

Atlanta Regional
MANAGED LANES
Implementation Plan



FINAL REPORT

Appendix C

Technical Reports

Prepared for



Prepared BY

HNTB Corporation

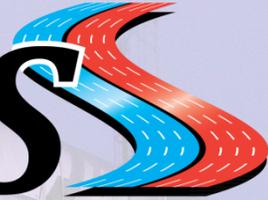
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Metro Atlanta
OPS
OPERATIONAL PLANNING STUDY



**Active Traffic Management
Case Study**

February 22, 2013

PREPARED FOR



PREPARED BY

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1 INTRODUCTION

Growing congestion, coupled with limited transportation funding, has highlighted the need for more innovative and cost effective transportation management approaches to mitigate congestion across the United States, such as Active Traffic Management (ATM). ATM strategies include technologies and operational approaches such as variable speed limits, ramp metering, managed lanes, traveler information, dynamic shoulder use, and pricing schemes. The most common ATM practices used on U.S. highways today are managed lane facilities, including High Occupancy Vehicle (HOV), High Occupancy Toll (HOT), express lanes and ramp metering signals. Three less common ATM approaches are dynamic shoulder use, variable speed limits, and queue warning systems.

ATM is a method of actively managing traffic to increase peak capacity and smooth traffic flows on urban freeways. ATM operational strategies help to maximize the efficiency of a roadway by making improvements to trip reliability, safety, and overall person throughput.

2 ATLANTA METRO OPERATIONAL PLANNING STUDY (OPS) ATM CASE STUDY APPROACH

Active traffic management strategies are utilized throughout the world. There are a wide array of trade-offs associated with ATM deployment that need to be considered before they are implemented in the Atlanta metropolitan area. The locations identified for review are assembled from U.S. and European applications. The following sections describe in greater detail how dynamic shoulder lanes, variable speed limits, and queue warning systems are being used throughout the world and the strategies that have led to their successful implementation. The findings from this case study will be used to inform project recommendations as part of the Atlanta Metro Operational Planning Study (OPS) and Atlanta Regional Managed Lanes Implementation Plan (MLIP).

2.1 DYNAMIC SHOULDER LANES (HARD SHOULDER RUNNING)

Dynamic shoulder lanes (also referred to as hard shoulder running or temporary shoulder use) is an ATM strategy currently used on several European and U.S. freeways to manage peak period capacity and reduce travel time. Dynamic shoulder lanes (DSL) allow vehicles to use either the right or left shoulder lanes under pre-determined traffic conditions or when conditions warrant and can be portrayed to users through fixed roadside signage or variable message signs located on gantries above travel lanes. Figure 1 illustrates a DSL in Virginia.

Figure 1: DSL Sign in Virginia



In a typical application, general purpose motorists are allowed to use right shoulders during peak periods. In other cases, such as Bus Only Shoulders (BOS) in Minneapolis, freeway shoulder lanes on the right shoulder are used exclusively by transit buses during the same periods. Emerging applications allow all motorists to use left shoulders (sometimes at a cost, such as in priced-dynamic shoulder lanes in Minneapolis) as an extra driving lane during the AM and PM peak travel periods or during incidents. In all cases, the use of shoulder lanes provides a capacity increase for congested freeways during peak periods. Currently, in the Atlanta metro area, BOS lanes are utilized on GA 400 (south of Holcomb Bridge Road) in the northbound direction and any vehicle may use shoulder lanes during the AM peak hour in the southbound direction.

2.2 VARIABLE SPEED LIMIT (SPEED HARMONIZATION)

Variable speed limit (VSL) strategies involve managing speed limits in areas of inclement weather, traffic incidents, or high congestion to improve traffic operations and reduce secondary traffic collisions. VSLs utilize variable message signs posted over freeway lanes or along the side of the road to encourage users to maintain better traffic flow through congested freeway locations by advising motorists to adjust their speed before encountering slower traffic or traffic incidents. The primary benefit of VSL or speed harmonization systems is congestion reduction by smoothing overall traffic flows. VSL systems are beneficial at eliminating dangerous speed differentials and increasing traffic safety through congested bottlenecks.

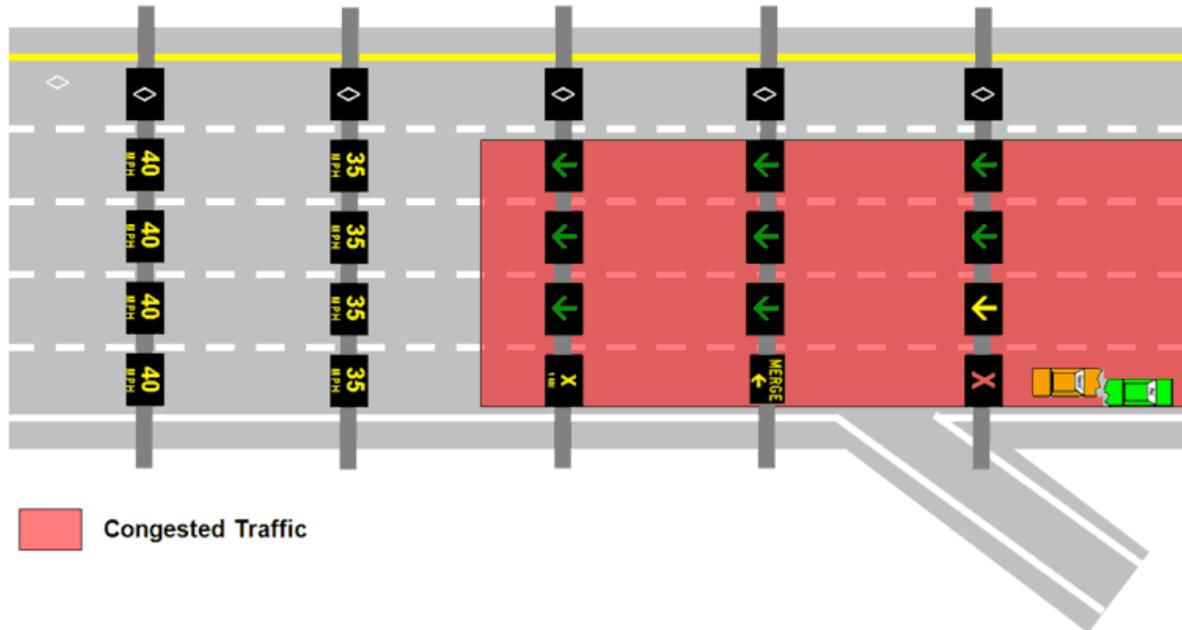
The primary benefit of variable speed limit systems is congestion reduction, but VSLs can also positively impact safety by smoothing traffic flows through congested bottlenecks.

Variable speed limit systems are most commonly used to manage traffic speeds during predictable periods, such as AM and PM peak travel times. VSLs are common in Europe, and becoming more widely used in the United States.

2.3 QUEUE WARNING SYSTEM

Queue warning systems (QWS) are an extension of VSLs that utilize real-time information and traffic data (not just during peak periods) to improve the overall safety and efficiency of freeway corridor operations. Queue warning systems notify motorists of downstream queues through overhead gantry signs and direct traffic to alternate (free flowing) lanes, thereby reducing the likelihood of speed differentials and collisions due to queuing. Figure 2 illustrates how corridors can utilize QWS to notify highway users of incidents ahead. This example uses overhead signs to notify drivers up to one mile upstream of an incident to give them ample time to slow down and/or change lanes to avoid congestion or incidents.

Figure 2: Active Traffic Management Lane Control Signals During an Incident



Source: FHWA Best Practices for Road Weather Management: Minnesota DOT I-35W Smart Lanes: Active Traffic Management. Located at: http://ops.fhwa.dot.gov/publications/fhwahop12046/rwm17_minnesota1.htm

Similar to variable speed limits, QWS are often implemented in conjunction with other ATM techniques. In these cases, the traffic sensors utilized for one technology are used to support both functions.

Similar to variable speed limits, QWS are often implemented in conjunction with other ATM techniques. In these cases, the traffic sensors utilized for one technology are used to support both functions.¹ Furthermore, there are very few examples of queue warning systems operating in the absence of other ATM strategies, which makes isolating the benefits and costs impractical.²

Queue warning systems have the potential to be an efficient traffic management technique as they allow traffic controllers the ability to constantly regulate freeway speeds based on prevailing traffic conditions. Speed limits can be reduced when freeway conditions are unsuitable for high speed operations, such as bad weather, congestion, or traffic incidents, thereby reducing the chances of secondary accidents and facilitating a smoother flow of traffic.

¹ Fontaine, Michael. *Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies*, Virginia Center for Transportation Innovation and Research, 2012.

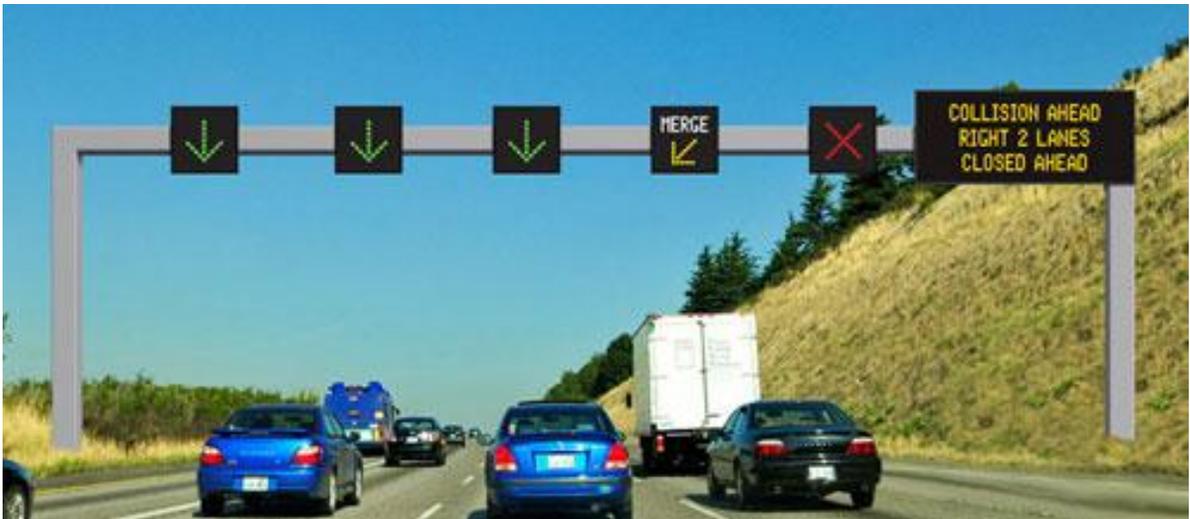
² Fuhs, C. *Synthesis of Active Traffic Management Experiences in Europe and the United States*, FHWA, 2010.

3 CASE STUDIES

3.1 WASHINGTON STATE

The Washington State Department of Transportation (WSDOT) was one of the first state transportation agencies in the United States to utilize active traffic management technologies. WSDOT uses ATM along portions of I-5 (5 lanes for 29 miles in each direction), I-90 (4 lanes for 9 miles in each direction), US 2 (3 lanes for 1.55 miles in each direction) and State Route (SR) 520 (3 lanes for 7.6 miles in each direction). The state's ATM strategies are part of its Smarter Highways Initiative, which uses integrated systems and coordinated response to improve roadway safety and traffic flows. WSDOT continues to study hard shoulder running, variable speed limits, and queue warning technologies in order to improve traffic flow and effectively manage traffic on the region's busiest routes. Figure 3 shows an example of an active traffic management sign in Washington.

Figure 3: WSDOT Active Traffic Management Sign



Source: Washington State Department of Transportation Smarter Highways: <http://www.wsdot.wa.gov/smarterhighways/>

WSDOT has been developing dynamic shoulder lanes (hard shoulder running) in the Seattle area since 2009, when it opened 1.55 miles of the right shoulder on US 2 near Everett to all traffic in the eastbound direction during the afternoon peak period. The objective of the project was to improve travel times, reduce the impacts of the bottleneck, and relieve the congestion at a critical interchange in the region. It cost WSDOT approximately \$70,000 (used primarily to construct emergency refuge areas) to install the 1.5 mile shoulder segment on US 2.³

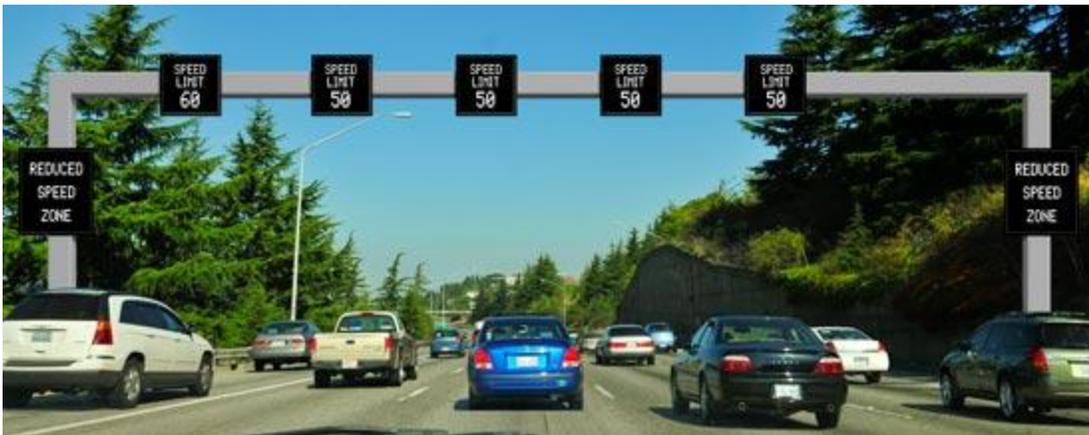
³ Kuhn, B. *Efficient Use of Highway Capacity Summary*, Texas Transportation Institute, 2010.

Hard shoulder running in Washington State has reduced travel times by 8 minutes and average speeds have increased from 10 to 37 mph along the 1.5 mile segment of US 2.

Since its implementation in 2009, hard shoulder running on US 2 has reduced travel times from 8-10 minutes to 1-2 minutes along the 1.5 mile segment. In addition, the average speed has increased significantly from 10 to 37 mph.⁴ To date, WSDOT has had difficulty quantifying the direct safety impacts of hard shoulder running because of the short time frame and because its deployment coincided with other traffic management strategies (ramp metering) on I-5; which feeds US 2. In general, the impacts of active traffic management strategies have been positive.

In Washington, variable speed limits are utilized on northbound I-5 in Seattle as well as I-90 and SR 520 between Seattle and Bellevue, WA. An example of a WSDOT installation is shown below. Average costs for implementing variable speed limits were \$3.2 million per directional mile for three-lane sections and \$4 million per directional mile for five-lane sections.⁵

Figure 4: WSDOT Variable Speed Limit Sign



Source: Washington State Department of Transportation Smarter Highways: <http://www.wsdot.wa.gov/smarterhighways/>

The Washington queue warning system is closely related to VSL. The main difference is that the QWS is automatically activated based on identified thresholds. The cost estimates for the WSDOT queue warning system are comparable to VSL systems; with QWS projected to range between \$2.4 and \$5.5 million per mile depending on the roadway segment.⁶

⁴ Kuhn, B. *Efficient Use of Highway Capacity Summary*, Texas Transportation Institute, 2010.

⁵ Fuhs, C. *Synthesis of Active Traffic Management Experiences in Europe and the United States*, FHWA, 2010.

⁶ *Active Traffic Management Conceptual Design and Cost Estimates*, WSDOT, 2008.

3.2 MINNEAPOLIS – ST. PAUL, MINNESOTA

MnPass allows customers to use the shoulder for a variable, congestion-based fee. The I-35 W shoulder lanes are unique in the U.S. because they utilize left-shoulder right-of-way.

The Minneapolis-St. Paul metro area employs several ATM strategies that make up a comprehensive network of freeway corridors and arterial roads totaling over 290 miles. The Minnesota Department of Transportation (Mn/DOT) has begun implementing new strategies to manage its transportation corridors through the use of dynamic shoulder lanes and variable speed limits.

A unique combination of strategies is in place on I-35W in Minneapolis where a 2.5 mile segment of the left shoulder is opened during the AM and PM peak periods. The State calls its newest shoulder strategy Priced Dynamic Shoulder Lanes (PDSL), and allows transit buses and carpools of two or more people to use the left shoulder for free while MnPASS (the state’s automated toll program) customers can use the shoulder for a variable, congestion-based fee. The PDSL strategy is illustrated in Figure 5. The corridor also employs a bus on shoulders (BOS) strategy that utilizes the outside shoulder requiring buses to yield to any vehicle entering, merging, or exiting through the shoulder and are allowed to drive no more than 15 mph faster than mainline traffic with a 35 mph maximum speed. This BOS strategy is illustrated in Figure 6.

