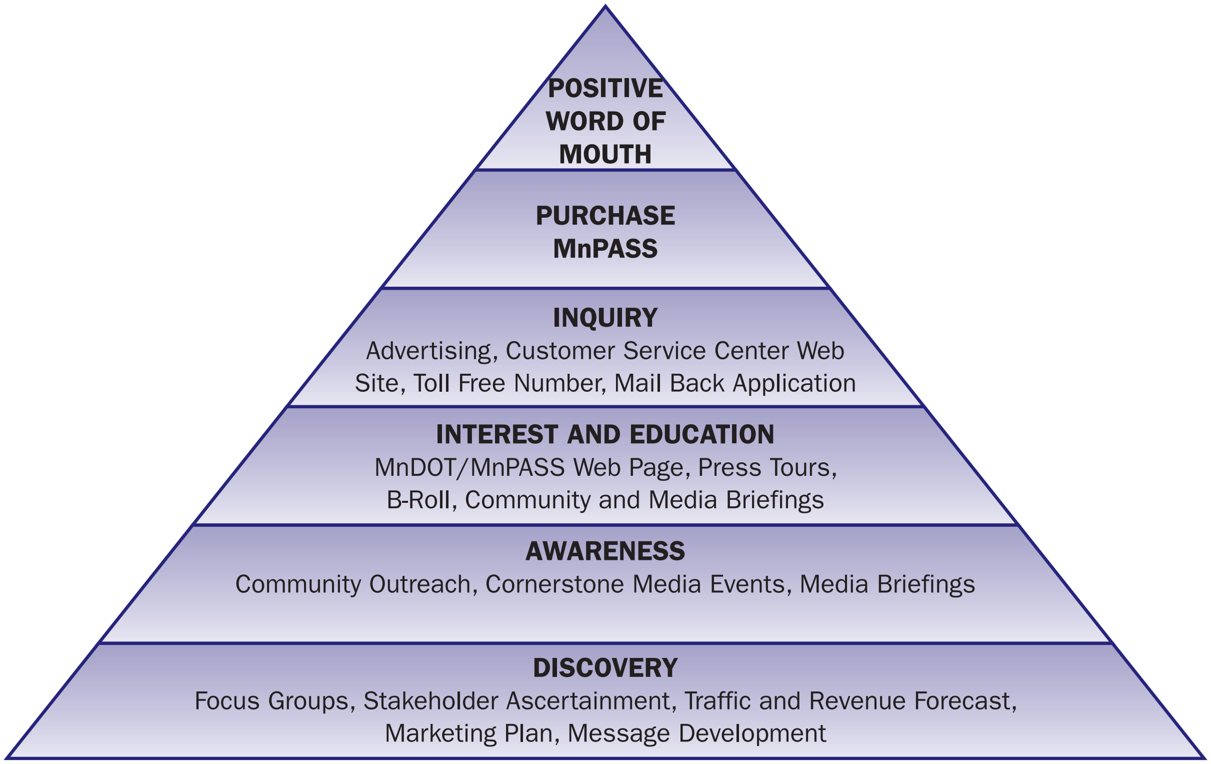

Chart provided by Frank Wilson Associates and Tanaka Advertising, PowerPoint presentation *MnPass I-394 Express Lane Marketing Outline*, October 28, 2004.

Figure 2-2: Public Outreach Model Used at MnPass

SANDAG as well as MnDOT (MnPass) began public outreach programs very early in the project planning. SANDAG conducted stakeholder interviews, established a program of continuing surveys with both stakeholder and the public and held numerous public forums through implementation. MnPass created a local taskforce, the I-394 Express Lane Community Taskforce, at the outset of the program to address issues, desires, and design options. In addition they also held continuing public forums to keep the public informed and to address relative issues.

2.3.3. Application of Project Development Approach

Figure 2-2 provides an overview of the multiple phases involved in the project development of the conversion of an HOV lane to HOT lane. Following an initial assessment of conversion feasibility and the decision to investigate the HOT lane conversion further, the conceptual framework for the HOT lane project is then developed and refined. The conceptual refinement stage evaluates various system design alternatives, and eventually recommends a preferred alternative.

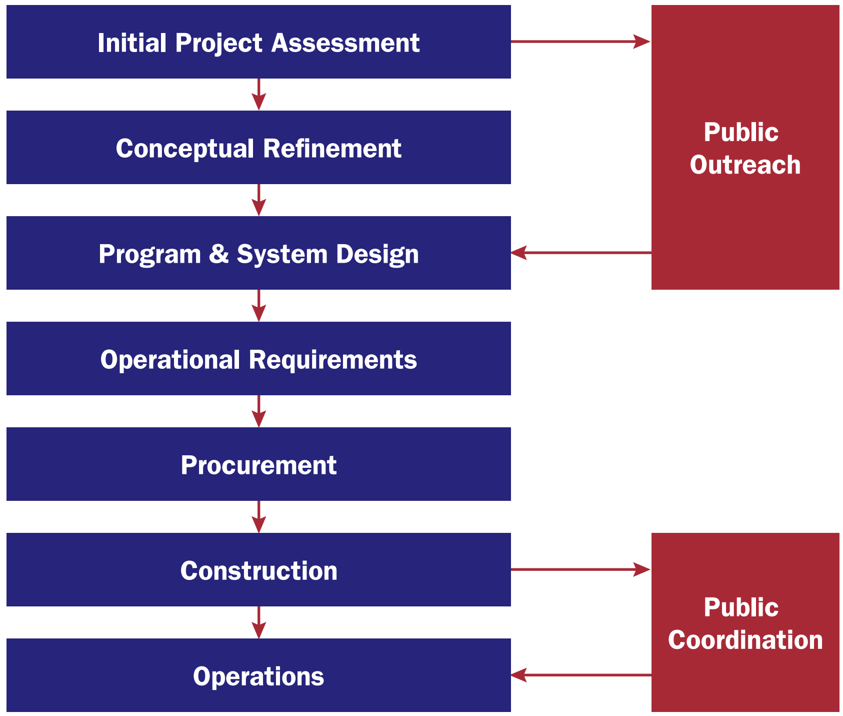

Figure 2-3: Sketch Development Approach

The third phase identified in Figure 2-3 – Program & System Design – focuses on clarifying the design, operational and technological elements of the HOT lane conversion project. The fourth phase of the project involves developing the operational requirements of the system. The project sponsor, most likely the state DOT, will complete detailed engineering and design studies for the recommended alternative and develop the design specifications for the HOT lane project. The fifth phase involves the preparation of procurement documents for the construction of the HOT lane project and the selection of a contractor through a competitive solicitation process.

2.3.4. Unique Project Risks/Challenges

While there are a significant number of technical, policy and public issues that provide both risks and challenges for the successful implementation, the success of an HOT implementation is the ability to meet stated program goals. These goals must have community support early on in the planning process, and the development of the project must be consistent with the public's expectations. In addition to public acceptance, there are a number of other critical hurdles that must be addressed in a successful implementation.

A risk mitigation plan is an important element of a successful HOT Lanes project. Risks should be outlined as a part of the alternatives analysis described above and used for evaluation of alternatives. Then, as the project moves through design and construction a risk management plan should be developed and periodically updated. The plan should identify all risks associated with the project, the degree of impact should the risk occur and the likelihood of that risk occurring. Examples of categories of these risks are schedule, technology, operating, public acceptance and environmental. Within these categories numerous sub-categories specific to the project can be identified and therefore mitigated.

All HOT implementations must address the following areas to minimize potential areas of risk:

- **Strong Interagency Support** – Creating a strong public campaign that explains intended benefits and outcomes is critical to advancing a HOT conversion project from the earliest planning through project construction implementation to promote understanding and support for the project. There must also be:

  – Strong support from local, regional and state transportation officials and State Legislature,

  – Strong Project Champion – Having a dynamic and respected public official publicly support and advance HOT lanes is critical to winning public support and can often accelerate the public outreach timeline.

  – Strong support from the Metropolitan Planning Organization (MPO), with HOT lanes identified in Regional Transportation Planning documents,

  – Strong local sponsor, typically a regional transportation agency with highway management and operations responsibilities.

- **Defining Program Objectives** – HOT conversion projects must identify program objectives clearly from the outset, because the program objectives influence both project financing and potential for public/private partnership (PPPs). The program objectives should be realistic and defensible.

- **Traffic Forecasting** – It is critical that traffic forecasts are rigorous and conservative in testing the program alternatives, as these projections serve as input into potential revenue bonding and other project financing mechanisms.

- **Capital and Operating Cost Forecasting –** It is also critical that estimates for the initial capital costs and ongoing operating costs are conservative and realistic, as these factors in combination with traffic forecasting, will determine the basic economic viability of the project.

- **Project Financing** – Some HOT conversion projects will be financed entirely with state and local funds, with some federal matching support. Others may be viable as investor-owned utilities underwritten by private investment. The financing arrangement may present risks to both the public and investors if project rates of return are lower than expected, and debt cannot be adequately serviced.

- **Procurement** – There are both financial and schedule risks associated with traditional versus more innovative procurement strategies; development of solid ETC system specifications and selection of a vendor (system integrator) is critical to the success of the project.

- **Achieving Operational Goals** – The HOT lanes can only be successful if they provide consistent and reliable Level-of-Service (although some degradation in LOS may occur from time to time). If the customer doesn't get value (i.e. travel time savings) commensurate with the toll charge, then public trust in the HOT lanes will erode and the system will fail.

- **Establishing the Right Operating Model** – It is critical that operating framework for the HOT conversion project reflect the program objectives. As further described in our case studies, (see MnPass) the operation and pricing strategies must be feasible, reasonable, and compatible with the program objectives.

- **System Design Consideration** – Creating a toll facility within an existing highway requires attention to all system design considerations including facility operations. Desired operational characteristics must be considered during both the planning and design phase of implementation so that the facility design is operationally functional. Where possible design should be flexible to allow for changes in operational policies. Modes of operation such as two-way flow, reversible flow and contra-flow, incident management and allowed vehicle types allowed affect the geometric configuration. In addition to the operational considerations that impact design consideration other design considerations are listed in Section 2.4.

2.4. Project Financing

Substantial resources are required to plan, design, construct, operate and manage a HOT facility. The method of financing selected for a given HOT lane conversion project can involve both public and/or private funding sources. Based on recent experience, HOT project financing typically rely on traditional sources of public funds (e.g., fuel tax revenues), with some opportunities to leverage federal grant support. In a few unique cases, HOT lane conversion projects may be suitable for some form of revenue bonding or the sale of a private concession to construct, operate and maintain the facility. This section describes how HOT program goals influence both the method of project financing and, ultimately, the operating model chosen for the HOT lane.

Project funds for transportation capital expansion and facility upgrades are traditionally allocated by state DOTs or other local agencies according to the goals of long-range plans and the availability of programmable funds. Because HOT lanes generate revenues, however, they need not necessarily rely on allocation of total project funding through the traditional planning and programming processes. Instead, agencies can take advantage of innovative financing mechanisms such as revenue bonding and private concessions in order to accelerate HOT conversion projects.

Revenue bonding for HOT lanes is similar to revenue bonding for other tolled transportation facilities. Under revenue bonding, a government agency issues bonds backed by future facility-generated revenues. Although revenue bonds typically carry higher interest rates than municipal bonds (which are guaranteed by more stable general tax revenues), they allow agencies to generate the capital necessary to implement projects quickly. Once the project is completed, the HOT lane revenues are, at least in part, dedicated to fulfilling obligations to the bondholders.

A second potential project financing mechanism is private concessions. Under the private concession model, a transportation agency leases the HOV facility to a private operator, sometimes in exchange for an up-front fee. The private operator is then responsible for any or all of the planning, design, construction, and operation aspects of the HOT conversion project. This arrangement makes most sense when the private operator is granted a contract to operate the facility and collect revenues for some fixed time frame, such as 30 or 50 years, beyond project completion. Benefits to the transportation agency include a transfer of project responsibility and risk as well as outsourcing of project activities (e.g., design and construction) to the private concessionaire. The concessionaire, on the other hand, must produce financial resources to complete the project, but is compensated by keeping a share of the revenues generated by the HOT facility once it opens.

On the other hand, revenue bonding may be sufficient to generate the capital necessary to complete the project in a reasonable and expedient time frame, in which case a private concession may not be desirable.

