MULTIMODAL OPTIMIZATION OF URBAN FREEWAY CORRIDORS

Final Report 582

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16. Abstract

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The SR 51 case study relied on existing data, modeled situations, and cost estimates to determine the most cost effective choice for multi-modal travel. Existing volume data was provided by Arizona Department of Transportation's Freeway Management System (FMS) and supplemented by a micro-simulation study previously conducted for the Arizona Department of Transportation (AzDOT) concerning the operations of the existing HOV lanes. Cost data was coalesced from literature review material and transportation data sources exclusive to Arizona. The computations factored in traffic flows under different freeway scenarios depicting different forms of multi-modal travel that would be reasonable for the SR 51 freeway. The results, ranked from most cost-effective to least cost-effective, are as follows (Note: "GP" refers to general purpose lane, and the ranges of cost values are due to different calculation methods for the projected volume by mode):

1. HOT Lane ($0.012 to $0.027 per person-mile)
2. Fourth GP Lane ($0.019 to $0.042 per person-mile)
3. HOV (w/BRT) Lane ($0.026 to $0.057 per person-mile) (existing condition)
4. Exclusive BRT Lane ($0.066 to $0.147 per person-mile)
5. Light Rail Transit ($0.161 to $0.358 per person-mile)

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	square meters	1.195	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")	mg (or "t")	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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GLOSSARY OF ACRONYMS

ATRC	Arizona Transportation Research Center
AzDOT	Arizona Department of Transportation
BRT	bus rapid transit
DOT	Department of Transportation
FHWA	Federal Highway Administration
FMS	Freeway Management System
GP	general purpose
GRTA	Georgia Regional Transportation Authority
HOT	high occupancy/toll
HOV	high occupancy vehicle
HRT	heavy rail transit
ITE	Institute of Transportation Engineers
LRT	light rail transit
MAG	Maricopa Association of Governments
MAX	Portland, Oregon's light rail system
MPH	miles per hour
NC	North Carolina
NB	north bound
NEPA	National Environmental Protection Act
ODOT	Oregon Department of Transportation
PPTA	public/private partnership
RAP	Reasonable Alternative Packages
SB	south bound
SOV	single occupant vehicle
SR	State Route
TAC	technical advisory committee
VDOT	Virginia Department of Transportation
VPH	vehicles per hour
VPHPL	vehicles per hour per lane
VRE	Virginia Railway Express
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

INTRODUCTION

The following chapters that comprise this research report present data and discussions concerning multi-modal applications on urban highways. The investigation was concerned with approaches to implementing multi-modal transportation from the perspective of state officials. Therefore, other states were contacted and surveyed in order to better understand how Arizona might utilize multi-modal travel in the future. The information gathered was then used to conduct a case study specific to Arizona in order to show the relative impacts and costs of plausible options for multimodal use of a freeway corridor.

What Is the Purpose of This Study

Although the scope and budget of this study did not allow for extensive research and investigation into multi-modal applications, its discussion and findings are intended to highlight the importance of selecting and supporting cost-effective multi-modal forms of travel within freeway corridors.

How This Study Was Conducted

The study consisted of three main tasks, which included a literature review/exploration of other states' use of multi-modal forms, a survey of other state departments of transportation, and an Arizona-specific case study to reveal some of the particulars that should be considered in the decision process for implementing multi-modal travel.

The literature review, as presented in Chapter 1, investigates and presents various examples of multi-modal applications used by various departments of transportation, cities, and transportation authorities. A secondary objective of this chapter is to discover any other projects, on a national scope, that may provide data or conclusions relating to the overall purpose of this research project.

The survey of other state departments of transportation, presented as Chapter 2, focuses on how other states decide what forms of multi-modal travel to support and implement. In the process, many of the multi-modal forms used (or that are planned for use) in other states were conveyed. The effectiveness of certain forms of multi-modal travel was related by some of the departments that were surveyed. Generally, the states that responded to the survey did not cite a specific decision-making process or criteria that they relied on to determine implementations of multi-modal travel.

Chapter 3 of this study contains a case study of the multi-modal implementation along State Route (SR) 51 in Phoenix, Arizona. The point of the exercise is to show the various factors that should be considered when deciding what form of multi-modal travel would be best for a particular corridor. Although the ultimate modal decision for the case study is of interest, the aspects that had to be considered in the process should be meaningful as well.

STUDY FINDINGS

The findings of the study are two-fold: the results of what forms of multi-modal travel are used by other states and the results of the case study. Many states employ or are planning high occupancy vehicle (HOV) lanes (of all forms/types, but primarily of the concurrent flow variety) for use in urban freeway settings. High occupancy/toll (HOT) lanes were in the planning stages according to about half of the survey respondents while bus rapid transit (BRT) was being considered by two-thirds of the departments responding. Light rail transit (LRT) was only listed in 33% of the responses as being currently in use. HOT Lanes, Exclusive-Use Lanes, By-pass/Separation Lanes, Dual Facilities, and LRT had the highest number of responses for not being used as a multi-modal application within a freeway corridor.

The SR 51 case study relied on existing data, modeled situations, and cost estimates to determine the most cost effective choice for multi-modal travel. Existing volume data was provided by Arizona Department of Transportation's Freeway Management System (FMS) and supplemented by a micro-simulation study previously conducted for AzDOT concerning the operations of the existing HOV lanes. Cost data was coalesced from literature review material and transportation data sources exclusive to Arizona. The computations factored in traffic flows under different freeway scenarios depicting different forms of multi-modal travel that would be reasonable for the SR 51 freeway. The basis of comparison was the cost per person-mile of travel for each alternative. The costs included capital, operating and maintenance costs for each alternative. If revenues were earned (as was the case for the BRT, LRT, and HOT alternatives) these were used to offset costs. These costs for each alternative were then divided by the forecast number of passenger-miles for each alternative. The end result is a "common denominator" that informs decision makers of the cost per unit of transportation benefit. The results, ranked from most cost-effective to least cost-effective, are as follows (note: "GP" refers to general purpose lane, and the ranges of cost values are due to different calculation methods for the projected volume by mode):

1. HOT Lane ($0.012 to $0.027 per person-mile)
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RECOMMENDATION

In the course of investigating multi-modal applications within other states and how they might operate in Arizona (per the SR 51 case study), it seems that HOT lanes would offer the most cost-effective means of maximizing travel via multiple forms of transportation within an urban freeway corridor. Moreover, BRT could use the HOT lanes thereby multiplying the benefit of the lanes, much as they are able to do currently with the HOV lanes in place throughout the Phoenix metropolitan area. The revenue generated by HOT lane tolls would also contribute to the state's ability to expand HOT facilities and, thereby, enhance the opportunities for BRT utilization.

CHAPTER 1: EXAMPLES OF MULTI-MODAL APPLICATIONS ON URBAN FREEWAY CORRIDORS

INTRODUCTION

The purpose of this chapter is to investigate and present various examples of multi-modal applications used by various departments of transportation/cities/authorities (hereafter referred to as "agencies"). A secondary objective is to investigate any other projects, on a national scope, that may provide data or conclusions relating to the overall purpose of this research project. Descriptions and details contained below serve as the foundation for the development and distribution of specific surveys to agencies whose facilities are discussed herein and that would be particularly suited to Arizona.

In order to discuss the various applications of multi-modal uses on freeway corridors, an explanation of the various types of modes possible is necessary. Based on research for this project, additional modes of travel that can be accommodated in freeway corridors usually fall into one of two general categories. The first encompasses a wide variety of applications under what is increasing being called "managed lanes." The second category contains applications relating to rail, with light rail being the primary mode. A potential third category is bus rapid transit (BRT) routes, although this mode of travel relies on the managed lane strategy of high occupancy vehicle (HOV) facilities.

MODES OF TRAVEL

Managed Lanes

Along a freeway corridor, the pervasive mode of travel is the personal vehicle. Moreover, most vehicles are single occupancy vehicles (SOVs). Current trends in traffic growth are generating new approaches to accommodating freeway traffic during the peak periods. Increasing freeway capacities through additional travel lanes is becoming less reliable due to costs, land preservation, community impacts, and environmental issues[1]. A managed lane is a newly coined term for a "facility that increases freeway efficiency by packaging various operational and design actions"[2] — the implementation of which offers an alternative approach to adding new general use lanes.

Managed lanes include several applications that introduce multi-modal travel on a freeway corridor. The following terms for the various applications will be discussed in this study:

- HOV Lanes
- Value-Priced Lanes and HOT Lanes
- Exclusive Lanes
- Separation and Bypass Lanes
- Dual Facilities

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[1] Texas Transportation Institute. *Managed Lanes: Current State-of-the-Practice for Managed Lanes Transportation System.* College Station, TX, 2002, p. 1.
[2] *Ibid, p.1.*

HOV Lanes
Probably the most widely used and recognized form of managed lanes are HOV lanes. This form of managed lanes was first introduced in the Washington D.C./northern Virginia area in 1969[3]. A lane is considered an HOV lane when it is restricted to vehicles with a specified occupancy. In the Phoenix area, HOV lanes are used on a large portion of the urban freeway corridors and are further distinguished in that they also allow alternative fuel vehicles (regardless of occupancy) to use the HOV facilities. There are three types of HOV lanes that can be implemented as part of freeway corridors: separated roadway, concurrent flow lanes, and contraflow lanes. The separated type of facility can be further designed to accommodate two-way traffic or reversible flow.

1) Separated HOV Lanes
These HOV lanes are physically separated from the other freeway lanes ("general use") by some type of barrier (usually concrete) or wide striped area. Two-way separated HOV lanes usually have one lane for each direction of travel and often have limited access with some exhibiting direct entry and exit points[4]. A reversible flow HOV lane is the most common type of separated HOV facility. The direction of travel on the lane or lanes is dependent on the time of day.

2) Concurrent Flow HOV Lanes
This type of HOV lane is the most common type of HOV facility and is sometimes referred to as a "diamond" lane[5]. The lane designated for use is usually the inside lane (the one closest to the centerline of the freeway) and is typically distinguished by in-lane markings (e.g., diamonds) and a wider-than-average striping to buffer the lane from the general-use lanes.

3) Contraflow HOV Lanes
These facilities are usually one lane that is common between both directions of travel on the freeway, but due to the presence of some type of changeable or movable barrier (a "zipper" barrier is sometimes used) the lane can be configured to be used by only one direction of travel depending on the time of day. An example would be an inbound lane to a downtown area being used for outbound travel during the afternoon peak period.

Value-Priced Lanes and HOT Lanes
A HOT lane (also called value-priced) is related to HOV lanes in that their primary purpose is to convey multi-passenger vehicles in exclusive lanes. However, the difference lies in the fact that the lanes can also accommodate SOVs if these vehicles choose to pay a toll to use the lane. The impetus behind HOT lanes is to increase the efficiency of HOV lanes that are not being fully utilized during a peak period by selling the available capacity to SOV vehicles.

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[3] *Ibid, p. 2.*
[4] *Ibid, p. 2.*
[5] *Ibid, p. 2.*

A study conducted by a consulting firm for Colorado Department of Transportation concluded that the following criteria should be established in order for a HOT lane to be successful:

- HOT lanes should be incorporated into an existing or planned HOV system.
- Congestion along the proposed HOT lane designated area must be recurring since this will enable SOV drivers to avoid the congestion on a regular basis by paying the toll.
- HOT lanes should not be established if it will require the conversion of a general use lane to a HOV/HOT lane designation.
- HOT lanes are not self-supporting.[6]

Since HOT lanes relieve the restriction placed on HOV lanes, its toll pricing must be closely monitored so as not to overburden the HOV lane. Usually this is accomplished through dynamic toll pricing, which can vary the toll to use the HOV lane(s) based on the congestion or time of day. Increased toll prices introduced as HOV/HOT demand increases will thereby curb the number of SOV motorists desiring to the use the HOT lane.

Exclusive Lanes

Although HOV/HOT lanes could be considered a subset of exclusive lanes, the context in which exclusive lanes are presented in this report pertains to the designation of the lane for specific vehicle type use—typically buses and trucks. An exclusive lane for buses may be targeted in an attempt to increase ridership by touting the decreased delay. Trucks on the other hand may be afforded an exclusive lane as a means of increasing safety, efficiency, and for environmental reasons.

1) Exclusive Busways

These facilities usually are separated roadways/lanes in freeway applications that are only for buses. Some agencies have considered busways as a cost-effective alternative to either subways or light rail lines[7].

2) Exclusive Truck Lanes

These are similar facilities to busways although are for truck use only. Various feasibility studies have concluded that a separated exclusive truck facility could be considered when truck volumes exceed 30% of the vehicle mix, peak hour volumes exceed 1,800 vehicles per lane-hour, and off-peak volumes exceed 1,200 vehicles per lane-hour[8]. Some of the potential benefits from an exclusive truck lane would be uninterrupted flow conditions for trucks which would in turn reduce emissions and fuel consumption when compared to their operation in congested conditions on the general-use lanes.

[6] *Ibid, p.3.*
[7] *Ibid, p.4.*
[8] *Ibid, p. 5.*

Separation and Bypass Lanes
This application is confined to select areas of a freeway corridor where weaving, significant grades, high truck percentage, and/or heavy congestion are present. The separation lane allows specific motorists to bypass the particular area if they have no need of interacting with it. Commonly, the separation/bypass lane is used by trucks in order to avoid weaving, merging, and congestion associated with a freeway interchange area thereby allowing them to disengage from the vehicle interactions and re-enter the general-use lanes downstream from the increased activity. Other vehicles not needing to utilize the interchange can also use the bypass lane.

Dual Facilities
Roadways that employ this type of managed lanes (also called "dual-dual" segments of a freeway) are few since it requires considerable right-of-way to enable separated multi-lane facilities in both directions along a freeway corridor. The separations are usually "inner" and "outer" roadways where typically the "inner" roadway (closest to the center) is reserved for light vehicles while the outer roadway is open to all vehicles[9]. Vehicles traveling in the inner roadway are usually physically separated from the outer roadway meaning their access to some exits may be restricted thus requiring a transition to the outer roadway in advance of reaching their desired exit.

Rail
In some cities/states, a portion of the freeway corridor is used to accommodate a rail line for use by subways and light rail cars. This can be particularly advantageous if the freeway cross-section is sufficient to support the introduction of the rail line in the median or is cost-effective when compared to right-of-way acquisition adjacent to the freeway corridor. Typically, the rail lines will only run within the median of the freeway for a portion of the total freeway route due to complications with existing interchanges and limited possibilities for passenger stops/stations.

Bus Rapid Transit (BRT)
Bus Rapid Transit is another means of optimizing the use of a freeway corridor in conjunction with available HOV lanes. This application would differ from busways in that the BRT buses would be taking advantage of its ridership in order to use existing HOV lanes. These routes typically provide service with limited or no intermediate stops.

EXAMPLES OF APPLICATIONS

Approach
The following section will summarize some existing applications of multi-modal optimization along a freeway corridor through the use of managed lane concepts and rail accommodations. The locations and agency in charge of these facilities will serve as the backbone for the further investigation through the survey to be developed and distributed amongst the various agencies. This list is not meant to be exhaustive, and there is certainly the possibility that other locations/situations will become apparent in the course of the study that will merit inclusion in the survey. The summaries are arranged by

[9] *Ibid, p. 6.*

multi-modal application. Most of the information is from the Federal Highway Administration (FHWA) website for their "HOV Pooled-Fund Study"[10]. The detailed listings by facility type are included in the appendix.