Figure 5: Minneapolis – St. Paul Priced Dynamic Shoulder Lane



Figure 6: Minneapolis - St. Paul Bus Only Shoulder Lane



The PDSL project cost \$13 million, which included a new pavement surface for all lanes on the entire 2.5 mile facility including general purpose lanes, shoulder lanes and emergency pull-out

areas.⁷ Costs can be significantly impacted depending on the amount of up-front capital investment required to construct new pavement and overhead infrastructure. Table 1 illustrates the per mile costs of PDSLs in Minneapolis-St. Paul, MN.

Table 1: Average Per-Mile Priced Dynamic Shoulder Lane Capital Costs in Minneapolis

Condition	Capital Cost Including Signaling & Striping
Shoulder width and bituminous depth ⁸ are adequate; Catch basins do not need adjustment; Signing and striping are only requirements.	\$1,500 per mile - Freeway \$2,500 per mile - Expressway
Shoulder width and bituminous depth are adequate; Minor shoulder repairs and catch basin ⁹ adjustments are needed.	\$5,000 per mile - Freeway \$5,000 per mile - Expressway
Shoulder width is adequate but bituminous depth requires a 2-inch overlay; This assumes shoulder and roadway can be overlaid at the same time.	\$12,000 per mile - Freeway \$12,000 per mile - Expressway
Same as above but adjacent roadway is not being overlaid; Shoulder must be removed, granular base ¹⁰ adjusted, and increased bituminous depth replaced.	\$80,000-\$100,000 per mile
Shoulder width and depth replacement are required.	\$42,000-\$66,000 per mile
Installing a 12-ft. shoulder rather than a 10-ft. shoulder in a new construction project.	\$30,000 per mile

Source: Kuhn, B. *Efficient Use of Highway Capacity Summary*, Personal interview with Mn/DOT Staff, Mn/DOT Metro District, 2009.

Mn/DOT has identified implementation challenges to operating dynamic shoulder lanes. One of the potential challenges with using shoulders for travel lanes is the mediation of fixed objects in close proximity to roadway shoulders. In some cases, Mn/DOT has had to move guardrails to meet minimum pavement width requirements.¹¹ The safety of general purpose traffic is also a major concern as buses must yield to any vehicle entering, merging within, or exiting through the

⁷ Kuhn, B. *Efficient Use of Highway Capacity Summary*, Texas Transportation Institute, 2010.

⁸ The depth of primary roadway materials such as tar, asphalt, and aggregate.

⁹ A concrete, masonry, or cast iron box-like receptacle set into the pavement or road surface.

¹⁰ The layer directly below the pavement surface that acts as the load bearing material.

¹¹ Kuhn, B. *Efficient Use of Highway Capacity Summary*, Texas Transportation Institute, 2010.

ACTIVE TRAFFIC MANAGEMENT CASE STUDIES

shoulder. Emergency vehicle access and incident management concerns have been mitigated by developing emergency pull out bays along the length of the corridor.

Figure 7: Minneapolis – St. Paul Smart Lanes Signs



Minnesota also employs variable speed limit and queue warning ATM strategies as part of their Smart Lanes initiative that provides motorists with real-time traffic information (including advisory speeds, queue warnings, and incidents). The Smart Lanes signs were fully complete in the summer of 2012. Figure 7 illustrates the incident warning system where vehicles are pre-warned to merge ahead of a traffic queue.

3.3 BOSTON, MASSACHUSETTS

Figure 8: Massachusetts Breakdown Lane

Since 2002, the Massachusetts Department of Transportation (MassDOT) has developed 45 miles of temporary shoulder lanes along Massachusetts SR 3, I-93, and I-95 in the Boston metropolitan area to add roadway capacity as part of its Add-a-Lane project. All vehicles (with the exception of commercial motor vehicles) are permitted on the right shoulder, or breakdown lane, during the AM and PM peak periods.

MassDOT's main objective for opening the breakdown lanes to general purpose traffic during peak periods is to increase capacity and reduce congestion. The maximum allowed speed on the shoulder is 60 mph, which is also the posted speed for the general purpose lanes. A minimum of a 10-foot shoulder width is required for the breakdown use operations, with 12 feet being the desired shoulder width. MassDOT treated the deployment as a traditional widening project by moving drainage features and guardrails to the new edge of pavement wherever new construction was required. Emergency pull-off areas were installed approximately every ½ mile along the facilities to allow for incident management and response. Some of the region's shoulders were resurfaced as part of these projects as well.¹² MassDOT is still evaluating the benefits of its breakdown lanes across the state.



¹² Kuhn, B. *Efficient Use of Highway Capacity Summary*, Texas Transportation Institute, 2010.

3.4 UNITED KINGDOM (UK)

The Great Britain Highways Agency developed a system-wide ATM approach in 2006. The agency developed a pilot project combining the strategies of variable speed limits (speed harmonization) and temporary shoulder use to provide additional capacity during periods of recurring congestion and traffic incidents along a 16-km. (10-mi.) stretch of the M42 highway.¹³

Figure 9: UK ATM Strategy



Temporary shoulder use in Great Britain is deployed as a component of the region's overall ATM scheme. One unique element of the UK ATM strategy is that temporary shoulder use is only deployed when speeds are reduced to 50 mph or less. The shoulder strategy utilizes overhead VSL signs to notify drivers of current speed limits. The system is automated based on real-time data, and is initiated by an assessment algorithm which requires no intervention by an operator unless it becomes necessary to override the algorithm. It only operates during time periods

of congestion or when incidents occur. Although it can be difficult to compare infrastructure costs between the U.S. and Great Britain, the M42 project (which includes hard shoulder running and speed harmonization) is estimated at approximately \$18 million per mile.¹⁴

Even though Great Britain has only recently developed a combined ATM strategy, it has been using variable speed limits and queue warning signs for many years and there is significant data showing the encouraging safety, emissions, and travel time impacts. A study in 2005¹⁵ examined the M25 and reported that the VSLs produced an estimated:

One unique element of the UK ATM strategy is that temporary shoulder use is only deployed when speeds are reduced to 50 mph or less.

- 15 percent reduction in injury crashes;
- 2 to 8 percent reduction in emissions;
- 10 percent reduction in fuel consumption;
- 1.5 percent increase in throughput;
- 5 percent improvement in speed limit compliance; and a
- Neutral impact on travel time and travel time reliability.

¹³ Berman, Wayne. *Managing Travel Demand: Applying European Perspectives to U.S. Practice, American Trade Initiatives, 2006.*

¹⁴ Fuhs, C. *Synthesis of Active Traffic Management Experiences in Europe and the United States, FHWA, 2010.*

¹⁵ Tucker, S. *The Control of Traffic Using Variable Speed Limits: The UK Experience of Controlled Motorways, ITS America, 2005.*

3.5 NETHERLANDS

Figure 10: Netherlands ATM Strategy

The Netherlands was one of the first countries to develop variable speed limits, and has been utilizing ATM strategies since 1981 to manage traffic speeds and highway congestion. The country uses Dynamic Route Information Panels (DRIP) to notify traffic of congestion and incidents ahead. The Dutch road network has about 1,000 km (620 mi.) of VSL signing and has installed nearly 100 DRIPs since 1990.¹⁶ The lane control and speed limit signs are placed approximately every 1,500 feet.



The Netherlands ATM system works through the Motor Control and Signaling System (MCSS); an advance queue warning system that utilizes variable speed signs to alert drivers of congestion and lane closures. Should the system detect a traffic queue within a certain area, it notifies other travelers one mile upstream from the queue and lowers the advisory speed limits for traffic approaching the congested area.

Figure 11: Netherlands Variable Speed Limits



Temporary shoulder use in The Netherlands is only deployed in conjunction with speed harmonization and queue warning systems. The Netherlands implemented temporary shoulder use on more than 620 miles of roads in 2003 as part of a larger program to improve use of the existing transportation infrastructure. Typically, a gantry with lane control signals indicates when the shoulder is available for use. In addition to allowing temporary use of the right shoulder, the Dutch also deploy the use of traveling on a dynamic lane on the median side of the roadway. This

treatment, also known as the plus lane, is a narrowed extra lane provided by reconstructing the existing roadway while keeping the hard shoulder and is opened for travel use when traffic

¹⁶ Berman, Wayne. *Managing Travel Demand: Applying European Perspectives to U.S. Practice, American Trade Initiatives*, 2006.

volumes reach levels that indicate congestion is growing. Deployment is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator. It only operates during periods of congestion or when incidents occur along instrumented roadways.¹⁷

Facilities under the MCSS system have seen significant network benefits between 1983 and 1996:^{18 19}

Active Traffic Management strategies in the Netherlands have shown significant system-wide benefits.

- Overall throughput increased between 4 and 5 percent;
- Capacity increased from 7 to 22 percent during congested periods;
- Travel times decreased up to 3 minutes per mile;
- Primary accidents decreased by 15 to 25 percent; and
- Secondary incidents decreased by 40 to 50 percent.

¹⁷ Kuhn, B. *Efficient Use of Highway Capacity Summary*, Texas Transportation Institute, 2010.

¹⁸ Mirshahi, M. *Active Traffic Management: The Next Step in Congestion Management*. FHWA. 2007.

¹⁹ Taale, H. *Regional Traffic Management Method and Tool*. AVV Transport Research Centre, Rotterdam, The Netherlands: Ministry of Transport, Public Works, and Water Management, Directorate-General of Public Works and Water Management, June 2006. Presentation to Planning for Congestion Management Scan Team.

4 EMERGING TRENDS

New technologies, such as online mapping services, on-board GPS devices, and smartphones may be the future of providing real-time, personalized information on road pricing, travel time, and conditions.

While case studies of ATM strategies give an idea of how other locations across the country and the world have implemented ATM to positively influence system-wide traffic operations, it is important to stay abreast of emerging trends that may impact traveler information technologies in the future. It is likely that new technologies, such as online mapping services, on-board GPS devices, and smartphones may be the future of developing and distributing real-time, personalized ATM information.

These new devices are likely to provide more personalized information than existing ATM strategies, such as variable message signs.²⁰ By extrapolating the abilities of today's smartphone applications, we can envision future mobile devices that not only provide real-time travel information and travel patterns, but also queue warnings. These future devices will be able to do everything from finding the closest available parking space, to alerting drivers of

traffic congestion, advisory speeds, or on-road debris ahead. New technologies could even make suggestions about time-saving routes or mode change suggestions; all with accurate, personalized, real-time information on pricing, travel time, and road conditions.²¹

In addition, smartphones provide a low-cost, free-market approach to providing and collecting travel data. Rather than requiring the government to spend limited dollars on new sensors or real-time information displays, third parties are developing applications that provide this information at a significantly lower cost to transportation providers.

²⁰ Vautin D. and Walker J., *Transportation Impacts of Information Provision & Data Collection via Smartphones*. 2011 Transportation Research Board Conference.

²¹ Manasseh, C., Yaser, F., Sengupta, R., and J. Misener. *Using Smartphones to Measure the Effect of a Situational Awareness Application on Driver Behavior*. 2011 Transportation Research Board Conference.

5 CONCLUSIONS AND RECOMMENDATIONS

The overall intent of ATM is to improve person throughput along a corridor and smooth out driver performance to reduce the likelihood of traffic incidents.

Active Traffic Management is a holistic approach for maximizing system-wide transportation efficiency. There are many ATM strategies, and all are often called by many names, depending on where they are implemented. The overall intent of ATM is to improve person throughput along a corridor and smooth out driver performance to reduce the likelihood of traffic incidents. This research provides insights into future trends for active traffic management strategies and the delivery of traveler information that are already being successfully deployed in the U.S. and Europe. In general, traffic information is being delivered to transportation users with more of a focus on the impacts on individual vehicles and users. Traffic data is collected and disseminated dynamically and interactively, allowing for a much more efficient

transportation network. The strategies discussed in these case studies will help to develop an effective and efficient ATM implementation strategy for the metropolitan Atlanta region as part of the Atlanta Metro Operational Planning Study and Atlanta Regional Managed Lanes Implementation Plan.

VSL and queue warning strategies do not operate well after heavy congestion forms, but do effectively provide preventative relief if notifications are given before delays occur.

Variable speed limit and queue warning strategies are growing in popularity across the US. Currently, they are used primarily to increase safety during adverse weather conditions (e.g., rain and fog), and as a traffic management strategy to create more uniform travel speeds. VSL and queue warning strategies typically do not operate well after heavy congestion forms, but do effectively provide preventative relief if notifications are given before delays occur.²² In general, VSL and other dynamic highway sign technologies continue to be evaluated but are rarely implemented as a stand-alone ATM strategy. The most current research on VSLs shows the displays can work in harmony with travel time and queue length prediction, ramp metering, tolling schemes, and dynamic shoulders.²³

There is a wide range of issues when determining whether dynamic shoulder lanes are appropriate for corridors throughout the Atlanta region. Experience both overseas and domestically, and summarized herein, provide a wealth of knowledge from which agencies can learn to make informed decisions. From the European perspective, dynamic shoulder lanes are only used during congested periods or traffic incidents when queues begin to build and are almost always deployed in conjunction with variable speed limits. In the U.S., many transportation agencies allow general purpose motorists to use shoulders

²² Mazzenda, N.J. *Investigation of Solutions to Recurring Congestion on Freeways*, Virginia Transportation Research Council, 2009.

²³ Berman, Wayne. *Managing Travel Demand: Applying European Perspectives to U.S. Practice*, American Trade Initiatives, 2006.

Dynamic shoulder lanes are a unique solution that facilitates many system-wide benefits, while also providing the potential to produce revenue, if priced.

While ATM deployments have been limited, the experience has been positive in U.S. applications.

Domestically, almost all applications of temporary shoulder use have occurred on the right side, while shoulder conversions to permanent lanes have tended to be more prominent on the left side.

during peak periods when demand is highest or during an incident. However, dynamic shoulder lanes also provide the potential to produce revenue if priced.

Active traffic management challenges that should be considered include design, traffic control devices, safety benefits, maintenance, enforcement roles and processes, incident response, personnel training, capital and operating costs, and public outreach and education. Safety is a concern when implementing shoulder lane strategies; as emergency access can become complicated due to the loss of an emergency area for disabled vehicles during traffic incidents. Careful consideration of these issues can help ensure a shoulder use deployment is effective without having negative impacts on safety and operations. The most common mitigation strategy is to develop emergency pull-outs along the corridor to provide refuge areas.

Areas that need further analysis are the use of the left shoulder versus the right shoulder and which types of vehicles are allowed to use the shoulder lanes. Each application has a different subset of design and operational considerations to analyze.²⁴ Right shoulder lanes are a common way for transportation agencies to quickly add capacity at relatively low costs as they usually don't require any additional ROW acquisition costs. Many of the agencies utilizing right shoulder lanes across the U.S. initially installed the lanes as a stop-gap measure to add capacity because of the opening of the HOV lane on the left side of a highway facility. In these instances, the left lane is commonly changed from a general purpose lane into an HOV lane and general purpose traffic is negatively affected because roadway capacity decreases in general purpose lanes. Therefore, many shoulder lanes were initially implemented to maintain an existing baseline level of service. However, over time these lane additions often remain in operation and become a long-term traffic management strategy due to funding shortfalls and the high cost of constructing additional travel lanes.

²⁴ Kuhn, B. *Efficient Use of Highway Capacity Summary*, Texas Transportation Institute, 2010.

For dynamic shoulder lanes allowing all vehicle types, facilities should ideally meet these characteristics:²⁵

- Considerable rush hour congestion (defined by speed and duration);
- A segment of significant length (approximately three miles or more);
- No regular bottleneck at the downstream end of the segment;
- Limited interference from ramp traffic entering and exiting the freeway facility;
- Available right-of-way for emergency areas and acceleration/deceleration tapers; and
- Sufficient pavement strength on the shoulder to bear the traffic.

For transit-only shoulder use, a facility should ideally have:

- Predictable congestion delays during the peak period;
- A minimum 10-ft shoulder width available;
- Sufficient pavement strength to sustain bus load; and
- A significant number of buses (or express buses) per hour.