Selling Concessions

The advantages of private concession arrangements and revenue bonding depend on the particular situation and the goals ultimately set by the transportation agency. Private concessionaires can access both debt and equity stakeholders to finance the conversion project, which may increase the capital available for the project, thereby accelerating its completion, lowering construction costs, and generating revenues from the facility sooner.

Regardless of the arrangement for financing the conversion project, HOT lanes will generate revenues, which accrue to either the operating agency or to the private concessionaire. In almost all cases, some proportion of the revenues generated will be dedicated to operating the HOT facility. Operations costs include lane management, toll collection and administration, enforcement, service patrols and incident management, basic infrastructure maintenance, back-office support, and perhaps facility depreciation (these activities are discussed in Chapter 4). Under a private concession or revenue bonding financial arrangement, the next obligation for generated revenues is to the debt and/or equity investors. Finally, once the obligations to all stakeholders are fulfilled, there is reasonable expectation that the operating agency or concessionaire may generate excess revenues from the HOT lane operation.

The allocation of excess revenues, should they materialize, depends on the goals and objectives determined by the operating agency prior to project initiation. Revenues can be dedicated for improvements to the HOT facility itself, applied to the entire HOT corridor, or distributed regionally to other corridors and/or other travel modes such as mass transit. In some instances, agencies may even determine appropriate uses outside of the transportation arena.

Regardless of whether excess revenues materialize, the success of HOT conversion hinges on the ability of any particular project to meet two requirements. First, revenues should support the maintenance and operation of the HOT facility. Secondly, revenues should be sufficient to meet financial obligations to project investors. Consequently, accurate project cost estimates and realistic revenue forecasts are essential to the financial success of a conversion project.

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Chapter 3. HOT Lane Implementation & Design

The previous chapters addressed issues related to the planning, design and operational considerations when converting existing HOV lanes to HOT lanes. This chapter is intended as guide to all aspects of the implementation phase from project organization, procurement and financing through construction.

System/Sketch Planning	HOT Lane Implementation and Design	Procurement	Final Design and Construction	Operations and Management
■ Feasibility Assessment ■ Project Champion ■ Stakeholder Support ■ Develop Conceptual Framework ■ Legislative Action ■ Public Outreach	■ Define Objectives ■ Ensure Stakeholder Understanding ■ Clarify Design ■ Engineering and Design Studies ■ Develop Engineers Cost Estimate ■ Develop Specification ■ Public Outreach	■ Determine Method ■ Prepare Procurement Document ■ Competitive Selection Process ■ Continued Champion Support	■ Technology ■ Toll Rate Concept ■ Separation Type ■ Ingress / Egress ■ Signage ■ Toll Zone Location ■ Construction and Test ■ Public Information	■ Hours of Operation ■ HOV Use / Fee ■ 24/7 Maintenance ■ Account Management ■ Enforcement ■ Violation Noticing ■ Stakeholder and Champion Support ■ Public Information

Figure 3-1: Stages of HOT Lane Project Development

The remainder of this section discusses the various elements of the key stages of project development necessary to convert an existing HOV lane facility to HOT lane.

3.1. Organization and Management

3.1.1. Participation

There are several transportation organizations that can successfully plan, build, operate and manage an HOT lane program. The specific organizational and management structure may differ based on a variety of factors: state enabling legislation, asset ownership, project financing (e.g., revenue bond or general funds), and the role of the state DOT, regional planning organizations (RPOs) and metropolitan planning organizations (MPOs) in the region. It is important to identify the players involved in the HOT lane implementation process and describe their roles and responsibilities. In addition, it is important to establish an interagency framework that enables their participation.

Described below are entities that should be involved in the planning and implementation of the program:

- **Owner:** agency that legally owns the HOT facility and right of way, usually the state Department of Transportation (DOT).
- **Sponsor**: the agency with responsibility for overall project planning, design and implementation (Note: the sponsor can be the same as the owner but may be a separate transportation agency).
- **Operator**: the organization responsible for the operations and management of the HOT lane facility (Note: the operator can be the same as the owner and sponsor but may be a different organization).

- **Interfacing organizations and institutions**: There are several other agencies, including those involved in the development, implementation and operation of the HOT lanes. Examples are:

  – *Emergency Services and Incident Management* – The HOT lane system will need to interface to these services and coordinate provision of incident management and emergency management services. Decisions must be made on which entities are responsible for control of lanes in emergency and incident situations and protocols and interfaces must be established.

  – *511 and other information services*, including Web based links to regional traffic information. Traveler information should be provided on a local and regional basis on the HOT lane operation.

  – *State DOTs* who may govern policy and in some cases own or operate the roadway or intersecting roadways.

  – *Intersecting roadways* – There will be temporary impacts to these roadways during construction and more permanent impacts due to changes in traffic patterns resulting from the HOT lanes that need to be coordinated with intersecting roadways. Also, advanced signage for the HOT lanes will need to be placed on these roadways.

  – *Regional Interoperability Groups* – As discussed below, depending upon the state or region in which the planned HOT lane is located, the Sponsor will most likely need to work with the regional group (e.g., SunPass, E-ZPass, CTOC) in order to use a transponder technology that has regional penetration.

  – *MPOs and RPOs* – These organizations may be involved only in elements of planning in some cases and in other cases may take a more active role in the regional implementation of HOT lanes and related programs.

  – *Stakeholders* – Stakeholders including local, regional and state government agencies, interested parties and the general public must be considered at appropriate points in the implementation.

3.1.2. Organization and Management Plan

Early in the planning and implementation process, it is strongly recommended that the interim sponsoring agency establish an organization and management plan. At a minimum, the organization and management plan should identify:

- Roles and responsibilities;
- A detailed responsibility matrix that clearly identifies each element of work and varying responsibilities associated with that work element (e.g., who has direct responsibility, support responsibility);
- An overall program schedule (developed under this process or another related process); and,
- A communication and meeting plan to establish how the project team will interact, obtain consensus and approvals and what types and frequencies of meetings can be expected.

This plan will evolve and should be updated periodically as the project moves toward implementation. In order to ensure transparency, the organization and management plan should be reviewed and approved by each of the entities directly involved in the project.

3.2. Public Private Partnerships (PPPs)

Over the past several years, public private partnerships have become an increasingly intriguing method of introducing new highway capacity when and where conditions are suitable for these innovative but sometimes controversial arrangements. While most PPPs have emerged in the context of traditional expressway projects, there are a number of PPPs either in place or planned in niche transportation markets involving Express Lanes and HOT lanes.

It is important to develop clear lines of responsibility for the PPP entity and the public entity, or DOT, especially in regard to operational and maintenance decisions on the HOT lanes or the general purpose lanes that have an operational impact on the other facility.

+ Potential Benefits of PPP

- An infusion of funds to the state associated with a long term lease or purchase of the toll road.
- A reduction in the state costs to operate and maintain the road.
- Potentially greater flexibility in setting toll rates and charges than a public entity has.
- Potential cost and operational efficiencies if the toll road partner (operator) is operating other toll roads and has the resources and expertise to leverage this experience.

– PPP Areas of Potential Risks

- A loss of control of operations that could affect operations and roadway quality and the rates the customers pay to use the facility
- Risk of revenue bond downgrading if the facility revenue bond financed and revenue or trip volumes are below what has been assumed in the financing.
- Long term questions of financial viability of the roadway in the event of market changes, operator bankruptcies or changes in ownership.
- Potential opportunity cost losses if toll revenues are greater than anticipated.

Figure 3-2: Benefits vs. Risks

The decision to proceed with a PPP requires consensus at the highest levels in state government on program objectives, tolerance to financial risk and benefits to the public interest. States such as California have tested the PPP waters by authorizing the California Department of Transportation (Caltrans) to enter into franchise agreements with private companies to operate and maintain private toll roads. Other states struggling with traffic congestion have also investigated private toll roads as a means of addressing expanding roadway capacity through private toll roads.

3.3. Procurement Strategies

Once the concept of operations is defined and operational requirements are established, the sponsoring agency must develop a procurement strategy through which the components of the HOT lane system are acquired. Given the time frame required for most HOT lane procurements, this decision should be made no later than approximately two-and-a-half to three years prior to the planned live date for reasons described in more detail below.

3.4. Procurement Options

There are two major elements of the HOT lane system that will be procured: 1) roadway-related work, and 2) the electronic toll collection (ETC) system. For several important reasons, the two elements should not necessarily be procured using the same strategy:

- **Roadway Work**. Improving the roadway involves civil work such as widening, paving and surfacing, gantry installation and electrical work, including power and communications to the ETC and variable message sign (VMS) equipment. Much of this work lends itself to competitive bidding on a low price basis from qualified bidders. There are two procurement options for roadway work:

  – **Design-Bid-Build**. Under this option, the sponsoring agency provides all of the roadway design detail and puts the package out for bid on a low bid basis.

  – **Design-Build.** Here, the sponsoring agency develops preliminary designs and then puts the package out for bid to a design-build team. (Note: this procurement option may lend itself to the RFP process discussed in the next bullet in order to facilitate an evaluation of the design/build team's overall design capabilities and concepts).

- **ETC Systems Work**. ETC work involves designing (including developing and integrating), installing and potentially maintaining and operating an ETC system, including software and communications to the lane equipment and critical back office operations. Because the ETC work is highly specialized, it does not lend itself to a selection solely on a low bid basis.

  A request for proposal (RFP) is the recommended approach to ensure that the selection of the system integrator considers all critical factors including technical solution, team qualifications and experience and price. As mentioned above, the scope of the ETC procurement can be limited to design and installation of the ETC system or it can cover all aspects of operations as well. There are three basic models to consider in the ETC system integrator procurement:

  – **Design-Build.** The System Integrator designs, builds and installs the system and then turns it over to the Sponsor, who then hires a separate entity to maintain the system (or use in-house resources). The Sponsor will also have to a separate agreement with a Customer Service Center (CSC) operator to process the transactions and bill customers and handle violations. The sponsoring agency can obtain these services through a separate RFP or can make an agreement with another agency to "piggyback" on their existing customer service center operations.

  – **Design-Build-Maintain.** Where the System Integrator not only designs, builds and installs the ETC system, but also maintains the system for fixed period of time, for example, five years. Here, the sponsoring agency would again have a separate agreement for CSC operations or could operate the CSC.

  – **Design-Build-Operate-Maintain.** The System Integrator is completely responsible for all aspects of HOT lane implementation and operations, including maintenance and CSC operations for an agreed to period of time.

If the sponsoring agency does not have experience maintaining ETC systems, it is recommended that the Sponsor use a design-build-maintain RFP. Whether the sponsor agency also chooses to include

CSC operations in the RFP depends on a number of factors such as the availability and cost effectiveness of using an existing CSC of another agency and the desire to separately procure CSC operations through a separate RFP.

3.4.1. Procurement Sequencing

The proper sequencing of roadway infrastructure and ETC procurements is critical to project success. Specifically, it is desirable to have the System Integrator in place prior to the completion of the roadway design package. *This will enable the System Integrator to have input into the placement, type and number of ETC equipment gantries, communications infrastructure requirement, placement and types of equipment cabinets, and roadway issues related to any in-road ETC equipment.* This will minimize change orders to both the roadway contract and the ETC contract. As the roadway improvements are constructed, the System Integrator can work with the Sponsoring Agency to complete the system design and development, which typically takes approximately 12 months.

3.5. Procurement, Implementation and Construction Issues

A prerequisite to initial and long-term success of a HOT lane implementation is proper management of all stages of project development (from procurement through construction and final testing). The project development process must be viewed as a unified process, with multiple interdependent links. Several key guidelines should be kept in mind while planning the ETC construction process:

- **A detailed design, implementation and construction schedule should be stated in the RFP.** The schedule should be refined prior to notice-to-proceed (NTP) and updated regularly throughout the design and installation process. The schedule must also recognize all of the key design, testing and installation elements and consider coordination with roadway design and construction.

- **The RFP should require the System Integrator to prepare a transition plan.** The transition plan, which will be refined in the design process, should clearly identify a timeline for the construction and transition of the HOV lanes to HOT lanes.

- **Construction planning, staging and project costs must accommodate maintenance and protection of traffic.** Performing work on an existing roadway with live traffic operations is a major challenge, and plans to mitigate the impact of construction on parallel roadway operations must be developed.