Existing Separated HOV Lanes

Two-Way Operations

There are only a few existing locations/facilities that use barrier-separated HOV lanes providing two-way travel. The locations are all less than 5 miles in length and are located in Los Angeles, California (I-10, San Bernardino Freeway); Orange County, California (I-5); Houston, Texas (I-610/US 290); and Seattle, Washington (I-90).

Reversible Flow

These type of HOV lanes are a little more widely used that the barrier-separated two-way flow lanes. Locations where these facilities are in use include: Denver, Colorado (US 36 & I-25); Minneapolis, Minnesota (I-394); Pittsburgh, Pennsylvania (I-279/579); Dallas, Texas (I-35E); Houston, Texas (I-45 & US 59); Northern Virginia (I-95); Norfolk, Virginia (I-64); and Seattle, Washington (I-5 & I-90).

Existing Concurrent Flow HOV Lanes

This type of HOV facility is by far the most widely used based on the relative ease in implementation. Most of the facilities have a buffer area between the HOV lane and the general purpose lane. California has the greatest amount of these facilities (about 45 separate route sections) with most in Los Angeles County (about 170+ route-miles). Most of the facilities have one lane available in each direction and require at least a 2+ HOV designation. In North America, the concurrent flow HOV lanes are used in 19 states and 2 Canadian provinces.

Existing Contraflow HOV Lanes

These type of HOV lanes are only used in a select number of locations, presumably because right-of-way and/or available freeway cross-section is not available to implement more than just one new HOV lane. Examples of these facilities are in Honolulu, Hawaii; New Jersey; New York City; Dallas, Texas; Boston, Massachusetts; and Montreal, Quebec in Canada.

Existing HOT Lanes

There are relatively few of these facilities, but there are feasibility studies being conducted in nine states as well as other countries already using them (France, Norway, Singapore, Canada, Germany, South Korea, Hong Kong). San Diego has a HOV/HOT lane facility (single occupant vehicles are required to pay a toll) implemented on I-15 with two reversible lanes along a 9.8 mile route. There is a 16-mile route along the I-10/Katy Freeway in Houston that has one lane devoted to HOV/HOT users where vehicles with one or two passengers are required to pay a toll for use of the lane in peak hours (off-peak hours only require 2+ HOV). Similar parameters are in effect on the US

[10] Federal Highway Administration website: http://hovpfs.ops.fhwa.dot.gov/inventory/inventory.cfm. *HOV Pooled-Fund Study*. Website last accessed February/March 2005.

290 route (13.5 miles) in Houston as well. Orange County, California has HOV/HOT lanes established on SR 91 for 10.1 miles with two lanes in each direction.

Busways

Busways seem to be more popular in other countries rather than the U.S. where only a few facilities exist. The East Patway, South Patway, and Airport Busway in Pittsburgh (about 15 route miles) represent the most extensive use of the facilities in the U.S. Miami and Seattle also have busways in use.

Truckways

According to Reich, *et al*[11], very few truly exclusive truck facilities on highways were found to exist in the U.S. There are some applications where trucks have the exclusive use of a certain roadway for a limited range. In these cases, the facilities were usually associated with special trucking uses like port-related freight or border crossings. Feasibility studies for truckways have been conducted in Virginia, California, and in Europe[12].

Separation/Bypass Lanes

Although these types of facilities are on the fringe of being considering multi-modal optimization techniques, they do offer opportunities to separate out different vehicle types (namely trucks and passenger vehicles), which can assist in the operational efficiency of the particular freeway section. Bypass lanes are in place for trucks (although passenger vehicles can use them as well) on I-5 in Portland, and on I-5 in the Los Angeles area associated with three heavily-used interchanges. There is also another application at Route 99 near Grapevine and at the interchange of Route 110 and I-405 in California[13].

Dual Facilities

The primary example of this type of freeway optimization through lane management is the New Jersey Turnpike. For a 35-mile segment, the interior lanes are available only to passenger cars while the exterior lanes are for a mixture of trucks, buses, and cars[14].

Rail

This listing of examples is focused on applications of rail lines being integrated in the freeway cross-section. It is not a comprehensive listing of all rail systems (existing and planned) in the U.S., although this information is available and will be used to ascertain whether other systems currently or plan to rely on freeway corridor integration:

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[11] Reich, Stephen L., Janet L. Davis, Anthony J. Ferraro and Martin Catala. *Exclusive Facilities for Trucks in Florida: An Investigation of the Potential for Reserved Truck Lanes and Truckways on the State Highway System.* Center for Urban Transportation Research, University of South Florida. Tampa, FL, July 2003, p. 3.

[12] Texas Transportation Institute. *Managed Lanes: Current State-of-the-Practice for Managed Lanes Transportation System.* College Station, TX, 2002, p. 5.

[13] *Ibid, p. 6.*

[14] *Ibid, p. 6.*

- In Portland, Oregon, the MAX light rail line has a couple of examples where light rail routes are part of the freeway corridor, both at-grade and elevated and within the median and to the side of the travel way. Some of this routing along I-205 is possible based on an existing transitway that was created when the freeway was constructed and is located off to one side of the freeway lanes but within the freeway right-of-way corridor[15]. A different route has elevated segments that are located in the freeway median and include an elevated station with pedestrian connection to a park-and-ride lot.

- The Metro subway in Washington DC has a rather lengthy segment of one of its routes that travels in the median of I-66 from central Washington out to the western suburbs.

- The Santa Clara Valley light rail utilizes the median of freeways for portions of its line, with maximum speeds of 55 mph[16].

- There are some sections of freeway in the San Francisco Bay area that have rail lines positioned in the median of the freeway.

- The light rail line along I-105 in the Los Angeles area runs in the median (with periodic stations) between I-605 and the Los Angeles Airport[17].

The following list represents current and planned light rail systems that will be included in the survey portion of this project[18]:

Existing	*Planned/Proposed*
Baltimore, MD	Albuquerque, NM
Boston, MA	Aspen, CO
Buffalo, NY	Atlanta, GA
Cleveland, OH	Austin, TX
Dallas, TX	Bangor, ME
Denver, CO	Birmingham, AL
Houston, TX	Charleston, SC
Los Angeles, CA	Charlotte, NC
Minneapolis, MN	Chicago, IL
Newark, NJ	Cincinnati, OH
Philadelphia, PA	Columbus, OH

[15] Tri-Met website: http://www.trimet.org/i205/index.htm. *I-205 Light Rail Project.* Website last accessed February/March 2005.

[16] Santa Clara Valley Transit Authority website: http://www.vta.org/services/light_rail_overview.html. *Light Rail Service Overview.* Website last accessed February/March 2005.

[17] Roads to the Future website: http://www.roadstothefuture.com/I-105_Century_Fwy.html. *I-105 Glenn Anderson Freeway (Century Freeway).* Website last accessed February/March 2005

[18] American Public Transportation Association website: http://www.apta.com/links/transit_by_mode/lightrail.cfm. *U.S. Light Rail Transit System Links.* Website last accessed February/March 2005.

Portland, OR
Sacramento, CA
St. Louis, MO
Salt Lake City, UT
San Diego, CA
San Francisco, CA
San Jose, CA
Tacoma, WA

Corpus Christi, TX
Detroit, MI
El Paso, TX
Fort Worth, TX
Grand Canyon, AZ
Jacksonville, FL
Louisville, CA
Madison, WI
Miami, FL
Milwaukee, WI
New York, NY
Norfolk, VA
Oceanside, CA
Orange County, CA
Orlando, FL
Phoenix, AZ
Raleigh, NC
Richmond, VA
Rochester, NY
San Antonio, TX
Seattle, WA
Spokane, WA
Tampa, FL
Tucson, AZ
Washington, DC

Bus Rapid Transit (BRT)
There are existing, demonstrational, and planned BRT uses in the following locations: Albany, Alameda County (California), Boston, Charlotte, Chicago, Cleveland, Eugene (Oregon), Hartford, Honolulu, Kansas City, Las Vegas, Los Angeles, Louisville, Miami, Minneapolis/St.Paul, Montgomery County (Maryland), Northern Virginia, Phoenix, Pittsburgh, San Juan (Puerto Rico), Santa Clara (California), Seattle, and Virginia Beach.[19,20]

RESEARCH ON PAST PROJECTS CONCERNING MULTI-MODAL CHOICES AND EFFECTIVENESS

Since one of the overall objectives of this research project is to collect and evaluate data pertaining to agency choices concerning multi-modal options and the resulting effectiveness, it was important to determine whether any other such projects had already

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[19] Federal Transit Administration website: http://www.fta.dot.gov/initiatives_tech_assistance/technology/brt/projects/2404_ENG_HTML.htm. *Bus Rapid Transit Overview.* Website last accessed February/March 2005.

[20] Metro Magazine (Bus Rapid Transit) website: http://www.metro-magazine.com/t_brt_home.cfm. *BRT Projects.* Website last accessed February/March 2005.

been conducted. Moreover, this literature review research would be interested in finding any actual data from multi-modal options, especially in a comparative context between the various modes. This section of the chapter will document the research conducted with this intent.

In addition to the literature sources used to present the above discussion of multi-modal examples, some 15 more documents were obtained in an effort to ascertain whether any past projects, nationwide, concerned measures of effectiveness comparisons between multi-modal options and how agencies select which mode to implement.

Selecting the Mode for Multi-Modal Implementation

Although the literature research did not yield any specific project reports/results dealing with the choices agencies are faced with when planning for and implementing multi-modal systems, there were some situations referred to in the various sources obtained for this project. The 11th International Conference on High-Occupancy Vehicle Proceedings[21] provided a few pieces of information that hint at the choices that agencies are faced with when considering multi-modal applications. Dave Schumacher from the San Diego Metropolitan Transit Development Board presented information concerning BRT and commented that when the planning process began, most of the public preferred LRT over BRT for the particular I-15 corridor. However, as the information concerning BRT circulated, more and more people began to favor BRT. Mr. Schumacher elaborated on the agency's decision favoring BRT over LRT for the corridor by citing the pre-existence of a successful commuter express bus service; noting the need for short-term and long-term improvements to the system; the suburban land uses are more conducive to BRT operations; and because light rail would require separate right-of-way (and thus increase capital costs) since they were not open to the idea of converting the present use of the existing HOV lanes. In the end, LRT was retained as a long-term solution in favor of HOV/BRT for the short and mid-terms and because they area perceived as more representative of a multi-modal solution. Another speaker at the same conference confirmed that officials in Toronto are coming to the same conclusion—that BRT is preferable mode since it can make use of existing HOV lanes in the near-term while working towards a bus-only busway system across the city.

A similar pitting of LRT against other modes of transit/managed lanes was presented in a Texas Department of Transportation document titled "Marketing the Managed Lanes Concept"[22]. The report mentions the Minnesota Department of Transportation experience with the public perception of LRT. In their case the public, in the form of focus groups, were presented with problems, the alternatives being considered, and HOT lanes as the solution. The focus groups generally saw the HOT lanes as a short-lived solution, instead favoring LRT as a long-term solution to congestion. These same sentiments were voiced through supplemental interviews with businesses, land-use organizations, and minorities.

[21] Federal Highway Administration. *11th International Conference on High-Occupancy Vehicle Systems – Conference Proceedings.* Seattle, WA, October 2002, p. 34.

[22] Collier, Tina and Ginger Daniels Goodin. *Marketing the Managed Lanes Concept.* Texas Transportation Institute. College Station, TX, January-April 2002, p. 19.

The same report also presents results from a survey sponsored by the Washington State Department of Transportation. The survey was directed to 1,200 residents along the I-405 corridor and focused on their opinions of how congestion should be addressed. The respondents indicated that a mixed-mode solution would be best with the following break-downs: 85% in favor of expanding bus service; 86% supporting person-trip reduction efforts; 76% wanting more general-purpose lanes; and 71% supporting a high-capacity transit system. The survey also indicated that residents would likely not be in favor of HOT lanes since they either disagreed with SOVs being charged a fee to use the HOV lane or they would not change their carpooling/ vanpooling or transit habits if HOT lanes were available.

A consultant in the Seattle area made a presentation at the 11th International Conference on High-Occupancy Vehicle Proceedings[23] concerning HOV and transit priority solutions for I-90. A re-examination of corridor has been prompted by the following factors: 1) daily traffic volumes are about 150,000 vehicles; 2) transit ridership is growing for both directions of travel; 3) merging of HOV traffic where the lanes are discontinued; and 4) HOV traffic demand and volumes are on the rise. The multi-modal options being considered for the corridor are: no-build (maintain current two-lane reversible center roadway and three directional lanes on the outer roadway), a two-way center roadway (only for HOV and transit), a transit shoulder (via widening to the outer roadway), and a reversible center roadway with HOV lanes on the outer roadway. Specific measures of effectiveness that were being investigated for these options include travel time savings, trip time reliability, person throughput, person hours of travel, and safety. Currently, agency staff are working to develop a preferred alternative.

A private consultant working with Oregon Department of Transportation (ODOT) gave a presentation that highlighted three projects where ODOT was considering different modes of travel as part of improvement projects for different corridors. One project was assessing HOT and HOV treatments and the efficiency of the general-purpose lanes for a 7 to 8-mile segment. Another 5-mile corridor was being evaluated for possible HOT lane implementation. The final project considered BRT, LRT, and busway alternatives.

The specific accounts discussed above should offer excellent survey sources for use in this study. Moreover, the *ITE Journal* article “Managed Lanes: The Future of Freeway Travel” (February 2005)[24] highlights a few cities/locations that have either recently contended with deciding multi-modal solutions or will be in the near future. The various cities/locations include Minneapolis, Denver, Seattle, Dallas, San Diego, Alameda County (California), and Houston and are specific to HOT implementations. Design characteristics being evaluated include HOV lane conversions to HOT lanes and whether new managed lanes should be introduced as HOT lanes and under what pricing/operation parameters. Most of these projects are estimated to open in 2005 or 2007.

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[23] Federal Highway Administration. *11th International Conference on High-Occupancy Vehicle Systems – Conference Proceedings.* Seattle, WA, October 2002, p. 93.

[24] Goodin, Ginger. *Managed Lanes: The Future of Freeway Travel.* ITE Journal, Institute of Transportation Engineers. Washington DC, February, 2005, pp. 1-5.

Also, the Federal Transit Administration provides an Annual Report on New Starts[25], which details the funding allocations for city/agency projects pertaining to new LRT systems or extensions of existing systems. Although LRT systems can be more confined to operations within arterial roadway settings, some of the projects listed in Table 1 (at the end of this chapter) are associated with freeway/highway corridors and thus would have required the agency to consider other forms of travel before selecting LRT. Therefore, these agencies and their associated projects will be good primary sources for information concerning their decision-making process and possibly data relied upon in that process. Also, since the information is from an older report, some of the projects may already be in operation and thus may have particular operations and effectiveness data available.

Effectiveness Statistics

Despite the multitude of resources obtained through the literature search, very limited data was located that specifically presented statistics for measures of effectiveness and none did so within the context of comparing one mode to another mode within the realm of multi-modal travel.