The following are key factors to consider that can help facilitate successful deployment of hard shoulder running:²⁶

- When implemented with variable speed limits, speed limit signs and lane control signals need to be visible to all vehicles; therefore, it is most effective if signs are placed on gantries over every lane of traffic. During normal operation (when the use of the shoulder is prohibited) all the signs, including the sign over the shoulder, are blank;
- Either the left or the right shoulder can be used for the application, depending on the facility conditions;
- Video cameras should be regularly spaced to allow operators to check for obstacles before opening the shoulder to traffic and to monitor operations while shoulder use is permitted;
- Emergency refuge areas should be located at regular intervals along the shoulder with proper signing to avoid having stranded vehicles on an open shoulder; and
- When the shoulder is open to traffic, guide signs should provide information to the shoulder lane as if it was a permanent travel lane. This can be accomplished with dynamic message signs.

Dynamic shoulder lanes are more successfully deployed if they operate in harmony with traffic monitoring centers (to oversee incident management, existing sensors, and intelligent transportation systems) and other supportive ATM technologies, such as variable speed limits and queue warning systems.

²⁵ Mobility Investment Priorities – Active Traffic Management Strategies, Texas Transportation Institute, 2012

²⁶ Levecq, C. General Guidelines for Active Traffic Management Deployment, Texas Transportation Institute, 2011.

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**Priced Managed
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June 7, 2013

Prepared for



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PRICED MANAGED LANES CASE STUDY

1 BACKGROUND

The Georgia Department of Transportation's (GDOT) award-winning Atlanta Regional Managed Lane System Plan (MLSP) was the first system-wide evaluation of managed lanes in the United States – an innovative approach to urban area mobility. The plan met the following goals:

- Protect mobility.
- Maximize person/vehicle throughput.
- Minimize environmental impacts.
- Provide a financially feasible system (using a blend of traditional, federal and state funds, and public-private partnerships).
- Design and maintain a flexible infrastructure for varying lane management.

This report is intended to provide an understanding of priced managed lanes (PMLs) and the considerations that must be weighed to evaluate opportunities to develop new priced managed lanes on Metropolitan Atlanta freeways.

The Metro Atlanta Managed Lanes Implementation Plan (MLIP) is an update to the MLSP. The MLIP will reflect current funding constraints and the knowledge gained by GDOT from projects implemented around the country since the MLSP was published in 2010.

Specifically, the MLIP will focus on identifying feasible locations for capacity-adding projects, redefining and reprioritizing projects from the previous plan based on current and future needs, and developing a funding plan for implementing these projects.

The intent is to have a prioritized list of managed lane projects, which reduce the state's reliance on long-term private financing agreements.

2 OVERVIEW OF MANAGED LANES

As highway volumes have increased over time, transportation professionals have assessed multiple methods to managing demand on urban freeways. Managed lanes have been in existence for nearly 30 years and represent many operational strategies designed to address a wide array of transportation goals. "Managed lanes" is an umbrella term describing any restricted lane that is not a general purpose lane. Figure 2-1 illustrates how managed lanes are defined based on three principle characteristics: access control, pricing and vehicle eligibility. According to the Federal Highway Administration (FHWA), there are many permutations of a managed lane. The most common managed lane types include: high occupancy vehicle (HOV), high occupancy toll (HOT), express toll lanes (ETL), and truck only toll (TOT) lanes.

PRICED MANAGED LANES CASE STUDY

Figure 2-1: Principle Characteristics of Managed Lanes



Details about each characteristic, or lane management strategy, are provided below.

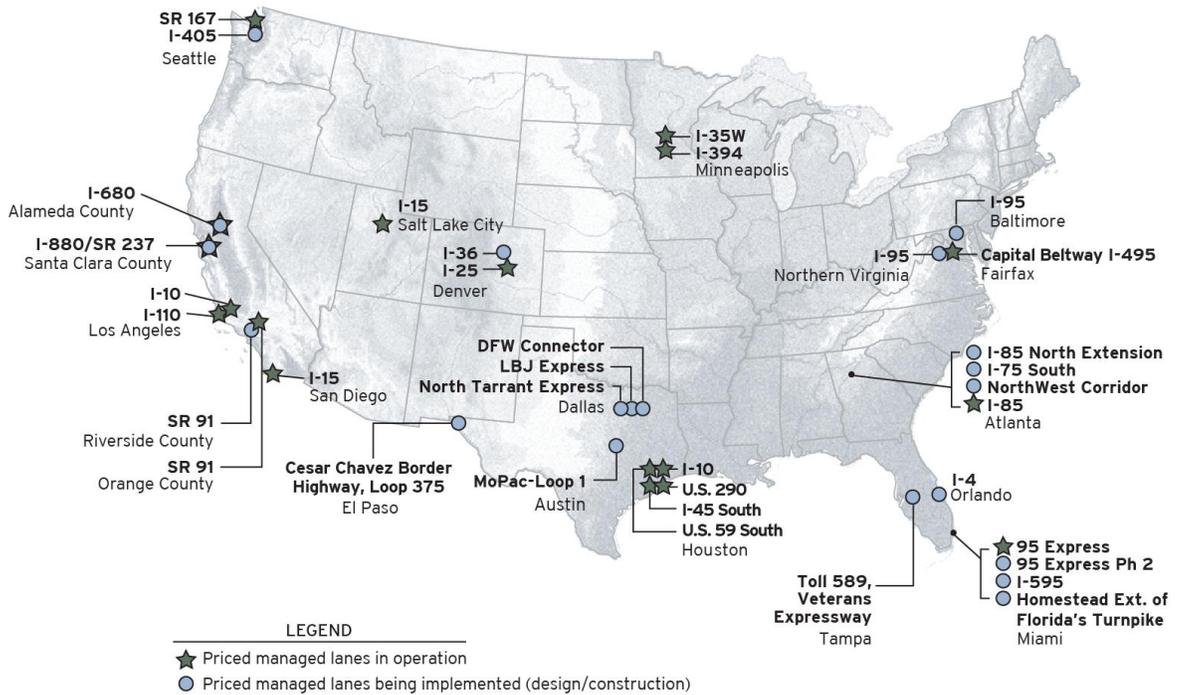
- **Pricing** restrictions are based on controlling traffic volumes and generating revenue for managed lane facilities to maintain a desirable traffic flow. Pricing may be fixed, set on a variable schedule or dynamic where access costs increase during peak periods. Higher tolls are charged when congestion is heaviest and delay is at its worst, while lower tolls or free access may be provided to some or all users during periods of lowest demand. Pricing is used to balance demand and lane capacity, and may encourage some peak-period users to shift their trips to periods of lower demand.
- **Vehicle eligibility** restricts vehicles from managed lanes based on the number of occupants or vehicle type. Traditional HOV lanes restrict single occupancy vehicles (SOVs), whereas in HOT lane applications, motorists are allowed to access facilities with the payment of a toll. Restrictions based on vehicle type generally restrict specific types of vehicles from entering a facility, such as large commercial trucks, or provide free entrance for others, such as transit buses, low emission vehicles or motorcycles.
- **Access control** physically separates a managed lane facility from other facilities. Access control can be accomplished using a fixed or moveable barrier, or by pavement markings to identify access points.

PRICED MANAGED LANES CASE STUDY

3 OVERVIEW OF PRICED MANAGED LANE TYPES

Georgia State Transportation Board policy states that all new capacity will be priced; therefore the remainder of this case study will focus on priced managed lanes (PMLs). Today, there are 18 operating PMLs with another 20 in some stage of implementation (see Figure 3-1).

Figure 3-1 Priced Managed Lanes in the United States



A new America THINKS survey¹ shows nearly 75 percent of U.S. drivers would be likely to use PMLs if given the opportunity. The survey also shows that 68 percent of U.S. drivers would pay (\$5 on average) to save 15 minutes on roads, bridges or tunnels. When educated about PMLs, 70 percent of U.S. drivers think they should be considered when making improvements to U.S. highways.

Table 3-1 lists the various business rules and considerations for different PML types, including HOT, ETL, and TOT lanes.

¹ HNTB's America THINKS national priced managed lanes survey polled a random nationwide sample of 1,000 Americans Jan. 24-30, 2013. It was conducted by Kelton Research, which used an email invitation and online survey.

PRICED MANAGED LANES CASE STUDY

Table 3-1: Priced Managed Lane Considerations

PML Type	Facilities Currently in Operation in the U.S.	Business Rules	Considerations
HOT	17	<ul style="list-style-type: none"> • Price, access and eligibility restrictions • SOVs can buy in 	<ul style="list-style-type: none"> • Easy to convert from HOV (due to minimal engineering and construction costs) • Used to manage demand & ensure reliable travel times • Requires additional toll operating cost above and beyond ETLs, such as back office, customer service, etc. (due to vehicle occupancy detection requirements)
ETL	1	<ul style="list-style-type: none"> • All vehicles pay 	<ul style="list-style-type: none"> • Easier to operate and enforce (since all vehicles pay) • Significantly more revenue generated vs. HOT • Potential perception of inequity by the public
TOT	0	<ul style="list-style-type: none"> • Only trucks are allowed in a restricted lane 	<ul style="list-style-type: none"> • Could improve freight distribution & safety • More expensive (due to additional wear and tear of truck only use and design requirements) • Un-tested nationally (no TOT lanes currently in operation in the U.S.)

3.1 HOT LANES

The first HOV lanes in the U.S. focused on adding managed capacity to encourage more efficient use of urban freeways through carpooling. Their implementation progressed slowly during the 1970s and 1980s, but major growth occurred from the late 1980s to the late 1990s as policymakers utilized HOV facilities to mitigate the high cost of expansion and rising congestion levels. Since the mid-1990s, managed lanes have evolved into priced managed lanes (PML) with the introduction of HOT lanes. PMLs have continued to receive increased attention as a viable congestion management strategy and also as a way for transportation agencies to generate much needed transportation revenue.

GDOT has been involved with several previous studies evaluating PMLs in the Atlanta metropolitan area. In 2005, the Georgia State Road and Tollway Authority (SRTA) evaluated the potential for HOT and TOT facilities on 24 corridors in the Atlanta region. The *Galvin Mobility Project* completed in 2006 explored PMLs in metro Atlanta. Also in 2006, GDOT conducted a study evaluating the feasibility of HOT, TOT, and bus rapid transit (BRT) alternatives on the I-75 Northwest Corridor. The regional Managed Lanes System Plan completed in 2010 shifted

PRICED MANAGED LANES CASE STUDY

regional focus from HOV lanes to implementation of HOT lanes and investigated various public and private funding opportunities. In addition to PML studies, GDOT also completed a HOV system plan study in 2003 and a statewide truck lanes needs identification study in 2008.

As of 2012, there were 126 HOV facilities covering 4,800 miles of freeways in the U.S. Of those, there are 18 PML projects now operational in the U.S., many of which have involved the conversion of HOV lanes to HOT lanes. All but one of the PML projects currently in operation are HOT lane facilities, with the other one being an ETL (in Orange County, California). There is another 2,800 miles of PMLs in some stage of development across the U.S. In HOT lane “conversion” projects, existing HOV lanes are converted into HOT lanes, while in other cases the HOT lane is a new lane. HOV to HOT lane conversions are less expensive than constructing a new lane. Furthermore, the U.S. experience with HOT lane operations in general has found the following:

- HOT lanes allow the lane to carry its optimum operational efficiency in the peak hours and during incidents.
- HOT lanes can provide more reliable travel times.
- HOT lanes provide a mobility alternative for high priority auto trips (i.e. when people have a high value of time because they absolutely must be on time).
- Gross revenue generation of HOT lanes is highly dependent on vehicle eligibility and exemptions.
- Net revenue generation from HOT lanes depends on how the toll is collected (i.e. transponder-based tolling is significantly cheaper to operate than video-based tolling) and how the HOT lane is operated.

3.2 ETL LANES

The difference between HOT lanes and ETLs is that with HOT lanes, not everyone has to pay to use to the lane, whereas with ETLs, all vehicles must pay. As a result, ETLs are typically easier to operate and enforce, which also reduces operating costs. Furthermore, since all vehicles must pay, more revenue is generated.

There is currently only one ETL project in operation in the U.S., which is on State Route (SR) 91 in Orange County, California. Further detail is provided in the case study in Section 4.2.1. However, it should be noted that I-595 in Ft. Lauderdale, Florida, which is currently under construction, will operate as an ETL. Furthermore, the Florida Department of Transportation has adopted a policy that all future priced managed lane projects will operate as ETLs.

3.3 TOT LANES

TOT lanes are truck only lanes that are tolled. Truck only lanes are typically barrier separated and have the potential to improve freight distribution and safety. TOT lanes must provide enough benefit for the truckers to be willing to pay for use of the lanes (i.e. the reduced travel

PRICED MANAGED LANES CASE STUDY

time and increased productivity must outweigh the cost). Furthermore, construction of TOT lanes can be expensive dependent upon the design standards, right-of-way requirements, etc.

Although there are a few truck only lane (TOL) operations currently in place in the U.S., there are no TOT lane facilities currently operating in the U.S. As noted earlier, SRTA evaluated the potential for HOT and TOT facilities on 24 corridors in the Atlanta region in 2005. Furthermore, GDOT conducted a study evaluating the feasibility of HOT, TOT, and bus rapid transit (BRT) alternatives on the I-75 Northwest Corridor in 2006, followed by the Truck-Only Needs Identification Study and the Managed Lanes System Plan.

This case study is intended to provide an understanding of PMLs and the considerations that must be weighed when developing new PMLs on Metropolitan Atlanta freeways, specifically HOT and ETL facilities.

4 U.S. CASE STUDIES ON PRICED MANAGED LANES

Priced managed lane facilities in the U.S. began with the opening of the SR 91 express lanes in California in 1995. Since then there has been increased federal interest in PMLs to determine if they have the ability to manage urban congestion and provide sustainable mobility. Several regions with existing PMLs and others looking to develop new PMLs have begun to develop managed lane plans to coordinate the implementation of PMLs at a regional scale to improve regional connectivity and improve travel options including transit and carpool programs. Cities that have adopted regional plans include: Atlanta, Charlotte, Houston, Miami, Northern Virginia, Minneapolis, Phoenix, San Diego, San Francisco, and Seattle.²

PML facilities have achieved project goals in the communities where they operate. PML projects have proven they can improve congestion, provide reliable travel times for transit and autos and help produce revenue to offset their operating costs.

Over the last 20 years there have been several federal-aid programs to assist state DOTs with funding in order to implement these facilities. Beyond federal interest, high population states, such as Florida, Texas and California, continue to invest more of their state dollars in tolled facilities. More recently, private concessionaires have become interested where there are multi-lane facilities that they can construct and monetize.

As noted earlier, 17 HOT lane projects and one ETL project is currently operating in the U.S. No TOT lanes are currently in operation in the U.S. As a result, case studies are provided below for ETL and HOT lanes.

4.1 HOT LANE CASE STUDIES

Below are five case studies of HOT lanes in the U.S. that provide a cross-section of different ways to implement them.

² *Priced Managed Lane Guide. FHWA. U.S. Department of Transportation. 2012.*

PRICED MANAGED LANES CASE STUDY

4.1.1 Miami, Florida: I-95 Express HOT Lanes

The I-95 Express PML opened in two phases starting in December of 2008. As illustrated in Figure 4-1, the first phase carried the express lanes northbound from downtown Miami to northern Miami-Dade County (Phase 1A) and completed the southbound lanes between the same points in January 2010 (Phase 1B). Phase 2, completed in January 2012, finished the 11-mile project by adding four new PMLs (two lanes were added in each direction by converting one HOV lane to a HOT lane and converting the inside shoulder to a HOT lane as well). The I-95 Express Lanes operate as HOT3+, allowing carpools of three or more, transit, vanpools, motorcycles and hybrids to travel for free. No trucks with three or more axels are allowed to use the I-95 Express Lanes.

What makes the I-95 Express HOT Lanes case study unique?

- Long-term phased project implementation approach
- Conversion of existing lane (HOV) and construction of one additional lane
- Carpools (3+), vanpools, and hybrid vehicles are required to register with South Florida Commuter Services in advance

A larger regional study is now being conducted to develop a network of PMLs in South Florida, and there are six additional projects in various stages of development.

