Managed Lanes:
Current Status and Future Opportunities

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16. Abstract

The continuous increase in automobile use is directly related to the increase in congestion and decline in air quality in urban settings. In response to this reality, transportation agencies across the nation employ a number of strategies to reduce traffic demand or spread it over time and space. This can be done by using lane management strategies that regulate demand, separate traffic streams to reduce turbulence, and utilize available and unused capacity. In recent years, application of such operational policies has evolved into the notion of "managed lanes." This study examined the potential role of managed lane strategies in addressing traffic congestion issues in the Birmingham, Alabama, metropolitan area. More specifically, the study first reviewed the state-of-practice on managed lanes and summarized best practices and lessons learned from earlier deployment efforts. Then an assessment of potential operational impact from implementation of High Occupancy Vehicle (HOV) and designated truck lanes along I-65 in Birmingham was performed. This was accomplished through detailed traffic simulation modeling using the VISTA mesoscopic tool. Alternatives considered included a) the conversion of an existing lane into an HOV or truck designated lane and b) the addition of a new HOV lane along the study corridor. A detailed sensitivity analysis was performed to determine the impact of various percentages of HOV and truck use on traffic operations. A comprehensive cost-benefit analysis was also performed to determine the most economically efficient alternative among all HOV options considered. The research findings from this study are expected to benefit both the scientific community and those agencies and authorities responsible for planning, designing, implementing, managing, and operating transportation facilities.

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Contents

List of Tables

List of Figures

Abbreviations

AADT	Average annual daily traffic
AADTT	Average annual daily truck traffic
ALDOT	Alabama Department of Transportation
AVO	Average vehicle occupancy
CBA	Cost Benefit Analysis
CALTRANS	California Department of Transportation
DMS	Dynamic message signs
DOT	US Department of Transportation
DTA	Dynamic traffic assignment
ETC	Electronic toll collection
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
GP	General Purpose
HOT	High Occupancy Toll
HOV	High Occupancy Vehicles
IDAS	Integrated Development Assessment System
I-65	Interstate 65
ILEV	Inherently Low Emission Vehicles
ITS	Intelligent Transportation Systems
MOE	Measures of Effectiveness
MUTCD	Manual of Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
O-D	Origin-destination
ROW	Right-of-way
RPCGB	Regional Planning Commission of Greater Birmingham
TTI	Texas Transportation Institute
TSIS	Traffic Software Integrated System
TxDOT	Texas Department of Transportation
VISTA	Visual Interactive System for Transport Algorithms

Executive Summary

The continuous increase in automobile use is directly related to the increase in congestion and decline in air quality in urban settings. In the past 20 years, the total number of Vehicle Miles Traveled in the United States has increased over 70%, whereas highway capacity grew by only 0.3%. Increased construction costs, right-of-way constraints, and environmental and social issues shifted the interest of transportation agencies from building new roadways to strategies that maximize the operational efficiency of existing facilities.

Transportation agencies across the nation employed a number of strategies to reduce traffic demand or spread it over time and space. This can be done by using lane management strategies that regulate demand, separating traffic streams to reduce turbulence, and utilizing available and unused capacity. In recent years, application of such operational policies is evolving into the notion of "managed lanes."

This study examined the potential role of managed lane strategies in addressing traffic congestion issues in the Birmingham, Alabama, metropolitan area. High Occupancy Vehicle (HOV) lanes and truck-only lanes are among the strategies being considered. More specifically, the study first reviewed the state of practice and summarized best practices and lessons learned from earlier deployment efforts. An investigation of the potential operational impact of managed lane implementation along selected Birmingham facilities followed. This was done through traffic modeling and analysis using sophisticated simulation modeling tools.

Overall, the analysis showed that the conversion of an existing general-purpose lane into HOV has a potential to improve the network performance. The addition of designated HOV lanes is expected to yield even greater benefits as far as traffic operations and cost-benefits are concerned. This finding provides further evidence of the potential of HOV lane use to address urban congestion and environmental concerns. Moreover, it was found that network performance improved when a general-purpose lane is converted to a designated truck lane. Allowing passenger cars to use the designated truck lane yielded the greatest benefits.

The research findings from this study are expected to benefit both the scientific community and those agencies and authorities responsible for planning, designing, implementing, managing, and operating transportation facilities.

Section 1
Introduction

The continuous increase in automobile use is directly related to the increase in congestion and decline in air quality in urban settings. In the past 20 years, the total number of Vehicle Miles Traveled in the United States has increased over 70% whereas highway capacity grew only by 0.3% (FHWA 2004). Increased construction costs, right-of-way (ROW) constraints, and environmental and social issues shifted the interest of transportation agencies from building new roadways to strategies that maximize the operational efficiency of existing facilities by reducing traffic demand or spreading it over time and space. One such strategy is the managed lanes approach that allows for designated lanes to be used only by certain modes or vehicles that meet vehicle occupancy or other requirements. Examples include High Occupancy Vehicle (HOV) lanes; High Occupancy Toll (HOT) lanes or Express Toll lanes; truck-only lanes; and bus-only lanes. Rail on dedicated freeway lanes is also considered as a managed lane option. Managed lanes help to increase the efficiency of roads and thus reduce congestion and decrease travel delay.

Urban areas in Alabama face similar challenges with respect to flow management and congestion mitigation similar to those identified nationwide. In 2005, for example, 12.4 million person-hours were wasted in Birmingham alone due to congestion. This translates to a cost of congestion in the area of $234 million dollars, or nearly five times the figure reported 12 years earlier ($53 million in 1993). The 2005 Urban Mobility Study by the Texas Transportation Institute (TTI) listed Birmingham, AL, as one of the medium-sized urban areas with higher congestion or faster increases in urban congestion than their counterparts (Schrank and Lomax 2005).

Project and Objectives

To address the continually growing problem of urban congestion in the Birmingham, AL, area, this study examined the potential of managed lane strategies for improving traffic operations and assisting in congestion mitigation. This was accomplished through an extensive literature and state-of-the practice review of traffic simulation modeling and cost-benefit analysis (CBA).

The overall study objective was to develop a better understanding of managing lanes and their potential to address congestion issues in urban settings through:

- Identification of key issues related to planning, implementation, and operation of managed lanes.

- Examination of the feasibility of managed lane implementation in the Birmingham, AL, area.

This study is organized into six sections:

- Section 1 discusses the scope and objectives of the research.
- Section 2 summarizes the review of literature related to the implementation of managed lanes.
- Section 3 presents the design of the study and the features of the simulation model used in the analysis, along with model requirements and functions.
- Section 4 summarizes the results obtained from the simulation runs.
- Section 5 discusses the methodology and results obtained from the cost-benefits analysis.
- Section 6 presents conclusions drawn from the results, along with recommendations for future research.