The 11th International Conference on High-Occupancy Vehicle Proceedings[26] had one presentation that provided detailed statistics on operations of BRT systems. Below are some of the pertinent statistics conveyed in the presentation:

- Between 18 and 30% of Houston transitway riders on HOV buses did not use transit before the HOV lanes were open.
- BRT routes in Los Angeles have experienced ridership gains of 26 to 33%, a third of which are new riders.
- Vancouver has seen 8,000 new riders with 20% of them having converted from driving their personal vehicles.
- BRT systems using busways and freeway HOV lanes typically save people 32 to 47% in travel time.
- The Los Angeles system saw a 23 to 28% improvement in bus travel times.
- The BRT systems in many cities provide speeds comparable or better than LRT systems – this is the case in San Jose, San Diego, Pittsburgh, Dallas, and Denver, but not in Los Angeles.
- In 1999 dollars, the capital cost per mile for LRT was estimated at $34.8 million as compared to $13.5 million for busways and $0.7 million for arterial street bus applications.
- Operating costs per vehicle-revenue-hour and per vehicle-revenue-mile were lower for the HOV and BRT systems than the LRT system in 1999 for all but one of the six cities previously mentioned—with most cases seeing a significant difference.
- BRT vehicle seating capacities are comparable to LRT.

[25] Federal Transit Administration. *Annual Report on New Starts: Proposed Allocations of Funds for Fiscal Year 2003.* Washington DC, 2002 (via website: http://www.fta.dot.gov/publications/reports/planning_environment_2635.html).

[26] Federal Highway Administration. *11th International Conference on High-Occupancy Vehicle Systems – Conference Proceedings.* Seattle, WA, October 2002, p. 109.

- Average vehicle speeds for both are similar—15 to 20 mph.
- The right-of-way cost per mile of BRT route typically ranges from $0.02 million to $25 million whereas LRT routes range from $20 million to $55 million.
- Vehicle costs for BRT ($0.45 million to $1.5 million) are about a third of LRT vehicles.
- The costs to operate and maintain BRT is $65 to $100 million and LRT is as much as $200 million.

Other statistics from around the country are presented in an article titled "Managed Lanes" as presented in the Public Roads publication sponsored by the FHWA[27]. A 2001 survey of I-15 users in San Diego indicated that 92% thought that managed lanes were an effective congestion-relief solution on I-15.

Data from the Virginia Department of Transportation in 2003 indicated that the reversible-flow HOV lanes on I-95 in northern Virginia carried 54% of the total number of people in 27% of the total vehicles on only 40% of the freeway lane capacity during the 3-hour AM peak period. Commuters using HOV lanes in Texas have average travel times of 2 to 18 minutes shorter during the peak hour. When compared to adding general purpose lanes, HOV lanes have benefit-to-cost ratios ranging from 6:1 to 48:1. HOV lanes are viable when HOV traffic is somewhere in the 400 to 600 vehicle per hour range, which is only about a third of the lane capacity.

Four HOT lanes in the median of SR 91 in Orange County, California supplement travel for the eight lanes of freeway for general purpose. Speeds in the HOT lanes were about three to four times as fast while two HOT lanes carried almost twice as many vehicles per lane as the four adjoining general-purpose lanes.

[27] Obenberger, Jon. *Managed Lanes.* Public Roads, Vol. 68, No. 3. Federal Highway Administration. Washington DC, November/December 2004, p. 5.

Table 1. Recently Implemented or Planned Light Rail Projects

Agency	City (Area)	Project Purpose	New Facilities	Projected Daily Ridership (by year)	Revenue Operations Begin	Capital Costs ($M)	Comments
Metropolitan Atlanta Rapid Transit Authority (MARTA)	Atlanta	Extension of North Line to serve rapidly growing area north of Atlanta	2.3 miles of rail; 2 new stations	33,000 (2005) - 11,000 new	2005	463	
Maryland Transit Administration	Baltimore	Upgrade from single to double track on Baltimore Central Corridor Light Rail Line	9.4 miles of track	44,000 (2020) - 6,800 new	2007	154	
Massachusetts Bay Transportation Authority (MBTA)	Boston	Develop underground transitway to make connection to South Boston Piers area	1.5-mile tunnel; 5 underground stations	22,000-34,100 (2010)	2004	601	Part of the construction is being coordinated with the Central Artery highway project
Metra (Regional Transportation Authority)	Chicago	Second mainline track on 55-mile North Central Service commuter rail line.	14 miles; 2.3 miles of third track; 5 stations	8,400 (2020)	2007	226	
Metra (Regional Transportation Authority)	Chicago	Extension/improvements to South West commuter rail line	12 miles; 3 miles of second mainline track; 3 stations	13,800 (2020) - 7,600 new	2007	198	
Metra (Regional Transportation Authority)	Chicago	Extension/improvements to Union Pacific West commuter rail line	8.5 miles; 2 stations	3,900 (2020)	2007	135	Extension will use existing railroad track and right-of-way currently used by both Metra and the Union Pacific freight railroad
Dallas Area Rapid Transit (DART)	Dallas	Extension from Park Lane to City of Plano	12.5 miles; 9 stations	17,000 (2020) - 6,800 new	2004	517	
Regional Transportation District (RTD)/CDOT	Denver	New implementation between downtown Denver and Lincoln Avenue in Douglas County	19 miles; 13 stations	38,100 (unk.) - 12,900 new	2006	879	Route to be along I-25 with a spur along I-225 - will operate over an exclusive right-of-way
Tri-County Commuter Rail Authority (Tri-Rail)	Ft. Lauderdale	System improvements: new second mainline track, facilities	44 miles	42,100 (2015) - 10,200 new	2005	327	Headways to be improved from 1 hour to 20 minutes
Los Angeles County Metropolitan Transportation Authority (LACMTA) - Metro Rail	Los Angeles	Third construction phase of minimum operable segments - North Hollywood section extension	6.3 miles; 3 stations; all subway	125,000 (2000 actual)	2000	1,310	
Memphis Area Transit Authority (MATA)	Memphis	Extension	2 miles; 6 stations	not available	2004	75	On-street system; possible first segment of a regional system
Metro Transit/MnDOT	Minneapolis	New implementation between downtown Minneapolis with the airport and Mall of America	11.6 miles, 17 stations	24,800 (2020) - 19,300 in opening year	2005	675	The line would operate along Hiawatha Avenue and Trunk Hwy 55
New Jersey Transit Corporation (NJ Transit)	Hudson County, NJ	Segment 1 of a larger system	9.6 miles; 16 stations	94,500 (unk.) - for full system	2002 (Segment 1)	992	
New Jersey Transit Corporation (NJ Transit)	Hudson County, NJ	Segment 2 of a larger system	5.1 miles; 7 stations	34,900 (2010)	2005	1,215	
New Jersey Transit Corporation (NJ Transit)	Newark City	First segment extension of City subway light rail line	1 mile; 5 station	13,300 (2015)	2005	208	The third segment will connect with the City of Elizabeth
Port Authority of Allegheny County	Pittsburgh	Reconstruction of old 25-mile trolley line as Stage II of overall project started in 1980s	12 miles; double tracking of some segments	not available	2004	386	Final portion of Stage II will be built as local funding becomes available
Tri-County Metropolitan Transit District of Oregon (Tri-Met)	Portland	Extension of Metropolitan Area Express (MAX) to connect CBD with regional Expo Center	5.8 miles; 10 stations	18,100 (2020) - 8,400 new	2004	350	Extension has portion along Interstate route
Bi-State Development Agency - Metrolink	St. Louis	Existing portion of larger 26-mile system from downtown East St. Louis, IL to Mid America Airport	17.4 miles; 8 stations (all existing)	not available	2001	339	The existing route makes extensive use of abandoned railroad rights-of-way
Utah Transit Authority (UTA)	Salt Lake City	Existing system	15 miles	19,000 (2001)	2000	313	Follows lightly-used railroad alignment owned by UTA to access suburbs; project is one component of the I-15 corridor improvement initiative which includes reconstruction of a parallel segment of I-15
Metropolitan Transit Development Board (MTDB)	San Diego	Extension of existing Blue Line	5.9 miles; 4 stations	10,800 (2015)	2006	431	Corridor runs parallel to I-8 in eastern San Diego
Bay Area Rapid Transit (BART)	San Francisco	Extension to serve San Francisco International Airport	8.7 miles; 4 stations	73,800 (2010) - 17,800 airport-related	2002	1,510	Some costs being borne by the airport for BART
Washington Metropolitan Area Transit Authority (WMATA)	Washington, DC	Extension of Blue Line to Prince George's County, MD	3.1 miles; 2 stations	28,500 (unk.) - 16,400 new	2005	434	Follows an alignment that has been preserved as a rail transit corridor

Source: Federal Transit Administration - *Annual Report on New Starts 2002* - http://www.fta.dot.gov/library/policy/ns/ns2003/ns7existingffc.html

$M – Millions of Dollars

CHAPTER 2: SURVEY OF DEPARTMENTS OF TRANSPORTATION REGARDING MULTI-MODAL APPLICATIONS ON URBAN FREEWAY CORRIDORS

INTRODUCTION

A majority of the information pertaining to the current practices of multi-modal optimization of freeway corridors was collected through formal surveys of transportation agencies and state departments of transportation (DOTs). Since this project is particularly interested in actual data and results, the survey was developed in order to elicit this information, if available, from the DOTs surveyed. The survey was directed at the various DOTs since their situations and perspectives with respect to multi-modal applications would be most meaningful to the AzDOT and their use of the project data and findings.

SURVEY DEVELOPMENT & DISTRIBUTION

Survey Intent

The survey was developed for distribution to transportation officials in order to obtain, either directly or indirectly, information concerning multi-modal applications involving the use of the freeway right-of-way area. A cover letter was drafted that described the overall intent of the research project and the purpose of the enclosed survey (the cover letter and survey are included in the appendix). Seven questions were included in the survey which focused on multi-modal applications used by the DOT, decision-making processes, and whether specific data was available pertaining to effectiveness and/or cost of the various multi-modal applications. The technical advisory committee (TAC) for this project was given an opportunity to review and suggest additions and/or revisions to the cover letter/survey prior to distribution.

Distribution

Preliminary investigations were undertaken in order to determine a point of contact at the various DOTs. Forty-four DOTs were contacted or an attempt to contact was made, which resulted in specific contact people or information for 29 DOTs. The cover letter and survey were then e-mailed to the 29 DOT contacts and given a period of 5 weeks to respond. Survey responses were accepted via fax, email, postal mail, and by phone.

SURVEY RESULTS

A total of nine responses were received with varying degrees of detail and usefulness from the following DOTs:

- Connecticut.
- Georgia.
- Illinois.
- North Carolina.

- North Dakota.
- Oregon.
- Virginia.
- Washington.
- Wisconsin.

Table 2 is a summary of the responses provided in the surveys. The answers served mainly to direct any follow-up investigations or clarifications since actual data could not be easily conveyed just by answering the survey questions. In some cases, actual studies were provided as an enclosure with the survey response. The returned surveys are included in the appendix.

Table 2. Survey Responses Summary

Question	**ANSWER SUMMARY OR NUMBER RESPONDING**			
1: Multi-Modal Forms	A majority of responses indicated that HOV lanes were presently used and/or were planned for use. HOT lanes were in the planning stages according to four responses while BRT was being considered in six of the nine responses. LRT was only listed in three responses as being currently used. HOT Lanes, Exclusive-Use Lanes, By-pass/Separation Lanes, Dual Facilities, and LRT had the highest number of responses for not being used as a multi-modal application within a freeway corridor.			
2: Decision Process	None of the responses really described a decision-making process that concerned the selection of one multi-modal application versus another. Some responses referred to "last-minute" decisions to include a multi-modal application as part of another roadway construction project. Others indicated that the process was dependent on studies and their results.			
	YES	**NO**	**NOT SURE**	**N/A**
3: Studies to Assist Decision	7	1	1	
4: Effectiveness Data Collected	6	1	2	
Available?	2	1	3	3
5: Cost Data Collected	4	3	1	1
Available?	3	0	1	5
6: Park & Ride Involvement	6	1	2	
7: Legislation Issues	3	2	4	

Some of the responses provided details for follow-up investigations and as a means to actually obtain data pertaining to the aspects of this project. Below is an accounting of the more useful information provided by some of the DOT contacts.

Connecticut Department of Transportation

The response from the Connecticut DOT contact provided a fair amount of detail, but the only data referred to and/or provided was in the form of a 2004 report titled *High Occupancy Vehicle Lane Report*. According to the survey response to Question 1 about multi-modal applications, Connecticut DOT has experience with HOV lanes only and is currently planning a BRT component. The contact responded that the HOV lanes were implemented along Interstates 84, 91, and 384 as part of reconstruction projects with the impetus being FHWA suggestions for facilities that would: 1) reduce overall fuel consumption, 2) improve air quality in an ozone non-attainment area, 3) provide a congestion free trip alternative to the predominant single occupant automobile trip, 4) preserve the person carrying utility of the roadway, and 5) provide a transit friendly facility.

The planning for a BRT on I-84 from New Britain to Hartford is currently in the final design stage. The DOT's decision to incorporate a BRT component was based on the following key factors: 1) final alternative choice from a traffic study conducted in 1997, 2) Federal Transit Administration's selection for a demonstration project, 3) environmental benefits, 4) public support, 5) compatible with existing and future land use plans, 6) supports transit, 7) physical constraints along I-84 from New Britain to Hartford would not allow for roadway expansion, 8) existence of active and inactive rail right-of-way in the study corridor, 9) inability and/or uncertainty of obtaining necessary environmental resource permits to expand the Interstate roadway, 10) lack of public support for roadway expansions, and 11) costs of busway versus roadway expansion.

The contact also provided information pertaining to the park-and-ride lots. He stated that Connecticut currently has 185 non-rail park-and-ride facilities and the average utilization rate is 18 percent, but can be as high as 41 percent when located adjacent to freeways. No detailed costs associated with the construction, operation, or maintenance of the facilities were included.

Hartford-West Major Investment Study[28]

The *Hartford-West Major Investment Study* compiled impact and cost data for a number of options it called "reasonable alternative packages (RAPs)." The RAP alternatives are generally described as follows:

- RAP1 No build/continue current operations.
- RAP2 Improved transit operations.
- RAP3 Freeway reconstruction & operations improvements.
- RAP4 Transit construction—light rail, commuter rail or busways.
- RAP5 HOV lane construction.

[28] *Hartford-West Major Investment Study* by Wilbur Smith Associates (2005) (Connecticut Department of Transportation, 2800 Berlin Turnpike, Newington, CT 06131-7546; Phone: (860) 594-2134) http://www.ct.gov/dotinfo/cwp/view.asp?a=2179&Q=299712.

The estimated cost per person-mile of travel[29] served for each of these packages is shown in Table 3. Freeway improvements are the most cost-effective package in terms of person-miles served. The main reason for this is the high volume of travel served compared to the other packages.

Table 3. Hartford-West Major Investment Study Alternative Evaluations		
Reasonable Alternative Packages (RAPs)	**Annual Person-Miles in Millions**	**Cost/ Person-Mile**
RAP3 Freeway Improvements	146.3	$ 0.18
RAP1 Existing Transit Operations	26.1	$ 0.47
RAP2 Expanded Transit Operations	28.0	$ 0.57
RAP4C-1 New Britain Busway	37.7	$ 0.64
RAP4C-2 I-84 Busway	33.6	$ 0.77
RAP4B New Britain Commuter Rail	35.1	$ 0.79
RAP4A-3 Farmington Ave. LRT	33.6	$ 0.84
RAP4A-1 New Britain LRT	35.7	$ 0.91
RAP5 I-84 Bus on HOV	25.6	$ 0.91
RAP4A-2 I-84 LRT-Route 9 Terminus	36.2	$ 1.01
RAP4A-4 I-84 LRT-Fienemann Rd. Terminus	36.1	$ 1.31

Hartford East BRT Feasibility Study[30]

The *Hartford East Bus Rapid Transit (BRT) Feasibility Study* compiled impact and cost data for two improvements over current services (no build option). The alternatives are generally described as follows:

- No Build — Continue current transit operations.
- HOV-BRT — Establish a BRT on an HOV Lane.
- HOV-Rail — Build LRT in the HOV Corridor.