Project Characteristics

- 2 HOT lanes in each direction (HOV and shoulder lane conversions)
- Buffer separation with delineators
- Transponder tolling only
- Operates as HOT3+
- Transit, vanpools, motorcycles and hybrids travel free
- No 3+ axle trucks are allowed

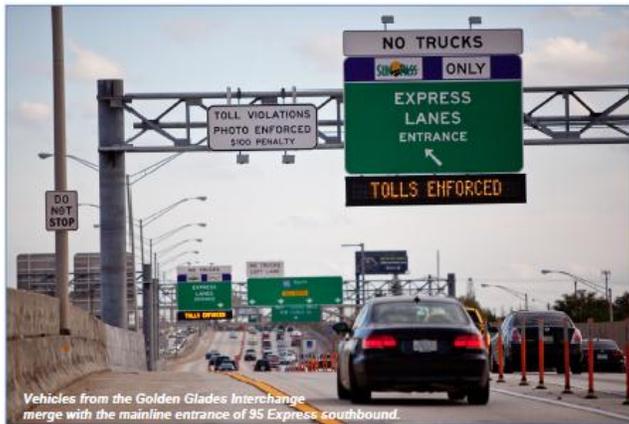
Figure 4-1: I-95 Express (Miami)



Source: Florida Department of Transportation: 95 Express Annual Report, February 2012.

PRICED MANAGED LANES CASE STUDY

Figure 4-2: I-95 Express (Miami)



Source: Florida Department of Transportation: 95 Express Annual Report, February 2012.

Project Performance and Features

- Has served over 60 million trips since its inception in 2008
- Monthly revenues of approximately \$1.36M
- Annual operating cost: \$7.63M
- Total capital cost: \$132M
- Operates above 45 mph 99.95% of the time
- First project to require HOVs and other exempt vehicles to register their vehicles
- Congestion-based tolls range from \$0.25 to \$7.10
- Average toll rates are \$1.60 (SB) and \$1.90 (NB)

Miami Lessons Learned

- Enforcement is a significant concern, and thus, highway patrol should be involved to ensure enforcement technologies are interoperable.
- Complete camera coverage aids in operations and enforcement.
- Effective public outreach is essential and must continue throughout project planning, implementation, and operation.
- The tolling facility should be simplified so that signage and communications technologies are easy to understand for motorists in the corridor.
- Improved and enhanced signage is required to identify access points.
- How transportation agencies refer to the terminology of congestion pricing (“toll,” “price,” “fare,” “fee,” etc.) will influence public and decision-maker support.

PRICED MANAGED LANES CASE STUDY

4.1.2 Seattle, Washington: State Route 167 HOT Lanes Pilot

The State Route (SR) 167 HOT lanes project is a pilot project undertaken by the Washington State DOT and partially funded through the Federal Highway Administration’s Value Pricing Pilot Program (VPPP). The VPPP encourages the implementation and evaluation of value pricing pilot projects to manage congestion on highways through tolling and other pricing mechanisms.

What makes the SR 167 HOT Lanes case study unique?

- Lanes separated by striped two foot buffer
- Operates as HOT2+ during the peak with an option for SOVs to buy in to the lane and open to all vehicles during the off peak

The SR 167 pilot project consists of the conversion of an HOV2+ lane to a HOT2+ lane where single occupancy vehicles (SOVs) can buy in to the lane during peak travel periods. The project is 11 miles in length in the northbound direction and 9 miles in the southbound direction operating southeast of Seattle. The project developed one buffer separated HOT lane in each direction and began operations in May 2008. It is open to all vehicles during the off peak and does not allow trucks over 10,000 pounds to use the lanes. The addition of PMLs on I-405 to the north of SR 167 is currently being designed.

Figure 4-3: SR 167 HOT Lanes (Seattle)



Source: Washington State DOT

Project Characteristics

- 11 miles NB, 9 miles SB
- 1 HOT lane per direction
- Buffer separation
- Transponder tolling
- Operates as HOT2+ during the peak with an option for SOVs to buy in to the lane
- Open to all vehicles during the off peak
- No trucks over 10,000 pounds

Project Performance and Features

- Total capital cost: \$18M
- Annual operating cost: \$843,000 (FY2011)
- Approximately 3,400 weekday tolled trips
- Tolls range from \$.50 to \$9.00
- Average toll per trip is \$1.25
- Operates above 45 mph 99 % of the time
- HOT lane speed averages 60 mph
- Lane is open to general purpose traffic from 7 pm to 5 am
- HOT lane accepts four different types of transponders

PRICED MANAGED LANES CASE STUDY

Figure 4-4: SR 167 HOT Lanes (Seattle)



Source: Washington State DOT:
<http://www.wsdot.wa.gov/Tolling/SR167HotLanes/default.htm>

Seattle Lessons Learned

- Dynamic signs should be used to provide users with travel time estimates and speed limits.
- Access points may need to be modified after implementation.
- Flexible design and operation of PMLs to accommodate fluctuating traffic patterns is ideal.
- Improved and enhanced signage is required to identify access points.
- A package of benefits (consumer choice, better transit, faster trip, more network capacity, reliable technology and carpooling opportunity) will provide a broader base of support.
- How transportation agencies refer to the terminology of congestion pricing (“toll,” “price,” “fare,” “fee,” etc.) will influence public and decision-maker support.

4.1.3 Salt Lake City, Utah: I-15 Express HOT Lanes

The original I-15 HOV lanes were opened in 2001. In 2006, the lanes were converted from a HOV2+ lane to a buffer-separated HOT2+ lane (one in each direction). In March of 2006, the State Legislature approved tolling some SOVs, while transit, motorcycles and clean fuel vehicles are still allowed to use the lanes for free. In April of that year, the Utah Transportation Commission gave the Utah Department of Transportation (UDOT) the authority to toll, and by September of that year, UDOT implemented the longest HOT lane in the U.S. (38 miles).

The I-15 Express Lane originally utilized a sticker decal to identify SOVs that could legally use the lane (i.e., clean fuel vehicles). However, in 2010, the decal program was converted to a technology solution using transponders that allow for self-declaration.

The I-15 Express Lane project is an example of how a project can be expedited to deliver a large project on a short timeline using a phased approach, such as by transitioning from a sticker decal to a technology solution.

What makes the I-15 Express Lanes Unique?

- *40 mile long corridor*
- *Dynamic pricing broken into four geographic zones*
- *Lanes separated by striped two foot buffer*
- *Visual enforcement only (17% violation rate)*

PRICED MANAGED LANES CASE STUDY

Project Characteristics

- 1 lane per direction
- 38 miles in length (longest in the U.S.)
- Buffer separated
- Operates as HOT2+
- Transit, motorcycles and select clean fuel vehicles travel free
- Tolling based on four distinct geographic priced zones

Project Performance and Features

- Tolls range from \$.25 to \$4.00
- Total capital cost: \$150M+
- Annual operating cost: \$600,000 (FY 2010)
- Annual toll revenue: \$500,000 (FY 2010)
- Toll rate: \$50 per month for SOVs, provided extra capacity is available

Figure 4-5: I-15 Express (Salt Lake City)



Source: www.ManagedLanes.org

Salt Lake City Lessons Learned

- Effective public outreach is essential and must continue throughout project planning, implementation, and operation.
- The tolling facility should be simplified so that signage and communications technologies are easy to understand for motorists in the corridor.
- Improved and enhanced signage is required to identify access points.
- How transportation agencies refer to the terminology of congestion pricing (“toll,” “price,” “fare,” “fee,” etc.) will influence public and decision-maker support.

PRICED MANAGED LANES CASE STUDY

4.1.4 Minneapolis, Minnesota: MnPass I-394 Express HOT Lanes

Figure 4-6: MnPass I-394 Express Lanes (Minneapolis)



The MnPass I-394 express lanes opened in May of 2005. The project converted an existing HOV lane to the state’s first HOT lane. The I-394 Express lanes span a total of 11 miles in length. For eight of those 11 miles, the project consists of one lane per direction separated by a buffer, with the three eastern most miles operated as two reversible lanes separated by a permanent barrier. Carpools with 2 or more people (HOV2+), transit, vanpools, and motorcycles travel

in the HOT lanes at no cost. Vehicles not meeting those descriptions (i.e. SOVs) are allowed to use a transponder to buy access into the HOT lanes. The lanes are dynamically priced during peak hours and are free to all users during non-peak hours.

What makes the MnPASS I-394 Express HOT Lanes Unique?

- 8 miles of single lane directional; 3 miles of double lane reversible
- Operates as HOT2+ during the peak with an option for SOVs to buy in to the lane and open to all vehicles during the off peak
- Varied access – 25% open access, remainder is permanent Jersey barriers
- Developed as a Public-Private Partnership (PPP)
- Primarily enforced visually, however State Troopers are equipped with transponder readers

The goal of this project was to improve traffic flow and transit reliability. The project has received strong public support and a recent study by Mn/DOT showed that 91 percent of users were satisfied with the HOT lanes.

Project Characteristics

- 1 lane per direction, with a two lane reversible section at the eastern end
- Transponder only
- HOV2+ toll free during the peak (SOVs can buy in to the lane)
- Transit, vanpools, and motorcycles travel free
- Congestion-based toll: \$0.25 minimum and \$8.00 maximum
- Average toll between \$1.00 and \$4.00 during peak hours
- Both buffer and barrier separated depending on the segment
- Annual revenue does not cover the operating cost (never intended to)

PRICED MANAGED LANES CASE STUDY

Project Performance and Features

- Consistently operates above 45 mph
- Implemented as a Public-Private Partnership (PPP)
- Transponder technology allows for mobile enforcement
- Approximately 150,000 vehicles per day
- Total capital cost: \$10M (only required technology improvements and minor restriping)
- Annual revenue does not cover operating cost

4.1.5 Houston, Texas: I-10 Katy Freeway HOT Lanes

Texas has had a unique experience in addressing operational concerns by modifying vehicle eligibility requirements in HOV lanes and then closely evaluating the impacts of those changes. The Katy Freeway HOV lane was constructed with support from Federal Transit Administration (FTA) funds when it opened in 1984, and only authorized buses and vanpools were allowed. Gradually between 1984 and 1987, 4+ carpools, then 3+ carpools, and then 2+ carpools were allowed.

The Katy Freeway QuickRide was introduced in 1998 as Texas' first HOT lane operation that converted the existing HOV lanes to HOT lanes on the freeway. The project converted a reversible-flow HOV lane to a HOT lane facility that allowed HOV2 vehicles to pay to use the facility during peak periods and HOV3+ vehicles to use the facility at no cost. In 2009, an expanded HOT lane facility replaced the Katy Freeway QuickRide. The Katy Freeway is now a 12-mile HOT facility utilizing two new lanes in each direction located in the median of I-10 between SH 6 and SH 610.

Minneapolis Lessons Learned

- It is important to develop a project vision and concept of operations early; but be flexible.
- Dynamic signs should be utilized to provide users with travel time estimates and speed limits.
- Enforcement is a significant concern, and thus, highway patrol should be involved to ensure enforcement technologies are interoperable.
- Complete camera coverage aids in operations and enforcement.
- Effective public outreach is essential and must continue throughout project planning, implementation, and operation.
- The tolling facility should be simplified so that signage and communications technologies are easy to understand for motorists in the corridor.
- Improved and enhanced signage is required to identify access points.
- Potential funding resources should be evaluated early.
- How transportation agencies refer to the terminology of congestion pricing ("toll," "price," "fare," "fee," etc.) will influence public and decision-maker support.

What makes the Katy Freeway HOT Lanes Unique?

- *Newly constructed HOT lanes separated from GP lanes by flexible pylons*
- *Allows 3+ axle trucks with a minimum toll of \$7.00 and a maximum toll of \$21.00*
- *Sponsored by TxDOT, but operated by Harris County Toll Road Authority (HCTRA)*

PRICED MANAGED LANES CASE STUDY

Under the Katy Freeway's current configuration, SOVs are not allowed on the QuickRide facility due to the FTA's original investment in the lane. The Katy Freeway includes 13 miles of barrier separated HOT lanes on the Katy Freeway in Houston. The Katy Freeway has three general purpose lanes in each direction and one barrier-separated reversible lane. The lanes are fully automated, and users must have a registered account to use the lanes. HOV2 must pay \$2.00 during peak congestion periods while transit, motorcycles and HOV3+ carpools travel free. Trucks with three or more axles pay \$7.00 to use the lanes during all times of day.

Project Characteristics

- I-10 (Katy Freeway) 13-mile reversible lane
- Barrier separated
- Full automated; must have registered account
- HOV2 must pay \$2.00 during peak hours
- Transit, motorcycles and 3+ carpools travel free
- Trucks with 3+ axles pay minimum \$7 toll at all times
- Operates only during morning peak hours

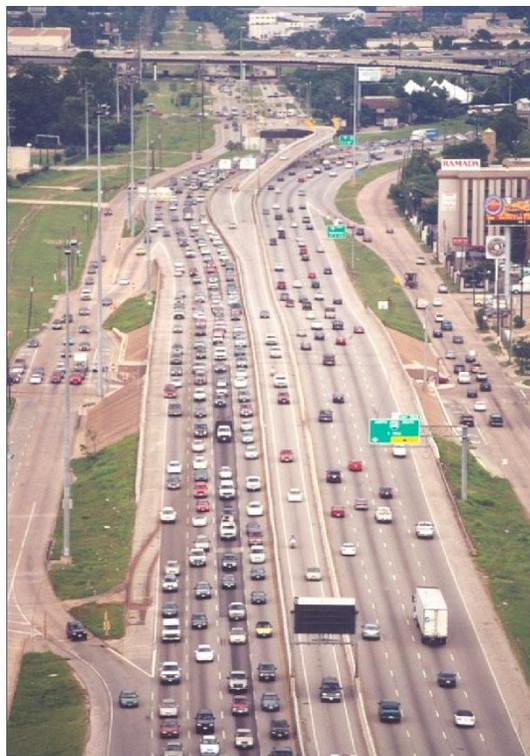
Project Performance and Features

- Katy Freeway designed to carry 79,000 vehicles per day, now carries over 200,000
- Revenue covers operating costs

Figure 4-7: QuickRide Network (Houston)



Figure 4-8: Katy Freeway (Houston)



PRICED MANAGED LANES CASE STUDY

Houston Lessons Learned

- A project vision and concept of operations should be developed early; but be flexible.
- Enforcement is a significant concern, and thus, highway patrol should be involved to ensure enforcement technologies are interoperable.
- Improved and enhanced signage is required to identify access points.
- Potential funding resources should be evaluated early.
- Pricing is an effective way to balance HOV demand; carpool occupancies can be raised to help manage priced lane capacity.
- How transportation agencies refer to the terminology of congestion pricing (“toll,” “price,” “fare,” “fee,” etc.) will influence public and decision-maker support.

4.2 ETL CASE STUDY

Currently, there is only one ETL facility in operation in the U.S., which is SR 91 in Orange County, California. However, it is anticipated that I-595 in Ft. Lauderdale, Florida and the MoPac-Loop 1 in Austin, Texas will operate as ETL facilities once implemented.

4.2.1 Orange County, CA: SR 91 ETL Lanes

The SR 91 express lanes were constructed in 1995 in Orange County, CA. The facility consists of four express lanes (2 in each direction) for 10 miles within the median of SR 91. Tolls vary by time of day and are highest during peak hours. Account holders with three or more people traveling in their vehicle travel toll-free except Eastbound, Monday through Friday from 4-6 PM. During this PM peak period, carpools with three or more occupants receive a 50 percent discount on the posted toll. Special access accounts are available for customers who always drive with three or more people in their vehicle, drive a motorcycle, a zero-emission vehicle, or have a disabled veteran or disabled person license plate.

What makes the SR 91 Express ETL Lanes Unique?

- *Only ETL currently operating in the U.S. (no occupancy requirements)*
- *Originally constructed by private company, but bought out in 2003*
- *Limited access is controlled by 3ft. tall delineators spaced 12 ft. apart*
- *Carpools of 3 or more receive a 50% discount during Eastbound peak hours*
- *Video enforcement authority in place*
- *Disabled persons must apply for an account, but can travel in the lanes for free*

The express lanes provide limited access at the east and west terminus for the lanes and tolls are collected by electronic transponders. The SR 91 express lanes facility was originally constructed for approximately \$135 million as a private for-profit investment. In January 2003, a public agency, the Orange County Transportation Authority (OCTA), purchased the operating franchise for \$207.5 million.

PRICED MANAGED LANES CASE STUDY

Project Characteristics

- 10 miles, two lanes in each direction
- Limited access, restricted to east and west ends
- Lanes separated by flexible delineators
- HOV 3+ free Westbound, 50% discount Eastbound during PM peak
- Operates 24 hours a day
- Variable tolls by time of day
- Maximum toll – \$9.75, minimum toll - \$1.30

Project Performance and Features

- Annual operating costs:
\$22,381,000 (2011)
- Annual revenue generation:
\$41,245,000 (2011)

Orange County Lessons Learned

- Limiting the number of access points can provide for better operations and simplified tolling strategies.
- While many PML's are newly under operations, many are not expected to collect significant revenue beyond what will cover O&M costs. However, SR 91 is an exception and typically collects more the twice the revenue compared to its O&M costs.
- There is a trend nationally moving from HOT based facilities to ETL facilities.