- **The RFP should include rigorous performance standards for the installed equipment and the overall system.** It is recommended that the RFP be developed as a performance-based document rather than an equipment specification. The RFP should specify rigorous performance standards, which place the burden of designing a system to meets those requirements squarely on the System Integrator.

- **Include sufficient time for testing in factory, on-site pre-live and live acceptance testing in the RFP.** The system should not be considered complete until a live acceptance test for a period of 30 to 60 consecutive days verifies system operation.

3.6. HOT Lane System Design

Creating a toll facility within an existing highway requires attention to system design considerations, which must be evaluated on its potential impact within a corridor or region. A feasibility study assists in the developing support for the venture and provides the basis for developing a project design plan.

The design plan for the implementation of a specific HOV system conversion is generally developed from a corridor study that provides feasible alternatives for consideration. It most likely will be corridor-specific, or applicable to a network of lanes on several corridors, depending on the specified problem and demand characteristics. Regional consistency is desirable, and many areas (e.g. Los Angeles, Seattle, and Atlanta) have implemented systems where most facilities operate in the same manner and appear consistent to the user.

Design Considerations

- Signage (fixed and variable message), both on the HOT lanes and at ingress and egress locations
- Placement of Ingress and egress locations,
- Placement of visual enforcement and equipment maintenance areas
- Type of violation enforcement
- Placement of electronic tolling equipment gantries and utilities,
- Incorporating the proper toll system equipment design on the lane and back office sides,
- Buffering and facility separation

3.6.1. Geometric Requirements

HOT lanes may involve single or double lanes operated on a reversible-flow basis or one or two lanes providing continual service in each direction, or multiple lanes that can operate concurrently. An example of the latter is the planned SANDAG I-15 Managed Lanes which will comprise four lanes which can operate on a concurrent flow basis such as 2/2 or 3/1. However, in order to maintain premium traffic service levels and discourage toll violations, HOT lanes generally require access control along with effective enforcement. Additionally the physical configuration of HOT lanes and accesses to the HOT lanes should minimize excessive weaving between highway mainlines.

Guidelines from AASHTO, TxDOT, Caltrans and FHWA provide varying design standards for implementing managed lane facilities. For example, for total clear width for a single-lane barrier separated reversible lane, AASHTO advises 20-22 feet, TxDOT suggests 20-26 feet, Caltrans suggests 27 feet and FHWA recommends 20-32 feet for HOT lanes.[8] In the absence of HOT design standards, highway design standards and guidelines pertaining to HOV lanes are often applied to HOT lanes. Since express lanes are essentially HOT lanes with all traffic being tolled, these design standards are also compatible for implementing express lanes.

Barrier separation on 2-lane reversible I-15 Express Lanes

8 *Toycen, C., (2006), "Tough To Be Single," TM+E, July, Vol. 11, No. 2*

Table 3-1 provides the recommended cross-section standards for HOT lanes, or tolled managed lanes, as recommended by the FHWA.

Table 3-1: Managed Lane Cross-section Standards

Cross-section	Element Standard
Lane Width	■ 12 feet, 3.6 meters
Shoulder Width (Right and Left)	■ 10 feet, 3.0 meters preferable 2 feet, 0.6 meters minimum (dependent on number of lanes, type of operation, sight distance).
Separation (Buffer) Width for non-barrier separated operation	■ 4 feet, 1.2 meters.
Sight Distance	■ Standard stopping sight distance for facility type
Safety Considerations	■ Crash attenuation for exposed barrier ends ■ Transition treatments with HOV or general-purpose lanes ■ Adequate access opening lengths

As the national guidance for HOV facilities, AASHTO's ranges establish the minimum values for state DOT's. Development of Express Lane or HOT facilities by various DOTs are typically based on shoulder widths and controlling project parameters anticipated at the time project design guidelines were established.

Geometrics for managed lane facilities can be divided into four general categories

- Barrier Separated
- Buffer Separated
- Contiguous
- Grade Separated

Because right-of-way availability varies from one location to another there are various design standards to consider for separating HOT lane traffic from the general purpose lanes. In addition there may also be situations where deviations from recommended design standards may have to be considered because of additional corridor constraints. Geometrics for managed lane facilities can be divided into four general categories.[9]

Table 3-2 provides a summary of the physical design options that may be implemented and the benefits and issues that may be associated with each type.

9 *Caltrans High-Occupancy Vehicle Guidelines, 2003 Edition*

Table 3-2: Operational Impacts of Physical Design Options

Physical Design Options	
Concrete Barrier **Benefits:** ■ Reversible lane concept ■ Safety from general purpose lanes ■ Easier to enforce compliance **Issues:** ■ Users have feeling of confinement ■ No way out during accidents unless removable rail or gates are installed	**Flexible Delineators (Pylons)** **Benefits:** ■ Inexpensive and achieves visible separation ■ Easy removal ■ Have a way out **Issues:** ■ Frequent maintenance / replacement ■ Safety due to vehicles able to drive through delineators ■ Possible flying hazard when hit by vehicles at speed
Buffer Separated **Benefits:** ■ Inexpensive ■ Vehicles have a way out ■ Easy removal ■ Easy to install **Issues:** ■ Safety due to vehicles cutting in and out ■ Extra right-of way requirements	**Non-Buffer Separated (Pavement Markings)** **Benefits:** ■ Inexpensive ■ Vehicles have a way out ■ Easy removal ■ Easy to install **Issues:** ■ Safety and enforcement issues due to vehicles cutting in and out
Non-separated Shoulder **Benefits:** ■ Provides extra capacity without having to add a lane **Issues:** ■ Confusion over lane use ■ Lack of emergency pull outs for disabled vehicles ■ May have to be rebuilt if transit buses are allowed to use.	**Grade Separation** **Benefits:** ■ Exclusive use ■ Safest **Issues:** ■ No way out ■ Lengthy construction ■ Expensive ■ Users have a feeling of confinement ■ Easier enforcement

Access Control Strategies

Another key design consideration is the extent to which drivers have multiple opportunities downstream of the first HOT access point to buy-in to the HOT lane. The number of access points is linked to the corridor geometry, safety, facility revenue collection objectives and violation enforcement.

For example, in the case of the 91 Express Lanes, Riverside County officials perceived the 91 Express Lanes as a tube, with few opportunities to enter the facility westbound beyond the eastern access location. For MnPass, MnDOT identified multiple access strategies to accommodate their system configuration; very restricted access for the 3-mile reversible segment and multiple access point for the 8 mile concurrent flow segment. Besides safety considerations, separate pricing strategies were implemented to manage demand in each section.

Additionally, in developing the number and locations of exit and entry access points, consideration must be given to the tradeoff impacts of items such as the additional infrastructure, operating and violation enforcement, the cost of additional entry/exit points, and the attractiveness of additional entry and exit points for SOV, HOV, and transit (where applicable) users.

Figure 3-3: Access Control Diagram for MnPass

Electronic Toll Collection (ETC)

The technologies involved in electronic toll collection are all well-proven and in use on nearly every significant toll road, bridge, and tunnel in the country. Electronic toll collection systems generally rely on four major components: Automated Vehicle Identification, Automated Vehicle Classification, Violation Enforcement and Transaction Processing.

All of these systems are included in A Highway 407 ramp toll zone. However, depending on agency objectives, some implementations do not employ all four components. In this section, we will briefly introduce and discuss these components:

TransCore eGo Plus sticker tag

- Automatic Vehicle Identification (AVI) System. An AVI system determines the identity of a vehicle traveling through either toll gates in a traditional barrier configuration toll plaza, or through an open road (high speed) tolling area. In either facility configuration the object is to correctly identify the vehicle in the tolling area and to apply the applicable toll charges to the correct account.

  Current AVI systems rely on radio frequency identification (RFID), where an antenna located above the roadway communicates with a transponder, similar to the TransCore eGo Plus Sticker Tag, also known as an RFID tag, and mounted on the vehicle via Dedicated Short Range Communications (DSRC). RFID tags have proven excellent accuracy, and can be read at highway speeds. All transponder tags currently in use by toll agencies in the United States operate at 915 MHz. While all of the AVI system providers in the US, operate in the 915 MHz band they are not all interoperable. Generally there is regional interoperability, where agencies in the region use the same transponder, antennas and associated protocols. Examples of this are CTOC (California), E-ZPass (Northeast and portions of the Midwest) and SunPass (Florida). There is some movement toward the use of multi-protocol readers, which could read more than one transponder type and protocol but this has not yet been implemented on any large scale.

- **Automatic Vehicle Classification (AVC) System**. Vehicle classification determines the toll rate to be charged a vehicle using the HOT facility. It may also be used in combination with the AVI and VES technology to determine if a vehicle is violating vehicle access restrictions.

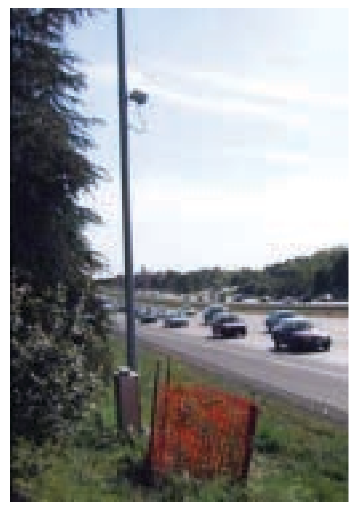
  Various sensors may be used to determine classification. Some agencies may opt to use a single type of classification sensor while other agencies may use more than one sensor type in order to eliminate classification errors or mismatches. The various sensors include:

  – Inductive sensors embedded in the road surface can determine the gaps between vehicles, to provide basic information on the presence of a vehicle and the approximate vehicle length.

  – True Presence Microwave Radar can determine vehicle classification by length in a manner similar to the inductive sensors. Remote Traffic Microwave Sensor (RTMS) by Electronic Integrated Systems (EIS) and Smart-Sensor by Wavetronix are examples of this type of detector which monitor traffic from the roadside as shown.

  – Treadles permit counting the number of axles as a vehicle passes over them and, with offset-treadle installations, also can detect dual-tire vehicles.

  – Light-curtain laser profilers record the shape of the vehicle, which can help distinguish trucks and trailers. Active Infrared Detectors have the ability to classify vehicles by measuring and identifying their profiles. Some examples of Active Infrared Detectors are Autosense II and Autosense III by Schwartz Electro-Optics, Inc and the Laser Scanners by Sick, Inc.


Remote Traffic Microwave Sensor (RTMS)

- **Violation Enforcement System (VES).** Enforcement is critical if a HOT lane facility is to be successful and effective. The enforcement strategy and the technology implemented must be reliable, highly visible and one that promotes fairness. Most facilities currently use visual (manual) enforcement together with some technical support to monitor HOT lanes. Although utilizing enforcement vehicles to stop apparent violators may not be the most efficient method to actually gain compliance with the managed lane restrictions it is the most visible to the public, including the public traveling in the general purpose lanes. This visible enforcement effort demonstrates that the agency or entity controlling the use of the

The MnPass Solution

MnPass has supplemented the violation indicator light by adding a portable transponder reader in the enforcement vehicles enabling enforcement officers to validate operational transponders while driving along side of or immediately behind a target vehicle.

managed lanes is serious about maintaining the integrity of use by vehicles qualified to be in the designated managed lanes.

The technical support that often is used to supplement manual enforcement may consist of a gantry mounted violation indicator light to provide an indicator for near-by enforcement vehicles to act on. Additionally some facilities use video cameras together with optical character recognition (OCR) system to capture the license plate image of the vehicle as it passes through the toll zone. The camera may be mounted above the roadway or along side the roadway, depending on the geometry of the HOT facility and the violation objectives of the facility. Once the license plate image is captured it must be correctly 'read' by the OCR in order to successfully locate the vehicle owner to collect the toll and if applicable, the toll evasion fine.

- *Transaction Processing System.* The transaction processing component, is commonly referred to as the 'back office) of most systems. It also may be referred to as the "Customer Service Center" which in many respects, performs activities that resemble banking functions. Transaction Processing deals with maintaining customer accounts, posting toll transactions and customer payments to the accounts, handling customer inquiries and determination and processing of violations.

  For transaction processing to be both accurate and effective requires a reliable communication network to transmit the ETC and/or image transaction information from the lane to the back office processing center. It is imperative that appropriate data collection and delivery techniques, as well as redundant and manual systems, are in place to guard against data loss or corruption particularly with any transactions, images, or operational information.