The estimated cost per person-mile of travel served for each of these options is shown in Table 4. Lower construction cost is the main reason why the HOV BRT option has a lower cost per person-mile served than the HOV-Rail (LRT) option.

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[29] Cost per person-mile is the cost to carry one person one mile. It is calculated by dividing total costs for an option over an estimated life span by the total number of persons traveling on that option over this span.

[30] *Hartford East Bus Rapid Transit Feasibility Study* by Wilbur Smith Associates (December 2004) (Connecticut Dept. of Transportation, Bureau of Policy and Planning, 2800 Berlin Turnpike, P.O. Box 317546, Newington, CT 06131-7546; Len Lapsis , Project Director, Phone: 860-594-2143); http://www.ctbusway.com/man/reports_and_newsletters.htm.

Table 4. Hartford East Bus Rapid Transit Alternative Evaluations		
Option	**Annual Person-Miles in Millions**	**Cost/Person-Mile**
No Build	10.5	$ 0.77
HOV-BRT	15.9	$ 1.14
HOV-Rail Corridor	15.6	$ 1.57

Georgia Department of Transportation

The survey response from the Georgia DOT contact indicated that HOV lanes are currently used and that HOT lanes and BRT routes are being considered for the future. The contact person related that the DOT decision process regarding multi-modal applications was based on three levels: 1) system-wide studies, which were used to develop the 2005 Regional Transportation Plan, 2) viable alternatives to present in the National Environmental Protection Act (NEPA) documents, and 3) reliance on the metropolitan planning organization planning process.

The DOT collects data concerning the effectiveness of the HOV lanes through auto occupancies and violations. Initially, the data was collected as part of a before and after study pertaining to the expansion of one section of the HOV lane system. Presently, the DOT has commissioned an HOV monitoring plan for a systematic, long term data collection program to provide data for use in both future planning efforts and public information concerning the effectiveness of the HOV lane system.

Georgia DOT had some involvement with park-and-ride lots as they assisted the Georgia Regional Transportation Authority (GRTA) and the Atlanta area MPO in recommending locations during the development of the HOV Strategic Implementation Plan. The contact response regarding legislative issues relating to multi-modal applications was that a HOT lane feasibility study was requested by the State Legislature which was then carried out by the State Road and Tollway Authority.

The contact provided several website links as a means to possibly obtain data relating to the multi-modal applications investigated through the studies referenced in the survey response.

High Occupancy Toll Lanes: Potential for Implementation in the Atlanta Region[31]

The *HOT Lanes: Potential for Implementation in the Atlanta Region* examined the potential traffic and financial impacts that might ensue from implementing HOT lanes in the Atlanta metropolitan region. The idea is to convert the existing HOV lanes that are currently restricted to vehicles with two or more persons on-board (i.e., HOV 2+ w/o HOT) into HOT lanes where non-qualifying vehicles could use the lane in exchange for paying a toll. The HOT 2+ option is the one that would maximize the number of person-

[31] *High Occupancy Toll Lanes: Potential for Implementation in the Atlanta Region* by Parsons, Brinckerhoff, Quade & Douglas, Inc. (April 2005) (State Road & Tollway Authority (SRTA), Erik Steavens, Project Manager, at (404) 893-6139 or via email at esteavens@georgiatolls.com; http://www.georgiatolls.com/pdf/HOT_Final_Report_July2005.pdf.

miles served. While this option would not be self-financing (costs would exceed toll revenue), the incremental net cost for serving the additional travel would approximate 4 cents per person-mile as shown in Table 5. The HOT lane system could turn an annual profit of around $23 million if the HOV qualifying number of persons per vehicle were raised to four and carpools with fewer persons were charged a toll.

Table 5. Atlanta HOT Lane Evaluation

Option	Annual Person-Miles in Millions	Annual Costs in Millions	Annual Revenues in Millions
HOV 2+ w/o HOT (current operation)	7,365	NA	NA
HOT 2+	7,731	$ 52	$ 38
HOT 3+	6,766	$ 66	$ 53
HOT 4+	4,389	$ 80	$ 103

Illinois Department of Transportation

The survey response from the Illinois DOT was fairly limited, but did reference a couple of key items. First off, the contact responded that HOV lanes were being planned but not existent today (attempts were made in the Chicago area in the 1990s but failed because of lack of support by local authorities). BRT routes are also in the planning stage while dual facilities and heavy rail transit (HRT) lines exist today. The contact indicated that HRT lines currently exist in the medians of several Chicago area freeways. He also referred to a HOV feasibility study for the Chicago area freeways. An overall feasibility study concerning different multi-modal forms of travel is also available through the local rail transit authority.

Northwest Corridor Transit Feasibility Study[32]

The *Northwest Corridor Transit Feasibility Study* compiled incremental impact and cost data for a number of options generally described as follows:

- HRT via I-90 — Build HRT in I-90 median .
- LRT via I-90 — Build LRT in I-90 median.
- BRT via I-90 — Build a separate busway & access ramps on I-90.
- LRT via Arterials — Build LRT on city streets.
- CR via NCS — Operate commuter rail on Metra North Central Service Line.
- CR via MWD — Operate commuter rail on Metra-Milwaukee Line.
- HOV via I-90 — Build HOV lanes on I-90.
- Express Bus — Using existing shoulders of I-90.

[32] *Northwest Corridor Transit Feasibility Study* by Parsons Brinckerhoff (April 2000) (Regional Transportation Authority, 175 W. Jackson Blvd, Suite 1550, Chicago, IL 60604; (312) 913-3200); http://www.rtachicago.com/CMS200Sample/uploadedFiles/NW_projectsummary.pdf.

The estimated cost per incremental person-mile of travel served for each of these options is shown in Table 6. Higher travel volume is the main reason why the HRT via I-90 option has the lowest cost per person-mile served.

Table 6. Northwest Corridor Transit Incremental Impact Evaluation

Option	Annual Transit Person-Miles in Millions	Cost/Person-Mile
HRT via I-90	220.2	$ 0.06
LRT via I-90	183.9	$ 0.07
BRT via I-90	180.3	$ 0.07
LRT via Arterials	134.1	$ 0.10
CR via NCS	68.7	$ 0.19
CR via MWD	65.7	$ 0.20
HOV via I-90	45.0	$ 0.29
Express Bus	22.8	$ 0.57

North Carolina Department of Transportation

From reviewing the North Carolina DOT response to the survey, it appears that HOV lanes are the only form of multi-modal travel being utilized and planned. The decision to incorporate HOV lanes into an Interstate 77 reconstruction/widening project was made hastily without any supporting studies being conducted. Further information concerning the project as well as the consideration of HOV lanes on I-40 are available through a website link provided in the survey response.

I-40 High Occupancy Vehicle/Congestion Management Study[33]

The *I-40 High Occupancy Vehicle/Congestion Management Study* looked at four HOV configurations as summarized below.

Simple – This configuration consists of one concurrent flow HOV lane in each direction separated by a pavement stripe buffer. No HOV-only access interchanges were included.

Complex – This configuration consists of one barrier-separated HOV lane in each direction and HOV-only access interchanges. An Express lane for general purpose traffic would be added to the HOV lane on I-40 between NC-147 and I-540. In addition, eighteen new HOV-only access interchanges were included at or near existing interchange locations.

Modified Complex – This configuration is a variation of the Complex scenario, and consists of the same barrier-separated HOV and Express lanes. It includes six HOV-only access interchanges at high demand locations.

[33] *I-40 High Occupancy Vehicle/Congestion Management Study* (March 2003) (North Carolina Department of Transportation, 1500 Mail Service Center, Raleigh NC, 27699-1500; phone: 919.733.2520; http://www.ncdot.org/hov/pdf/chapter7.pdf).

Elevated – This configuration includes two two-lane viaducts (one on each side of the I-40 freeway). This configuration required an extra general purpose lane along the entire length of the viaducts due to safety and operational considerations. The configuration includes the same six access points as the Modified Complex configuration. Managed lane access at NC 147 and I-540 is provided for HOV vehicles only while the other four locations provide access to HOV and Express lane traffic. In addition, the geometric requirements of the viaduct limit the possibilities for providing additional HOV interchanges in the future.

The study did not report on the total traffic or persons affected by the evaluated options. As shown in Table 7, it did report on projected impact on traffic delay for each option in terms of percentages compared to the "no build" option. The "Complex" option offered the largest reduction in delay and had the lowest cost per percentage of improvement. The "Simple" option was projected to increase traffic delay due to vehicles weaving between HOV and general purpose lanes. Consequently, adding a simple HOV lane degrades traffic flow compared to having only general purpose lanes.

Table 7. North Carolina HOV Option Evaluation

Option	Average Impact on Traffic Delay	Millions of Dollars/ Each Percentage Reduction in Delay
Simple	+48%	NA
Complex	-31%	$ 38
Modified Complex	-22%	$ 45
Elevated	-19%	$ 194

Oregon Department of Transportation

Several forms of feedback were received from the Oregon DOT. Although the surveys were filled out in sufficient detail, most of the information pertinent to this project will be accessible via website links referenced in the DOT response. Almost all of the multi-modal forms of travel exist or are planned for in Oregon. A BRT system is being established in the Eugene/Springfield urban area, but is primarily along local roadway routes and thus does not involve freeway corridors or right-of-way considerations. An expansion of the current LRT lines will likely introduce a segment along the I-205 corridor within the freeway right-of-way. Although the survey response indicated that effectiveness and cost data are collected by the DOT, their availability for use in this project was uncertain and therefore data gathering should be facilitated through the website links provided in the response.

Cost Effectiveness and Financial Feasibility of Improvements to Highway 217[34]

The *Estimates of the Cost Effectiveness and Financial Feasibility of Selected Improvements to Highway 217* study evaluated the relative cost-effectiveness of six options.

- Alternative 1 Arterial, Transit & Interchanges.
- Alternative 2 6-Lane without Interchange Improvements.
- Alternative 3 6-Lane with Interchange Improvements.
- Alternative 4 Carpool Lanes.
- Alternative 5 Rush-Hour Toll Lanes.
- Alternative 6 Tolled Ramp Meter Bypass.

For each option the roadway user time savings for a 2-hour PM peak period were estimated and valued. These benefits were then compared to the costs required to achieve them. Since only the single PM peak period was used in the analysis, it is not a comprehensive evaluation of the benefit/cost of each alternative, but only a measure of the relative effectiveness of the compared alternatives. Given this limitation, it cannot be ascertained whether any alternative provides more benefit than cost compared to a "no build" option. Within the limits of the comparison shown in Table 8, it appears that a tolled ramp meter bypass yields the most benefit for the least cost.

Table 8. Relative Cost-Effectiveness of Alternatives

Option	PM Peak User Benefits	Annual Cost in Millions	Benefit/ Cost Ratio
Arterial, Transit & Interchanges	$(3,228)	$28.1	-0.11
6-Lane without Interchange Improvements	$(13,416)	$21.1	-0.63
6-Lane with Interchange Improvements	$10,142	$25.8	0.39
Carpool Lanes	NA*	$27.1	NA*
Rush-Hour Toll Lanes	$13,338	$30.5	0.44
Tolled Ramp Meter Bypass	$20,561	$27.8	0.74

* Variations in modeling for this alternative do not allow for a comparable benefit presentation. However, benefits estimated to be of the same order of magnitude for Alternatives 3, 5, & 6.

[34] *Estimates of the Cost Effectiveness and Financial Feasibility of Selected Improvements to Highway 217* (29 September 2004) (Portland Office 888 SW Fifth Avenue, Suite 1460, Portland OR 97204; Phone: 503.222.6060; http://www.metro-region.org/library_docs/trans/financial_analysis.pdf).

South Corridor I-205/Portland Mall Light Rail Project[35]

The Portland, Oregon Metro planning council conducted a study of alternatives to relieve traffic in the city. The initial alternatives considered included the following:

- No-Build.
- Commuter Rail.
- River Transit.
- HOV Lane.
- HOT Lane.
- Bus Rapid Transit.
- Busway.
- Light Rail.

Based on qualitative objectives that included support for land use goals, community values, and providing high quality transit service in the corridor, all alternatives except light rail were eliminated.

The resulting proposed project envisioned a 6.5 mile light rail line between Clackamas and Gateway Transit Center (parallel to I-205) and a 1.8 mile light rail line between Portland State University and downtown Portland. A number of performance and impact statistics are presented in Table 9.

Table 9: Portland LRT Extension Performance & Impact

LRT Elements	**Performance/Impact**
Cost to build LRT[a]	$483 million
Cost to operate/year[b]	$7.2 million
Annual LRT passenger trips 2025[c]	15.2 million
Incremental LRT passenger trips[d]	6.2 million
Peak hour traffic reduction on I-205[e]	1.3%
Peak hour transit travel time reduction[f]	22.5%
Cost per LRT passenger trip[g]	$3.12
Cost per incremental LRT passenger trip[h]	$7.70

[a] Cost to build & equip the new LRT in year 2004 dollars.
[b] Cost to operate the new LRT line segment.
[c] Total number of passenger trips on the new line in the year 2025.
[d] Number of transit passengers over-and-above those carried by pre-existing bus service.
[e] Estimated reduction in traffic volume on I-205 as a result of the new LRT line.
[f] Estimated reduction in travel time for the new LRT vs. the pre-existing bus service.
[g] Amortized annual capital + operating costs divided by annual LRT passenger trips.
[h] Amortized annual capital + operating costs divided by incremental LRT passenger trips.

[35] *South Corridor I-205/Portland Mall Light Rail Project* (Metro, 600 NE Grand Ave., Portland, OR 97232-2736; (503) 797-1700; http://www.metro-region.org/article.cfm?articleid=223) (November 2004).

Virginia Department of Transportation

All multi-modal applications highlighted in the survey are either being used today by Virginia Department of Transportation (VDOT) or are planned for the future. Moreover, Metro Rail and Virginia Railway Express (VRE), a commuter rail system, are also used in the Washington, D.C. area. The survey response indicates that the following aspects contribute to the decision-making process concerning multi-modal applications: 1) limited right-of-way versus need to accommodate increasing demand, 2) provision for more traveler choices, 3) separation of trucks from passenger vehicles, 4) public/private partnerships (PPTAs) supporting the potential for future toll facilities which include HOT lanes, and 5) limited funding. The DOT relies on studies to help make informed decisions with most accessible through website links provided in the survey response. Data pertaining to effectiveness and costs are collected by the DOT, but appear to be of limited use based on the survey responses. The DOT does track park-and-ride usage since they view them as important aspects of carpooling success. Legislation related to PPTAs has increased planning for multi-modal facilities, and recent legislation has permitted the use of HOV lanes by hybrid vehicles, which has led to scrutiny from the FHWA and negative press from carpool groups. VDOT does not assess the cost-effectiveness of various modal options in any freeway corridors and the published data are too general in nature for us to attempt such an analysis.

Washington State Department of Transportation (WSDOT)

As is the case for the Virginia DOT, within the State of Washington, all multi-modal forms of travel exist or are being considered. The use of HOV lanes and BRT routes emerged from growing traffic demands in the 1990s. HOT lanes are being considered in order to make more efficient use of the HOV system. Decisions regarding multi-modal applications were based on studies performed which are available through website links referenced in the survey response. Effectiveness data was collected in the form of usage of general purpose and HOV lanes as well as transit ridership. Cost data is available on a cost per mile of general purpose lane and transit costs per hour, trip, and mile (again, all available via the Internet). WSDOT has been involved with park-and-ride facilities in the past, but not as many recently.