Section 2
Literature Review

With growing traffic demand on US roads, transportation professionals are constantly trying to find new ways to operate existing transportation networks more effectively. Lane management strategies have been used for decades to better maintain the traffic flow on facilities, but the so-called managed lanes concept has emerged recently as a way to utilize existing facilities more effectively. The first examples of managed lanes were seen in late 1960s as curbside lanes dedicated to buses. In the mid 1970s, the term *HOV lane* was introduced and referred to as a managed lane strategy that offered dedicated lanes for vehicles with three or more occupants. By the mid-1980s, federal legislation changed this requirement to two or more occupants. In the mid-1990s, a pricing strategy was considered for several HOV lanes, and the *HOT lane* term was coined. Today there are more than 2,900 lane-miles of managed lanes on US freeways (NCDOT HOV 2007). A summary of lane management operations is shown in Figure 2-1 and a comprehensive list of managed lane projects is available in Table 2-1.

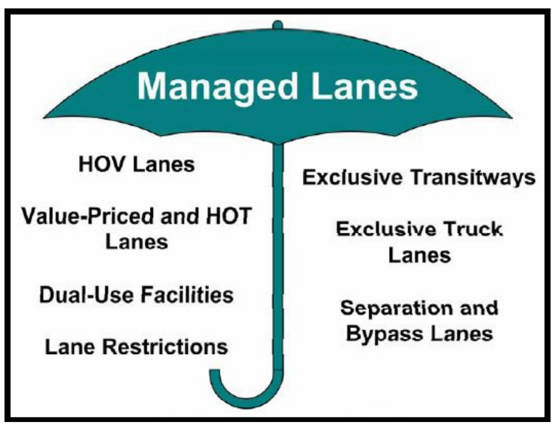

Figure 2-1. Lane management operations (Kuhn, *et al.* 2005)

The literature review revealed numerous definitions for managed lanes as offered by various transportation agencies. The Texas Department of Transportation (TxDOT) defined managed lanes as "a facility that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals" (Lewis 2001). The Federal Highway Administration (FHWA) defined managed lanes as "highway facilities or a set of lanes where operational strategies are proactively implemented and managed in response to changing conditions." They also offer another definition, stating that "the managed lane concept is typically a freeway-within-a-freeway where a set of lanes within the freeway cross section is separated from the general-purpose lanes" (FHWA 2004).

Table 2-1. Comprehensive list of managed lanes projects (TTI 2007)

Location	Name	Length (mile)	Total Lanes
OPERATING			
Houston, TX	Katy I-10 QuickRide	13	1
	Northwest US 290 QuickRide	13.5	1
Minneapolis, MN	I-394 MNPASS	11	2
San Diego, CA	I-15 FasTrak	8	2
Orange County, CA	SR 91 Express Lanes	10	4
Denver, CO	I-25 HOT Lanes	6.5	2
Salt Lake City, UT	I-15 Express Lanes	38	2
UNDER CONSTRUCTION			
Houston, TX	Katy Freeway I-10	23	4
Maryland	I-95 Kennedy Expressway Express Toll Lanes	9	4
UNDER DEVELOPMENT			
Austin, TX	Loop 1 (MoPac)	11	2
Dallas / Ft. Worth, TX	I-635 LBJ Managed Lanes	24	4
	I-30 Managed Lanes	60	2
	I-820/SH183 Managed Lanes	27	2
	I-35W Managed Lanes	20	2
Houston, TX	SH 288 Managed Lanes	18	4
Seattle, WA	I-405 Managed Lanes	30	4
	SR 167 HOT Lanes	9	2
San Diego, CA	I-15 FasTrak Expansion	20	4
	I-5 HOT Lanes	32	4+
	I-805 Managed Lanes	27	4
San Francisco Bay Area, CA	I-680 HOT Lane	14	2
Denver, CO	US 36 Express Toll Lanes	25	4
	I-70 Express Toll Lanes	10	4
	C-470 Express Toll Lanes	14	4
	I-25 North Express Toll Lanes	26	2 to 4
	I-70 Mountain Corridor	35	2
Miami, FL	I-95 HOT to HOT Express Toll Lanes	12	3
Ft. Lauderdale, FL	I-595 Express Lane	13	2
Atlanta, GA	I-285 HOT Lanes	14	2
	I-75/I-575 HOT Lanes	36	4
	GA 400 HOT Lanes	20	4
Maryland	Intercounty Connector (ICC)	18.8	6
	I-270 Express Toll Lanes	23	2 to 4
	I-495 Capital Beltway Express Toll Lanes	42	2
Raleigh/Durham, NC	I-40 HOT Lanes	20	1
Portland, OR	Highway 217 Express Toll Lanes	8	2
Salt Lake City, UT	I-15 Express Lane Extension	9.5	2
Virginia	I-495 Capital Beltway HOT Lanes	12	4
	I-95/I-395 HOT Lanes	54	3 and 2

The main goals for implementing managed lanes include increasing the person-moving capacity of the roadway, supporting the use of transit and ridesharing, optimizing vehicle-carrying capacity, providing travel time savings, and improving air quality (NCDOT HOV 2007).

Three lane management strategies exist: vehicle eligibility, access control, and pricing. These strategies can be used alone or combined with each other (FHWA 2004). Figure 2-2 shows these relations between strategies.

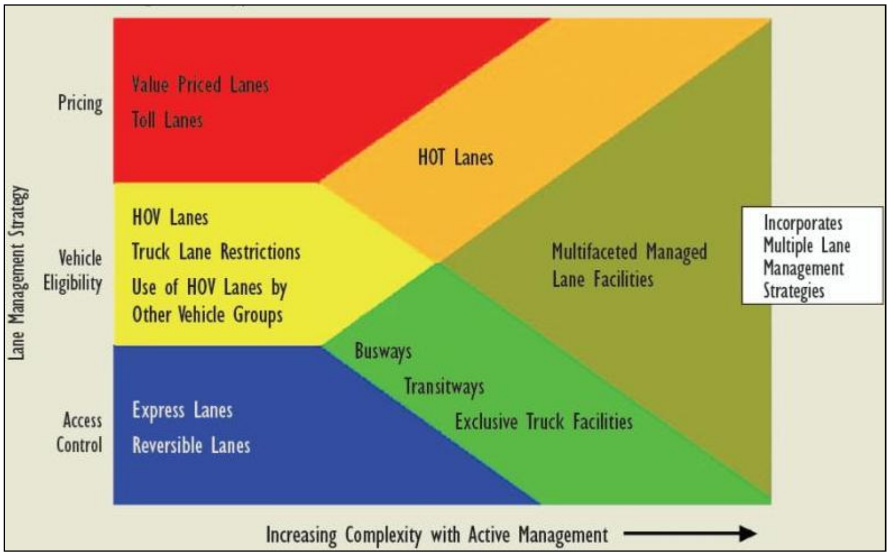

Figure 2-2. Managed lane applications (FHWA 2004)

More specifically, vehicle eligibility refers to managing lanes by allowing access to specific users or restricting others. For example, HOV lanes generally operate on the principal of minimum occupancy, which is based on the number of persons in the vehicle. However, HOV lanes may also allow motorcycles, inherently low emission vehicles (ILEVs) or hybrid vehicles, emergency vehicles, deadheading buses, paratransit vehicles, etc. Vehicle eligibility on managed lanes may be in effect 24 hours/day or vary by time of day or day of week. Especially during peak hours, vehicle occupancy can be set to a minimum of three or more per vehicle on HOV lanes, whereas lower occupancy vehicles may be allowed to enter HOV lanes during off-periods or weekends (FHWA 2004*)*. Figure 2-3 shows an example of lane designation based on vehicle eligibility from the New Jersey Turnpike.