  The transaction data transferred to the 'back office' for processing not only must be accurate, processed and reported in a timely and consistent manner to support a dynamic 24/7 operation, but must also be auditable. Of singular importance is the issue of security and integrity of all data collected by the toll collection system.

Supporting Systems

With ETC, there are several supporting systems that need to be integrated into the overall system architecture to ensure that the functional requirements of the system are met, and the customer interfaces with the system in a simple-to-understand and seamless manner.

- **Closed Circuit Television (CCTV).** The use of video CCTV cameras along the facility may be used to support general traffic surveillance, detect incidents within the HOT lane facility, confirm message accuracy displayed on VMS or variable toll message signs and provide supplemental image support for violation enforcement.

Video camera mounted to overhead gantry

- **Variable Message Signs (VMS).** VMS provide traveler information, traffic, construction or incident alerts, and travel time advantage comparison and costs for use of the HOT lane. A special application of VMS is the announcement of the toll in effect at the time of entry into the HOT facility. This specific application is referred to as a Variable Toll Message Sign (VTMS) and may either be implemented as a stand alone electronic VMS type of sign or it may be a hybrid combination with static information with a variable insert to provide either the toll rate or estimated travel times to some down stream locations.

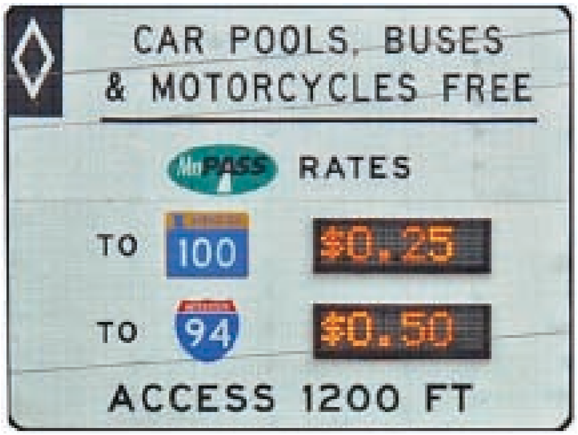


Figure 3-4: MnPass Variable Message Sign

- **Digital Video Audit Systems (DVAS).** DVAS provide an audit capability of transactions at a toll zone location. The systems provide a time based video record of activity in a given toll zone that ties an image to the transaction data generated by the system. The DVAS system provides remote access for both real time monitoring and file query to verify a transaction record. The transaction data record consisting of the location, time of day, lane (if more than one), vehicle classification and transponder ID is overlaid on the video record permitting fast and accurate assessment of any anomaly.

- **ITS Support Systems.** ITS is being integrated with HOT system requirements to provide traveler information and for integration into regional traffic management systems. Some of the support systems that are being employed along HOT corridors include:

  – 511 Interface;

  – DMS signage for regional traffic information;

  – incident detection systems to assist in both facility and regional traffic management and control;

  – traffic monitoring devices for integration in the regional monitoring plan;

  – CCTV surveillance; and

  – highway advisory radio

Variable Message Sign (VMS)

HOV Enforcement

Accurately determining the number of occupants in a vehicle is difficult at best and often results in having an enforcement officer mistakenly stopping HOV vehicles because an occupant, such as a child, in addition to the driver, is not readily visible in the back seat. *Enforcement of occupancy requirements is the most difficult operational challenge facing toll agencies and enforcement officers in HOT lane implementations because automatic technologies have not yet met reliability and field* *accuracy requirements required for operational deployment.* In addition, there are a host of cost and privacy considerations associated with the technology.

Facility design also influences the types of enforcement needed. Barrier separation features act as a deterrent to potential violators, but require areas along the facility to monitor, apprehend and cite violators. Barrier separated facilities generally make apprehension fairly easy, since the violator is confined in the lanes after entering the facility; however, it should be noted that the larger the facility (i.e., number of lanes) and the larger the quantity of entry and exit points, the more difficult manual enforcement is.

Non-barrier separated HOT lanes are the most difficult to enforce, since it is easy to enter and exit the lane simply by changing lanes. Facilities that use delineators, such as the SR91, deter violators, but may still experience violators 'diving' through the delineators. Locations where delineators are used typically do not have adequate shoulder space for effective road side enforcement.

Some actions that can be taken to enhance the performance for HOV violation enforcement may include:

- During the design phase have engineers meet with highway patrol officers to determine locations best suited (safe adequate space) for road side enforcement.
- If there is adequate space lanes consider installing concrete barriers.
- Prominently and with consistency post the fine for HOV/HOT violations on roadside signs.
- Use random and prominently visual, special enforcement followed by routine enforcement.

The MnPass Approach

MnPass uses a solid double white line to separate HOT lanes from general use lanes.

Dotted stripped line indicated authorized access / exit points.

According to MnDOT, after lane stripping implemented, the violation rate has dropped from >20 % to less than 10%.

Most drivers observe the double and stripped markings. Violators of marked stripping are fined $165.00 per occurrence.

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Chapter 4. HOT Lane Operations and Management

Vehicle movements between highway mainline lanes and HOT lanes must be managed carefully, with well-designed ingress and egress to avoid unnecessary bottlenecking, violation and unsafe weaving. Special attention to enforcement techniques, particularly with respect to verification of vehicle occupancy, is necessary to regulate demand and maintain facility integrity.

Effective lane or facility geometry is a critical prerequisite to achieving LOS design and safety goals. Another important function is the ability to capture and identify user data for automatic billing. This requires an integrated system of in-lane devices with back office support that not only provides account management, customer service support and violations processing but also ITS support functions such as 511, advanced traveler information and incident management. The purpose of this chapter is to describe the basic element of effective HOT lane operations and management.

4.1. Lane Management

When converting to a HOT lane within a larger highway network, consideration must be given to weighing appropriate balance between eligibility, level of service and pricing conditions in order to achieve effective and sustainable lane management. Determining peak hour volumes in highway mainline lanes and HOT lanes and establishing the minimum desired LOS in the HOT lane is the initial step in establishing a lane management process. *The lane management system must establish LOS performance objectives and determine the maximum allowable peak hour volumes to achieve those objectives.* The HOT lane pricing conditions function as a tool to manage traffic flow against the LOS performance objectives.

Without effective lane use management, there is a risk that the commodity being sold to the public – i.e. time savings over highway mainline lanes – will be greatly compromised. HOT lane traffic levels should be limited to volumes that provide reliable speed advantages over adjacent highway general purpose lanes. There are two critical issues that affect lane management:[10]

- Determining the HOT lane capacity for paying vehicles before congestion occurs; and
- Understanding the types of lane management strategies that can be applied to regulate demand.

HOT lane capacity is a function of the number of access points, the vehicle mix, roadway slope and configuration, separation treatments, and the number of travel lanes, among other variables. HOT lanes with fewer access points have higher lane capacity with those with more access points. Likewise, a multilane HOT facility will have a higher managed capacity (vehicles per lane per hour) than a single HOT lane configuration. For example, flows on the Houston I-10 Katy Freeway QuickRide – a one lane, reversible-flow facility are kept to 1,500 vehicles per lane per hour.[11] In contrast, the 91 Express Lanes – which provide two travel lanes in each direction – operate at acceptable conditions with flow rates of 1,800 vehicles lane per hour.

On an unpriced highway, increasing volumes result in decreased speed. When the volumes reach an unstable point, speeds to drop to around 15-20 miles per hour. With this reduction in speed, lane capacity will drop from 2,000 to 2,100 vehicles per lane per hour to about 1,300 vehicles per lane per hour.[12] In order to maintain "free flow" conditions in HOT lane facility, vehicle throughput is

10 "A Guide for HOT Lane Development", U.S. Department of Transportation, Federal Highway Administration

11 Ibid, Chapter 6

12 Ibid, Chapter 6

regulated through variable pricing to a level below maximum capacity. This volume threshold serves as the benchmark for ensuring premium level of service for HOT lane users.

Table 4-1: Lane Management Control Strategies

Tool	Operational Impact
Occupancy	Limiting lane use to vehicles carrying a minimum number of passengers. HOV 2 and HOV 3 are typical occupancy constraints, however there can be variations on this theme if the managed lane facility is an express lane project where every vehicle pays a fee with vehicles carrying more than one occupant receiving a discount (similar to SR-91 HOV3+ discount).
Eligibility	Limiting lane use to specific types of users, such as two axle vehicles only, motorcycles, low emission vehicles, or trucks.
Access	Limiting the number of access points or using ramp metering for lane access so that demand cannot overwhelm the managed lane capacity.
Pricing (Variable, Fixed, or Dynamic)	Imposing a user fee that help regulate demand by time of day or day of week. The fee increases during expected periods of highest demand if time-of day pricing is employed or the fee increases dynamically as demand increases.

In summary, lane management strategies to regulate traffic flow on HOT lanes include:

- Eligibility,
- Vehicle Occupancy,
- Access,
- Toll Rate (variable or fixed),
- Type of variable pricing (dynamic based on travel value, time of day, etc.)

The impact of each lane management tool is briefly presented in the adjacent table. Applied in combination, these tools offer the flexibility needed to maintain strong LOS on the HOT lanes. An appropriate range for HOT lane capacity in most project settings would be approximately 1,600 to 1,800 hourly automobile equivalents per lane.

4.2. Toll Collection Operations

Toll collection systems may consist of conventional cash lanes, dedicated electronic toll collection lanes or Open Road Tolling (ORT). If at all possible, toll collection must have a seamless customer interface and, equally importantly, have no negative impact on traffic flow. ETC is used on nearly every significant toll road, bridge, and tunnel in the country. These technologies are well-proven and provide the type of seamless customer interface and transaction reliability that make them critical to HOT lane operations. The technologies used for electronic toll collection and pursuit of toll violators consist of Automated Vehicle Identification and Transponder Technology, Automated Vehicle Classification Video Image Capture and Account Processing and Customer Service. The electronic toll collection technologies for capturing tolls automatically is generally referred to as ETC (with a transponder) and Video Tolling (no transponder).

4.2.1. Transponder and AVI Technology

Most current AVI systems rely on Radio Frequency Identification (RFID) technology, which enables communication with a transponder affixed to a vehicle via Dedicated Short Range Communications (DSRC). A transponder is an RFID device that, when mounted on a vehicle's windshield, enables the electronic collection of highway tolls by an AVI system as it passes through the toll zone. The 'reading' of the transponder may occur while the vehicle is traveling at stop and go or highway speeds. The AVI system typically consists of an antenna and reader installed above a toll lane to automatically "read" or identify the transponder, and the vehicle associated with it.

Vehicle Transponder used in 91 Express Lanes

ORT and HOT lane implementation requires that tolling occur at highway speeds up to 100 mph. The difference between an HOT and an ORT implementation is the toll zone for an HOT implementation is lane based, generally one or two lanes, while in an ORT implementation a toll zone consists of multiple lanes. With both ORT and HOT implementations, there are no physical toll plazas, but the factors that determine gantry locations and how tolls are assessed are no different than those which determine conventional toll plaza locations. The features observed by the driver are the toll gantry (basically a highway sign structure) with the electronic toll collection equipment on it, the related support infrastructure, and toll signage to tell drivers that they are passing a payment point and how much is being charged. The technologies used in both implementations are basically the same.

Users who have established an automatic toll account are provided a transponder to install in their vehicle. The data written to the transponder at the time an account is established typically include information on vehicle classification, special group discounts, or special authorizations for a given vehicle type. When passing through a toll zone, the transponder data is compared with the in-lane monitoring systems to validate vehicle classification, special discounts or special authorizations that transponder and vehicle combination for a given account. Once proper account authorization has been verified, the applicable toll is then charged to the account and automatically deducted from a pre-paid account balance.

If the information on the tag and vehicle data do not correspond with a valid account, or if for some reason there is insufficient funds available in an account, or if the vehicle does not have a transponder, or has an improperly mounted transponder, the vehicle will be treated as a violator.

For many HOT lanes, SOV users are required to have a transponder while HOVs are exempted. Recent studies, however, have shown that requiring transponders on all vehicles improves enforcement through the use of visual indicators and/or video image capture of license plates. Requiring transponders in all vehicles, HOV, SOV, and transit, provides for easier identification of SOV and HOV vehicles or violators without a transponder, and for quick and easy implementation of special discount program rates at the back office and not in the lane.