HOV Lane Performance Monitoring: 2000 Report[36]

Eleven HOV route segments were portrayed in this report. The measure of effectiveness used was the number of persons traveling in the HOV lane versus the number traveling in the GP lanes. Table 10 shows number of persons per lane for a 4-hour peak period for each segment. In seven of the eleven segments, the HOV lane carried more persons per lane than the abutting GP lanes. In several instances the HOV lane carried substantially more persons/lane than the GP lanes.

Table 10. Seattle Region HOV Lane Performance

	Persons/Lane During 4-Hour Peak Volume	
HOV Segment	**HOV**	**GP**
I-5 near Northgate	18,513	8,497
I-5 near South Everett	9,574	7,861
I-5 South of Seattle	17,969	8,492
I-5 South of Southcenter	14,601	7,415
I-405 near Kirkland	11,524	7,633
I-405 near Newcastle	13,226	7,924
I-405 near Southcenter	9,297	5,520
I-90 Floating Bridge	5,387	7,024
I-90 near Issaquah	4,349	6,986
SR-167 near Kent	8,006	8,313
SR-520 near Medina	5,274	6,028

[36] *HOV Lane Performance Monitoring: 2000 Report* by Jennifer Nee, John Ishimaru, Mark Hallenbeck (April 2002) (Washington State Transportation Center (TRAC), University of Washington, Box 354802, University District Building, 1107 NE 45th Street, Suite 535, Seattle, Washington 98105-4631; http://depts.washington.edu/trac/bulkdisk/pdf/506.1.pdf.

CHAPTER 3: SR 51 CASE STUDY EVALUATION OF MULTI-MODAL OPTIONS

INTRODUCTION

Multi-Modal Travel on Arizona Urban Freeways

Although Arizona would not be considered at the forefront of multi-modal options on its urban freeways, the continual growth and increasing traffic demands mean that additional forms of freeway travel will need to be utilized in the near future. The most prevalent form of multi-modal travel currently used on Arizona urban freeways is the HOV lane. Their use spans almost 20 years in the Phoenix area, with totals on the order of 150 lane-miles to date, and plans for extending current lanes while introducing new lanes on existing freeways. The lanes are provided as concurrent flow lanes, although at select interchanges, dedicated connection ramps are provided. Bus rapid transit is also currently utilized in the Phoenix metropolitan area. Four routes are in operation on I-10 (West and East), I-17, and SR 51. All routes cater to commuter trips to/from the Phoenix downtown area. These are the only two active forms of multi-modal travel, as categorized in this study, within urban freeway corridors utilized in Arizona.

SR 51 Multi-Modal Options

The anticipated need for other forms of travel along urban freeways provides the impetus for this research project and more specifically the following hypothetical case study of multi-modal options for the SR 51 freeway corridor. Other forms of urban freeway travel are being considered in Arizona including light rail, commuter rail, dedicated BRT lanes, and HOT lanes. All forms aside from the commuter rail would be candidates for multi-modal travel within the urban freeway corridor (right-of-way). Moreover, all applicable forms of multi-modal travel are currently used or are being considered for use along the SR 51 corridor. The freeway currently accommodates HOV and BRT (using the HOV lanes) travel in addition to vehicular travel in the GP lanes.

Purpose of Case Study

This case study will demonstrate the considerations and data that have to be employed when considering viable applications of multi-modal travel within an urban freeway corridor. Although conditions on other freeways in the Phoenix area may be more congested or better candidates for particular multi-modal applications, the SR 51 corridor provided an example where research data pertaining to all multi-modal forms of travel were available for reference. Each form will be evaluated based on existing freeway operations data and projected operations when considering potential forms of multi-modal travel.

SR 51 MULTI-MODAL CASE STUDY

Data Acquisition

Existing traffic data along SR 51 was obtained through AzDOT and their FMS. The FMS-based data provides extensive information concerning the roadways in the Phoenix metropolitan area. The AzDOT Freeway Management System gathers data from roadway sensors located about every 1/3 mile on local freeways. Every 20 seconds, speeds, volumes, and occupancy are gathered by the FMS from each traffic controller, and archived for later retrieval. This traffic data is used to create the real-time maps on operator workstation screens, the control room projector screen, and the Internet. Details such as lane-by-lane speeds, volumes, and truck usage are collected by the FMS sensors and aggregated by specified time intervals. The FMS data relied upon for this case study was for all of 2005 and entailed data summarized into 1-hour values for all sensors/stations in the system.

In order to reduce the extensiveness of the case study, only a portion of the yearly FMS data was referenced. From AzDOT-sponsored seasonal factors, it was determined that April would be a typical month as compared with the monthly average for a total year. Moreover, there are no particular holidays within April that would greatly affect traffic conditions. Other AzDOT data also indicates that Tuesday would represent a "normal" traffic use/activity day during the work week. Therefore, the complete FMS dataset was partitioned so that only 4 days of data were available: April 5, 12, 19, and 26 (all Tuesdays). Specific data values were limited to the peak periods—6 to 9 AM and 4 to 7 PM (which are also valid times for HOV lane operations).

In another effort to reduce the extensiveness of the case study, only four locations/ sections of the SR 51 were considered for data analysis. The locations were selected to represent different portions of the SR 51 freeway, both in lane configurations and traffic use/congestion. In order to minimize other influencing variables, the roadway sections were selected so as not to have auxiliary lanes which may influence vehicular speeds because of weaving traffic flows. The resulting sections, for both the northbound and southbound directions, are shown below with their characteristic aspects:

- North of Thunderbird (three GP lanes in each direction, no HOV lanes)
- Between Northern & Shea (five GP lanes in each direction, one HOV lane in each direction)
- At Camelback (three GP lanes in each direction, one HOV lane in each direction)
- Between Thomas & Indian School (three GP lanes in each direction, one HOV lane in each direction)

For the most part, FMS data from the sensors at these locations for the dates/time periods analyzed were free from errors (per diagnostic data included with the roadway traffic data). In the limited instances where some of the sensor periods were malfunctioning, the data for that period of time (1 hour interval) was not included in the overall sums/averages representing Tuesdays in April 2005.

Data Analysis

Only certain aspects of the extensive FMS data were needed in order to evaluate the forms of multi-modal travel possible on SR 51. The following travel aspects were gleaned from the partitioned FMS dataset for both the GP lanes and the HOV lane (where applicable):

- Average vehicles per hour per lane, VPHPL
- Average speed (for combined GP lanes and for HOV lane)

- Average lane occupancy (an indicator for congestion level, as based on percent of the sensor time interval where a vehicle is detected)
- Average trucks (Type 1: 30 to 55 feet in length) per hour per lane (within the GP lanes and HOV lane)
- Average trucks (Type 2: 55+ feet in length) per hour per lane (within the GP lanes and HOV lane)

The resulting data for the above aspects were summed and averaged for the four Tuesdays within April 2005 and are shown in Table 11. The information presented is representative of the AM and PM peak period conditions (which include the non-specified peak hour).

The data presented in Table 11 was also used to estimate the travel times for motorists in the GP lanes and the HOV lanes. Since the data only represents specific locations along the corridor, each location was assumed to be representative of the traffic conditions for about a 2-mile segment around each location in order to facilitate the estimated travel time calculations. Therefore, the corridor length considered is 8.5 miles (which is less than the full extent of the freeway) and is only for comparative purposes within this case study. Table 12 shows the estimated travel times for the two peak periods in both directions for travel in the GP and HOV lanes.

Table 11. Peak Period Travel Conditions for Selected Sections of SR 51

Freeway Location	Direction	Lane Config	Time	Detector I.D.	GP Lanes Average VPHPL	GP Lanes Average Speed [mph]	GP Lanes Trucks(1) VPHPL	GP Lanes Trucks(2) VPHPL	HOV Lane Average VPH	HOV Lane Average Speed [mph]	HOV Lane Trucks(1) VPH	HOV Lane Trucks(2) VPH
SR 51 n/o Thunderbird	SB	3	6-9am	307	1725	47.6	22	6				
SR 51 b/w Northern & Shea	SB	5+HOV	6-9am	297	1370	67.2	16	1	533	65.9	6	1
SR 51 at Camelback	SB	3+HOV	6-9am	200	1831	50.8	54	2	715	55.1	1	0
SR 51 b/w Thomas & Ind.Sch.	SB	3+HOV	6-9am	192	1995	54.5	42	1	611	62.2	2	0
SR 51 b/w Thomas & Ind.Sch.	NB	3+HOV	6-9am	207	1605	59.8	29	0	330	62.7	2	0
SR 51 at Camelback	NB	3+HOV	6-9am	211	1121	65.4	6	0	308	64.3	0	0
SR 51 b/w Northern & Shea	NB	5+HOV	6-9am	320	861	61.8	25	1	245	64.8	4	0
SR 51 n/o Thunderbird	NB	3	6-9am	331	1108	62.0	43	8				
SR 51 n/o Thunderbird	SB	3	4-7pm	307	1311	65.2	20	4				
SR 51 b/w Northern & Shea	SB	5+HOV	4-7pm	297	946	67.6	13	0	337	66.9	4	0
SR 51 at Camelback	SB	3+HOV	4-7pm	200	1446	60.3	17	0	381	59.4	0	0
SR 51 b/w Thomas & Ind.Sch.	SB	3+HOV	4-7pm	192	1663	58.8	34	1	437	64.4	1	0
SR 51 b/w Thomas & Ind.Sch.	NB	3+HOV	4-7pm	207	1540	52.8	25	2	708	57.8	3	0
SR 51 at Camelback	NB	3+HOV	4-7pm	211	1464	56.3	19	1	721	57.7	1	0
SR 51 b/w Northern & Shea	NB	5+HOV	4-7pm	320	1458	60.5	23	1	512	64.8	3	0
SR 51 n/o Thunderbird	NB	3	4-7pm	331	1873	56.8	17	3				

n/o – north of
b/w – between

Table 12. Estimated Travel Times on SR 51 by Direction and Lane Type

			Approx. Segment Distance [miles]	GP Travel Time [minutes]	HOV Travel Time [minutes]	HOV Travel Time Savings [minutes]
SR 51 n/o Thunderbird	SB	AM Peak Period	2	2.522	2.522	0.000
SR 51 b/w Northern & Shea	SB	AM Peak Period	2	1.787	1.820	-0.034
SR 51 at Camelback	SB	AM Peak Period	2.25	2.660	2.451	0.209
SR 51 b/w Thomas & Ind.Sch.	SB	AM Peak Period	2.25	2.477	2.172	0.305
SR 51 b/w Thomas & Ind.Sch.	NB	AM Peak Period	2.25	2.259	2.154	0.105
SR 51 at Camelback	NB	AM Peak Period	2.25	2.065	2.098	-0.033
SR 51 b/w Northern & Shea	NB	AM Peak Period	2	1.943	1.853	0.090
SR 51 n/o Thunderbird	NB	AM Peak Period	2	1.935	1.935	0.000
	SB Total	AM Peak Period	8.5	9.446	8.965	0.481
	NB Total	AM Peak Period	8.5	8.204	8.041	0.162
SR 51 n/o Thunderbird	SB	PM Peak Period	2	1.840	1.840	0.000
SR 51 b/w Northern & Shea	SB	PM Peak Period	2	1.776	1.793	-0.018
SR 51 at Camelback	SB	PM Peak Period	2.25	2.241	2.272	-0.031
SR 51 b/w Thomas & Indian.School.	SB	PM Peak Period	2.25	2.296	2.096	0.200
SR 51 b/w Thomas & Indian.School.	NB	PM Peak Period	2.25	2.555	2.334	0.221
SR 51 at Camelback	NB	PM Peak Period	2.25	2.398	2.341	0.057
SR 51 b/w Northern & Shea	NB	PM Peak Period	2	1.983	1.853	0.130
SR 51 n/o Thunderbird	NB	PM Peak Period	2	2.114	2.114	0.000
	SB Total	PM Peak Period	8.5	8.152	8.001	0.151
	NB Total	PM Peak Period	8.5	9.049	8.642	0.407

n/o – north of
b/w – between

By referencing the information presented in Tables 11 and 12, it is apparent that travel in the HOV lane does not provide much time savings. For the 8.5 mile approximation of the freeway corridor, the maximum time savings is on the order of 30 seconds.

Supplemental Data

Although the results from examining the FMS data do show that the HOV provides some savings in travel time, it is hampered by relying on data from only four locations along the corridor. A previously conducted traffic assessment[37] investigated the road user cost savings of implementing the existing HOV lane in each direction along SR 51. The study utilized FMS data (from 2004), but translated it into parameters governing a simulation of the traffic conditions. Results and conclusions from the study were based on numerous simulation runs representing the AM, PM, and Mid-day peak periods.

The simulation model was used to determine the travel time effects (and ultimately road user cost savings) relating to the presence of the HOV lane (in each direction) along the study corridor (Shea Boulevard to I-10). Interpretation of the results was two-fold: the travel time savings for HOV and GP motorists under the now existing configuration, and the effects on all traffic if the HOV lanes were not present and no additional GP lanes were considered.

AM Peak Period Results

The results indicated that during the AM peak period, an HOV motorist had an average travel time of 8.8 minutes in the southbound direction (peak flow) while a motorist in the GP lanes had an average travel time of 14.0 minutes. In the northbound direction (non-peak flow), the travel times in the HOV and GP lanes were about the same (8.6 to 8.8 minutes) with the HOV lane travel time being slightly more.

In the scenario where the HOV lanes were not considered in place (i.e., only the existing GP lanes were available to traffic), the travel time in the southbound direction increases to 20.7 minutes and is unchanged in the northbound direction.

PM Peak Period Results

The results indicated that during the PM peak period, an HOV motorist had an average travel time of 9.0 minutes in the northbound direction (peak flow) while a motorist in the GP lanes had an average travel time of 14.2 minutes. In the southbound direction (non-peak flow), the travel times in the HOV and GP lanes were about the same (8.6 to 9.0 minutes) with the HOV lane travel time being slightly less.

In the scenario where the HOV lanes were not considered in place, the travel time in the northbound direction increases to 17.8 minutes and increases to 14.9 minutes in the southbound direction. So, the presence of the HOV lanes not only allows HOV motorists to travel in less time, but the lane also benefits the other motorists using the GP lanes by segregating a certain portion of the traffic volume using the corridor.

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[37] *SR 51 Benefit Cost Analysis: Shea Boulevard to I-10,* prepared for Arizona Department of Transportation by Lee Engineering, July 19, 2004, pp. 1-18.

Travel Characteristics for Multi-Modal Possibilities
The data and conclusions discussed above were possible because HOV lanes are currently present on SR 51 (for the portion being studied). Another form of travel on SR 51 is BRT which utilizes the HOV lanes, although the same level of detail concerning its operations is not available. Other forms of multi-modal travel such as light rail and HOT lanes are certainly possible along the SR51 corridor, but their effects will have to be estimated based on other information gathered during this project. The primary means of comparing these various forms of travel will be the number person-miles per hour accommodated which incorporates the aspects of mass transit and higher operating speeds. Other aspects consisting of costs and implementation will also be considered in the comparison. Comparisons will only be conducted for the AM and PM peak periods in the direction of peak flow (i.e., southbound in the AM and northbound in the PM) since these would represent the situations of maximum advantage for those traveling by alternative form.