Figure 4-9: Location of SR 91 Express Lanes (Orange County, CA)



Source: CalTrans,

Figure 4-10: SR 91 Express Lanes (Orange County, CA)



Source: CalTrans

PRICED MANAGED LANES CASE STUDY

Figure 4-11: Signing of SR 91 Express Lanes (Orange County, CA)



Source: The Transit Coalition, http://www.thetransitcoalition.us/a_better_inland_empire/proj_hot.html

5 SUMMARY OF LESSONS LEARNED

The PML projects in operation today are successful models for using multiple operating strategies to achieve intended objectives. The case studies documented previously have provided several key lessons learned, as indicated within each case study section. All lessons learned are summarized below:

- A project vision and concept of operations should be developed early; but be flexible (Minneapolis, Houston, and Los Angeles).
- Dynamic signs should be used to provide users with travel time estimates and speed limits (Minneapolis and Seattle).
- Enforcement is a significant concern, and thus, highway patrol should be involved to ensure enforcement technologies are interoperable (Miami, San Diego, Houston, and Minneapolis).
- Complete camera coverage aids in operations and enforcement (Miami and Minneapolis).
- Effective public outreach is essential and must continue throughout project planning, implementation, and operation (Salt Lake City, Miami, Los Angeles and Minneapolis).
- PMLs are often used by people of all incomes (America THINKS Survey and San Diego).
- The tolling facility should be simplified so that signage and communications technologies are easy to understand for motorists in the corridor (San Diego, Miami, Minneapolis and Salt Lake City).

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- Access points may need to be modified after implementation (Seattle).
- The design and operation of PMLs should be flexible enough to accommodate fluctuating traffic patterns (Seattle and Minneapolis).
- Improved and enhanced signage is required to identify access points (All).
- The potential funding resources should be evaluated early (Houston and Minneapolis).
- A package of benefits (consumer choice, better transit, faster trip, more network capacity, reliable technology and carpooling opportunity) will assure a broader base of support (Seattle, Dallas-Ft. Worth and Los Angeles).
- Pricing is an effective way to balance HOV demand; carpool occupancies can be raised to help manage priced lane capacity (Houston).
- Occupancy detection, declaration and enforcement impact revenues (Dallas-Ft. Worth).
- How transportation agencies refer to the terminology of congestion pricing (“toll,” “price,” “fare,” “fee,” etc.) will influence public and decision-maker support (All).
- While many PML’s are newly under operations, many are not expected to collect significant revenue beyond what will cover O&M costs. However, SR 91 is an exception and typically collects more the twice the revenue compared to its O&M costs.
- There is a trend nationally moving from HOT based facilities to ETL facilities.

6 TRENDS

All trips on a roadway are not the same, so all lanes on a roadway should not be the same. Urban corridors need to provide choices for motorists who can evolve into customers of PMLs, a mobility option available to motorists when they need it.

Urban corridors are congested and need to provide mobility options to motorists seeking a free-flowing trip. Mobility on these corridors can be improved by implementing congestion pricing strategies such as priced managed lanes.

While there is not 50 years of history with PMLs (managing or tolling specific lanes) as there is with traditional tolling (tolling all lanes on the facility) in the U.S., there are now 18 data points to look at. With 2,800 miles of PML projects on the way, they offer a look at where the U.S. is heading with PMLs and what the industry has learned from implemented projects.

There are two major trends regarding PMLs in the U.S: 1) the movement to more multilane projects; and, 2) the movement to implementing networks of PMLs in urban regions.

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6.1 MOVEMENT TO MULTILANE PROJECTS

The majority of PML projects in the U.S. began as single-lane projects, whereby State DOTs could pilot the concept in a region to test its feasibility. The federal government has encouraged these pilot activities and in many cases helped fund the pilots with Federal dollars. The next generations of PMLs are more likely to be multilane, when feasible, and in some instances involve private financing.

6.2 MOVEMENT TO PRICED MANAGED LANE NETWORKS

Beyond the expanded width of PML corridors, state DOTs and their partners are looking at how they can create a seamless interconnected network of PMLs in a congested urban area. Urban areas such as Miami, Atlanta, Minneapolis, Los Angeles, Phoenix, San Francisco, and Houston either have or are undertaking efforts that will lead to multiple PML corridors in their urban area within three years. This is leading to a new series of questions regarding how they are operated as a regional network and how integrated corridors need to be managed to benefit the network as a whole.

7 BEST PRACTICES

It is important to determine the ultimate goal of the priced managed lane(s) (i.e. mobility, revenue generation or a hybrid approach) and define what long-term success will look like for GDOT.

As transportation professionals evaluate various PML operating alternatives, new implementation strategies emerge as the state of the practice. Agencies now recognize the importance of developing a vision and concept of operations early. However, it is important to recognize challenges and remain flexible. Consideration should be given to emerging operational strategies such as vehicle occupancy and price variances, distance based pricing, and reversible lane operations with limited access points.

Many considerations must be addressed and decided upon as GDOT evaluates PML applications. Front-

end policy decisions will drive future design and operational elements of the network which will ultimately affect future mobility in the Atlanta region.

This study has evaluated some of the PMLs in operation today and outlined the variation between the strategies and characteristics that have led to their successful operation. The case studies presented in this document outline many successful models for PML facilities. In summary, successful projects:

- Define roles and responsibilities.
- Define project goals for a PML investment (i.e. mobility, revenue generation, or a hybrid approach) and develop performance measures to meet them.

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- Develop a toll policy to establish how tolls are set and eligibility requirements.
- Conduct outreach and collaborate with the media to help inform the public.
- Follow a multi-modal approach to increase public acceptance by creating dual-purpose investments, such as allowing transit usage in the PMLs.
- Investigate available financing options and their implications.

Each of these successful aspects is described in more detail below.

7.1 DEFINE ROLES AND RESPONSIBILITIES

PML projects are often large projects that cross jurisdictional boundaries, making agency cooperation and coordination critical to PML success. It is important to determine who will be the lead agency and any secondary partnering agencies/private entities participating in the development of the PML network. These determinations should be documented with project agreements that define each agency's role as it applies to design, construction, implementation, operations and maintenance. The Houston Quickride PML program required the cooperation of the Texas DOT and the local transit authority. Quickride took advantage of agency arrangements stemming from the operation of their existing HOV network.

Public agencies in the U.S. have traditionally provided operations and maintenance services on PMLs but have looked to regional or state toll authorities to provide their toll collection function for them through existing toll back offices. On projects where transit is allowed to operate the public entity implementing them has worked with the local transit agency for the provision of transit services. It may, however, be necessary to forge new relationships with partners not previously involved. As noted earlier, managed lanes projects may encompass a number of different operating strategies. This will bring more players to the table, including transit authorities, toll authorities, and private interests.

7.2 DEFINE GOALS AND DEVELOP PERFORMANCE MEASURES TO MEET THEM

One of the most important considerations is to understand the ultimate goal of PMLs and what would constitute a successful implementation. Some implementing agencies are driven by a desire to improve mobility and manage congestion while others are seeking to generate revenue from PMLs with a secondary goal of mobility. These two goals are not mutually exclusive and hybrid approaches are available.

Defining what the performance goals are for the PMLs will be related to how success is defined (i.e. mobility based and/or revenue based). It will also improve communications with all audiences as to the benefit of the PMLs and how the benefits will be measured. Many agencies establish operating thresholds for PMLs. FHWA policy requires the lane to maintain a 45 miles per hour (mph) speed in the peak periods 90 percent of the time over a 180 day time period. Potential performance measures may include:

- Travel speeds in peak periods.

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- Increase in transit person throughput.
- Increase in vehicle occupancy.
- Increase in vehicles per hour throughput.
- Gross toll revenue.
- Net toll revenue.
- Percentage of O&M cost covered by toll revenue .
- Return on Investment (ROI).

The eventual performance measures selected will be based on the policy decisions made on the project or system. No matter how success is defined for the lanes and what goals are established, it is essential to quantify those goals through the use of performance measures.

7.3 DEVELOP TOLL POLICY

How rates are set, who sets them, and who has to pay to use the lanes are the largest policy decisions that need to be considered. These questions will ultimately determine how much revenue the lanes can generate and if there is any potential to monetize them.

Equity is a major issue often raised during discussion of PMLs. Although the option to pay or not pay a toll is typically discretionary among prospective users, the concerns raised still need attention in the planning and development process. Tolling policy must weigh management needs against public and user understanding.

Some of the most important toll rate policies to be considered and questions that need to be resolved include:

- **Toll rate policy**
 - Will the toll rate policy be set to maximize revenue?
 - Will the toll rate be set to maximize the usage of the lanes?
 - Will a hybrid approach be developed to emphasize both?
- **Toll cap**
 - Will there be a maximum, upper limit, toll rate above which the operator will not charge even if general purpose lane congestion conditions would allow for it?
- **Reimbursement policy**
 - Will customers' tolls be reimbursed if they are traveling in the lanes and defined performance targets are not being achieved (e.g. 45 miles per hour)?
- **Table based tolls versus dynamic tolls**

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- Will toll rates be pre-published on a monthly basis or operated dynamically in real-time?
- Are the increased capital and O&M costs of dynamically priced tolls worth the slight operational improvement they provide for PMLs?
- **Minimum toll**
 - Will operators charge minimum tolls in the off-peak hours to cover collection costs or might they turn off the system and open it up to all drivers for free?
- **Vehicle eligibility**
 - Will HOVs get a discounted or free trip?
 - How will HOVs be defined?
 - Will transit vehicles be tolled?
 - Will emergency vehicles be tolled?
 - Will motorcycles or alternative fuel vehicles be tolled?

7.4 CONDUCT OUTREACH

It is important to consider multiple audiences when discussing education, communications, and outreach regarding new priced managed lane projects.

Successful implementation of PMLs is contingent on clearly explaining what PMLs are, what the benefits are to the customers of the lanes, and what the benefits are to the motorists operating in the general purpose lanes.

There are multiple audiences that should be considered when discussing new PML projects:

- 1) Elected officials and decision-makers who will be asked to support these new types of projects;
- 2) Media outlets that will report on the concept, development and implementation of these projects; and
- 3) The general public that may be future customers of the lanes, who are also constituents of the elected officials and consumers of the information produced by the media outlets.

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How issues of fairness and equity are handled through public policy and discussions with elected officials and decision-makers will be the key driver of getting to implementation.

7.4.1 Elected Officials

Tolling has always had a higher hurdle to overcome in getting elected official buy-in compared to free HOV lanes. In the case of PMLs, there may be the perception that people are being further burdened beyond the fuel taxes they already pay. The issues of fairness and equity are always in play. However, in recent years, polling has shown that public opinion favors tolling when compared to increases in motor fuel tax, and recently, metro Atlanta voters decided they did not want to pay a higher tax to further transportation improvements. How the issues of equity and fairness are handled through public policy and discussions with elected officials and decision-makers will be the key driver of getting to implementation.

7.4.2 Media

Some regions may not be as familiar with tolling and PMLs as others, which can lead to misinformation being presented in the public arena. It is essential to remember that the media may report out on PML projects before any formal public involvement will occur as part of a project. The key to preventing misinformation is to bring the media into the project as early as absolutely possible. Brief them on the merits of the project and the drawbacks and continue to brief them throughout the project duration. They will report on the project regardless, and therefore, it is better if they are provided information and armed with facts.

The key to preventing misinformation is to bring the media into the project as early as possible.

7.4.3 General Public

How successful the communication and education efforts are with elected officials and media outlets will directly impact how successful communicating with the general public will be. If media outlet outreach is effective in reporting the facts about PML projects, then the following communications with the general public will be that much easier. If good education and outreach occurred with elected officials, project support that will benefit the implementing agency could still result even with any public misgivings about the project.

Messaging should be focused on what the benefits are to the public as a result of implementing priced managed lanes.

Tolling and road pricing can be a tricky message to portray, but if provided the right context that outlines options and benefits, it can be done successfully. In 2008, a report produced by the National Cooperative Highway Research Program, "Compilation of Public Opinion Data on Tolls and Road Pricing," sought to collect all available public opinion on tolling and road pricing and synthesize it to determine what themes emerge.

The eight themes that emerged regarding what the public valued and wanted to see are:

1. The public wants to see the value.
2. The public wants tangible and specific examples.

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3. The public cares about the use of the revenues.
4. The public learns from experience.
5. The public uses the knowledge and information available.
6. The public believes in equity and wants fairness.
7. The public wants simplicity.
8. The public favors tolls to taxes.

7.5 FOLLOW A MULTI-MODAL APPROACH

Priced managed lanes directly contribute to multi-modal travel-time reliability. One of the goals of PMLs might be to reduce trip times by increasing multi-modal connections. This strategy protects transfers between both transit (e.g., bus, subway, and commuter rail) and non-transit (e.g., shared-ride) modes, and facilitates coordination between multiple agencies to accomplish the tasks. In certain situations, integration with other dynamic transit operational strategies may be required to coordinate connections between transit and non-transit modes.

7.6 INVESTIGATE AVAILABLE FINANCING & IMPLICATIONS

There is no consensus on the best strategy for funding PMLs. In many of the case studies evaluated for this project, financing has been secured as a result of taking advantage of opportunities and developing funding packages utilizing various sources.

It is common for Federal grants to play an important role in funding the majority of PML applications. However, Federal grants are usually only a part of the total funding required and are often supplemented by other stakeholders of the project which might involve state DOTs (e.g. Katy, Houston), transit service providers (e.g. Regional Transit District in Denver for I-25) and toll authorities (HCTRA in Katy, Houston), the gas tax (SR 167 in Seattle) or the private sector (I-394, Minneapolis). In most instances, funding has been cobbled together from several sources.

7.6.1 MAP-21 Impacts

It is currently mainstream federal policy to convert under-performing HOV lanes to HOT lanes. Beyond this, the passage of Moving Ahead for Progress in the 21st Century (MAP-21) relaxes certain federal policies with regards to tolling general purpose lanes. However, it is important to understand the restrictions of using FTA funds for PMLs that are converted from HOV facilities. If FTA funds were used to help construct the facility, specific guidelines must be followed or funds must be repaid. PML funding guidelines are outlined below.

MAP-21 made significant changes to the federal Section 129 Tolling Program. The changes have relaxed the previous prohibition of imposing

In most instances, funding for PMLs has been cobbled together from several sources.

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tolls on federal-aid highways. Public agencies may impose new tolls on federal-aid highways in the following cases:

- Initial construction of a new highway, bridge, or tunnel.
- Initial construction of new lanes on highways, bridges, and tunnels (including Interstates) as long as the number of toll-free lanes is not reduced.
- Reconstruction or replacement of a bridge or tunnel.
- Reconstruction of a highway (other than an Interstate).
- Reconstruction, restoration, or rehabilitation of an Interstate highway as long as the number of toll-free lanes is not reduced.

Prior to MAP-21's provisions taking effect on October 1, 2012, public authorities were required to execute a tolling agreement with FHWA to impose tolls on a federal-aid highway, but this requirement no longer exists. For toll facilities that have executed Section 129 tolling agreements prior to October 1, 2012, the terms of those agreements will continue in force.

Under Section 166 of Title 23, existing HOV lanes may be converted to tolled operation provided that the local MPO endorses the use and amount of tolls on the converted lanes. All tolls on new lanes must be variably priced and collected electronically in order to manage travel demand. To implement tolls on an existing HOV lane, project sponsors must demonstrate that the conditions on the facility are not already degraded and that the presence of paying vehicles will not cause conditions on the facility to become degraded. Ongoing annual reporting documenting conditions on the converted lanes is also required, and if the HOV facility becomes degraded the sponsor must bring the facility into compliance either by increasing HOV occupancy requirements, increasing tolls, increasing capacity, or eliminating access to paying motorists. The prior requirement to execute a tolling agreement with FHWA for HOV lane conversion is no longer in place under MAP-21, same as with the Section 129 General Tolling Program.