4.2.2. Video Tolling

Video tolling generally makes use of the open road toll enforcement cameras and the computer systems that support image and license capture, character recognition, and user location or citation processing. Video tolling allows the occasional user, tourist, or rental car motorist to establish a valid toll account either prior to using an ORT lane, or within a specified time after completing their trip. The time after trip completion is typically on the order of up to 72 hours. Generally a video toll account may be established by phone or WEB based interface with the motorist providing a credit or debit card number, vehicle license plate, make, model and type of vehicle.

Video toll accounts, using valid vehicle license plate numbers, are downloaded to the toll zone or lane controller and the video controller in the lane in accordance with procedures established by the facility's Business Rules. If the motorist does not have either a valid transponder or valid video account the captured image is retained to be processes as a violation transaction.

The violation will be subjected to an image review process to determine if the license plate belongs to either a transponder customer or video toll account. If verified to be a valid license plate account the 'violation image' is converted to a toll transaction using the video image review and posted to the customer account.

The implementation of video toll systems in the lane use one or two video cameras with supplemental lighting to capture either the rear of the vehicle centered on the license plate area or two cameras to capture an image of both the rear and front of the vehicle. In facilities that restrict vehicle traffic to cars or two axle vehicles a single camera is sufficient to capture the rear of the vehicle and satisfactorily obtain an unobstructed and readable license plate image. For facilities that permit towed vehicles or semi-trailers, it is recommended that both front and read image capture cameras be used to ensure an unobstructed capture the truck's front license plate and possibly the license plate of the towed trailer. It is essential that a front image capture be utilized for facilities with high truck and/or semi-trailer traffic since the rear license plate of the truck will normally be blocked by the towed trailer.

Image capture systems with camera and supplemental lighting may be mounted either overhead or along the side of the toll lane(s). The majority of image capture implementations use pulsed or flashed, high intensity LED white lighting since it is best suited to handling multiple colored license plate characters and backgrounds, and infrared lighting for license plate character capture in a black and white image. However, there are some implementations that measure ambient lighting and supplement with continuous lighting as needed to successfully perform optical character recognition on the captured image.

The millisecond flashes for pulsed and strobe lighting that are only triggered when an apparent violation (includes Vtolls) has occurred, or is detected must be unnoticeable by the user. Cameras mounted overhead with continuous white lighting is likely to cause visual impairment to the driver and should not be deployed for front license plates capture. Flashed/pulsed, strobe and infrared lighting solutions should be considered to avoid impairing the driver's vision.

4.2.3. System Operations

In order to ensure reliable system operations, the HOT lane facility must include operational resources to provide maintenance, customer service, and account management.

- **Maintenance.** Since HOT lane systems employ totally automated electronic toll collection equipments, it is critical to the seamless use of the system by customers and to maintain revenue collection capability to employ 24/7 maintenance of the system. To minimize down time and to facilitate maintenance actions, it is critical that a maintenance on line monitoring (MOM) system is included with the HOT ETC system. Monitoring of all toll zone collection equipment status for failures or malfunctions that could impact the collection of revenue will minimize down time and revenue losses.

- **Customer Account Service Center.** Customers should have easy access to account information via a variety of means including web-based, telephone and mail and should be able manage their accounts with the tools provided. The Service Center must provide customer support and handle customer problems and complaints promptly handle customer problems and complaints; it must maintain ongoing communication with the public as well as stakeholders; and provide ongoing outreach information to provide the latest information on the HOT lanes operations and status.

- **Video Processing Center.** As video tolling becomes more widespread together with video image capture of violators the Account Service Center may well develop into dual purpose Customer Service and Video Processing Center (CSC/VPC) that not only establishes and manages transponder and Video Toll accounts, but also ensure that true violations are processed and funds are recouped.

4.3. HOT Lane Enforcement

Enforcement is critical to the successful operation of any HOT lane facility. An effective HOT lane enforcement program should ensure that operating requirements, including enforcement of toll-exemption eligibility based on vehicle occupancy, are maintained to preserve travel time savings, discourage unauthorized vehicles, and maintain a safe operating environment.

This section reviews HOT lane operational concepts and identifies unique issues and challenges associated with HOT lane enforcement. Enforcement strategies used in several HOT lanes similar in scale and length to the projects reviewed in this study are discussed.

4.3.1. Concept of Operations

HOT lanes are toll facilities that charge a toll to all HOT lane users except for vehicles that meet the minimum occupancy for toll-exemption eligibility. In order to deter violations and reserve capacity for users, the HOT lane operator must be able to identify violators who use the HOT lane without paying. In addition, the HOT lane operator must be able to distinguish between vehicles required to pay the toll and HOVs that are eligible for toll-exemption.

Most HOT lanes today that utilize electronic toll collection require users to establish a pre-paid account from which toll transactions are debited for HOT trips taken. The requirement for users to have an active HOT lane account provides a partial solution for toll lane enforcement. Because all vehicles are required to have an active HOT lane account, motorists entering the HOT lane without a valid account are, by definition, considered in violation of the usage policy. Image capture technology is very reliable and can be utilized to read and capture license plate information. With this information, HOT lane operators can issue violation citations, collect tolls owed, and process fees.

The technology used for violation enforcement is similar to Video Tolling for image capture and license plate reading. All images of the license plates of suspected violators are sent to the VPC, the interface to the CSC for toll violation processing. The CSC contains infrastructure equipment, software and services to process violations and license plate read images. Once the VPC has confirmed that the captured license plate is not linked with a valid transponder, the VPC will link to associated VPC and/or DMV databases to obtain the identity and address of the vehicle's registered owner, prepare billing for notification to the violator, and, if required, pursue that individual for reimbursement of tolls, fees, and penalties.

The enforcement system must be able to recognize HOVs that meet the minimum occupancy requirement and exempt them from the toll. In addition, the system must be able to distinguish toll-exempt

HOVs from violators. Can this be accomplished without requiring all vehicles to establish a pre-paid account, including vehicles that will use the HOT lane primarily as toll-exempt HOVs? Based on the experience of recent HOT lane projects, the answer is no. Given the current state of technology, it is not possible to distinguish a violator from an eligible HOV from among the population of non-transponder equipped vehicles. ***Consequently, most HOT lane operators have chosen to require all vehicles, including toll-exempt HOVs, to establish active accounts with the HOT lane.***

For HOT lanes that offer toll-exemption for eligible HOVs, the task of enforcement remains a major operational challenge. Why? Because there is currently no technology available that allows a HOT lane operator to assess a differential toll or provide a toll exemption based on observed vehicle occupancy. As a result, determination of vehicle occupancy has to be performed manually through visual inspection either at a fixed post or in transit. Another important wrinkle – given the operator's inability to determine vehicle occupancy prior to a vehicle entering the HOT lane – is that the burden of realizing the HOV toll exemption is on the driver, not the HOT lane operator. In other words, the driver of the toll-exempt HOV must de-activate the transponder to prevent the HOT lane operator from inappropriately charging the toll. This in turn requires the enforcement system to be able to verify occupancy for HOVs that might otherwise be confused for a violator.

4.3.2. Facility Design Considerations

Facility design is also an important element of HOT lane enforcement. Barrier separation features can be effective in deterring potential violators, but barrier separated systems also require additional space along the facility to monitor, apprehend, and cite violators. Barrier separated facilities generally make apprehension fairly easy, since the violator is confined within the lanes after entry; however, it should be noted that the larger the facility (i.e., number of lanes) and the larger the quantity of entry and exit points, the more difficult manual enforcement becomes.

Non-barrier separated HOT lanes are more difficult to enforce, since it is easy to enter and exit the lane simply by changing lanes. Lane delineators such as those in use on the 91 Express Lanes in California can deter violators, with some instances of violators 'diving' through the delineators. Locations where delineators are used typically do not have adequate shoulder space for effective road side enforcement.

Some actions that can be taken to enhance the performance for HOV violation enforcement may include:

- During the design phase, have engineers meet with state highway patrol officials to determine locations best suited (safe, adequate space) for road side enforcement.
- If there is adequate space, consider installing concrete barriers.
- Prominently post the fine for HOV/HOT violations on roadside signs.
- Use random visual, special enforcement followed by routine enforcement.

4.3.3. HOT Lane Enforcement Functions

Enforcement is critical if a HOT lane facility is to be successful and effective. The enforcement strategy and the technology implemented must be reliable, highly visible, and one that promotes fairness. Most facilities currently use visual (manual) enforcement together with some technical support to monitor HOT lanes. Although utilizing enforcement vehicles to stop apparent violators may not be the most efficient method to catching violators, it is the most visible to the public, including the public traveling in the general purpose lanes. This visible enforcement effort demonstrates that the agency or entity controlling the use of the managed lanes is serious about maintaining the integrity of use by vehicles qualified to be in the designated managed lanes.

Enforcement of HOT lane usage must accomplish the following key operational functions:

- Verify toll payment (or credit)
- Verify vehicle occupancy
- Assess fine to violators.

Verify Toll Payment

Most current AVI systems rely on RFID technology, which enables communication with a transponder affixed to a vehicle via Dedicated Short Range Communications. A transponder is an RFID device that, when mounted on a vehicle's windshield, enables the HOT lane operator to collect an electronic toll as it passes underneath the toll zone.

The 'reading' of the transponder may occur while the vehicle is traveling at stop and go or highway speeds. The AVI system typically consists of an antenna and reader installed above a toll lane to automatically "read" or identify the transponder, and the vehicle associated with it.

Verify Vehicle Occupancy

As stated earlier, accurately determining the number of vehicle occupants poses a tremendous challenge. When volumes rise, it is difficult to catch all violators, let alone distinguish violators from eligible HOVs. From time to time, an enforcement officer mistakenly stops HOVs because an occupant in addition to the driver (e.g. small child) is not readily visible in the back seat. Enforcement of occupancy requirements is perhaps the most difficult operational challenge facing toll agencies; this is because automated technologies have not yet met reliability and field accuracy requirements needed for operational deployment. In addition, there are a host of cost and privacy considerations associated with the use of such detection technology.

The technical support used to supplement manual enforcement typically consists of a gantry-mounted violation indicator light to provide an indicator for near-by enforcement vehicles to act on. Additionally, some facilities use video cameras together with an OCR system to capture the license plate image of the vehicle as it passes through the toll zone. The camera may be mounted above the roadway or along side the roadway, depending on the geometry of the HOT facility and the violation objectives of the facility. Once the license plate image is captured, it must be correctly 'read' by the OCR in order to successfully locate the vehicle owner to collect the toll and if applicable, the toll evasion fine.

Assess Fine to Violators

Violations fall within two classes: a) enforceable (no transponder read, but license plate read; vehicle not linked to an active account), and b) Unenforceable (no transponder read and no license plate read). An effective HOT enforcement program should attempt to keep violations (enforceable and unenforceable) to at or below 10% of total trips.

HOT lanes typically require the creation of local ordinances that carefully document the process for resolving violations. The ordinance should establish a multi-stage notification process, in addition to establishing fine notification procedures that are consistent with the Georgia vehicle code. A multi-stage notification process with a graduated fine structure is typically used to provide differential penalties for first-time violators versus habitual offenders.

In California, for example, the 91 Express Lanes uses the following graduated violation structure:

- Notice of Toll Evasion (NTEV) – $20
- Notice of Delinquent Toll Evasion (NDTEV) – $55

- Notice of Toll Violation Assignment – $80
- Other Collections – per Georgia vehicle code penalties

The Orange County Transportation Authority (OCTA) reports that of the total number of enforceable violations, 60% are dismissed with no penalty, 11% pay toll + penalty and 20% go to collections. In total, 80% of all enforceable violations are addressed at the NTEV/NDTEV stage.

4.3.4. Recent Experience with HOT Lane Enforcement

I-15 Express Lanes (San Diego, CA)

The I-15 Express Lanes is a barrier-separated, reversible flow HOT lane that has recently expanded from an 8-mile facility (with two toll zones) to a 20-mile facility with multiple access points. Because of the limited roadway geometry and restricted shoulders, shoulder enforcement on the extended segment is a major challenge. The mode of enforcement will require more mobile enforcement capabilities, with use of supporting reader technologies in mobile units.