GP & HOV Lanes
The information presented previously with additional information from the *SR 51 Benefit Cost Analysis* study will allow for a reasonable estimate of accommodated person-miles per hour. The assumed number of GP lanes will be three, since this is the predominant cross section for the freeway corridor being studied (about 9 miles). Average passenger occupancy per vehicle in the GP lanes was assumed at 1.0 while the HOV vehicle occupancy was assumed at 2.1 (which negates violators and assumes some vehicles will have more than the required two people). Table 13 presents the information pertaining to GP lanes and the HOV lane for the study section of the SR 51 corridor.

Table 13. Travel Characteristics of GP and HOV Lanes

	Vehicles/Hour/ Lane[a]		Persons Carried/ Hour/Lane[b]		Person-Miles/ Hour/Lane[c]		Corridor Person-Miles/ Hour
	GP Lanes	HOV Lane	GP Lanes	HOV Lane	GP Lanes	HOV Lane	Lane Types Combined
AM Peak Period – Southbound SR 51 (both modes present)	1,516	622	1,516	1,306	13,644	11,756	52,688
PM Peak Period – Northbound SR 51 (both modes present)	1,652	860	1,652	1,806	14,868	16,254	60,858
AM Peak Period – Southbound SR 51 (3 GP lanes, no HOV)	1,542		2,035		18,319		54,957
PM Peak Period – Northbound SR 51 (3 GP lanes, no HOV)	1,718		2,354		21,183		63,549

a - Source: SR 51 Benefit Cost Analysis: Shea Boulevard to I-10 (no accounting for mass transit vehicles using the HOV lane—i.e., all vehicles considered personal vehicles with assumed occupancy)
b - veh/hour/lane * vehicle occupancy (in GP only scenario vehicle occupancies equal 1.32 in the AM and 1.37 in the PM based on the weighted distribution of assumed vehicle occupancies for GP and HOV vehicles
c – persons carried/hour/lane * 9 miles

BRT

BRT routes are currently functioning on SR 51 in both directions. The buses use the HOV lanes for enhanced travel times and about 10 bus trips occur in the peak direction during the AM and PM peak periods. The estimated number of passengers on a BRT bus is about 31 people[38], which includes times when all seats are occupied and additional riders must stand. Therefore, in a 1-hour period, about five buses carrying about 31 passengers each would have a person-mile per hour value of 1,674 (6 * 31 * 9) miles. Since this service exists today, the resulting person-mile per hour should supplement the HOV lane characteristics shown in Table 13. Alternatively, the HOV lane could be converted for exclusive BRT use only. In this case, the bus headways would likely be shorter (5 minutes), but it is unclear whether bus ridership would change, either positively or negatively (for the purposes of the case study calculations, the ridership average was assumed to remain the same as presently observed).

LRT

Information concerning the operation of a potential light rail transit line along the SR 51 corridor was obtained from a study[39] produced by the Maricopa Association of Governments (MAG). During the peak hour, the headways would likely be 10 minutes. Capacity of the light rail cars can vary from 66 (all seated) to 200 (seated and standing) with two cars making up the one train per headway. The MAG study provides data on the anticipated daily boardings (12,334), which was reduced to a peak period ridership average of 147 persons per train (two rail cars) relying on the following: 1) an assumption that 50% of the daily boardings would occur within the 7 hours of peak period travel, 2) the demand for travel/ridership was constant over the course of the peak periods, and 3) the train headways would be 10 minutes. Therefore, in a 1-hour period, six trains carrying an average of 147 passengers each would have a person-mile per hour total of 7,938.

HOT Lane

This mode of travel would be akin to HOV in that they would rely on the same physical configuration as the HOV system (although some additional physical components and equipment would be necessary). HOT lanes rely on the motorist's desire to minimize travel time. The excess capacity available in the HOV lane is "sold" to the other motorists in the GP lanes that would otherwise not be permitted to use the HOV lane. The toll can be a flat rate based on miles traveled in the HOV/HOT lane or it can vary based on the congestion level of the GP lanes and the relative congestion of the HOT lane. For the purposes of this study, the additional traffic volume that would be accommodated in the HOV if it were configured to operate as a HOT lane would be 33% more based on information from a HOT lane feasibility study in the Atlanta region.[40]

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[38] *RAPID – State Route 51, Northeast Phoenix and Express Route 512* from City of Phoenix website (http://phoenix.gov//PUBLICTRANSIT/rap51.html#choosing).

[39] *High-Capacity Transit Study: Final Report*, Maricopa Association of Governments, June 30, 2003, Appendix B.

[40] *High Occupancy Toll Lanes: Potential for Implementation in the Atlanta Region* by Parsons, Brinckerhoff, Quade & Douglas, Inc. (April 2005) (State Road & Tollway Authority (SRTA)), Erik Steavens, Project Manager, at (404) 893-6139 or via email at esteavens@georgiatolls.com; http://www.georgiatolls.com/pdf/HOT_Final_Report_July2005.pdf.

This increase would be representative of GP motorists opting to pay the toll and use the HOT lane while some HOV motorists may choose to use the GP lanes in certain areas because of the limited access nature associated with HOT lane operations.

Based on the information presented in Table 13, the vehicles per hour per lane value for the HOV lane (HOT lane) would increase by 33%. The weighted average vehicle occupancy would decrease to 1.82, but because of the increased traffic volumes the person throughput per hour and person-miles per hour (per lane) would be about 15% more than what was presented in Table 13.

Modal Comparisons

The comparisons between the travel mode choices on SR 51 will be based on the person-mile computations presented above and the available cost information for each mode. Costs will include installation/implementation, capital/equipment, operations and management, and enforcement.

The modes of travel being examined in this case study generate six corridor scenarios (with one being the existing state) that can be compared to provide context for what might be the best multi-modal choice. The six scenarios are as follows:

- Scenario 1: 3 GP lanes only.[41]
- Scenario 2: 4 GP lanes only.
- Scenario 3: 3 GP lanes + HOV lane (and accommodating current BRT). (Existing)
- Scenario 4: 3 GP lanes + LRT (implemented in the median/shoulder area).
- Scenario 5: 3 GP lanes + HOT (and accommodating HOV 2+ for no toll).
- Scenario 6: 3 GP lanes + dedicated BRT lane (smaller headways with current ridership).

Operations

The information presented in the previous section has been summarized in Table 14 along with the estimated costs for each scenario, which will be discussed later. This compilation of operational characteristics and ultimately the number of person-miles per hour per lane and corridor person-miles per hour (and per day) will allow for a primary comparison followed by a cost analysis assessment. To supplement the information and calculations contained in Table 14, the following notes are provided:

- The "Corridor Person-Miles During the Peak Periods" value was determined by using the sum of the weighted average corridor person-miles for both peak hours, multiplying by the total number of lanes in one direction for the scenario, and then multiplying by the ratio of peak period to peak hour percentages of daily traffic (i.e., 45% divided by 19%). The 6 hours of peak period travel includes the peak hours of travel, estimated to be 10% and 9% of the daily traffic volume. The remaining 4 hours of peak period travel were estimated to steadily decline from the peak hour percentages at 2% per hour.

[41] While this scenario is not relevant for a situation where a fourth lane already exists, as is the case on SR 51, it is being included in the comparison as the base case/scenario as a reference point for the other freeway configuration scenarios.

Table 14. Operational Comparisons of Travel Mode Scenarios

				Freeway Travel Scenario					
				1 (Base Case)	2	3	4	5	6
				GP Lanes Only (3 each direction)	GP Lanes Only (4 each direction)	GP Lanes (3 each direction) + HOV Lane (1 each direction)	GP Lanes (3 each direction) + LRT	GP Lanes (3 each direction) + HOT Lane (1 each direction)	GP Lanes (3 each direction) + BRT Only Lane (1 each direction)
OPERATING CHARACTERISTICS	Vehicles Per Hour Per Lane	AM Peak Period - Southbound	GP Lanes	1,542	1,542	1,516	1,542	1,516	1,542
			Alt. Mode			622	6	827	12
		PM Peak Period - Northbound	GP Lanes	1,718	1,718	1,652	1,718	1,652	1,718
			Alt. Mode			860	6	1,144	12
	Persons Carried Per Hour Per Lane	AM Peak Period - Southbound	GP Lanes	2,035	2,035	1,516	2,035	1,516	2,035
			Alt. Mode			1,306	882	1,506	384
		PM Peak Period - Northbound	GP Lanes	2,354	2,354	1,652	2,354	1,652	2,354
			Alt. Mode			1,806	882	2,082	372
	Person-Miles Per Hour Per Lane	AM Peak Period - Southbound	GP Lanes	18,319	18,319	13,644	18,319	13,644	18,319
			Alt. Mode			11,756	7,938	13,551	3,456
			Weighted Average	18,319	18,319	13,172	15,724	13,621	14,603
		PM Peak Period - Northbound	GP Lanes	21,183	21,183	14,868	21,183	14,868	21,183
			Alt. Mode			16,254	7,938	18,735	3,348
			Weighted Average	21,183	21,183	15,215	17,872	15,835	16,724
	Corridor Person-Miles During the Peak Periods			280,671	374,229	268,924	318,272	279,052	296,786
	Annual Corridor Person-Miles During the Peak Periods Only			70,167,849	93,557,132	67,231,066	79,568,112	69,763,004	74,196,533
	Daily Corridor Person-Miles			623,714	831,619	597,609	707,272	620,116	659,525
	Annual Corridor Person-Miles			155,928,553	207,904,737	149,402,368	176,818,026	155,028,898	164,881,184
COSTS AND REVENUES	Annual Costs	Install/Implement*		Base Case - all scenarios include this travel component	$3,960,000	$3,960,000	$20,462,873	$3,960,000	$6,349,736
		Capital/Equipment*			$0	$0	$2,242,538	$450,000	$338,800
		Operations & Maintenance			$0	$250,000	$7,000,000	$500,000	$4,735,000
		Enforcement			$0	$360,000	$0	$720,000	$0
		TOTAL			$3,960,000	$4,570,000	$29,705,411	$5,630,000	$11,423,536
	Annual Revenue	Fares					$1,203,017		$515,579
		Lane Use Violations				$741,000		$985,530	$7,410
		Tolls						$2,742,421	
		TOTAL			$0	$741,000	$1,203,017	$3,727,951	$522,989
	NET ANNUAL COST				$3,960,000	$3,829,000	$28,502,394	$1,902,049	$10,900,547
	NET ANNUAL COST PER ADDITIONAL CORRIDOR PERSON-MILE (vs. Base Case) Peak Period Volume Basis				$0.042	$0.057	$0.358	$0.027	$0.147
	NET ANNUAL COST PER ADDITIONAL CORRIDOR PERSON-MILE (vs. Base Case) Daily Volume Basis				$0.019	$0.026	$0.161	$0.012	$0.066

* up-front install/implementation and capital/equipment costs divided by life of component (20 years) to annualize cost

- The “Annual Corridor Person-Miles During the Peak Periods Only” was calculating using the “Corridor Person-Miles During the Peak Periods” value multiplied by 250, which is a reasonable estimate of the number of days during the year that exhibit typical commuter traffic conditions.

- The “Daily Corridor Person-Miles” value was determined by using the sum of the weighted average corridor person-miles for both peak hours, multiplying by the total number of lanes in one direction for the scenario, and then dividing by the estimated percentage of daily traffic represented by the 2 peak hours (i.e., 19%). The “Annual Corridor Person-Miles” was estimated by multiplying the “Daily Corridor Person-Miles” figures by 250.

Cost and Revenue
The cost and revenue figures presented in Table 13 for each multi-modal scenario include installation/implementation, capital/equipment, operations and management, and enforcement components. The annualized figures presented are for comparison purposes only since they are in terms of 2001 dollars as it was the predominant basis in the referenced sources. The values are estimates, and therefore should be used in comparisons with other scenario costs/revenues within the context of this study. Description of the cost/revenue components and the manner in which they were computed are presented below:

1) Annual Costs
The “Install/Implement” values for each scenario were based on information from the 2003 MAG Transportation Plan and the MAG transit study[42]. Some of the cost estimates were reduced proportional to the area comprised in this case study (9 miles) rather than the full length of SR 51 (17 to 18 miles) assessed in the MAG reports. The costs for Scenarios 2, 3, and 5 were based on a lane-mile cost estimate of $4.4 million and amortized based on a 20-year lifespan. Other scenarios had additional installation/implementation costs with the LRT scenario (#4) having costs three to five times more than the other scenarios.

The “Capital/Equipment” values shown in the table were obtained from the same sources used to estimate the install/implementation costs. The value shown for Scenario 5 (HOT Lane) is based on a study[43] which presented information for eight metropolitan areas across the U.S. The average capital and equipment cost to convert an HOV lane to a HOT lane was calculated from this information.

The “Operations & Maintenance” values shown in the table for Scenarios 4 (LRT) and 6 (BRT) were obtained from the MAG transit study (with appropriate proportional of values to match length of study area). The operations and maintenance of Scenario 3

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[42] *High-Capacity Transit Study: Final Report*, Maricopa Association of Governments, June 30, 2003, pp. 79-80.
[43] *HOT Networks: A New Plan for Congestion Relief and Better Transit* by Robert W. Poole, Jr. and C. Kenneth Orski (February 2003) (Reason Public Policy Institute), http://www.rppi.org/ps305.pdf, p. 8.

(HOV Lane) was assumed to be about 6% of the installation/implementation cost. Similarly, the estimate shown for Scenario 5 (HOT Lane) was assumed to be about 12%, as it requires more elaborate operations and involves more equipment to maintain.

"Enforcement" cost estimates were only applicable to Scenarios 3 (HOV Lane) and 5 (HOT Lane). The estimate of enforcement costs for HOV operations was based on information presented in an Arizona Department of Transportation Arizona Transportation Research Center (ATRC) research report,[44] which indicated that moderate enforcement costs were about $20,000 per mile per year. Similar to the reasoning for the operations and maintenance estimate for Scenario 5 (HOT Lane), the enforcement estimate for this scenario was assumed to be double the value estimated for the HOV lane scenario.

2) Annual Revenue
The fares collected from travelers in Scenarios 4 (LRT) and 6 (BRT Lane) offset their associated costs. Although the offset may not be a direct interaction, for the purposes of this case study, all costs associated with a particular scenario were countered with any associated revenue. The same MAG transit study, which had detailed information and estimates tailored to the future operations of SR 51, was referenced to obtain the fare revenue estimates (with discounting based on study are lengths) shown in the table. The particular calculation for the BRT fares was based on the fare estimate for the LRT scenario with a proportional adjustment based on the ridership data presented in the upper section of the table.

Other revenue is possible from lane use violations under Scenarios 3 (HOV Lane), 5 (HOT Lane), and 6 (BRT Lane). The revenue from HOV lane violations was based on the following assumptions/calculation:

Actual cited HOV violations assumed to be only 10% of the average 10% violation rate observed in other cities[45] (i.e., 1% of the AM + PM peak hour HOV volume shown in upper portion of table), which was then multiplied by 250 work days and then by the average traffic ticket amount of $200.

HOT Lane violations were assumed to be about the same, although the volume factor within the calculation differed between the scenarios. The lane use violations associated with Scenario 6 (BRT Lane) were assumed to be even lower, and were estimated at 10% of the value shown for the HOV Lane scenario.