Figure 2-3. New Jersey Turnpike truck/bus lane (Collier and Goodin 2004)

Access control regulates entry and exit movements on the facility according to the congestion level of the corridor without restrictions by user type. The main idea is to ensure that the lanes do not become oversaturated (FHWA 2004). There are a few strategies to control the demand on managed lane facilities, such as limiting access at specific ramps, metering demand at entrance ramps by using traffic meters or gates, and limiting the number of entrance and exit ramps to ensure free-flow speed (NCDOT HOV 2007).

Another related management strategy is pricing. Since the introduction of electronic toll collection (ETC) technology, congestion pricing has been used as a tool to regulate the demand on facilities. The concept is applicable to managed lanes in that it allows access to drivers who are not eligible for travel on managed lanes during peak hours in return for a fee. HOT lanes are examples of this strategy. They can be thought of as HOV lanes with tolls where single-occupant vehicles are given the privilege of using the facility for a reasonable price. The price may be fixed or change dynamically according to the level of congestion. In other words, HOT lanes sell available unused capacity on HOV lanes to vehicles that do not meet the minimum occupancy requirement. Table 2-2 summarizes various lane management strategies along with their management characteristics.

Table 2-2. Lane management strategies (Collier and Goodin 2004)

Management Strategy	**Management Characteristics**	
ELIGIBILITY Eligibility refers to management based on vehicle type or user group.	**Occupancy**	Lanes based on occupancy provide a priority to HOVs. Typically implemented in congested corridors to encourage shift to HOVs. Designed to provide travel time advantage and trip reliability.
	Vehicle	Management based on vehicle type. May provide a superior service as in the case of transit-only facilities. May seek to improve operations by separating vehicles types.
ACCESS CONTROL Limited or controlled access allows management of the flow and throughput of traffic on a facility.	**Express Lanes**	Express lanes have limited access and egress points thereby reducing weaving and disruptions in traffic flow.
	Ramp Meters	Meters control the flow of traffic onto a facility to reduce turbulence, resulting in smoother flow.
PRICE Price refers to management that uses prices to regulate demand	**HOT Lanes**	HOT lanes give access to vehicles that do not meet occupancy requirements by assessing a toll for these vehicles.
	Variable Toll Lanes	Toll lanes may charge a toll that fluctuates depending on time of day, day of week or amount of congestion in an attempt to more effectively distribute traffic.

As mentioned earlier, every corridor has its own operational characteristics. The success of managed lane implementation depends on these characteristics, and localized studies are needed to assess costs and benefits from managed lane implementation (Kuhn, *et al.* 2005).

High Occupancy Vehicle Facilities

HOV Facilities Overview HOV lanes have been used widely in many parts of the United States since the 1970s (NCHRP 1998). Today there are over 125 HOV lanes projects in 30 cities operating over 2,500 lane-miles of HOV facilities and carrying more than 3 million persons everyday (NCDOT 2007).

HOV lanes are restricted lanes for those vehicles that carry people with a minimum occupancy requirement. The main purpose of HOV facilities is to maximize the person-carrying capacity of the roadway, especially during peak hours. Figure 2-4 illustrates the number of vehicles that are needed to carry 45 people by different types of vehicles. Entrance restrictions typically apply to passenger cars carrying fewer than two persons. Also, in many cases, the use of HOV lanes by transit buses, vanpools, and carpools is encouraged to further increase the carrying capacity of HOV lanes and lighten the traffic load of adjacent general-purpose lanes.

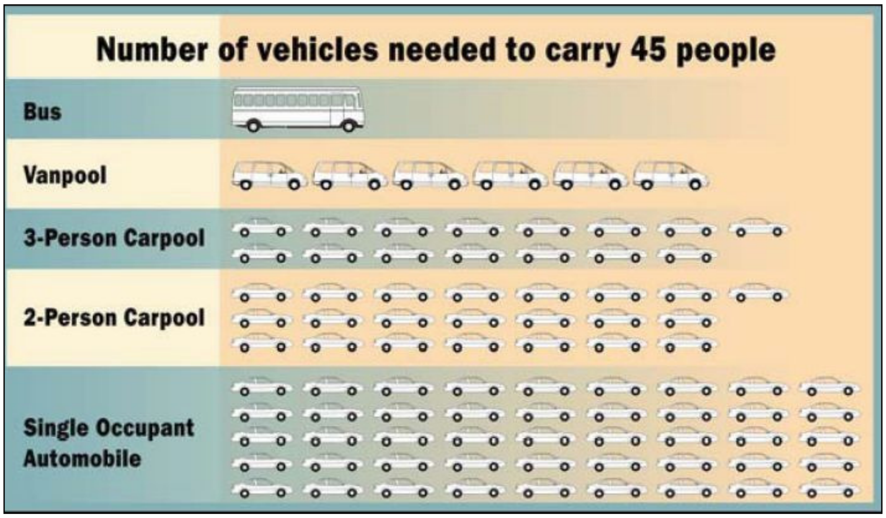

Figure 2-4. Number of Vehicles Needed to Carry 45 People (Turnbull 2006)

In order to ensure that HOV lanes are effective in traffic management and to gain public support and acceptance, it becomes important to determine the conditions under which an HOV lane is suited to a traffic corridor. NCHRP Report 414 offers the criteria to be considered, which include the congestion level of the corridor, travel patterns of the area, current vehicle and truck volumes, passenger vehicle capacity, projected demand of the HOV lane travel times, trip distances, enforcement options, as well as operational and environmental issues related to the implementation of HOV lanes (NCHRP 1998).

The following paragraphs discuss HOV facility options, planning needs, and operational and enforcement issues based on information gathered from an extensive literature and state-of-the-practice review conducted for this study.

Types of HOV Facilities HOV lanes are implemented on freeways or arterial streets (Stockton, *et al.* 1999). HOV lanes on arterial streets are not as popular as HOV lanes on freeways. There are only 32 arterial HOV lane projects throughout the US (Schijns 2006), compared to more than 100 freeway HOV lane projects (NCDOT 2007). There are three types of HOV facilities on freeways (Kuhn, *et al.* 2005): concurrent-flow lanes, contraflow lanes, or separated roadways.