The San Diego Association of Governments (SANDAG) contracts with the California Highway Patrol (CHP) to perform manual enforcement at designated enforcement areas. Under this contract, CHP periodically supplements the fixed post visual enforcement with mobile enforcement units. SANDAG reports enforcement remains one of the biggest challenges facing the day-to-day operations of the I-15 Express Lanes, especially given the opportunities to violate the facility along the extended segment. I-15 Express Lanes violation rates range between 5% and 15%, with some time-of-day and seasonal variations.

91 Express Lanes (Orange County, CA)

On the 91 Express Lanes, visual enforcement is performed at three locations where the median was widened to accommodate a vehicle. Flexible delineators separate the Express Lanes from the SR-91 mainline lanes, with no intermediate access locations between the eastern and western entry points of the facility. The entry points have a dedicated HOV3+ lane and an Express Lane. Only eligible HOV3+ vehicles can enter the HOV3+ lane; these vehicles are charged a half-toll.

The Orange County Transportation Authority (OCTA) contracts for enforcement with the California Highway Patrol (CHP), which performs visual enforcement at three locations along the 91 Express Lanes. OCTA reports that the violation rate for the 91 Express Lanes is approximately 8%.

MnPass (Minneapolis, MN)

MnPass uses a solid double white line to separate HOT lanes from general use lanes. A dotted striped line indicates authorized access / exit points. According to MnDOT, after lane striping was implemented, there was a drop in the violation rate from over 20% to less than 10%. Violators of marked striping are fined $165.00 per occurrence.

The enforcement strategy, which was considered critical to the success of the MnPass program, combines visual enforcement with mobile reader technology. It is worth noting that there was very little enforcement of the I-394 HOV lane prior to conversion to MnPass, with violation rates between 20-30%. With the opening of MnPass, enforcement was carried out through a partnership with the Minneapolis Highway Patrol, Minneapolis Police Department, and Golden Valley Police Department. Combined, the enforcement contracts cost approximately $165,000 annually.

Enforcement of valid trips is accomplished through three methods:

- Enforcement tags – special transponders in police vehicles that register an audible tone if a valid transponder is read.
- Mobile reader – this device is mounted on police vehicles and can provide information on last valid reads.
- Enforcement beacons – stationary flashing light that flashes when a valid transponder is read at the access point.

Figure 4-1: Enforcement equipment used in MnPass

MnPass has supplemented the violation indicator light by adding a portable transponder reader in the enforcement vehicles enabling enforcement officers to validate operational transponders while driving along side of or immediately behind a target vehicle.

SR-167 HOT Lanes (Seattle, WA)

SR-167 uses an electronic toll collection system that features an in-vehicle transponder, over-roadway transponder readers mounted on overhead gantries, and variable message signs that post the time-of-day toll. Similar to MnPass, SR-167 uses a solid double white line buffer to separate the HOT lane from adjacent highway mainline lanes.

When a vehicle passes through the access point with an active transponder, a flashing enforcement light activates. If the light does not flash, state highway patrol checks to see if the vehicle has two or more occupants. If not, the vehicle is cited with a violation.

4.3.5. Best Practices in HOT Lane Enforcement

The successful operation of a HOT lane facility is dependent upon a visible and effective enforcement program that the public perceives as fair and consistent. For the time being, the ability to deter violations and abuses of the HOV exemption allowance is strongly tied to the visibility of HOT lane enforcement presence. When lane enforcement presence is weak or non-existent, violation rates can rise above the generally accepted range of between 8-15%.

The enforcement strategies used HOT by lane operators provide some useful insights on best practices and lessons learned. Below is a summary of key findings:

- All users should be required to have a valid account for the HOT lane, regardless of vehicle occupancy status.
- Establishing contracts with state highway patrol and local law enforcement is the most effective and practical means of monitoring vehicle occupancy.
- Providing enforcement vehicles with mobile transponder readers helps law enforcement with verification of valid transactions.
- Barrier-separation of the HOT lane from mainline lanes is more effective in deterring in-and-out-weaving and opportunistic violations.
- Allowing HOVs to turn off transponders is an effective but flawed way (since it relies on the driver taking an action that they forget to take) to allow HOVs to self-provide the toll exemption.
- Space along a widened median should be provided at strategically located enforcement zones, where law enforcement can visually inspect vehicle occupancy from a fixed location.
- The other method of allowing HOVs to receive a toll exemption or discounted toll, is to set aside a separate HOV entry lane that segregates HOVs from toll-paying SOVs.
- Having a strong enforcement presence is a key to deterring violations and maintaining the integrity of HOT lane operations.
- The following table provides a summary of enforcement strategies, their complexity, and effectiveness.

4.4. Signage

Accurate, informative signs are essential in explaining operational procedures of HOT lane facilities and ensuring safe access and egress from the managed lanes. HOT signs should provide motorists with information on:[13]

- Access and egress location
- Occupancy requirements
- Operating hours
- Toll rates
- Enforcement

A major element in HOT operations and management is signage, both upstream and downstream of the facility's ingress/egress points. Inadequate signage can diminish the customer's ability to make an informed travel decision and may compromise vehicle safety. Often there are possible conflicts between signing for general purpose lanes and for managed lanes. Drivers in both lane types can see not only a message intended for their lane use but can also see the message for the other lanes as well. The signage needs to be such that each driver clearly understands which message should be followed.

13 *Perez, B.G., and G. Sciara.* "A Guide for HOT LANE DEVELOPMENT", *Federal Highway Administration Report FHWA-OP-03-009, Washington, DC, 2003*

Coordination of signage both from a visual and an operational perspective is important. FHWA, in collaboration with the International Bridge, Tunnel and Turnpike Association (IBTTA), recently completed a study of traffic control strategies at toll plazas and issued a report entitled, “State of the Practice and Recommendations on Traffic Control Strategies at Toll Plazas.” The recommendations contained in the report address (1) solutions to improve safety and operations of existing toll plazas; (2) contemplating replacement or modification of an existing toll plaza; or (3) planning a new toll plaza. While potentially applicable to HOT lanes, the report includes recommendations for Advance Signage and the Color of Toll Signs, but does not specifically address HOT operations. Unfortunately, The Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways 2003 Edition does not provide a recommendation or standard for HOT signage. Some current toll agencies and other future ORT toll facilities have implemented purple-background signs to differentiate the facility from conventional roadways or other toll facilities. The Harris County Toll Road Authority (HCTRA) uses purple-background signs on their WestPark Tollway in Houston as part of an Experimentation Project (see Section 1A.10 – Interpretations, Experimentations, Changes, and Interim Approvals, pages 1A-4 through 1A-7 of Chapter 1 from the 2003 MUTCD. The MUTCD 2003 Edition does not prohibit such use, but also does not endorse/recommend its use. The two signs[14] below where used for conventional toll plazas, but their color distinctions should be considered as an example to provide unique and distinct HOT signage.

Sun Pass

E Pass

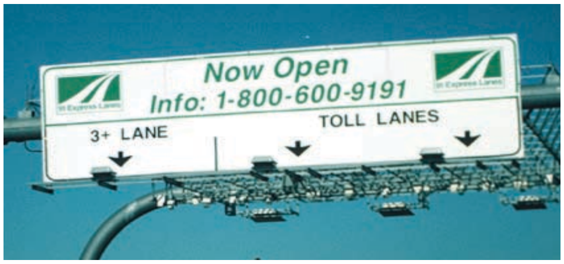
Figure 4-2: Sample HOT Signage

Since SAFETEA-LU failed to fund the development of the 2008 MUTCD, no new recommendations or standards are planned at this time that would include toll roads or HOT lane applications. Until the MUTCD provides standards for toll road or HOT signage, it is recommended that agencies or DOT’s plan to use purple signs, similar to the HCTRA signs used for the WestPark Tollway, and that that application be made to FHWA for an Experimentation Project, similar to the HCTRA project, for use of the purple signs. This will permit the use of the signs, while not officially covered by the MUTCD at this time.

While the MUTCD currently provides no guidance on signing for HOT lanes it is particularly important to have good signage when variable tolls are involved and it is critical in directing motorist to access and egress locations. Although MnPass chose not to use purple for their implementation the figure here is a good example of a distinctive sign that is in use by MnPass on their HOT implementation on I-394. It is clear, easy to understand, and provides the driver with information on the toll and distance to the HOT access. Two additional examples of informative and clear signage are shown in the figures below.

14 Excerpt from FHWA Memorandum, Subject: Traffic Control Signage for Toll Plazas, October 10, 2006,

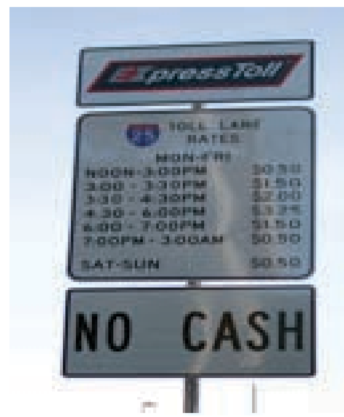
SR 91



MnPass

Figure 4-3: Sample HOT Lane Signage

Signage placement must be located at a sufficient distance to provide the motorist with enough time to safely execute the directions provided or to change lane if needed to comply with the signage. The chances for operational success of a managed lane facility will be enhanced by good informational and directional signs.



Toll Rate Sign

It is equally important to ensure that signage displaying enforcement provisions for lane violations is displayed consistently and frequently along the HOT corridor. It has been found that the lack of consistent enforcement signage contributes to unauthorized users accessing the facilities.

Additionally, the inadequacy of enforcement signs also appears to contribute to the practice of lane diving from the general purpose lanes into the HOT lanes that are not barrier separated which can create safety hazards.

4.5. Incident Management

The sponsoring agency must develop a comprehensive incident management plan to address a wide range of situations that can impact facility operations. For example, if there were a major accident on highway mainlines that resulted in severe backups, should the HOT lane eligibility requirements be temporarily waived to maximize corridor-wide throughput until the accident is cleared? Conversely, if there were a major incident on the HOT lanes and they were to be closed, how should the event be handled? How will necessary information be conveyed and what information should appear on VTMS?

The functional requirements for HOT lanes are best integrated into a region's traffic operation center. The development of a Regional Incident Management Plan that addresses incident types and mitigation options for each type must be developed and updated regularly. For an Incident Plan to be effective, the plan must be tested and training on the execution of the plans must be performed on a regular basis. If transit operations are integrated in the facility, then transit vehicle incident management must be included in the Incident Management Plan.

With a regional traffic operations center, on-site personnel may be employed to monitor and address traffic incidents and enforce rules and regulations that cannot be addressed remotely. For example, although SANDAG's I-15 Express Lanes is operated by a private company, incident management is under the sole control of Caltrans, who make decisions to divert traffic from or onto the Express Lanes depending on the nature of the incident. Reversible flow lanes, in particular, must have on-site staffing to ensure safe and efficient opening and closure of lane operation, regardless of the level of automation applied to the deployment of traffic control devices. Typically, staffing resources varies with the amount of automation, but a minimum of one person per peak period needs to drive the lane and make sure all of the traffic control devices are fully deployed in a correct manner.

HOT lanes are increasingly turning to ITS systems to track users, monitor operation performance, confirm whether tolls have been paid, and confirm lane status when incidents occur. The implementation of a basic incident detection system must include automated interfaces, typically with video and incident detection software application to effectively detect incidents and to deal with regional traffic issues in a timely manner.

As soon as the severity of an incident is determined by operations personnel, information on travel options should be posted in real time on VTMS and DMS in the area. If Highway Advisory Radio, (HAR) is included in the region's ITS suite of equipment, incident alerts should be announced through this medium as well. Along with the message sign and HAR notifications, website posting of separate real-time travel speeds, travel options, and service reliability for the HOV lanes should also be used. In some cities such as Atlanta, Seattle, Houston and Orange County, California, website postings are already occurring, enabling users to quickly assess incident travel options, and available travel benefits between the parallel roadways.

Functional requirements for the HOV/managed lane system should be reviewed periodically as design upgrades in technology and traffic operations management allow.