The last component of revenue would be from tolls, which would only be associated with the HOT Lane scenario. The estimate shown in the table is from the HOT Lane conversion study,[46] which presented an average fare of 23.5 cents per mile per non-HOV

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[44] *HOV Lanes: Issues & Options for Enforcement*, Final Report 552, Arizona Department of Transportation ATRC, June 2004, p. 25.
[45] *Ibid, p. 28, 31.*
[46] *HOT Networks: A New Plan for Congestion Relief and Better Transit* by Robert W. Poole, Jr. and C. Kenneth Orski (February 2003) (Reason Public Policy Institute), http://www.rppi.org/ps305.pdf, p. 8.

vehicle type. The operational volume data and the previously presented assumption of a 33% increase in lane volume representing non-HOV (tolled) traffic were then referenced and converted to annual values (i.e., 250 working days per year) in order to facilitate the estimated revenue from HOT Lane tolls.

Scenario Comparisons

The net annual costs shown in Table 13 reflect the relationship of costs and revenues for each scenario. The values cannot be compared directly as is because each scenario offers a different capacity for transporting people. Therefore, the net annual costs (no scenario was estimated to generate more annual revenue than cost) were divided by the additional corridor person-miles associated with the scenario relative to the base case—Scenario 1 (three GP lanes in each direction only). This calculation was performed in two ways, using the peak period volume basis and the daily volume basis, since some of the scenarios involved operations that are only in effect for portions of the day.

The results of the calculations show that the most cost effective way to transport additional corridor person-miles, given the base configuration of three GP lanes in each direction, is to implement a HOT Lane that allows for free use by HOV vehicles and tolled use by non-HOV vehicles. The results show that the HOT Lane scenario is about 35% more cost effective than the next best scenario—implementing a fourth GP lane. For perspective, the HOT Lane would be about 92% more effective than the LRT option.

Conclusions

Within the parameters of this case study, several multi-modal choices could have been possible for implementation within the study section of the SR 51 freeway. The evaluation of these hypothetical conditions results in the following ranking of the modes that provide the most cost-effective means of accommodating increased person-miles of travel:

1. HOT Lane ($0.012 to $0.027 per person-mile)
2. Fourth GP Lane ($0.019 to $0.042 per person-mile)
3. HOV (w/BRT) Lane ($0.026 to $0.057 per person-mile) (existing condition)
4. Exclusive BRT Lane ($0.066 to $0.147 per person-mile)
5. Light Rail Transit ($0.161 to $0.358 per person-mile)

The implementation of the above forms of travel would vary in complexity and time. With respect to the freeway configuration (i.e., 3 GP lanes in general) prior to the existing conditions (3 GP + HOV lane), the addition of a fourth GP lane would have been the easiest. Implementation would have increased in complexity for the following modes: 1) Exclusive BRT lane / HOV lane (with BRT); 2) HOT Lane; and 3) Light Rail Transit. This qualitative ranking then suggests that the implementation of the fourth GP lane may be even more comparable with the HOT Lane scenario despite the differences in cost-effectiveness.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATION

CONCLUSIONS

Examples of Multi-Modal Applications in Other States

The concept of managed lanes is becoming more popular as states cope with increasing traffic demands. Alternative forms of travel within the freeway corridors, such as rail and light rail are also being employed. Although states have considered the benefits and disadvantages to certain multi-modal forms of travel, and especially with respect to public opinion, very limited data was located as part of this study that specifically presented statistics for measures of effectiveness.

Survey of Other Departments of Transportation

The survey distributed to other state DOTs was developed to obtain, either directly or indirectly, information concerning multi-modal applications involving the use of the freeway right-of-way area. Forty-four DOTs were contacted or an attempt to contact was made, which resulted in specific contact people or information for 29 DOTs, of which 9 responded. HOT Lanes, Exclusive-Use Lanes, By-pass/ Separation Lanes, Dual Facilities, and LRT had the highest number of responses for not being used as a multi-modal application within a freeway corridor. The survey replies did allow for a more detailed discovery of department-specific studies that had been conducted in order to compare multi-modal use and effectiveness. Many of the conclusions from those studies were dependent on local conditions for the area being studied as there was no one mode that prevailed from state to state. This additional information supported the conclusion that although states are aware that selecting multi-modal forms for implementation involves many factors, no one state had complied the steps into a formal process.

SR 51 Case Study for Multi-Modal Selection

The point of the case study is to show the various factors that should be considered when deciding what form of multi-modal travel would be best for a particular corridor. Although the ultimate modal decision for the case study is of interest, the aspects that had to be considered in the process should be meaningful as well. The SR 51 case study relied on existing data, modeled situations, and cost estimates to determine the most cost effective choice for multi-modal travel, which was concluded to be HOT lanes with the added functionality that BRT buses would be able to use the lane as well.

RECOMMENDATION

In the course of investigating multi-modal applications within other states and how they might operate in Arizona (per the SR 51 case study), it seems that HOT lanes would offer the most cost-effective means of maximizing travel via multiple forms of transportation within an urban freeway corridor. Moreover, bus rapid transit could use the HOT lanes thereby multiplying the benefit of the lanes, much as they are able to do currently with the HOV lanes in place throughout the Phoenix metropolitan area. Since HOT lanes would generate revenue to offset and eventually pay for the cost of implementation, at some point excess revenue would be available to finance HOT lane upgrades like direct access ramps and expansion of the system. The operation of HOT lanes would also allow for continued BRT operations, which would only enhance the cost-effectiveness of the system as a whole since it would be accommodating single occupant vehicles, high occupancy vehicles, and large capacity buses. Furthermore, the existing HOV system of lanes provides the foundation for implementing the HOT lane facilities.

APPENDIX: OPERATIONAL CHARACTERISTICS OF SELECTED FREEWAY/EXPRESSWAY HOV FACILITIES (JULY 2003)

HOV Facility	Number of Lanes	Route Length kilometers (miles)	HOV Operation Period[1]	General Eligibility Requirements	Changes in Rules Since Opening
Busway					
Miami, FL (US 1, southwest corridor)	1 each direction	5 (3)	24 hours	Buses only	Feeds Metro rail line
Ottawa, Ontario, Canada 32.2 kilometers (19.3 miles)					
Southeast Transitway	1 each direction	10 (6)	24 hours	Buses only	No
West Transitway	1 each direction	8.5 (5.1)	24 hours	Buses only	No
Southwest Transitway	1 each direction	3.6 (2.2)	24 hours	Buses only	No
East Transitway	1 each direction	6.6 (4)	24 hours	Buses only	No
Central Transitway	1 each direction	3.5 (2.1)	24 hours	Buses only	No
Pittsburgh, PA					
East Patway	1 each direction	9.9 (6.2)	24 hours	Buses only	No
South Patway	1 each direction	6.6 (4.1)	24 hours	Buses only	No
Airport Busway	1 each direction	8 (5)	24 hours	Buses only	No
Wabash reversible HOV/busway	1 reversible	1.6 (1)	Peak periods	2+ HOVs	No
Minneapolis, MN					
Univ. of Minnesota Intercampus Busway	1 each direction	5 (3.1)	24 hours	Buses only	Internal circulator
Dallas, TX					
SW Texas Medical Center elevated busway	1 each direction	1 (0.6)	24 hours	Buses only	Internal circulator
Seattle, WA					
E-3 Busway/downtown bus tunnel	1 each direction	3.5 (2.1)	24 hours	Buses only	No
Barrier-Separated (concrete): Two-Way					
Los Angeles, CA					
I-10 (El Monte) San Bernardino Freeway	1 each direction	6.4 (4)	24 hours	3+ HOVs	Changed to 3+ peak hours, 2+ off peak
I-105/I-110 freeway/freeway connectors	1 each direction	1.6 (1)	24 hours	2+ HOVs	No
Orange County, CA I-5	1-2 each direction	7.2 (4.5)	24 hours	2+ HOVs	No
Houston, TX I-610/US 290 elevated, opposing flow not separated	1 each direction	2.4 (1.5)	5 am to 12 noon, 2-9 pm	2+ HOVs	No
Seattle, WA					
Seattle, WA I-90	1 each direction	2.4 (1.5)	24 hours	2+ HOVs	No
Seattle, WA I-5/I-90 ramps to bus tunnel	1 each direction	1 (0.7)	24 hours	2+ HOVs peak buses only reverse peak	No
Barrier-Separated: Reversible-Flow					
San Diego, CA I-15[5] HOV/toll facility	2 reversible	16.3 (9.8)	6-9 am SB, 3-6:30 pm NB	2+ HOVs/ toll SOVs	HOV/tolling demo in effect since 1996
Denver, CO					
US 36 (incl. connector to I-25)	1 lane reversible	2.0 (1.2)	5-10 am SB, M-F, 12 pm-3 am M-F& Sat-Sun	2+ HOVs	No
I-25	1 and 2 lanes reversible	8.3 (4.9)		2+ HOVs	No, cong pricing under study
Minneapolis, MN I-394	2 reversible	4.3 (2.7)	6-1 pm, 2-12 am weekends vary	2+ HOVs	No
Pittsburgh, PA I-279/579	1-2 reversible	6.6 (4.1)	5-9 am, noon-8 pm	2+ HOVs, all traffic NB after 8 pm during sports games	Originally 3+
Dallas, TX					
I-35E RL Thornton/Marvin D. Love Freeway	1 lane reversible, downtown ramps	18.5 (11.1)	6-9 am, 3:30-7 pm	2+ HOVs	No

HOV Facility	Number of Lanes	Route Length kilometers (miles)	HOV Operation Period[1]	General Eligibility Requirements	Changes in Rules Since Opening
Houston, TX					
I-10 (Katy Freeway) HOV/toll facility (priced for 2-occupant buy-in during 3+ only operation periods)	1 reversible	25.8 (16)	5 am-12 noon EB, 5 am-5 pm WB; Sat. WB, Sun EB 5 am-9 pm.	3+ peak hours, 2+ other times, HOV-2 priced in peaks	Yes, started for authorized vehicles, then 3+, then 2+ prior to current operation
I-45 (Gulf Freeway)	1 reversible	21 (13.1)	5 am to 12 noon, 1-9 pm	2+ HOVs	Originally 3+
US 290 (Northwest Freeway)	1 reversible	21.6 (13.5)	same as I-10 above	same as I-10 above	same as I-10 above, HOV-2-is priced
I-45 (North Freeway)	1 reversible	31.6 (19.7)	5 am to 12 noon, 1-9 pm	2+ HOVs	Peak periods expanded 12/99
US 59 (Eastex Freeway)	1 reversible	30.5 (18)	5 am to 12 noon, 1-9 pm	2+ HOVs	No
US 59 (Southwest Freeway)	1 reversible	20 (12.5)	5 am to 12 noon, 1-9 pm	2+ HOVs	Peak periods expanded 12/99
Northern Virginia					
I-95 (Shirley Highway)	2 lanes reversible	46 (27)	6-9 am NB, 3:30-6 pm SB	3+ HOVs	Was 4+, now mixed use on weekends
Norfolk, VA I-64	2 reversible	11.8 (7)	6-8 am, 4-6 pm	2+ HOVs	Peak hours reduced
Seattle, WA					
I-5 North (Express Lanes)	2-4 reversible	SB 6.9 (4.3), NB 3.1 (1.9)	5-11 am SB, noon-11 pm NB	GP in 3-4 lane section, 2+ HOVs on ramps and 2-lane portion	Originally 3+ NB
I-90	2 reversible	9.9 (6.2)	5-11 am, noon – 11 pm	GP to Mercer Island, 2+ HOVs beyond	No
<u>Concurrent-flow: Buffer-Separated and Non-Separated</u>					
Phoenix, AZ (all buffer separation)					
I-10 W	1 each direction	33.6 (21)	6-9 am, 4-7 pm	2+ HOVs	Originally 3+
I-10 E (91st to Chandler Road)	1 each direction	8 (5)	6-9 am, 4-7 pm	2+ HOVs	No
SR 202	1 each direction	14.4 (9)	6-9 am, 4-7 pm	2+ HOVs	Changed hours
I-17	1 each direction	11.2 (7)	6-9 am, 4-7 pm	2+ HOVs	Changed hours
Vancouver, BC, Canada					
H-1 Trans Canada Highway	1 each direction	4 (6)	24 hours	2+ HOVs	No
H-99	1 each direction	SB 6.4 (4), NB 1.6 (1)	24 hours	3+ HOVs	Originally bus only
Los Angeles County, CA (all buffer separation)					
I-10 (El Monte) San Bernardino Freeway-(wide buffer separation)	1 each direction	12.8 (8)	24 hours	3+ peaks, 2+ HOVs off-peak	Now 3+ during peaks, 2+ off peak as of 1/01[5]
I-105	1 each direction	25.6 (16)	24 hours	2+ HOVs	No
I-110	2 each direction	17.8 (10.7)	24 hours	2+ HOVs	No
I-210	1 each direction	35.8 (21.5)	24 hours	2+ HOVs	No
I-405	1 each direction	75.6 (44.6)	24 hours	2+ HOVs	No
I-405 (San Fernando Valley)	1 each direction	5 (8)	24 hours	2+ HOVs	No
I-605	1 each direction	29 (17)	24 hours	2+ HOVs	No
SR-14[5]	1 each direction	10.8 (6.4)	5-9 am SB 3-7 NB	2+ HOVs	Demo. project for part time operation
SR-30	1 each direction	10 (6)	24 hours	2+ HOVs	No
SR 57	1 each direction	7.6 (4.5)	24 hours	2+ HOVs	No
SR 60	1 each direction	12 (7)	24 hours	2+ HOVs	No
SR 91	1 each direction	22.9 (14.3)	24 hours	2+ HOVs	Originally peak periods
SR 118	1 each direction	18.2 (11.4)	24 hours	2+ HOVs	No
SR 134	1 each direction	22.1 (13.3)	24 hours	2+ HOVs	No
SR 170	1 each direction	9.8 (6.1)	24 hours	2+ HOVs	No