The most common form of HOV lane is the *concurrent flow HOV lane,* which operates in both directions of a corridor, as shown in Figure 2-5. Concurrent flow HOV lanes are characterized as “buffer” and “no buffer” separated. Of all concurrent HOV facilities in the US today 48% are buffer-separated concurrent flow lanes.

Figure 2-5. Concurrent flow, buffer-separated HOV lane, Dallas, TX (Kuhn, *et al.* 2005)

Contraflow HOV lanes (Figure 2-6), on the other hand, use a lane from off-peak direction during peak hours to accommodate HOVs. Usually a moveable barrier is used as a separation. Buses primarily use this type of HOV lane.

Separated HOV lanes are lanes physically separated with a concrete barrier or a wide painted buffer to limit interaction with general-purpose lanes. Separated HOV Lanes can be two-way or reversible. Figure 2-7 illustrates a *two-way barrier-separated* HOV lane in Los Angeles, CA.

Reversible separated HOV lanes (Figure 2-8) are separated HOV lanes where the direction of travel changes by time of day. They generally operate as inbound lanes in the morning and outbound lanes in the afternoon. This strategy provides the maximum use of the lane during peak periods (Kuhn, *et al.* 2005).

Figure 2-6. Contraflow HOV lane, IH-45 North, Houston, TX (Turnbull 2003)

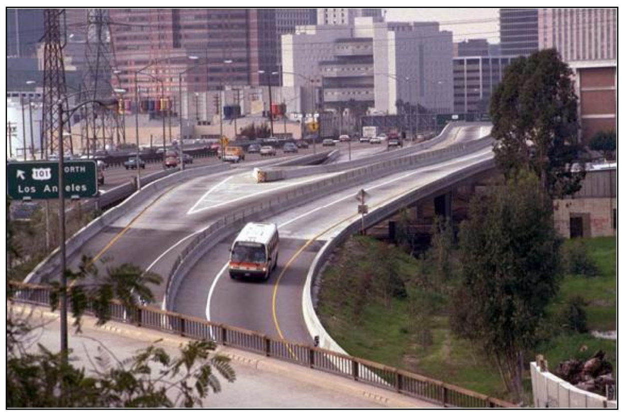

Figure 2-7. Two-way, barrier-separated HOV lane, Los Angeles, CA (Kuhn, *et al.* 2005)

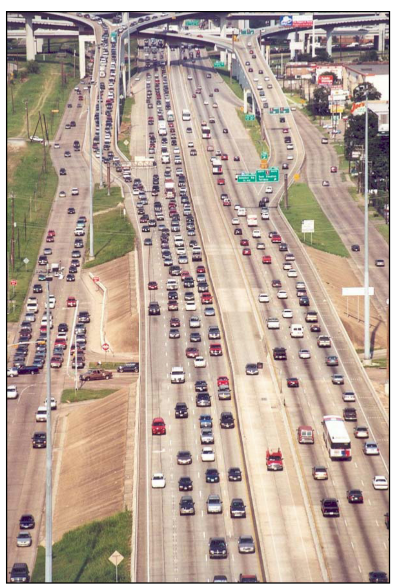

Figure 2-8. Reversible, barrier-separated HOV lane, Houston, TX (Kuhn, *et al.* 2005)

HOV Lane Design Characteristics HOV lane design characteristics are different for each type of HOV lane design. The next paragraphs summarize the main design features of each HOV configuration.

Concurrent Flow HOV Lanes. The travel direction of concurrent flow HOV lanes is the same as the direction of general-purpose lanes. A 12-ft lane is designated in each direction for the use of HOVs. If the concurrent flow lanes are buffer separated, an 8- to 10-ft inside shoulder and a 4-ft buffer should be provided. The buffer should not be less than 1.5 ft. A cross section of buffer-separated concurrent flow lanes is shown in Figure 2-9 (PB 2006).

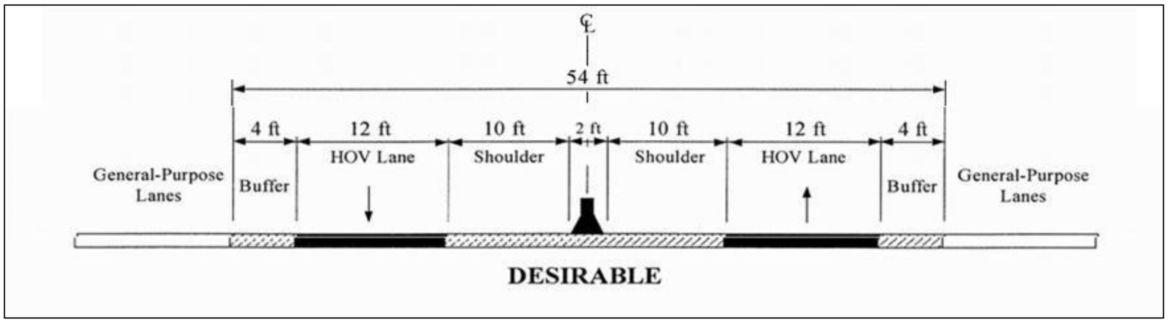

Figure 2-9. Cross section of buffer-separated concurrent flow HOV lanes (PB 2006)

Separated HOV Lanes. A barrier separation can provide a more effective and controlled environment. However, the need for ROW and the cost would be higher under this design, while access is limited. Figure 2-10 illustrates a typical example of two-way barrier-separated HOV lanes (PB 2006).

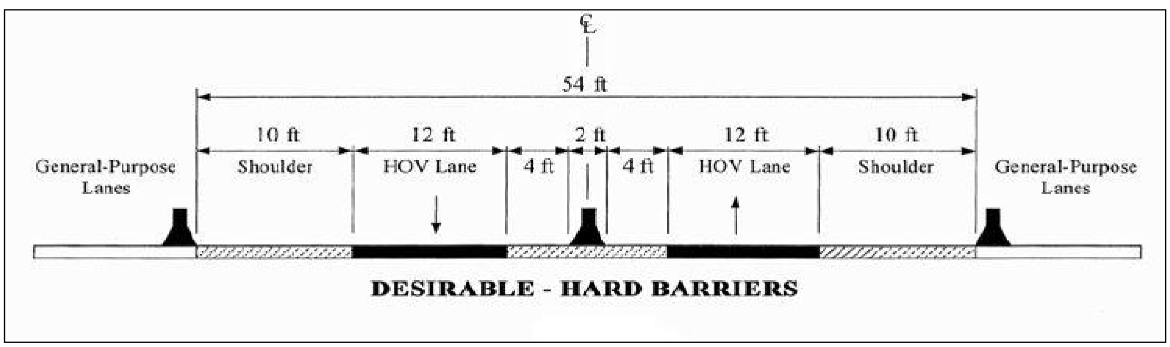

Figure 2-10. Cross section of two-way barrier-separated HOV lanes (PB 2006)

Reversible Separated HOV Lanes. Reversible HOV lanes are typically located in the median and separated from general-purpose lanes with hard barriers. The typical design includes 12-ft lanes with 4-ft shoulders on each side. An example of a cross section of a reversible separated lane is shown in Figure 2-11 (PB 2006).