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Chapter 5. Case Studies of HOT Lane Conversion Projects

The purpose of this chapter is to identify lessons learned from three case studies of HOV to HOT conversion projects:

- I-15 Express Lanes (San Diego, CA)
- MnPass (Minneapolis, MN)
- I-25 Express Lanes (Denver, CO)

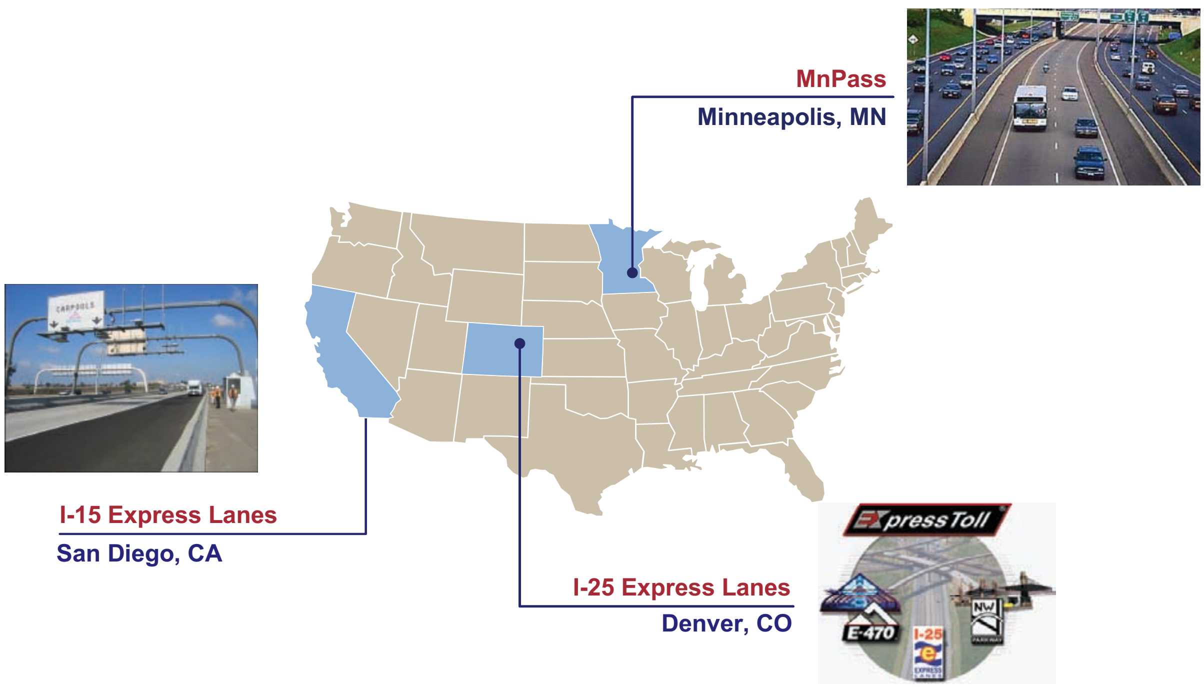

Figure 5-1: Location of Hot Lane Case Studies

These three case studies were chosen to supplement the growing body of research exploring the relationship between program objectives, system design, concept of operations, toll collection strategies and operational requirements. Each case studies attempts to identify outcomes (intended and unintended) based on specific operational choices and address key lessons learned, or best practices in the planning, design and implementation.

5.1. Data Collection Approach

Information available form published data for each of the operational case study sites was integrated with focused interviews conducted at the project site, when possible. To provide a common baseline, or starting point for the interviews, a focused interview guide was developed to facilitate in-depth probing of key project development issues and challenges in four main areas, including:

- Public Outreach and Communications
- Planning and Policy
- System Design Procurement
- Management and Operations

5.2. Focused Interviews

The three systems were specifically chosen for the case studies because they were converted from HOV lanes to HOT lanes or were in the planning process for expanding existing facilities to HOT lanes and had been operational for at least one year.

On-site interviews with the management and operations staff were conducted at the I-15 Express Lanes in San Diego, California and MnPass in Minneapolis, Minnesota. For I-25 Express Lanes in Denver, Colorado, remote discussions were conducted with key management staff. As mentioned previously, the interviews were designed to address specific issues and challenges faced at each stage of project development to include public outreach, planning, design, implementation and operations. Tables 5.1 and 5.2 provide a comparative summary comparison of the three operational case sites key site properties and operational characteristics.

Table 5-1: Facility Characteristics

Site	Length	Type Lane	# Access Points	Toll Points	GP – ML Separation
I-394	11 mi	8 mi – SLn 3 mi – 2Ln Rev.	Multiple – SL Rev. Entry / Exit	7 WB 6 EB	Double White, Rev. with Barrier
I-15	8 mi	2 Ln Rev.	Entry / Exit	1	Rev. with Barrier
I-15 Exp	12 mi	2 Ln HOT	Multiple	Multiple	Dbl Yellow, Movable Barrier
I-25	10 mi	3 mi SLn 7 mi 2Ln Rev.	Entry / Exit	1	Dbl White, Rev. with Barrier

Note: I-15 HOT expansion includes four lanes (two in each direction), with movable barrier separation in southern section and double yellow strip separation in northern section between HOT and general use lanes.

Table 5-2: Operational Characteristics

Site	Open	Type	Hours of Ops	Authorized Users	Tag Requirement
I-394	2005	SL HOT R2L HOT	AM Peak PM Peak Non-Peak Closed	2 axle, HOV+2 Buses	Only SOV
I-15 Rev	1996	R2L HOT	AM Peak PM Peak Non-Peak Closed	2 axle, HOV+2 Buses	Only SOV
I-25	2006	SL HOT R2L HOT	AM Peak PM Peak Non-Peak Closed	Trucks, HOV+2 Buses	SOV, Bus, Truck

The following sections briefly summarize the key findings from the focused interviews for each of the operational sites, SANDAG's I-15 Express Lanes, MnDOT's MnPass, and CDOT's I-25 Express Lanes.

5.3. San Diego, CA I-15 Express Lanes

The I-15 Express Lanes (FasTrak) opened in January 1997 as a three year value pricing demonstration that has been operational since transitioning from HOV only to HOT Express Lanes in January 2000. The original facility was an 8-mile, two lane, reversible HOV facility. With over 10 years of operational experience, SANDAG will expand the existing reversible facility to four bi-directional HOT lanes with multiple intermediate access locations of over 20 miles in length.

5.3.1. Project Objectives

- Provide additional highway capacity on what had been a largely underutilized HOV facility.
- Provide better management and utilization of the HOV lanes.
- Achieve and maintain LOS C or better.
- Generate enough revenues to support ongoing operations and maintenance.
- Support new express transit service through toll revenues.
- Improve highway and transit in the corridor.
- Extend the original reversible lane segment to include and additional 12 miles of converted HOV lanes into an HOT corridor.

5.3.2. Concept of Operations

- The reversible section was operational only during the AM and PM peak periods and closed during the non-peak period.
- As the facility expands operations for both HOV and HOT will be 24/7. System will use movable barriers on the new extension.
- As with the existing reversible sections, HOV 2+ and transit will travel at not cost (free) while SOVs will be tolled for use of the facility. Trucks will not be permitted to use the facility.
- Current policy only requires SOV users to have a transponder. However, transponder use for HOV users is under consideration.
- While under consideration, there is currently no electronic enforcement, only manual enforcement provided by enforcement officers.
- Dynamic Pricing has been employed from the initial pilot system. Toll rates vary, on average from $.50 to $4.00 with a maximum of $8.00.

5.3.3. Innovative Project Features

- Having local and state leadership engaged in discussions early and often throughout the planning and design phases.
- Using dynamic pricing with adjustments based on time of day, congestion levels, and travel time differential with the general purpose lanes. Rates may be adjusted every 6 minutes.
- Sharing revenues with BRT in corridor widely accepted by transit agencies and the public.

5.3.4. Major Project Challenges/Mitigation Actions

- Higher risk of SOV use violations with continued manual enforcement by CHP – Prior to the expansion of the I-15 Express Lanes, enforcement was easier because it was a reversible lane facility that allowed access at a single toll point, with wide shoulders and one enforcement area. With multiple access points and limited shoulder widths, mobile enforcement will be needed to effectively target toll violations.

- The implementation of dynamic pricing required both local public and political support. Early and frequent (on-going) public awareness initiatives that included public outreach, active marketing and surveys contributed to the ready acceptance of dynamic pricing.

5.3.5. Major Lesson Learned

- Enlist the support of a strong political champion at both state and local levels to provide advocacy for HOT lane conversion.
- Roll out an extensive public outreach program involving stakeholder interviews, focus groups, and taskforces in parallel with early project planning efforts.
- Conduct corridor level market research early in the project and update frequently.
- Share information and research among other agencies, especially those involved along the corridor.
- Recognize the need for employing ITS technology to enhance the program and for adding to regional ITS capabilities.

5.3.6. Keys to Project Success

- The HOT program must provide viable and recognized travel options for the public.
- For project acceptance strong stakeholder and public outreach programs are a necessity.
- When possible it is important to develop a revenue plan that includes a transit component.

5.4. Minneapolis, MN I-394 Express Lanes

The I-394 Express Lanes, better known as MnPass, became operational in May 2005 and has nearly two years of operational lessons learned since it opened.

5.4.1. Project Objectives

- To improve efficiency of I-394 and to increase person and vehicle carrying capabilities of the HOV lanes.
- To maintain free flow speeds for transit and carpools.
- To improve highway and transit operations in the corridor with the revenues generated.
- To use electronic toll collection without toll booths.
- To employ dynamic pricing and in-vehicle electronic enforcement.

5.4.2. Concept of Operations

- Conversion of the existing HOV lanes to HOT lanes with concurrent travel to be operated 24/7 while operating the two-lane reversible section for HOT operations EB during the AM Peak and WB for the PM Peak.
- Only SOVs are tolled while HOV 2+ and Transit are not tolled (free). Trucks are not permitted to use the facility.
- For the non-reversible section there is no barrier between the HOT lanes and adjacent GP lanes. Only double white stripe is used to delineate HOT-GP separation.
- For the HOV converted segment there are multiple mid-point access locations to the HOT facility. Access to and from the reversible lane segment is controlled by three gates that are closed manually prior to beginning reverse operations.
- Variable dynamic tolling is used during peak travel times with an average toll rate between $1 and $4, with a maximum of $8.

5.4.3. Innovative Project Features

- The engagement of state leadership early and often throughout the planning and design phases was instrumental in passing key legislation and project acceptance.
- A local taskforce, the I-394 Express Lane Community Taskforce, was created to address issues, desires and design options.

- The program received local and state support by ensuring that 50% of revenues generated were shared with transit for improvements.
- To maintain support and to encourage continued growth, it is important to conduct continuing and comprehensive evaluations of the facility to provide to the public and for use in marketing campaigns.

5.4.4. Major Project Challenges/Mitigation Actions

- Prior to the conversion to HOT lanes there was a high rate of HOV lane violations, over 20%. To maintain the integrity of the HOT facility a more effective enforcement presence was needed to detect and to deter violators. Mobile violation detection equipment was employed along with contracts with three law enforcements agencies along the corridor to beef up law enforcement presence. Contracts are with Minnesota Highway Patrol, Minneapolis Police Department and the Golden Valley Police Department.
- Opposition from pro-transit constituent groups had to be convinced that HOT lanes would provide a strong benefit to transit. With the strong projections provided from the Toll and revenue studies, and the proposed sharing of the revenue generated, the pro-transit constituent groups became strong supporters.
- The added SOV traffic on the HOT lanes created unexpected traffic backups in the downtown area that increase congestion. After opening of the HOT facility MnDOT constructed an auxiliary lane to provide additional vehicle storage capacity to mitigate the congestion created by the added SOV traffic.

5.4.5. Major Lesson Learned

- Have a fiber backbone and communications infrastructure in place to implement an effective traffic management system.
- The establishment of the I-394 Express Lane Community Task Force was critical to getting buy-in from the Governor, state legislators, and community groups. It provided an opportunity for the community to engage the decision makers early and often through a participatory process.
- Don't create new traffic problems and be prepared to add capacity to address unexpected congestion hot spots.

5.4.6. Keys to Project Success

- Implement an effective enforcement strategy to regulate demand and to maintain the integrity and effectiveness of the facility.
- Establish a robust public outreach and coordination framework through which to build political and public support.
- Develop a revenue plan that featured a transit component was critical in earning the trust and support of the transit community.

5.5. Denver, CO I-25 Express Lanes

The I-25 Express Lane opened in June 2006. Like SANDAG's I-15 Express Lanes, I-25 Express Lanes consists of two segments: a 2-mile reversible segment and a 7-mile barrier-separated HOT lane segment.