In addition to Sections 129 and 166, public agencies interested in implementing PML projects are also eligible to apply for grants under the FHWA Value Pricing Pilot Program (VPPP) or Interstate System Reconstruction and Rehabilitation Pilot Program. VPPP grants have been used to develop facilities in Houston, Minneapolis, Atlanta (I-85 North) and Seattle. The I-95 Express lanes in Miami utilized funding granted through the Urban Partnership Agreement (UPA). More information on the UPA is located here: <http://www.upa.dot.gov/index.htm>. Addressing funding needs has slowed PML adoption on current projects and demonstrations. The best example of this is in Houston, where a median HOV lane was constructed with support from FTA funds as a VPPP. The Katy Freeway was initially a dedicated transit facility, which was underutilized and now operates as a HOT lane facility. As a result of the initial FTA investment, the Katy Freeway cannot allow SOVs on the QuickRide facility and must negotiate a plan for transit access to any proposed future expansions. The final policy statement on HOV-to-HOT conversions is located here:

http://www.ntdprogram.gov/ntdprogram/pubs/reference/FedRegister/Policy_When_HOT_Lanes_May_Be_Classified_as_Fixed_Guideway.pdf.

8 CONCLUSIONS

In an era where transportation agencies face ever-growing congestion and reliability challenges combined with limited ability to expand freeway capacity and constrained budgets, PMLs can be a viable alternative. When conditions are right, they can allow metropolitan areas to make the most effective use of freeway capacity. Solving the transportation challenges of tomorrow requires a shift in thinking today.

PML facilities have achieved project goals in the communities where they operate. PMLs offer a flexible, cost-effective and sustainable solution for metropolitan areas to address congestion reliability and safety needs now and for the future. With 18 PML facilities currently in operation in the U.S., and at least another 20 PML facilities in design or under construction, many regions are moving towards PMLs to provide additional capacity and mobility options. The following conclusions can be drawn from this case study:

- **Define Investment Goals:** One of the most important considerations is to understand the ultimate goal of PMLs and what would constitute a successful implementation. Some implementing agencies are driven by a desire to improve mobility and manage congestion while others are seeking to generate revenue from PMLs with a secondary goal of mobility. These two goals are not mutually exclusive and hybrid approaches are available.
- **Establish Toll Policies Early:** It is essential to establish toll policies early. How rates are set, who sets them, and who has to pay to use the lanes are the biggest decisions that need to be considered. These questions will ultimately determine how much revenue the lanes can generate and if there is any potential to monetize them.
- **Manage Expectations for Revenue Generation:** Many PML facilities are not expected to collect significant revenue beyond what will cover O&M costs. There is a trend nationally moving from HOT lane facilities to ETL facilities, largely due to the reduced operating costs. ETLs require additional operating costs due to the need for occupancy detection, declaration and enforcement, resulting on an impact on revenues.
- **Develop a Message:** Effective public outreach is essential and must continue throughout the project planning, implementation, and operation. Demonstrating the benefits of PMLs to potential users and stakeholders is imperative. A package of benefits (consumer choice, better transit, faster trip, more network capacity, reliable technology and carpooling opportunity) will assure a broader base of support.
- **Plan a Flexible Design and Concept of Operations:** It is important to develop a project vision and goals early, but the PML design and concept of operations should be flexible enough to accommodate fluctuating traffic patterns that may impact access point locations after the PML has been implemented.
- **Provide User-Friendly Signage:** Signage and communications technologies should be simplified so that access points, travel time estimates, toll rates, and speed limits are easy to understand for motorists using the corridor.

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- **PML Networks:** Many state DOTs are looking at how they can create a seamless interconnected network of PMLs in a congested urban area. This is leading to a new series of questions regarding how they are operated as a regional network and how integrated corridor need to be managed to benefit the network as a whole.

Atlanta Regional
MANAGED LANES
Implementation Plan



Reversible Lanes Case Study

June 20, 2013

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1 BACKGROUND

The Georgia Department of Transportation's (GDOT) award-winning Atlanta Regional Managed Lane System Plan (MLSP) was the first systemwide evaluation of managed lanes in the United States – an innovative approach to urban area mobility. The plan met the following goals:

- Protect mobility;
- Maximize person/vehicle throughput;
- Minimize environmental impacts;
- Provide a financially feasible system (using a blend of traditional, federal and state funds, and public-private partnerships); and
- Design and maintain a flexible infrastructure for varying lane management.

This report represents an understanding of reversible lanes and the considerations that must be evaluated to develop new reversible lane systems on Metropolitan Atlanta freeways.

The Atlanta Regional Managed Lanes Implementation Plan (MLIP) is an update to the MLSP. The MLIP will reflect current funding constraints and the knowledge gained by GDOT from projects implemented around the country since the plan was published in 2010.

Specifically, the Atlanta Regional MLIP will focus on identifying feasible locations for capacity-adding projects, redefining and reprioritizing projects from the previous plan based on current and future needs, and developing a funding plan for implementing these projects.

The intent is to have a prioritized list of managed lane projects, which reduce the state's reliance on long-term private financing agreements.

2 OVERVIEW OF MANAGED LANES

As highway volumes have increased over time, transportation professionals have assessed multiple methods for managing demand on urban freeways. Managed lanes have existed for almost 30 years and comprise many operational strategies to address a wide array of transportation goals. "Managed lanes" is an umbrella term that describes any restricted lane that is not a general purpose lane.

Figure 2-1 illustrates how managed lanes are defined based on three principle characteristics: access control, pricing and vehicle eligibility. According to the Federal Highway Administration (FHWA), managed lanes have many permutations. The most common types are high-occupancy vehicle (HOV); high-occupancy toll (HOT); express toll lanes (ETL); and truck-only toll (TOT) lanes.

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Figure 2-1: Principle Characteristics of Managed Lanes



Details about each characteristic, or lane management strategy, are provided below.

- **Pricing** restrictions are based on controlling traffic volumes and generating revenue for managed lane facilities to maintain a desirable traffic flow. Pricing may be fixed, set on a variable schedule or dynamic where access costs increase during peak periods. Higher tolls are charged when congestion is heaviest and delay is at its worst, while lower tolls or free access may be provided to some or all users during periods of lowest demand. Pricing is used to balance demand and lane capacity, and may encourage some peak-period users to shift their trips to periods of lower demand.
- **Vehicle eligibility** restricts vehicles from managed lanes based on the number of occupants or vehicle type. Traditional HOV lanes restrict single-occupant vehicles (SOVs), whereas HOT lanes allow motorists to access facilities by paying a tolling fee. Restrictions on facility entrance generally apply to specific types of vehicles, such as large commercial trucks, or free entrance is provided for others, such as transit buses, low-emission vehicles or motorcycles.

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- **Access control** physically separates a managed lane facility from other facilities. Access control can be accomplished using a fixed or moveable barrier, or by pavement markings to identify access points.

Reversible lanes are considered managed lanes because they affect access control and, in some cases, vehicle eligibility. This case study will focus specifically on reversible lanes and the differences between permanent and moveable barriers.

3 INTRODUCTION TO REVERSIBLE LANE SYSTEMS

Growing congestion, coupled with limited transportation funding, has highlighted the need for more innovative and cost effective transportation management approaches. Various transportation planning strategies have been developed to mitigate the effects of highway traffic congestion, ranging from sophisticated systems such as active traffic management (ATM) and in-vehicle dynamic route guidance, to managed facilities such as carpool and toll lanes. Another technique used to mitigate increasing peak-period congestion, and specifically latent demand, is the implementation of reversible lane systems (RLSs).

Figure 3-1: I-394 Reversible Lane (Minneapolis)



Source: FHWA Freeway Management and Operations Handbook

More than a dozen RLSs are implemented on limited-access facilities across the country (Figure 3-1). Reversible lanes are a highly cost-effective way to increase the capacity of an existing roadway.¹ They are used to alleviate congestion and optimize roadway performance by borrowing one or more lanes from the opposing traffic direction during peak travel periods.

RLSs take advantage of the unused capacity of the minor flow direction to increase capacity in the major flow direction, eliminating the need to construct additional lanes.²

Reversible lanes temporarily increase the directional capacity of highways without the additional cost of acquiring right-of-way.

¹ "NCHRP Synthesis 340 – Convertible Roadways and Lanes," 2004.

² Institute of Transportation Engineers (ITE) Journal, "Planning and Operational Practices for Reversible Roadways," 2006.

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This report will focus on freeway applications of reversible lanes, in particular lessons learned and the differences between permanent and moveable barrier applications.

This report focuses on the use of reversible lanes to alleviate peak-period congestion on limited access freeway facilities. The intent is to provide an understanding of RLSs and the considerations that must be weighed when developing new RLSs on Metropolitan Atlanta freeways. The following case studies will evaluate the characteristics of three specific types of reversible lanes (permanent, moveable and emerging hybrid approaches). It will illustrate their similarities and differences and to evaluate what makes each unique and effective when implemented in different contexts across the United States.

The information is presented in a case study format to aide decision-makers in easily understanding the various costs, challenges, system designs, best practices and lessons learned from agencies that currently operate reversible lane facilities. Whenever possible, evaluation of the costs and benefits is included, as well as any information gained from direct telephone interviews with each operating agency. The findings from this report will be used to inform project recommendations as part of the Atlanta Metro Operational Planning Study (OPS) and Atlanta Regional MLIP.

3.1 OVERVIEW OF REVERSIBLE LANE DESIGN TYPES

Over the past 85 years, variations of RLSs have been developed throughout the world to address various transportation needs. Historically, RLS implementations have been driven by the need to increase lane capacity and travel speeds as well as decrease roadway congestion and travel time. RLSs are often initiated by identifying congested locations that have traffic volumes that are characterized directionally by time of day. The American Association of State Highway and Transportation Officials' (AASHTO) *Green Book*³ states that reversible operations are justified when 65 percent or more of the traffic moves in one direction during peak hours.

One of the earliest uses of reversible lanes was on an arterial roadway in Los Angeles, California in 1928, and their popularity continued to grow through the 1940s, 1950s, and 1960s as the U.S. freeway system developed. During the 1970s and 1980s, RLSs were used more extensively in harmony with other types of managed lanes in urban centers.⁴ Today, there are several unique applications of RLSs, and most can be related to one of the following categories:

- Alleviation of peak-period congestion;
- Traffic management for planned special events;
- Maintaining capacity through construction zone; and
- Emergency evacuation of threatened areas (Figure 3-2).

³ American Association of State Highway and Transportation Professionals (AASHTO) *Green Book*, 2011.

⁴ "NCHRP Synthesis 340 – Convertible Roadways and Lanes," 2004.

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Furthermore, RLSs are defined by:

- Terminology;
- Roadway functional classification;
- Physical separation (moveable, permanent, or paint);
- Type of lane control (overhead signals, roadside signage, access gate location and type, etc.);
- Segment distance; and
- Proposed usage times.

The designs of most RLSs are similar, but terminology can vary based on a lane's intended use, functional classification, access and eligibility characteristics, and separation method. "Tidal operations" is a common term used in European applications of RLSs, while domestic applications have been referred to, often interchangeably, as "reversible" or "contraflow"

RLSs are defined by functional classification, physical separation, type of lane control, segment distance, proposed usage times, and terminology.

Figure 3-2: Emergency Evacuation



Source: Texas Department of Transportation

lanes. Contraflow is a specific type of reverse flow lane, simply defined by AASHTO as the reversal of flow on a divided highway. Another common term used to describe RLSs is "zipper lanes," referring to temporary and/or permanent reversible lanes that incorporate moveable barriers that can be moved laterally across a pavement surface from one lane edge to another.

RLS applications have been implemented to reduce congestion on a variety of roadway types including freeways (I-5 Express in Seattle and I-15 Reversible Express Lanes in San Diego), bridges (Tappan Zee Bridge in New York and Coronado Bridge in San Diego), and arterial roadways (Stone Mountain Highway and Northside Drive in Atlanta). Other RLS applications have been implemented to alleviate temporary conditions, such as special events, construction, and emergency evacuation; but are less common and their benefits are harder to quantify. As previously stated, this case study will focus on RLSs that are most commonly implemented on a limited access freeway segment.

The following sections provide details on the types of reversible lane designs, including:

- Permanent reversible lane systems;
- Moveable reversible lane systems; and
- A hybrid approach.

REVERSIBLE LANES CASE STUDY

3.2 PERMANENT REVERSIBLE LANES

The traffic directions on RLSs are never permanent, but the reversible operation on a specific section of roadway may be permanent. Permanent reversible lane systems (PRLSs) are physically separated from the general purpose freeway lanes by immovable concrete barriers that are typically located within the right-of-way between or above existing freeway lanes. PRLSs usually operate inbound toward the central business district (CBD) or other major activity center in the morning and outbound in the afternoon. An example of a permanent reversible lane in San Diego is shown in Figure 3-3.

Figure 3-3: I-15 Permanent Reversible Lanes



Source: FHWA Freeway Management and Operations Handbook,

Access to PRLSs can vary depending on the intended use of the reversible lane(s). PRLSs are sometimes accessed by exclusive freeway ramps allowing direct access to the surface street network or other transit facilities, as shown in Figure 3-4. They may also be accessed by transition lanes that utilize gates to access the lanes shown in Figure 3-5.

Figure 3-4: Direct Access Ramps



Source: Dallas Area Rapid Transit

Figure 3-5: Gated Access Lane – Kennedy Expressway



Source: Illinois Department of Transportation

Reversible facilities require daily operational setup. Steps in this process often include opening the lanes in the morning, closing the lanes to inbound traffic, reopening the lanes in the reverse direction of travel in the afternoon, and closing the lanes in the evening. Both manual and automated techniques are used to open and close these types of managed lane facilities.

REVERSIBLE LANES CASE STUDY

3.3 MOVEABLE REVERSIBLE LANES

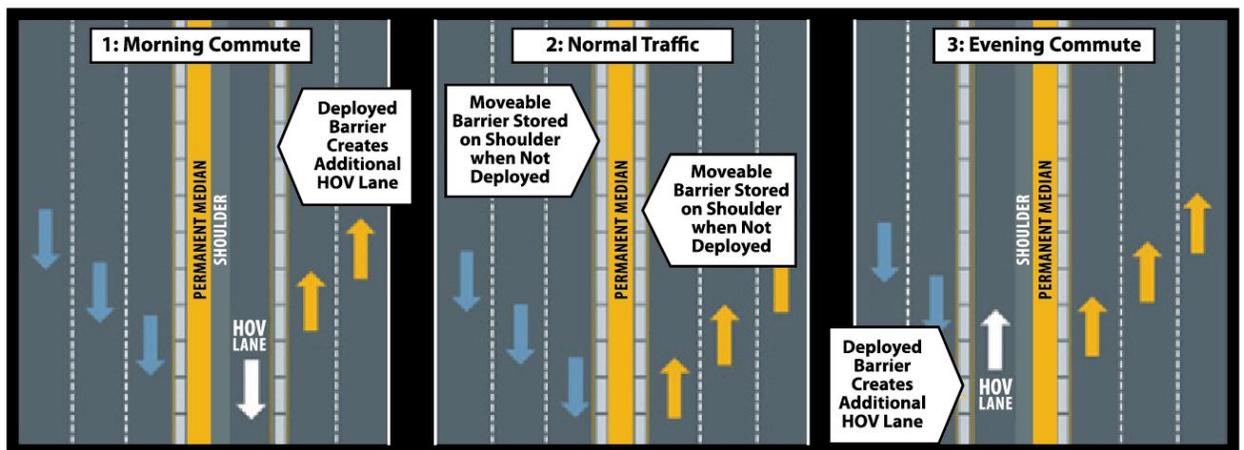
Like permanent reversible lanes, moveable reversible lane systems (MRLSs) (Figure 3-6) have been mostly used on congested freeways where directional flow imbalance permits their use. An MRLS utilizes a lane in the off-peak (or opposite) direction of flow during peak travel periods. MRLSs are typically placed in the inside freeway lane, and during non-peak hours the lanes revert back to normal use. MRLSs are separated from the off-peak flow by plastic cones, pylons, or moveable concrete barriers and are normally implemented where additional freeway right-of-way may not be available. The operational characteristics of an MRLS are illustrated in Figure 3-7. Similar to PRLS, their fundamental objective is to take advantage of underutilized capacity in one direction of travel by reorienting the direction of traffic flow in the opposite direction.

Figure 3-6: Moveable Reversible Lane System



Source: FHWA Freeway Management and Operations Handbook

Figure 3-7: Moveable Reversible Lane System Operation



Source: Barrier Systems, Inc.

RLSs utilizing moveable barriers are sometimes referred to as “contraflow” or “zipper” lanes; but for the purposes of this case study, the terminology that will be used is moveable reversible lane system.