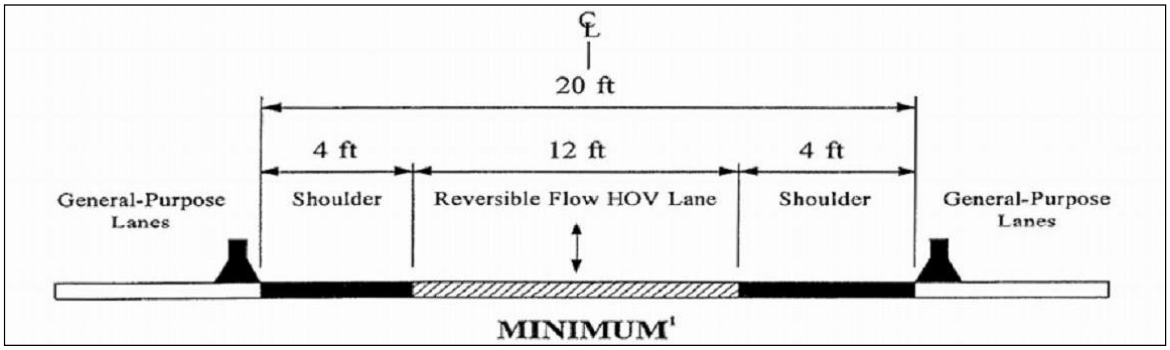

Figure 2-11. Cross section of reversible separated HOV lanes (PB 2006)

Traffic Control Devices and HOV Lanes Drivers may not be always familiar with the access, geometries, and operating rules of HOV lanes. Proper use of traffic control devices to provide such information to drivers is one of the main considerations for effective and safe HOV operation. The Manual of Uniform Traffic Control Devices (MUTCD) recommends the use of a diamond symbol or the word "HOV LANE" as a pavement marking to identify HOV lanes, as shown in Figure 2-12. Also, traffic signs should be installed to inform travelers about the minimum allowable vehicle occupancy requirements and vehicle eligibility. Figure 2-13 provides examples of HOV lane signs as presented in MUTCD-Section 2B (FHWA 2003) and Figure 2-14 shows an implementation site in Phoenix, AZ.

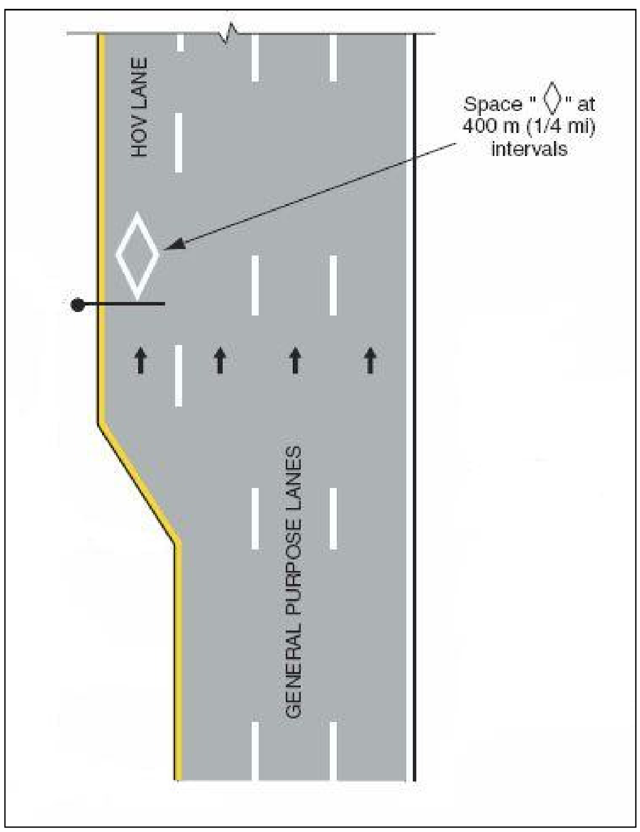

Figure 2-12. HOV lane markings (FHWA 2003)

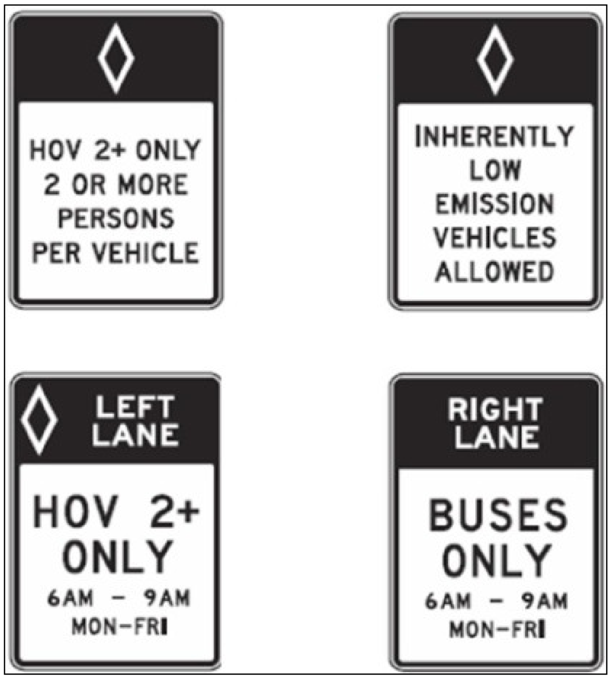

Figure 2-13. Ground-mounted HOV lane signs (FHWA 2003)

Sign placement is another important consideration of HOV facilities. Signs should be placed at appropriate locations (overhead or on the shoulder) to inform drivers about occupancy restrictions and actions that are not permissible. Generally, overhead signs are preferable on freeways. They are easy to notice and are less likely to be blocked by large vehicles; however, they are costly to install and maintain. An example of an overhead HOV lane sign is shown in Figure 2-15. Detailed guidelines for traffic control at HOV facilities are available in the MUTCD and should be adopted when HOV facilities are introduced (FHWA 2003).

Figure 2-14. HOV signage and pavement markings, Phoenix, AZ

Figure 2-15. Overhead HOV lane sign (FHWA 2003)

Special care should be placed on entrance and exit points to eliminate confusion and minimize the risk of crashes due to merging conflicts. HOV ground-mounted guide signs should be provided at least half a mile prior to the entry point of barrier-separated, buffer-separated, and concurrent flow HOV lanes. Recommended signing configurations at such locations are provided in Figures 2-16, 2-17, and 2-18.

Dynamic message signs (DMS) are also often used on HOV facilities. They display up-to-the-minute traffic alerts, construction updates, incident information, and other real-time traffic information. It is also possible to display a diamond symbol on DMSs and other HOV management information, such as restrictions and tolls (Figure 2-19) (Chrysler, *et al.* 2004).