HOV Facility	Number of Lanes	Route Length kilometers (miles)	HOV Operation Period[1]	General Eligibility Requirements	Changes in Rules Since Opening
Orange County, CA (all buffer separation)					
I-5	1-2 each direction	58 (34.3)	24 hours	2+ HOVs	No
I-405	1 each direction	38.4 (24)	24 hours	2+ HOVs	No
SR 55	1 each direction	19.7 (12.3)	24 hours	2+ HOVs	No
SR 57	1 each direction	19.2 (12)	24 hours	2+ HOVs	No
SR 91	1 each direction	15.7 (9.3)	24 hours	2+ HOVs	No
Orange County, SR 91 toll lanes[2]	2 each direction	16.2 (10.1)	24 hours	Toll SOVs w/ no HOV-3 toll	OCTA purchased private road in 2002
Riverside County, CA					
SR 91 (buffer separation)	1 each direction	27.2 (17)	24 hours	2+ HOVs	No
San Bernardino County, CA (buffer separation)					
I-10	1 each direction	17(10)	24 hours	2+ HOVs	opened 09/00
SR 30	1 each direction	NA	24 hours	2+ HOVs	No
SR 60	1 each direction	17 (10)	24 hours	2+ HOVs	No
SR 71	1 each direction	14.2 (8.4)	24 hours	2+ HOVs	No
Santa Clara/San Mateo Counties, CA					
US 101	1 each direction	51.6 (31)	5-9 am, 3-7 pm	2+ HOVs	No
SR 237	1 each direction	9.6 (6)	5-9 am, 3-7 pm	2+ HOVs	No
SR 85	1 each direction	38 (24)	5-9 am, 3-7 pm	2+ HOVs	No
I-280	1 each direction	17.6 (11)	5-9 am, 3-7 pm	2+ HOVs	No
Capitol Expressway (shoulders)	1 each direction	8.3 (5)	5-9 am, 3-7 pm	2+ HOVs	No
Lawrence Expressway (shoulders)	1 each direction	17 (10)	5-9 am, 3-7 pm	2+ HOVs	No
Montague Expressway (shoulders)	1 each direction	9.6 (6)	5-9 am, 3-7 pm	2+ HOVs	No
San Tomas Expressway (shoulders)	1 each direction	12.8 (8)	6-9 am, 3-7 pm	2+ HOVs	No
Alameda County, CA					
I-880	1 each direction	34 (20)	5-9 am, 3-7 pm	2+ HOVs	No
I-680	1 each direction	20.8 (12.3)	6-9 am , 3-6 pm	2+ HOVs	No
I-580	1 each direction	9.8 (6.1)	7-8 am EB, 5-6 pm WB	2+ HOVs	No
Contra Costa County, CA					
I-80	1 each direction	7.1 (4.2)	5-10 am WB, 3-7 pm EB	3+ HOVs	No
Marin County, CA US 101 (2 projects)	1 each direction	16.7 (10)	6:30-8:30 am SB, 4:30-7 pm NB	2+ HOVs	Changed from 3+
Sacramento, CA					
I-80	1 each direction	6.7 (4)	6-10 am, 4-7 pm	2+ HOVs	No
SR 99	1 each direction	6.2 (3.9)	6-10 am, 4-7 pm	2+ HOVs	Reduced hours
US 50	1 each direction	11 (7)	6-10 am, 4-7 pm	2+ HOVs	opened Aug 02
San Diego County, CA					
I-5	1 each direction	5 (3)	3-7 pm NB	2+ HOVs	No
SR 54	1 each direction	5.4 (3.2)	6-9 am WB, 3-7 pm EB	2+ HOVs	No
SR 163	1 ent. ramp	0.7 (0.4)	24 hours	2+ HOVs	No
Denver, CO, US 36 (buffer separated)	1 each direction	5.6 (3.3)	24 hours	2+ HOVs	Opened 3/01
Hartford, CT					
I-84 (wide buffer separation)	1 each direction	18.4(11.5)	24 hours	2+ HOVs	Extension opened ‘01
I-91 (wide buffer separation)	1 each direction	14.4 (9)	24 hours	2+ HOVs	No
Ft. Lauderdale, FL I-95 (buffer separated)	1 each direction	43.2 (27)	7-9 am, 4-6 pm	2+ HOVs	No
Miami, FL					
I-95	1 each direction	52 (32)	7-9 am SB, 4-6 pm NB	2+ HOVs	No
I-95 freeway/freeway ramp	2-way	5 (3)	7-9 am SB, 4-6 pm NB	2+ HOVs	No
Orlando, FL I-4	1 each direction	48 (30)	7-9 am SB 4-6 pm NB	2+ HOVs	No
Atlanta, GA (buffer separated)					
I-20	1 each direction	14 (8.5)	WB 6:30-9:30 am,	2+ HOVs	No

HOV Facility	Number of Lanes	Route Length kilometers (miles)	HOV Operation Period[1]	General Eligibility Requirements	Changes in Rules Since Opening
			EB 4:30-7 pm		
I-75/I-85 central section	1 each direction	12.5 (7.5)	24 hours	2+ HOVs	No
I-75	1 each direction	19.3 (11.6)	24 hours	2+ HOVs	No
I-85	1 each direction	41 (23.9)	24 hours	2+ HOVs	No
Honolulu, HI					
Moanaloa Freeway	1 each direction	3.8 (2.4)	6-8 am, 3:30-6 pm	2+ HOVs	No
Kalanianaole Highway	1 (WB only)	3.2 (2.0)	5-8:30 am	2+ HOVs	No
H-1	1 each direction	12.8 (8)	6-8 am, 3:30-6 pm	2+ HOVs	No
H-2	1 each direction	13.1 (8.2)	6-8 am, 3:30-6 pm	2+ HOVs	No
Maryland (buffer separated)					
US 29 (shoulders)	1 each direction	4.8 (3)	Peak periods only	Buses only	No
I-270	1 each direction	25.8 (15.5)	SB 6-9 am, NB 3:30-630 pm	2+ HOVs	No
I-270 (western spur)	1 each direction	5 (3)	SB 6-9 am, NB 3:30-630 pm	2+ HOVs	No
I-270 (eastern spur)	1 each direction	5 (3)	SB 6-9 am, NB 3:30-630 pm	2+ HOVs	No
US 50 (Prince George's County)	1 each direction	12 (7.5)	24 hours	2+ HOVs	No
Boston, MA I-93 North	1 (SB only)	1.8 (1.1)	6:30-9:30 am	2+ HOVs	Changed from 3+
Minneapolis, MN					
I-35W	1 each direction	NB 9.2 (5.7), SB 10.1 (6.3)	NB 6-9 am & 3-6 pm, SB 6-9 am & 3-6 pm	2+ HOVs	No
I-394	1 each direction	EB 12.4 (7.7), WB 9.8 (6.1)	EB 6-9 am, WB 3-6 pm	2+ HOVs	No
New Jersey Turnpike	1 each direction	16 (10)	Peak periods only	3+ HOVs	No
New York City, NY.[6]					
Gowanus Expressway	1 inbound only	2.2 (1.3)	6-10 am	2+ HOVs	No
Staten Island Expressway	1 inbound only	1.6 (1)	6-10 am	Bus only	Opened in 2000
Suffolk and Nassau County, NY I-495 (buffer separated)	1 each direction	50 (30)	6-10 am, 3-8 pm	2+ HOVs	Yes, changed hours 10-mile ext. opened in 1999
Portland, OR, I-5	1 northbound	5 (3)	NB (PM) peak period only	2+ HOVs	Opened 10/98, partial lane conversion
Ottawa, Ontario, Canada					
Hwy. 417 (outside shoulders)	1 each direction	4.8 (3)	Peak periods	Buses only	No
Road 174 Orleans (outside shoulders)	1 each direction	4.8 (3)	Peak periods	Buses only	No
To Toronto-Mississauga, Ontario, Canada Hwy. 403 (outside shoulders)	1 each direction	4 (2.6)	Peak periods	Buses only	Opened Nov. 03
Memphis, TN I-40	1 each direction	13 (8)	7-9 am WB, 4-6 PM EB	2 + HOVs	No
Nashville, TN					
I-65 (South)	1 each direction	11.5 (7.2)	7-9 am NB, 4-6 pm SB	2+ HOVs	No
I-40	1 each direction	8.3 (5)	7-9 am WB, 4-6 pm EB	2+ HOVs	No
Dallas, TX (buffer separated)					
US 67 Marvin D. Love Freeway	1 each direction	6.4 (4.0)	24 hours	2+ HOVs	Opened Aug. 2000
I-35E (Stemmons Freeway)	1 each direction	SB 11.7 (7.3), NB 9.7 (6.0)	24 hours	2+ HOVs	No
I-635 (LBJ Freeway)	1 each direction	EB 11 (6.8), WB 9.8 (6.1)	24 hours	2+ HOVs	No
Houston, TX					
I-10 Katy (narrow buffer separated)	1 each direction	9.3 (5.5)	5 am-12 noon EB, 2-9 pm WB, Sat WB,	3+ peak hours, 2+ other times	Opened March 2001

HOV Facility	Number of Lanes	Route Length kilometers (miles)	HOV Operation Period[1]	General Eligibility Requirements	Changes in Rules Since Opening
			Sun. EB.		
Salt Lake City, UT, I-15 (buffer separated)	1 each direction	10 (16)	Peak periods only	2+ HOVs	opened in summer '01
Seattle, WA (single solid stripe separated)					
I-5 North	1 each direction	22.5 (13.3)	24 hours	2+ HOVs	North end changed from 3+ in 1993
I-5 South (Kent-Des Moines to downtown)	1 each direction	40.6 (24)	24 hours	2+ HOVs	5 miles added 10/02
I-90	1 each direction	10.6 (6.3)	24 hours	2+ HOVs	No
I-405 (median only-used to be right side in some sections)	1 each direction	45 (26.5)	24 hours	2+ HOVs	Median conversion occurred in 1999
SR 167	1 each direction	16.1 (10)	24 hours	2+ HOVs	No
SR 520 (median east of I-405)	1 each direction	9 (5.4)	24 hours	2+ HOVs	Opened Feb. '00
SR 520 (shoulder)	1 WB only	3.7 (2.3)	24 hours	3+ HOVs	Changed from bus only in AM peak period
Northern Virginia					
I-66 (outside Beltway) [4]	1 each direction	30 (18.5)	EB 5:30-9 am WB 4-6 pm	2+ HOVs	Reduced operating periods
I-66 (inside Capital Beltway) 2 HOV lanes during restricted periods	2-3 each direction	15.2 (9)	EB 6:30-9 am, WB 4-6 pm	2+ HOVs	Was 4+, then 3+
I-267 (Dulles Toll Road)	1 each direction	22 (13)	6:30-9 am, 4-6:00 pm	2+ HOVs	No
I-267 (Dulles Toll Road connector)	inbound only	2.5 (1.6)	AM peak period	buses only	
Norfolk/Hampton/Virginia Beach, VA					
I-64 Hampton/Newport News	1 each direction	13.5 (8)	6-8 am, 4-6 pm	2+ HOVs	
I-64 Norfolk/Virginia Beach/Chesapeake	1 each direction	12 (7)	6-8 am, 4-6 pm	2+ HOVs	
I-264 Norfolk/Virginia Beach	1 each direction	12 (7)	6-8 am, 4-6 pm	2+ HOVs	
I-264 Norfolk	1 each direction	6.7 (4)	6-8 am, 4-6 pm	2+ HOVs	
Vancouver, WA, 1-5	1 each direction	6 (4)	6-8 am	2+ HOVs	Opened Nov. 2001
Vancouver, British Columbia, Canada Trans Canada Highway	1 each direction	12.8 (8)	NA	NA	No
Contraflow					
Honolulu, HI					
H-1(moveable barrier)	1	EB 10 (6)	AM period only	3+ HOVs	Opened 8/98
Kalanianaole Highway	1	WB 7 (4.4), EB 1.6 (1)	5-8:30 am, 4-6:30 pm	2+ HOVs	Changed from 3+
Kahekili Highway	1	1.8 (1.1)	5:30-8:30 am, 3:30-7 pm	2+ HOVs	No
New Jersey, Rte. 495 (to Lincoln Tunnel)	1 EB only	4 (2.5)	6-10 am	Buses only	No
New York City, NY					
I-495 Long Island Expressway	1	6.4 (4)	7-10 am	Buses, vanpools taxis	Moveable barrier pending
Gowanus Expressway/Brooklyn Battery Tunnel, (moveable barrier)	1 inbound only	10.4 (6.2)	6-10 am	2+ HOVs	Originally buses & taxis only
Dallas, TX I-30, (East R.L. Thornton Freeway) moveable barrier	1 each peak direction	8.3 (5.2)	6-9 am, 4-7 pm	2+ HOVs	No
Boston, MA I-93 Southeast Expressway (moveable barrier)	1 each peak direction	9.6 (6)	6-10 am, 3-7 pm	2+ HOVs	Additional hour added in AM period, lowered to 2+ HOVs on 6/99
Montreal, Quebec, Canada Rte. 10/15/20 Champlain Bridge	1	6.9 (4.3)	6:30-9:30 am NB, 3:30-7 pm SB	Buses only	Speed limit reduced
Queue Bypasses					
Bay Area, CA					
S.F./Oakland Bay Bridge toll plaza, I-80 and I-880	3	1.4 (0.9)	5-10 am, 3-7 pm	3+ HOVs	Number and location of lanes reoriented
Dumbarton Bridge toll plaza, SR 84	1	3.2 (2)	5-10 am, 3-6 pm	2+ HOVs	Changed from 3+
San Mateo Bridge toll plaza, SR 92	1	3.2 (2)	5-10 am, 3-6 pm	2+ HOVs	Changed from 3+
SR 4	1	0.8 (0.5)	Peak periods	3+ HOVs	No
SR 160 Antioch Bridge	1	NA	5-10 am, 3-6 pm	3+ HOVs	No

HOV Facility	Number of Lanes	Route Length kilometers (miles)	HOV Operation Period[1]	General Eligibility Requirements	Changes in Rules Since Opening
SR 80 Carquinez Bridge	1	0.1	5-10 am, 3-7 pm	3+ HOVs	No
SR 680 Benicia/Martinez Bridge	1	0.1	5-10 am, 3-7 pm	3+ HOVs	No
Various freeway entrance ramps	1	0.2 (0.1)	When demand warrants	2+ HOVs	No
Los Angeles and Orange Counties, CA					
Over 250 freeway entrance ramps	1	0.2 (0.1)	When demand warrants	2+ HOVs	No
San Diego, CA					
Various entrance ramps			As warranted	2+ HOVs	No
Coronado Bridge toll plaza	1 (WB only)	0.2 (.1)	24 hours	2+ HOVs	No
A Street entrance ramp to I-5 freeway	1	0.6 (0.4)	24 hours	Buses only	No
I-5/Mexico port of entry	4 gates	0.2 (0.1)	24 hours M-F	4+ HOVs	No
Honolulu, HI, H-2	1 (SB only)	1.3 (0.8)	6-8 am, 3:30-6 pm	2+ HOVs	No
Illinois, Chicago, I-90 toll plaza	1 (EB only)	0.8 (0.5)	Peak periods	Buses only	No
Minneapolis, MN, Various entrance ramps and bus-only use of right shoulders during selected hours under congested conditions	78 entrance ramps and various freeway routes	varies	Peak periods	2+ HOVs	No
Minneapolis, MN, Bus-only use of right shoulders on I-35W and other routes during selected hours under congested conditions	varies	varies	Peak periods	Bus only	No
New Jersey					
Ft. Lee, I-95 (to George Washington Bridge)	1 (EB only)	1.6 (1)	7-9 am	3+ HOVs	No
Ottawa, Ontario, Canada					
Hwy. 417 Bus only ramp (Acres Road)	1	0.3 (0.2)	24 hours	Buses only	No
Dallas, TX, I-35E Stemmons reversible lane	1 (NB and SB)	1.0 (0.7)	6-9 am, 4-7 pm	2+ HOVs	No
Union, Rte. 495 (Lincoln Tunnel toll plaza)	1 (WB only)	0.5 (0.3)	6-10 am	Buses only	No
Seattle, WA					
SR 509 shoulder	1 (NB only)	1.3 (0.8)	24 hours	2+ HOVs	Changed from 3+
SR 526	1	0.8 (0.5)	24 hours	Buses only	No
Freeway entrance ramps (69)[3]	1	0.2 (0.1)	24 hours	2+ HOVs	No
Ferry terminal docks, downtown and other locations	2	0.2 (0.1)	Peak hours	Registered car/ vanpools only	No

Footnotes:

1 Part-time periods are 5-day week, typically in both directions or in peak directions as noted.

2 This project is a privatized toll road with congestion pricing. Registered 3+ HOVs can travel for a reduced toll.

3 Included are 39 metered ramps and 30 non-metered ramps.

4 Portions of HOV lane are converted from left side general purpose lane, while outside shoulder becomes a general purpose lane.

5 Due to state legislation, the SR 14 HOV lanes are undergoing an 18-month demonstration project of part-time hours. The demonstration started January 2001. The southbound hours are 5-9 am and the northbound hours are 3-7 pm.

6 A number of HOV lanes were operated temporarily over various New York City bridge and tunnel crossings following the 9-11 terrorist attack. Most of these lane treatments had been suspended by the end of 2001 and are not reported in this inventory.