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The components of an MRLS include concrete barriers, a barrier transfer machine (BTM), gates, and signage. Moveable barriers are connected by heavy pins at both ends to form a continuous wall. Known as the Quickchange Moveable Barrier System (QMBS), the technology owned by Barrier Systems, Inc. has been used in Boston (MA); Dallas (TX); East St. Louis (MO); Washington, D.C.; Philadelphia (PA); Charlotte (NC); Miami (FL); New York (NY); San Diego (CA); Portland (OR); Paris (France); and Auckland (New Zealand); among others. The barriers have a T-shaped top allowing them to be laterally moved (from 8 feet to 24 feet in one pass) using a conveyor system to form a new lane. Lateral movements have the option to be positioned by guide wires located in the pavement bed that allow for precise placement of the barriers. The ends of the barrier are protected with water-filled crash cushions. The components (including the BTM and concrete barriers) of an MRLS are shown in Figure 3-8 and Figure 3-9.

Figure 3-8: Moveable Lane Components



Figure 3-9: Barrier Transfer Machine



Source: Barrier Systems, Inc.

REVERSIBLE LANES CASE STUDY

MRLSs can be more labor-intensive than permanent facilities, requiring full-time operational and maintenance staff. Some MRLSs require operators to set up pylons and gates manually. Others move concrete barriers using BTMs, which require significant daily maintenance and upkeep; especially as they age.

The capital cost for implementing moveable barriers can vary significantly based on the type of barrier required (curved versus straight); total project length (dictates number of machines required); and allowable time to complete the barrier shift (which also dictates the number of machines required). Each BTM ranges from \$1.4 million to \$1.6 million⁵, depending on the size (machine plus a storage facility), and each has a comfortable limit of ten linear barrier miles within a three-hour window (allowing for routine complications). The average cost to supply the barriers in place is an additional \$1.7 million per mile not including the machine or any changes required to the existing roadway. For instance, this cost does not account for any of the median barrier that may need to be removed or changes necessary to the light poles, overhead signs, drainage inlets, etc. Changes to the existing roadway must be determined on a case by case basis.

The capital cost for implementing moveable barriers can vary significantly based on the type of barrier required (curved versus straight); total project length (dictates number of machines required); and allowable time to complete the barrier shift (which also dictates the number of machines required).

The capital cost for one-mile of moveable barriers is \$3.20 million. However, the cost decreases per linear mile as the distance of the project increases due to the initial fixed cost of the BTM. The capital cost per linear mile could be reduced to \$1.85 million per mile up to 10 miles; however, if a project exceeds 10 miles in length, or if a quicker barrier shift window is necessary, an additional machine is necessary, which then will increase the cost.

In addition to the capital costs, there is an additional annual operating and maintenance cost of MRLSs that varies based on the distance of the project, average labor rate, number of operators and mechanics, length of shifts, days of the week in operation, number of barrier shifts, or moves, per day, and operating speed of the BTM. Furthermore, an average cost of \$100,000 per year⁶ can be assumed for consumables (diesel fuel, oil, filter, and conveyer wheels) and spare parts.

⁵ Barrier Systems, Inc.

⁶ Barrier Systems, Inc. (ranges from \$98,000 to \$119,000 per year over 10 years depending on which year given inflation at 1 percent per year).

REVERSIBLE LANES CASE STUDY

3.4 HYBRID REVERSIBLE LANES

Most often, permanent and moveable reversible lanes are implemented exclusively. However, there are some recent examples of emerging strategies that involve reversible lanes utilizing both permanent and moveable barriers in a reversible roadway segment. These emerging strategies employ a hybrid approach, allowing transportation operators to reverse one or more lanes within a section of permanent reversible lanes. An example of this reversible lanes hybrid approach using both permanent and moveable barriers is illustrated in Figure 3-10. On I-15 through San Diego, transportation officials have implemented reversible lanes that utilize both types of barriers within four reversible lanes; allowing operators to configure directional traffic within the roadway median based on peak period conditions. The hybrid approach is also being studied along I-394 in Minneapolis. Further detail on this approach is provided in Section 4.3.

Figure 3-10: Hybrid MRLS in San Diego



Source: San Diego Association of Governments (SANDAG)

4 U.S. CASE STUDIES

Many U.S. cities, including Atlanta, have used reversible lanes for decades. Many of the existing U.S. applications, however, have not been located on limited-access facilities. The case studies presented below provide detailed examples of several permanent and moveable reversible lane applications along limited access freeway facilities. Telephone interviews were conducted in the winter of 2013 with the following agencies to supplement the case studies:

- Minnesota DOT (I-394 PRLS in Minneapolis);
- Washington State DOT (I-5 PRLS in Seattle);
- Dallas Area Rapid Transit (I-30/Thornton Freeway MRLS in Dallas); and
- Massachusetts DOT (I-93 MRLS in Boston).

The following questions were asked of each agency and answers were provided when available:

- Please provide a brief description of your reversible lanes (e.g., length, operation times, moveable barrier, signage, tolls/cost, eligibility, unique characteristics). What type of corridor

REVERSIBLE LANES CASE STUDY

are they operating in (i.e. what are the characteristics of the non-reversible part of the corridor)?

- What was your reasoning for originally exploring a reversible concept?
- What was the total investment required to implement the reversible lane? What is the average annual operating and maintenance cost?
- Was this a shoulder conversion? Are you operating with full depth shoulders? If no, have you seen pavement degradation? What are your base layer depths?
- What types of vehicles are eligible to use the reversible lanes?
- How long do they stay closed while you reverse them?
- Who operates and/or maintains the reversible lanes; your agency or a contracted third party?
- Are any common maintenance issues associated with the reversible lanes? Specifically, are any maintenance issues associated with the barrier (moveable or permanent) or BTM?
- Have there been any safety issues associated with the reversible lanes? Has there been an increase in incidents? Do you have any analysis or data regarding their impacts on safety?
- How are incidents within the reversible lanes managed? What strategies do you employ to clear incidents quickly from the system (access from the opposite travel direction, barrier openings, etc.)?
- How are the reversible lanes enforced? Are there any plans for other types of enforcement strategies?
- What are the typical volumes of your reversible lanes?
- For moveable barriers, do you own or lease the equipment? What is your “rule of thumb” for how many transfer machines are needed? Where do you store the machines? How long does it take for the transfer machines to move the barriers?
- What were the challenges or issues associated with implementing the reversible lane(s)? How were they overcome? Would you implement the project in the same way again?
- Given these challenges, is your agency interested in implementing more reversible lane projects? If so, what are the lessons learned?
- What has been the response of the public? Was a large education effort needed? Did any policy issues arise? How were these overcome?

Answers to these questions, when available, are incorporated into each of the following case studies.

REVERSIBLE LANES CASE STUDY

4.1 PERMANENT REVERSIBLE LANES

PRLSs on freeways are currently in operation in over a dozen regions across the country. Below are case studies for the I-5 PRLS in Seattle and the I-394 PRLS in Minneapolis.

4.1.1 I-5 Reversible Express Lanes – Seattle, Washington

One of the earliest reversible lane studies was conducted by the Washington State Department of Transportation (WSDOT) in the 1960s to evaluate the feasibility of reversible lanes on I-5 in Seattle. The I-5 reversible express lanes shown in Figure 4-1 operate between downtown Seattle and Northgate, with direct connections to and from the I-5 mainline at each end. There are four lanes in the central portion, narrowing to one lane at the south end and two lanes at the north end. The express lanes generally operate 18 hours a day, seven days a week, southbound in the morning and northbound in the afternoon and are open to all traffic. However, some lanes and ramps are restricted to HOVs with two or more occupants. Figure 4-2 illustrates manually operated swing arm gates used to control access to the reversible lane facility in Seattle.

I-5 mainline lanes paralleling the express lanes are routinely congested for 12 hours on weekdays. It is

Figure 4-1: I-5 Reversible Express Lanes

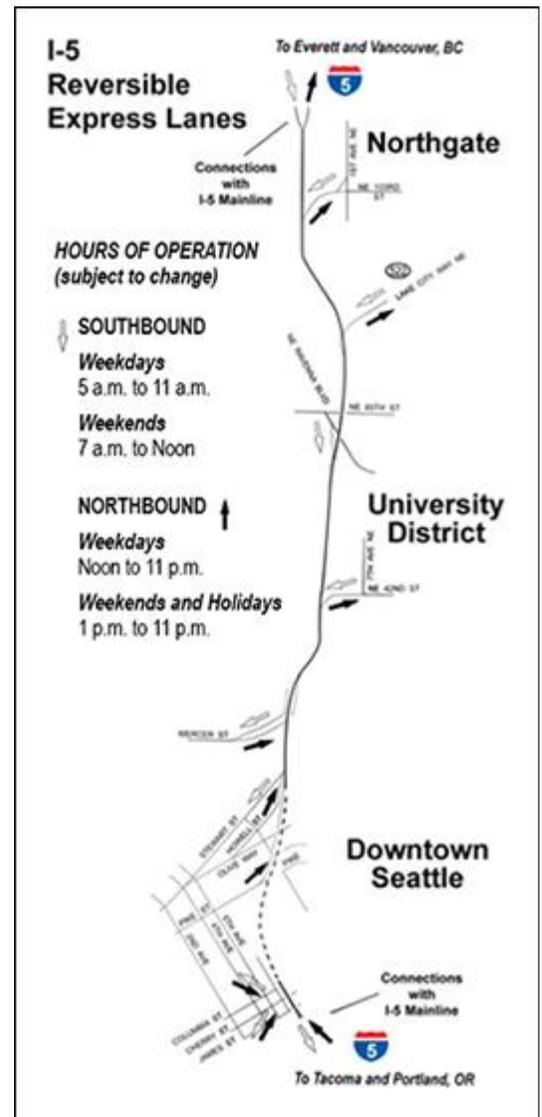


Figure 4-2: Manually Operated Swing Arm on I-5 Access Gates in Seattle



Source: FHWA Freeway Management and Operations Handbook

Source: FHWA Freeway Management and Operations Handbook

REVERSIBLE LANES CASE STUDY

not unusual for travel on the mainline in the opposite direction of the express lanes to take 30 minutes longer in the peak hour than under free-flowing off-peak conditions.

WSDOT is currently updating the I-5 reversible lanes with automatic access gates, allowing them to more quickly open and close access and reverse lanes during peak travel periods. The updating process is expected to be an ongoing process and gates will be replaced as funding becomes available.

Project Characteristics

- Built in 1960s in conjunction with I-5
- 7.5 miles
- Only transfer points are at each terminus
- Seven direct access interchanges with arterial streets
- Swing gates at each terminus
- Variable message signs on northbound segment
- Open to trucks
- Free to all vehicles

Project Performance and Operations

- Operated by WSDOT
- Recently began automating gates; one ramp/gate at a time
- Operates M-F:
 - 5 to 11 a.m. Southbound
 - 11:15 a.m. to 11 p.m. Northbound
- Operates Sat/Sun:
 - 8 a.m. to 1:30 p.m. Southbound
 - 1:45 to 11 p.m. Northbound
- No performance indicators available

Lessons Learned

- Automating the system has improved safety and relieved congestion (manually changing gates took over an hour)
- Sometimes buses use exclusive access ramps after the facility has been closed; clear signage is very important for transit safety

4.1.2 I-394 Reversible HOT2+ Lanes – Minneapolis, MN

The MnPass I-394 reversible HOT2+ lanes opened in May 2005 between State Route 100 and I-94 near Downtown Minneapolis. The project is a total 11 miles in length; eight of those 11 miles consist of one lane of traffic per direction separated by a buffer, with the three easternmost miles operating as two permanent reversible lanes. The goal of this project was to improve traffic flow and transit reliability.

Figure 4-3: MnPass Express Lanes on I-394 (Minneapolis)



Source: FHWA Freeway Management and Operations Handbook

REVERSIBLE LANES CASE STUDY

The two reversible lanes are located in the median that is separated from the eastbound and westbound lanes by a concrete barrier (Figure 4-3). This segment changes directions to accommodate the traffic flow at different times of day. In the morning, it is open to eastbound traffic traveling downtown, while it is open to westbound traffic in the evening. On weekends, the lanes may also be switched during special events to allow traffic to use the lanes when congestion occurs.

The Minnesota Department of Transportation (Mn/DOT) is currently investigating Phase 2 of the project on I-394, introducing two-way traffic within the 3-mile barrier separated HOT2+ reversible lanes. The new lanes would operate as a three-lane, two-way operation in which the middle lane would be reversible utilizing a moveable barrier system.

Mn/DOT continues to evaluate the potential of this project that would require significant modifications at system-to-system interchanges at each end of the 3-mile reversible segment.

Project Characteristics

- 2 reversible lanes
- 3-mile eastern segment of I-394
- Implemented in 2005
- HOV2+ toll free, SOV pays a toll
- Transit, vanpools, and motorcycles travel free
- Tolls by transponder only

Lessons Learned

- Engage the community in the process early
- Utilize knowledge gained from existing reversible lane facilities
- Enforcement of lanes has been easier than expected due to highway patrol transponder reader investment
- Quickly responding to problems as they arise is critical to achieving success

Project Performance and Operations

- Operated by Mn/DOT
- Eastbound from 6 to 10 a.m.
- Westbound from 2 to 7 p.m.
- Average variable toll between \$1 and \$4
- Lanes are open to the public on weekends and during non-peak hours
- Gates are operated automatically
- State troopers are equipped with transponder readers to aid in enforcement
 - \$1.6M annual revenue
- \$961k annual operating costs
- Reversible lanes accommodate approximately 1,500 vehicles per hour

REVERSIBLE LANES CASE STUDY

4.2 MOVEABLE REVERSIBLE LANES

Below are case studies for the I-30 MRLS in Dallas and the I-93 MRLS in Boston.

4.2.1 I-30 Thornton Freeway – Dallas, TX

The East RL Thornton Freeway, known as I-30, was completed in 1966. A reversible HOV lane was added in 1991. The corridor serves southern downtown Dallas, Fair Park and the White Rock Lake area. Congestion along this corridor occurs during both daily rush hour periods in the westbound direction. Congestion in the eastbound lanes occurs only during the evening peak period. Figure 4-4 illustrates the moveable barrier segment implemented on I-30, while Figure 4-5 illustrates the access points along I-30.

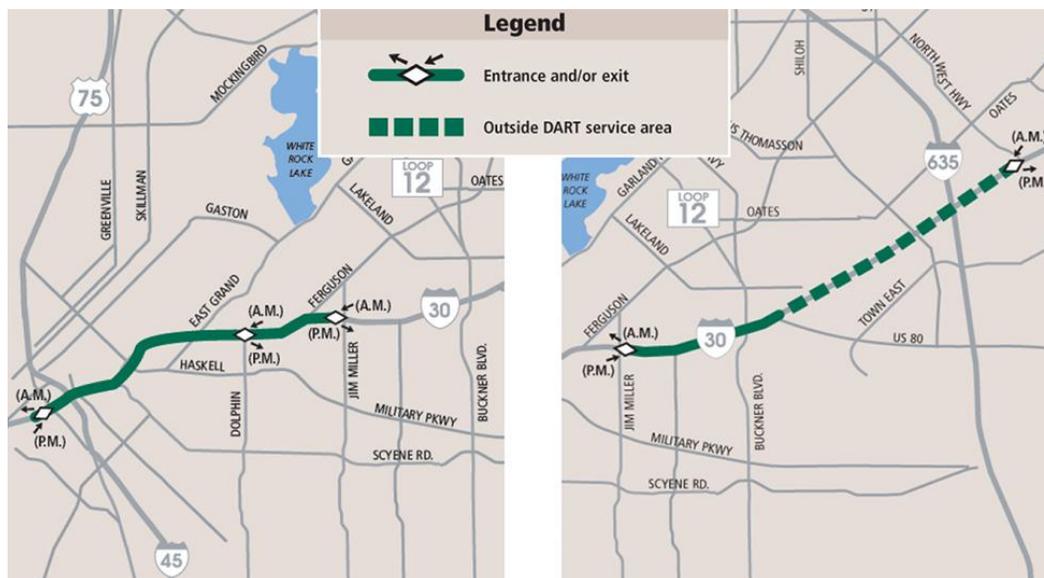
Figure 4-4: I-30 Reversible HOV Lanes



Source: Dallas Area Rapid Transit

East RL Thornton Freeway has a reversible HOV lane from downtown to Jim Miller Road. The HOV lane is created by moveable barriers taking excess capacity from the non-peak travel direction. The lane was extended to Northwest Highway in December 2007 as a buffer separated HOV lane. As of November 2010, the HOV lane carried 17,735 persons per day.