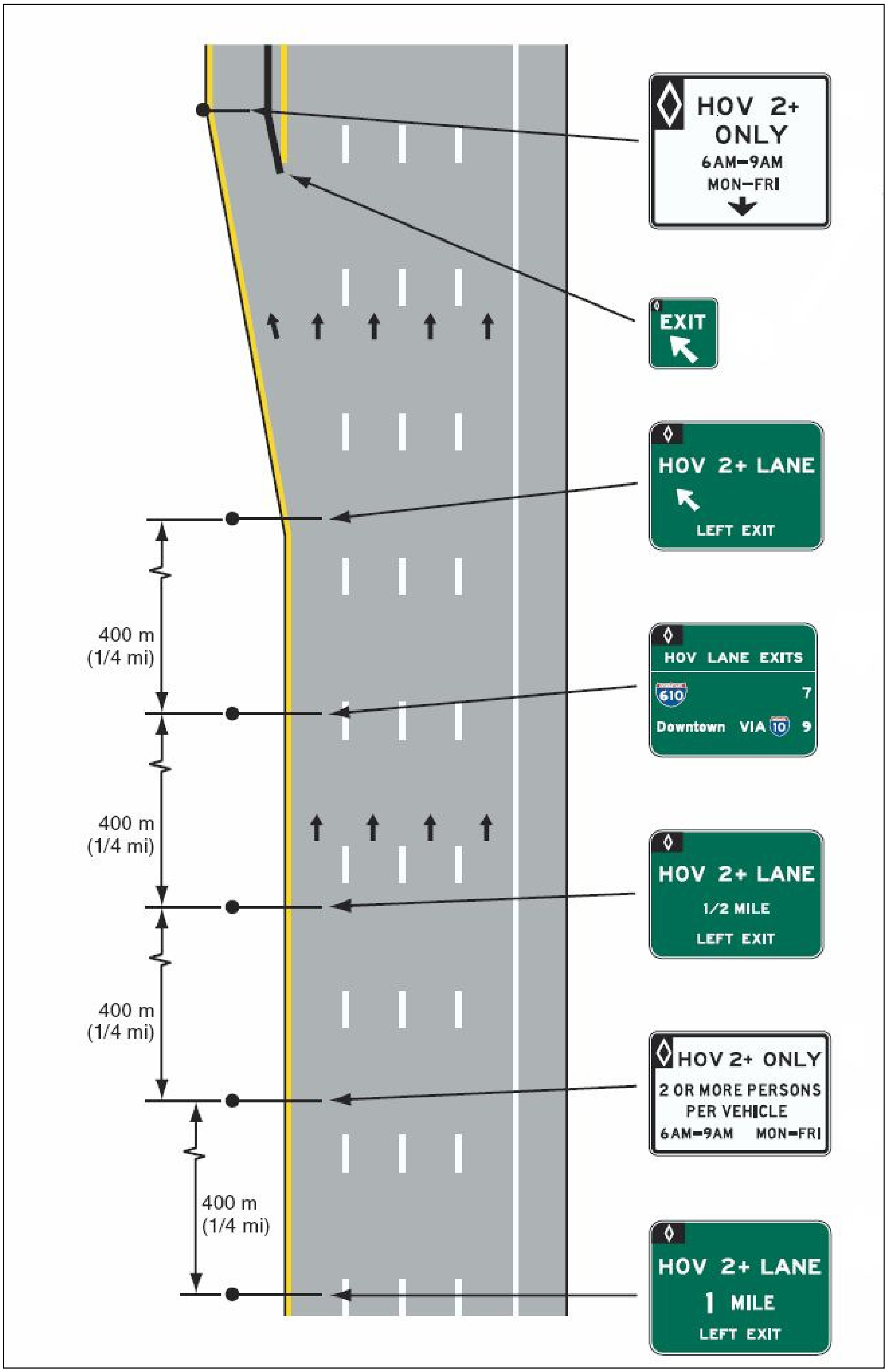

Figure 2-16. Recommended controls at the start of an HOV lane added on the left of the roadway (FHWA 2003)