5.5.1. Project Objectives

- Improve the efficiency and capacity of I-25 HOV/HOT lanes.
- Expand menu of travel options to the motoring public.

- Use the facility as a showcase congestion management tool.
- Generate sufficient revenue to cover operating expenses.

5.5.2. Concept of Operations

- The reversible section is operational during AM and PM peak periods. During non-peak periods the section is open outbound only.
- The HOT section (converted HOV) is only operational during the AM and PM peak periods.
- The entire facility is barrier separated with single entry and exit points.
- SOV's are tolled for use, while HOV2+ and transit travel without being tolled (free). Trucks over 3-axles using the facility are charged a premium rate of $18.00 plus the base toll rate which is per axle based.
- All HOT users, SOV, bus and trucks are required to have transponder.
- A fixed variable toll rate based on time of day dynamic tolling is used. Toll rates average between $.50 to a maximum of $3.25).
- VES enforcement is automatic using license plate photo and optical character recognition technology.

5.5.3. Innovative Project Features

- Instead of using LOS, bus travel speed is used as a performance measure on travel time. If bus speeds or time degrades by 8 min, 45 seconds then the toll rate is raised to push SOVs off of the facility. The tolls are increased on a pre-determined fixed amount based on time of day.
- The facility has single ingress and egress points with the northern section interfacing to two distributor connections and the southern end feeding directly into downtown.
- The facility has a single tolling point that requires traffic to divide into lanes for HOVs (free) and non-HOV (tolled) vehicles.
- During off peak hours the reversible lanes are switched using multiple gates along the facility to restrict access from direct access ramps. All gate closing is completely automated.
- Customer Service Center is outsourced to existing E-470 Service Center

5.5.4. Major Project Challenges/Mitigation Actions

- HOV/HOT violations are captured automatically for undetected transponder reads using V-tolls, or video tolls.
- Vehicle occupancy violations done by visual on-site inspection by Highway Patrol.
- Automatic vehicle classification system is required for axle classification needed to capture trucks with more than three axles.
- The reversible lane section in downtown required that travel through the section be safely and efficiently revered. Gates are used at the entrance and exit points as well as the direct access ramps to restrict access. Gate closing is completely automated, is done during off-peak hours is connected with traffic operations via a verifiable communication link to verify gate status.

5.5.5. Major Lesson Learned

- Have a political champion to ensure successful project implementation.
- Avoid justifying HOT lanes implementation as a revenue generation strategy for added capacity. Establish the primary program objective of HOT lane implementation as a congestion management tool.
- Ensure that managed lane projects are included in MPO plans early.

5.5.6. Keys to Project Success

- Promote future projects as “congestion relief” and promote early to the public. Don’t promote revenue enhancement; advocate use as a congestion tool.
- An effective enforcement strategy is a must for a success.
- A strong political champion at both state and local levels is key to successful project development and implementation.

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Chapter 6. Direction for Future Practice

The success of HOT lanes in a growing number of states suggests that there is a strong market demand for high quality, dependable Express Lanes that function as a safety valve from highway congestion. However, the case studies, in addition to the experience of new HOT lane projects elsewhere, indicate that HOT lanes – while they demonstrate the feasibility of several important operational concepts – are assets that have diminished valuation compared to other toll alternatives.

While there may be a compelling financial case for requiring all vehicles to pay a toll regardless of occupancy, the opportunity to leverage private financing and PPP mechanisms must be weighed against program objectives developed specifically to mitigate public concerns such as equity, fairness and privacy. In many cases, there is a strong consensus to accept suboptimal rates of return in exchange for mitigations that demonstrate the state's commitment to meeting public concerns.

As more agencies assess the feasibility of converting existing HOV to HOT lanes, it is important that planners, designers and other practitioners avoid 'relearning' lessons others have struggled with in converting HOV lanes to HOT lanes. One of the biggest challenges facing HOT lane planning and operations is and will continue to be enforcement. Perhaps the major lesson learned from the case studies is that while manual enforcement is imperfect, it can be an effective method of deterring violations in HOT lanes with limited access. Even with multiple enforcement zones, it is virtually impossible for law enforcement to perform 100% occupancy checks of vehicles that self-identify as HOVs.

This is especially true of HOT lane that are non- barrier separated and have multiple access points. As HOT lane facilities expand in length and grow from a facility-based to network-based system, manual enforcement will at some point experience diminishing effectiveness as a violation deterrent strategy. The following section briefly identifies the Best Practices Top 20 highlighting those areas HOT lane practitioners should be cognizant of to avoid problems and challenges that may arise during each phase of project development and implementation.

6.1. Best Practices

The purpose of this section is to identify best practices in each of the major stages of project development, per the discussion in Chapter 2. The best practices identified here are informed by information gathered as part of the focused interviews and research conducted on HOT implementation projects completed over the past 15 years.

6.1.1. Project Pre-Planning and System Planning

- Engage local and state leadership early and often during planning and design phases.
- Develop an extensive and effective Public Outreach Program that begins at the earliest stages and continues through operations.
- Ensure that the HOT project is included in the MPO planning requirements as soon as possible.
- Identify a strong Political Champions at the State and Local levels willing to advocate the HOT conversion project and participate in efforts to build support for the HOT conversion program.
- Foster a revenue and sharing plan that includes transit when possible to do so.

6.1.2. System Design

- Design for efficiency, safety and ease of participation by the public.
- Provide the public with a viable travel option.
- Utilize electronic and video tolling concepts; no toll booths.
- Consider using dynamic tolling strategies to control traffic volumes.

6.1.3. Project Financing

- Federal funds and grants are essential to implementing a project.
- Investigate PPP options either as stand alone or as supplemental to Federal funding.
- Use local Special Purpose Local Option Sales Tax (SPLOST) options as appropriate to address short falls.

6.1.4. Implementation

- Utilize electronic and video tolling concepts.
- Consider outsourcing back office and/or Customer Services with an established Customer Service Center.
- Ensure the establishment of maintenance services to provide 24/7 operations to include an On-Line Maintenance System (MOMs).

6.1.5. Operations and Management

- Determine if 24/7 toll operations meets objectives and is generally supported by resources and the public.
- Use dynamic pricing strategies to maintain free flow speeds.
- Implement an enforcement system that is visible, effective and fair (from the public's perspective) to ensure the integrity of the facility.
- Share information and research with agencies along the corridor to obtain their support and ensure the success of the facility.
- Implement a continuing and comprehensive evaluation of the facility to maintain support, to encourage continued growth, to use in marketing campaigns and to inform the public.

6.2. Lessons Learned

Although each of the case studies differed from one another and from a number of the implementations reviewed in the literature, there were several project development issues and challenges around which key lessons learned with similar themes were articulated. The lesson learned that resonated across several projects are presented here to alert and to assist practitioners to challenges likely to be encountered throughout the project development process.

1. Every HOV to HOT conversion project needs a political champion with strong credibility among state, regional and locally elected officials. Based on the case studies, the presence of a political champion at both the State and local levels was critical in building support within the State Legislature and developing mitigation strategies for potential deal-breakers.

2. An extensive public outreach program with stakeholder outreach, a multi-agency taskforce, public meetings are absolutely necessary for success and acceptance. A successful program built around three or four program objectives is critical for obtaining buy-in with the public and with elected officials.

3. HOT lanes should not be implemented as a revenue generator for added capacity. They should be 'sold' to the public and implemented as a congestion management tool first and a possible source of revenue second.

4. It is critical to fully understand the impact of creating added capacity to HOV lanes and potentially creating unexpected, new congestion hot spots.

5. Enforcement of occupancy requirements is the most difficult operational challenge facing toll agencies and enforcement officers because automatic technologies have not yet met reliability and field accuracy requirements required for operational deployment.

6. Signage among the various tolled facilities was not consistent especially when announcing enforcement provisions for lane violations. This lack of consistent enforcement signage was found to contribute to unauthorized users accessing the facilities and appeared to contribute to the practice of lane diving from the general purpose lanes into the managed lanes that were not barrier separated.

6.3. Direction for Future Practice

Tolling and dynamic pricing are gaining greater recognition among the State DOT's as a means of generating revenues for system improvements and for managing increasing traffic levels. Each HOV transition to HOT operations will, by necessity, be evaluated on the unique circumstances for each area. While each implementation will be a unique application dependent on road geometry, right of way availability, density and alternative corridors, it is important that consideration be given to the utilization of common, and to some degree, interoperable technologies for a HOT facility.

Some trends and practices that are emerging throughout the nation as HOT lane implementations grow include

6.3.1. Legislative

Legislatures are becoming more proactive in providing enabling legislation that will provide the states with the authority to collect tolls, to toll HOV facilities, to implement an effective violation enforcement policy, to provide authorization to collect administration and processing fees, and to provide for a PPP policy.

6.3.2. Electronic and Video Toll Payment

To minimize the impact to the traveling public, toll booths will not be used for HOT lane operations. As congestion increases and the average number of HOT lane facilities increases to beyond 2 lanes in each direction, the HOT implementations will begin to resemble ORT) implementations using a combination of electronic and video tolling.

6.3.3. Enforcement

As was mentioned numerous times, enforcement is critical to the successful operation of any HOV/managed lane facility. Visible and effective enforcement promotes fairness and maintains the integrity of the facility to help gain and maintain public acceptance of the project. Continued technology improvements will provide effective video capture and optical character recognition systems for license plate capture. However, these improvements alone will not be sufficient for an effective enforcement system. It will be necessary to implement a reliable and accurate mobile enforcement system that complements the improved video systems. Visible and effective enforcement promotes fairness and maintains the integrity of the facility to help gain and maintain public acceptance of the project.

6.3.4. Occupancy Enforcement

Probably the most frequent type of violation infraction that enforcement officers encounter is occupancy violations, which requires them to see inside a vehicle and to be able to count the number of occupants. Current technology does not exist to determine accurately the number of occupants in a vehicle. However, perhaps within the next ten to fifteen years an on board unit capable of determining vehicle occupancy will be fully integrated in a vehicle and capable of communicating this information to the enforcement officer at the roadside using DSRC technology. Until this technology is available it is likely that DOT's and toll agencies will require all HOT users to establish either a transponder or a video toll account to assist in separating HOV authorized users from SOV users.

Chapter 7. List of Acronyms

Acronym	Description
AASHTO	American Associate of State Highway and Transportation Officials
AVC	Automatic Vehicle Classification
AVI	Automatic Vehicle Identification
BRT	Bus Rapid Transit
CCTV	Closed Circuit Television
CDOT	Colorado Department of Transportation
CHP	California Highway Patrol
CSC	Customer Service Center
CTOC	California Toll Operators Committee
DOT	Department of Transportation
DSRC	Digital Short Range Communication
DVAs	Digital Video Audit Systems
EB	Eastbound
ETC	Electronic Toll Collection
FHWA	Federal Highway Administration
HCTRA	Harris County Toll Road Authority
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
IBTTA	International Bridge, Tunnel and Toll Authority
ITS	Intelligent Transportation Systems
LOS	Level of Service
LOV	Low Occupancy Vehicle
MnDOT	Minnesota Department of Transportation
MOM	Maintenance Online Monitoring
MPO	Metropolitan Planning Organization
MUTCD	Manual on Uniform Traffic Control Devices
NTDEV	Notic of Delinquent Toll Evasion
NTEV	Notice of Toll Evasion
NTP	Notice to Proceed
OCR	Optical Character Recognition
OCTA	Orange County Transportation Authority
ORT	Open Road Tolling
PPPs	Public Private Partnerships
RFID	Radio Frequency Identification
RFP	Request For Proposal
RPOs	Regional Planning Organizations
RTMS	Remote Traffic Microwave Sensor

Acronym	Description
SAFETEA-LU	Safe, Accountable, Flexible and Efficient Transportation Equity Act: A Legacy for Users
SANDAG	San Diego Association of Governments
SOV	Single Occupant Vehicle
SPLOST	Special Purpose Local Option Sales Tax
TDM	Transportation Demand Management
TSM	Transportation System Management
TxDOT	Texas Department of Transportation
VES	Violation Enforcement System
VMS	Variable Message Sign
VPC	Video Processing Center
VTMS	Variable Toll Message Sign
WB	Westbound

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