Figure 4-5: I-30 Reversible Lanes Map



Source: Dallas Area Rapid Transit

REVERSIBLE LANES CASE STUDY

Project Characteristics

- 8 miles
- 6-lane freeway
- Open from 6-10 a.m. and 3:30-7 p.m.
- 11-ft. lanes
- 4-ft. shoulder
- 1 lane lateral movement
- Manually close gates every day

Project Performance and Operations

- Operated by Dallas Area Rapid Transit (DART)
- Allows transit buses in lanes
- Enforcement zones to move wrecks quickly
- Store BTM in median on each end of facility with 4 storage barns (2 in middle and 1 at each end)
- Maintenance of machines can be significant, adding more machines to cover outages
- Average daily traffic: 148,200 vehicles
- 17,000 persons per day over 8 hour period
- Approx. 1,200-1,400 vph in HOV lanes
- Operation and maintenance cost \$80,000 per month including barrier moving machines
- HOV users save 9 minutes in the morning and 4.5 minutes in the evening
- Speeds increased by 86% from 22 to 41 mph

Lessons Learned

- Aggressive preventative maintenance on the BTMs is required to keep the equipment operational
- Dedicated enforcement is critical for managed lanes operations
- Faster speeds cause excessive wear and equipment breakdown of BTMs
- Adequate staffing for enforcement, managed lane operations, traffic incident management, field maintenance, and BTM maintenance is critical
- Backup BTMs should be seriously considered along with an inventory of spare parts
- Provisions should be made to deploy/utilize traffic control devices to enhance motorist safety during barrier transfer operations
- Procedural development and training is essential
- Extra caution is necessary during inclement weather scenarios
- Typical operating speed of the BTM is 5-6 mph; it takes 80 minutes to move 5 miles of barrier; DART's experience suggest it isn't worth the additional operating and maintenance cost to move any faster
- Guide wires buried in the pavement to assist with automating the transfer of barriers can complicate resurfacing projects
- Keeping a mechanic on staff to maintain vehicles is ideal
- Merging in to and out of the reversible lane at the beginning and end of the reversible segment can have a major impact on traffic operations if adequate distance to merge is not provided

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4.2.2 I-93 – Boston, MA

The Massachusetts Department of Transportation (MassDOT) operates the I-93 Southeast Expressway HOV lane, a 6-mile contraflow facility connecting Quincy and Boston. The HOV lane is based on a contraflow design, which borrows an underused off-peak direction lane and converts it to a peak-period direction HOV lane during periods of morning and afternoon congestion. The HOV lane is separated from oncoming traffic by a 6 mile flexible wall made up of moveable hinged concrete barriers, which are repositioned

twice each day. The moveable barrier system cost approximately \$10.3 million to install in 1995; each barrier transfer vehicle cost \$650,000. During the morning peak period (6 to 10 a.m.) the Southeast Expressway has five lanes (including one HOV lane) operating northbound, and three southbound general-purpose lanes. During the afternoon peak period (3 to 7 p.m.), the highway operates with five southbound lanes (including one HOV lane) and three northbound general-purpose lanes. Mass Highway opened the HOV lane in 1995. The eligibility requirement is two persons per vehicle. The HOV lane also incorporates an advanced transportation management system, whose principal components are a highway surveillance system (cameras, variable message signs, and volume and speed detectors), a communication link between the surveillance system and the centralized operations and information center, and a computer system to support a traffic operations center.

Two HOV lanes operate in the Boston metropolitan region: a reversible, barrier-separated lane on I-93/Southeast Expressway that connects downtown Boston and Route 3 at the Braintree split interchange; and a southbound, buffer-separated lane on I-93 North that approaches Boston from the north (Figure 4-6). MassDOT constructed these lanes to encourage ridesharing and to improve the flow of general-purpose traffic along the I-93 corridor.

Figure 4-6: I-93 Reversible Lane



Source: FHWA Freeway Management and Operations Handbook

REVERSIBLE LANES CASE STUDY

Project Characteristics

- 6-mile facility from Furnace Brook Parkway in Quincy to Freeport Street in Dorchester
- Vehicles must be less than 2.5 tons (most passenger cars) and have 2 or more occupants to use these lanes; motorcycles can use the lanes as well as buses
- Limited access points
- Enforcement and accident clearance areas provided with enforcement vehicles there during peak hours

Project Performance and Operations

- Operated by MassDOT
- Open Monday through Friday (except designated holidays), from 6 to 10 a.m. for northbound traffic and from 3 to 7 p.m. for southbound traffic
- No increase in accidents
- 5-7 minute travel time savings
- 120 buses per peak period
- Lane utilization is high (1,500-1,800 vph)
- Traffic flows at 55 mph posted speed
- Operation and maintenance costs approximately \$650,000 per year
- Currently using same two BTMs purchased in 1995 (18 years old) with no back-up machines

Lessons Learned

- Adequate capacity and smooth operations within the moveable barrier area is crucial, as it can dictate the capacity and quality of service conditions on the entire segment.
- Similarly, if there is a restriction at the outflow end of the MRLS segment, such as a lane drop merge, congestion will ultimately extend upstream into the MRLS segment, causing congestion and limiting the MRLS segment's effectiveness.
- Need at least four machines (two in each direction) and possibly six if the system is 16 miles due to the time it takes to transfer the moveable barriers.
- Need to include operation and maintenance costs in yearly cost considerations.
- Curves in the roadway require a higher cost moveable barrier that can accommodate the curve and should be included in the capital cost estimate and replacement costs.
- Storage and maintenance locations for machines should be identified and included in the cost.
- Partner with law enforcement and tow companies to monitor the area during open times to allow for quick closing, clearing, and reopening of the system due to accidents, events, etc.
- Determine locations for law enforcement and tow trucks to park for quick response to incidents.

REVERSIBLE LANES CASE STUDY

4.3 HYBRID APPROACH

4.3.1 I-15 Reversible Express Lanes – San Diego, CA

San Diego has implemented a “hybrid” approach to reversible lanes (similar to what is being studied on I-394 in Minneapolis). Permanent concrete barriers on I-15 separate the express lanes from the main freeway lanes, and entry and exit points allow vehicles to move between the express and general purpose lanes in 3-mile increments, as shown in Figure 4-8.

A unique element to the I-15 express lanes is the direct access ramps, shown in Figure 4-7. The ramps allow buses and HOVs to directly access the express lanes without yielding to traffic in the general purpose lanes. A moveable median barrier allows the number of express lanes to increase to three lanes in one direction for the 16-mile stretch where the barriers are located. This helps traffic flow during peak travel periods and to relieve congestion caused by traffic accidents and other incidents.

The total investment for the I-15 express lanes is estimated to be \$1.4 billion. The 8-mile-long middle segment of the project utilizes moveable barriers that extend the current reversible two-lane express lanes from State Route 56/Ted Williams Parkway to Del Lago.

Because lane configurations in the express lanes change based on congestion needs, advanced traffic control devices have been implemented on I-15. Devices such as innovative pop-up channelizers, in-pavement lighting, and variable toll message signs are expected to efficiently manage commuter traffic and ensure safety when using the new lanes. Pop-up channelizers guide traffic out of the new express lanes when traffic is moving in the opposite direction. Instead of painted stripes, in-pavement lighting delineates travel lanes where the existing express lanes transition to the new express lanes north of State Route 56. Variable

Figure 4-7: I-15 Project Map



Source: San Diego Association of Governments (SANDAG)

Figure 4-8: Direct Access Ramp on I-15



Source: SANDAG

REVERSIBLE LANES CASE STUDY

toll message signs, located at the express lane entrances, provide guidance to merge into the express lanes. These signs display toll rates and travel times to the nearest destinations.

Tolls for users will range from \$.50 to \$8 depending on the distance traveled, the time of day and the level of congestion in the express lanes. Tolls go up as congestion in the express lanes increases and are lowered when traffic volumes decrease.

Project Characteristics

- Dynamic pricing
- Open 24 hours/7 days a week
- No enforcement system
- VPD ranges from 197,000 to 312,000
- Use transponders to collect tolls

Lessons Learned

- Lessons learned are unknown at this time due to the recent implementation of this project

Project Performance and Operations

- Middle reversible segment is 8 miles long between State Routes 56 and 163, and uses a combination of permanent and moveable barriers
- More recent northern and southern reversible segments utilize permanent barriers extending 20 miles from State Route 163 to State Route 78 with the exception of the middle barrier
- Reversible lanes
- Free to transit, carpools, vanpools, motorcycles, and hybrid vehicles
- Operates as a HOT lane; FasTrak electronic toll for SOVs

5 LESSONS LEARNED AND BEST PRACTICES

As transportation professionals evaluate RLS operating alternatives, new implementation strategies emerge as the state of the practice. Agencies now recognize the importance of developing a vision and concept of operations early. However, it is important to recognize challenges and remain flexible. Consideration should be given to emerging operational strategies, such as limited access reversible lanes, hybrid approaches utilizing multiple barrier strategies, and signage and enforcement technologies to supplement these emerging techniques.

Many considerations must be addressed and decided upon as GDOT evaluates RLS applications. Front-end policy decisions will drive future design and operational elements of the network which will ultimately affect future mobility in the Atlanta region.

This document has evaluated some of the RLSs in operation today and outlined the variation between the strategies and characteristics that have led to their successful operation. The case studies presented in this document outline many successful models for reversible lane facilities.

REVERSIBLE LANES CASE STUDY

In summary, successful reversible lane projects typically:

- Evaluate the feasibility of reversible lanes first, including investigating available right-of-way, lane widths and bridge limitations;
- Develop a standard operating procedure (SOP) early outlining lane operation times, signage needs, access locations, barrier types, and enforcement/incident management response;
- Partner with law enforcement and tow companies to monitor lanes to allow for quick closing, clearing, and reopening of the system;
- Identify potential locations for implementation and ensure the general public understands the concept and operation;
- Develop a staffing plan for enforcement, managed lane operations, traffic incident management, and field maintenance; and
- Engage the community in the process early.

Specific to MRLSs, the following should be considered:

- Evaluate feasibility of MRLS first, including investigating directional traffic balance and BTM storage space;
- Budget for significant operation and maintenance costs, such as BTM spare parts and barrier replacement, as well as consumables and labor costs;
- Storage and maintenance locations for BTMs, as well as law enforcement and tow trucks should be identified and included in the cost;
- Curves in the roadway require a more expensive moveable barrier that can accommodate the curve and should be included in the capital cost estimate and replacement costs;
- Adequate staffing of operators and mechanics for BTM operation and maintenance is critical;
- Provisions should be made to deploy/utilize traffic control devices to enhance motorist safety during barrier transfer operations;
- Faster speeds cause excessive wear and equipment breakdown of BTMs; back-up machines and spare parts are necessary;
- Typical operating speed of the BTM is 5 to 6 mph; it takes 80 minutes to move 5 miles of barrier; DART's experience suggest it isn't worth the additional operating and maintenance cost to move any faster; and
- Guide wires buried in the pavement to assist with automating the transfer of barriers can complicate resurfacing projects.

REVERSIBLE LANES CASE STUDY

Specific to PRLSs, the following should be considered:

- Prepare for a potentially large capital investment for PRLS because it includes constructing a new lane as opposed to borrowing an existing lane; and
- Automating the system has improved safety and relieved congestion (manually changing gates took longer than an hour).

6 CONCLUSIONS

Reversible lanes that utilize permanent or moveable barriers provide flexibility in supplying highway capacity by realigning or reversing existing road space to better serve peak-period traffic demand. In addition, reversible lanes enhance the level of service provided to roadway users without having to build any additional lanes.

There are some general advantages and disadvantages that apply to all RLSs. Generally, it is difficult to develop a clear comparison of permanent and moveable barriers because each can have significant benefits in certain applications depending on project length, available right-of-way, existing pavement surface, and peak period congestion profile. Both permanent and moveable barrier options can result in similar impacts associated with the potential need to repave shoulders to allow vehicle use, remove bridge structures from the center median, and maintain adequate shoulder and lane widths. However, PRLSs may require significantly higher capital costs, due to the fact that they often require the development of entirely new pavement surfaces in the median of an existing freeway, whereas MRLSs typically operate on existing pavement borrowed from lanes in the opposite direction. One disadvantage of RLSs, regardless of the type of barrier, is the ongoing cost of daily surveillance and lane/ramp reversal activities. RLSs also must be designed to prevent wrong way movements, requiring extensive intelligent transportation systems (ITS) and traffic control devices for each access point. RLSs also require additional staff to visually inspect the roadway prior to each opening period to ensure a safe operation.

There are several key advantages and disadvantages of using permanent versus moveable barriers (outlined in Table 6-1); and it is important to understand these differences before either are considered for implementation.

REVERSIBLE LANES CASE STUDY

Table 6-1: Advantages and Disadvantages of Permanent vs. Moveable Barriers

	Permanent Barrier	Moveable Barrier
Advantages	<ul style="list-style-type: none"> • Lower operations and maintenance costs (since do not have to deploy a BTM, replace barriers as often, etc.) • Typically open throughout the day 	<ul style="list-style-type: none"> • Lower capital costs (since borrowing an existing lane from the opposite direction) • Good option with limited right-of-way (since not significantly expanding the footprint of the existing pavement) • Moveable barriers can be implemented in a fraction of the time (due to the engineering costs and time needed to build a permanent reversible facility in the median of an existing segment) • Opportunity for borrowing underutilized capacity from the opposite direction during peak periods
Disadvantages	<ul style="list-style-type: none"> • Higher capital costs (since constructing a new lane in the median) • Difficult to modify access locations once the permanent barriers are in place • May require significant right-of-way (since expanding the footprint of existing pavement) 	<ul style="list-style-type: none"> • Higher operation and maintenance costs (due to deployment of BTMs, more frequent replacement of barriers, etc.) • Only open during peak periods (due to time necessary to transfer the barriers) • May impact traffic in opposite direction, but net benefit • Higher need for driver education • Takes much longer to reverse lanes (due to deployment of a BTM versus opening and closing gates) • Difficult to deploy during inclement weather • Aggressive maintenance is required for BTMs

REVERSIBLE LANES CASE STUDY

This case study review of reversible lanes identified many facts, issues, and needs related to the implementation of permanent and/or moveable barriers to separate RLSs. It is clear that there are some similarities between the separation techniques, and their use should not be considered mutually exclusive. Of the locations reviewed as part of this case study, no two are exactly alike in their basic operations, design, and access control features. There are a variety of uses for RLSs, including managed lanes, construction zones, evacuation routes, and for special events. There are also some clear differences between permanent and moveable separation strategies, especially when considering capital, and operation and maintenance costs, ROW availability, and implementation timeframes.

These studies have indicated that RLSs should be considered on freeways on which volumes are at or near capacity, with predictable demand or congestion patterns; with limited (or limited ability to acquire) right-of-way to construct additional lanes; and a directional volume imbalance of approximately 65 percent to 35 percent, depending on the number of lanes.

Research shows that RLSs have been a transportation strategy for approximately 85 years, and nearly every large city and many small to medium sized cities across the U.S. have studied reversible lanes at some time.⁷

Furthermore, research suggests that RLS operations are generally safe, efficient, and readily accepted by users.⁸ However, many transportation agencies have been hesitant to implement reversible lanes due to cost, safety concerns, and user familiarity.

This case study review showed that costs for RLSs are largely based on the infrastructure that has to be negotiated such as bridge pilings, drainage grates, and roadside signage. Several of the case study locations presented in this document (Minneapolis, Denver, and San Diego) were cost effective because the entire freeway was reconstructed at the same time. The performance of many applications hasn't yet been quantitatively evaluated and although some literature is available, their results (volume, travel time, and safety) are not concretely presented; especially for freeway applications. In addition, AASHTO does not provide specific design criteria for installation of a RLS (it suggests that reversible lanes should be designed as a normal travel lane).⁹ Therefore, design exceptions may be necessary on a case-by-case basis.

⁷ "NCHRP Synthesis 340- – Convertible Roadways and Lanes: A Synthesis of Highway Practice," 2004.

⁸ Wolshon, Brian; Lambert, Laurence. "Reversible Lane Systems: Synthesis of Practice," Journal of Transportation Engineering, American Society of Civil Engineers (ASCE), December 2006.

⁹ "NCHRP Synthesis 340- – Convertible Roadways and Lanes: A Synthesis of Highway Practice," 2004.