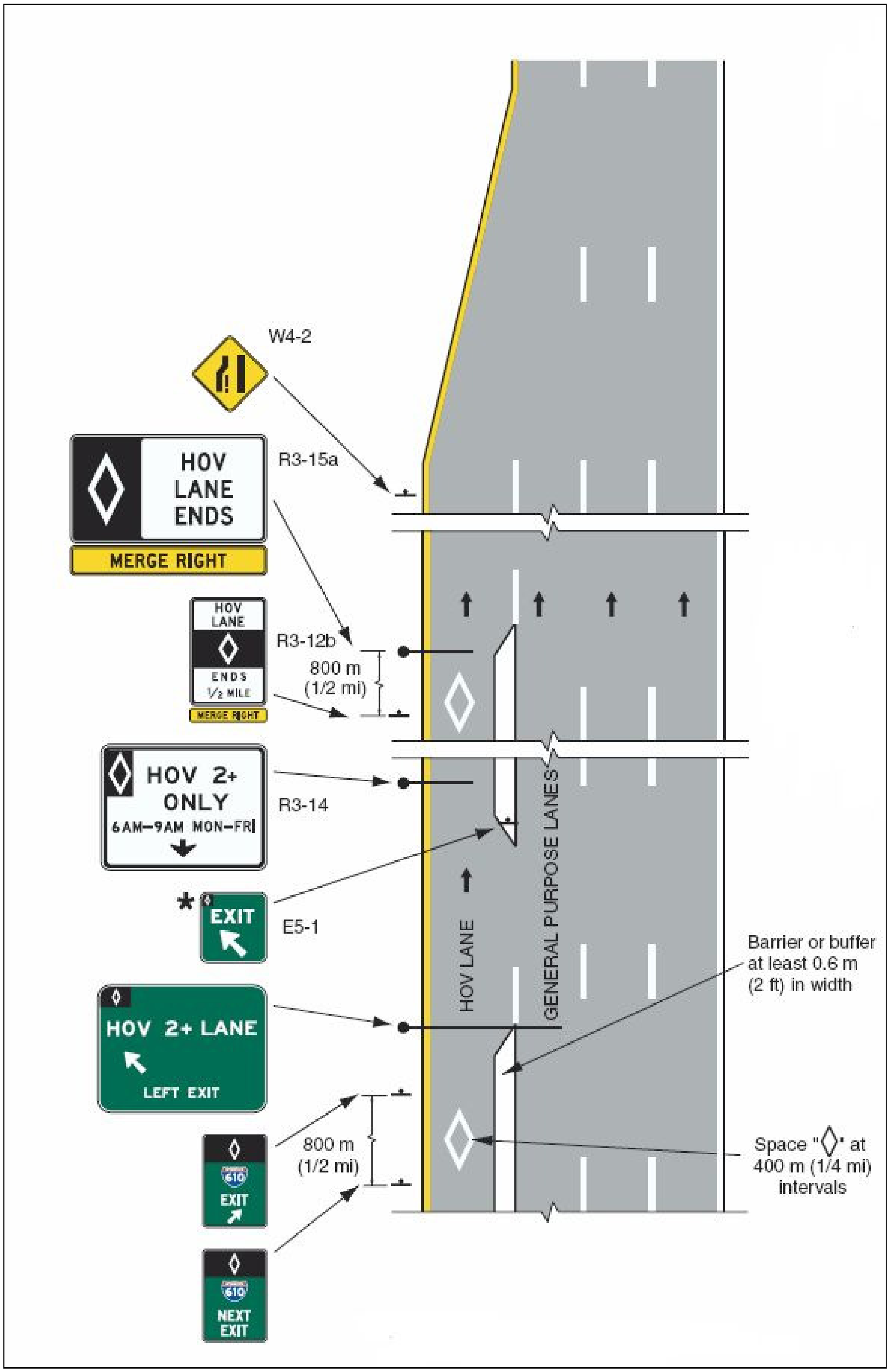

Figure 2-17. Example of signing for the intermediate entry to and exit from barrier- or buffer-separated HOV lanes (FHWA 2003)

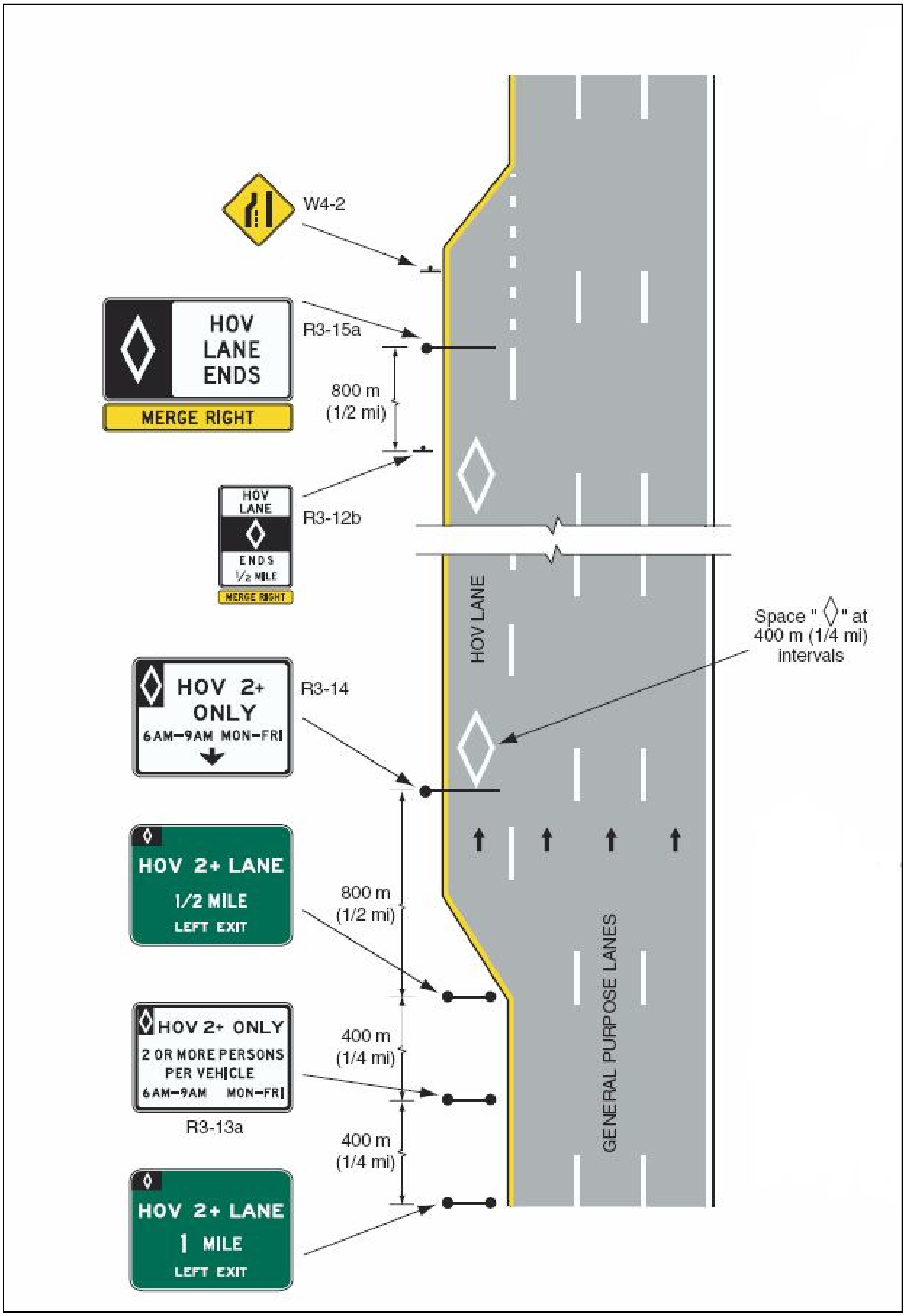

Figure 2-18. Example of signing for the entrance to and exit from an added HOV lane, planning for HOV facilities (FHWA 2003)

Figure 2-19. Overhead dynamic message sign, SR 91, CA (Chrysler, *et al.* 2004)

Planning for HOV Facilities As in all transportation planning, a number of agencies should be involved in the planning and implementation of HOV facilities (NCHRP 1998) to better address issues related to system efficiency and safety, as well as cost, operation, maintenance, enforcement, and local considerations. It is recommended that the planning process of HOV facilities goes through regional and corridor planning.

The *regional stage,* the first level of the planning process, considers general needs and opportunities and investigates potential fatal flaws in implementation. The *corridor stage*, on the other hand, focuses on more detailed analyses, such as alternative design evaluation, vehicle-occupancy issues, or access options. More specifically, after identifying the concordant groups, issues, and opportunities, it is important to set implementation objectives, select analysis techniques, and identify data needs and data-collection approaches. In the next step, alternatives should be developed with input from local stakeholders, including the public. The alternatives should be evaluated through simulation modeling prior to implementation to determine the feasibility and potential local and regional impacts of HOV implementation on traffic operations and safety. Finally, a cost-benefit analysis can take place to estimate the benefits and life-cycle costs to the public and private sectors from HOV lanes deployment.

HOV Facility Operation and Enforcement Operation and enforcement of HOV facilities are both critical to the success of the facility and depend on a number of factors, including the type and design of the facility, vehicle types and occupancy limits, hours of operation, and incident-management strategies. It is also important to offer design flexibility and meet the needs of larger design vehicles. Providing design or operation flexibility allows for effective use of the facility even when traffic conditions change in the future (FHWA 2004). A discussion of HOV operation and enforcement practices follows.

Type of HOV Facilities. Contraflow HOV lanes have different operating needs and requirements than their concurrent flow counterparts. Enforcement techniques also differ according to the type of HOV lanes employed (e.g. barrier-separated versus paint striping). Another related factor that affects operation and enforcement is the number of access points that the HOV facility has. Higher accessibility comes with the expense of lower operational efficiency, whereas fewer access points compromise convenience and reduce the attractiveness of HOV lanes to users. With respect to enforcement, some HOV facilities may need designated access enforcement to ensure compliance.

Types of Vehicles Allowed in HOV Facility. Vehicle eligibility, i.e. the types of vehicles allowed to use managed lanes, can differ by time of day or day of week. While the HOT lane strategy is based on both pricing and vehicle eligibility, the HOV lane strategy is based only on vehicle eligibility. As studied earlier, when HOV lanes were first introduced, they were for bus and carpool use only with required occupancies of 3+ people. After federal legislation in the mid-1980s this requirement was changed to 2+ people. This move was in response to criticism about HOV underutilization (i.e. "empty lane syndrome"), which may frustrate drivers and compromise the transportation system carrying capacity as a whole (Stockton, *et al.* 1999). Today, most HOV lanes on freeways meet the 2+ occupancy requirement (Fuhs and Obenberger 2002). In heavily populated cities such as Washington, DC, and Los Angeles, the 3+ occupancy requirement is enforced (ACCS 2008). Transit service on HOV lanes introduces additional challenges to the operation of HOV facilities. The volume of buses should be considered, and special provisions may be required, depending on the proportion of transit vehicles in the traffic stream.

Hours of Operation of an HOV Facility. Given that an HOV facility is in place, transportation agencies should determine the hours of operation of HOV facilities. Available options include continuous operation (i.e. 24 hours per day), operation during most of the day, or operation during peak periods. The decision depends on demand considerations and the HOV facility type.

Incident Management and HOV Lanes. Incident management is one of the issues that should be considered in all phases on HOV study and implementation, including design, operation and enforcement of HOV facilities. Transportation agencies should develop plans to address how incidents will be handled on HOV lanes in order to minimize their potential impact on safety and traffic operations.

Implementation of HOV Facilities A decision to implement an HOV lane involves short- and long-term investment and has an effect on the quality of traffic operations along the implementation corridor and neighboring facilities. In order to justify the need for implementation of HOV lanes and ensure that this strategy has potential for success, detailed evaluation of its potential impacts is needed prior to implementation. When HOV lanes satisfy the majority of the following criteria, they are warranted for use, assuming that local conditions allow for implementation:

- An increase in the people-carrying capacity of the facility.
- A reduction in congestion with a resulting impact on traffic operations and the environment.
- Delay and travel time savings and more reliable trip time for all users.
- Improved safety along HOV lanes without safety compromises along general-purpose lanes.
- Public acceptance and support.
- Demonstrated feasibility and cost effectiveness.

HOV Lane Evaluation Several states have implemented HOV lane strategies to combat urban congestion. Major HOV systems operate in Houston and Dallas, TX; Seattle, WA; Los Angeles, Orange County, and San Francisco Bay, CA; Newark, NJ; New York City, NY; Northern Virginia, VA; Washington, DC; Atlanta, GA; and Boston, MA, to name a few. Other facilities are in various stages of planning, design, and construction. The following paragraphs present selected HOV lane case studies around the US.

Washington, DC. Many studies available in the literature confirm that the implementation of HOV lanes resulted in travel time savings and more predictable travel times. In the Washington, DC, region there are three interstate HOV lane corridors in operation (HTH 2007). One of them is the I-95/I-395 corridor, which is a 30-mile long, two-lane HOV facility in the highway median (ACCS 2008) with an average 10,400-person-trip and 2,800-vehicle carrying capacity during the morning peak. During weekday rush hours, the lanes are restricted to vehicles with three or more people (HOV-3), northbound (toward DC) in the morning and southbound in the evening. The lanes are also available on the weekends, without the HOV restriction (ACCS 2008). Reported travel time savings in the facility due to HOV operation are approximately 31 minutes for morning rush hours and 36 minutes for the evening rush (Fuhs and Obenberger 2002). The other HOV facilities in the region are on I-66 and I-270. All lanes of I-66 are restricted to vehicles with two or more people (HOV-2) on weekdays, eastbound (toward DC) in the morning and westbound in the evening. I-270 has one HOV lane in each direction. While motorcycles are allowed in the HOV lanes, hybrid vehicles are not. On weekends and other times, the I-270 HOV facility is open to all traffic (ACCS 2008). Travel time savings for these HOV facilities range from 5 to 12 minutes on I-270 and from 17 to 28 minutes on I-66 (HTH 2007).

Dallas and Houston, TX. Studies show HOV lanes in Texas increase person-carrying ability. For example, according to a study done by TTI, person trips increased 14% on I-30, where a barrier-separated contraflow HOV lane was implemented, and I-35E North and I-635 in the Dallas area, where buffer-separated concurrent flow HOV lanes were implemented. It was also found that the HOV lane carried twice the number of people compared to an adjacent general-purpose lane during the peak hour, partly due to the fact that several bus routes use the I-30 HOV lane. Automobile occupancy was also increased in the range of 8% to 12%, while the average automobile occupancy on that route without an HOV lane has decreased by 2% (Skowronek, *et al.* 1999).

There are six HOV facilities in Houston: Katy on I-10 W, North on I-45 N, Gulf on I-45 S, Northwest on US 290, Southwest on US 59 S, and Eastex on US 59 N. In 2003, 212,079 passengers per day used the HOV lanes. The number of passengers that buses carried was 43,225, while vanpools accounted for 2,500 riders and carpools carried 74,867 occupants in one day. Moreover, an average of 407 motorcycles used the lanes daily. During the morning peak-hour, volumes were approximately 1,000 vehicles on the Katy HOV lane and 1,551 vehicles on the Northwest HOV lanes, and an average of 3,424 vehicles on the Gulf HOV lane and 4,836 vehicles on the North HOV lane. The HOV lanes carried 40% of the morning peak hour total person movement of these three freeways (Turnbull 2003).

Studies in Houston indicate that the HOV lanes provide travel time savings for all vehicles. The morning peak hour travel time savings range from approximately 2 to 22 minutes on the different HOV lanes, with the Northwest Freeway HOV lane providing the largest savings (22 minutes). The Katy HOV lane averages between 17 and 20 minutes in travel time savings, the North 14 minutes, and the Gulf and Southwest between 2 and 4 minutes. Moreover, HOV lane users have more reliable trip times. These reliable travel times and savings led commuters not to drive alone but to take the bus, carpool, or vanpool. It is worth noting that periodic surveys of HOV lane users show that nearly 45% of current carpoolers formerly drove alone, while 46% of bus riders previously drove alone. The HOV system also increased average vehicle occupancy (AVO) on the HOV lane corridors. While the morning peak-hour AVO was 1.28 in 1978 before the contra-flow HOV lane opened on the North Freeway, it was 1.41 in 1996 (Turnbull 2003).

Boston, MA. Another example of the successful use of HOV lanes comes from Boston, MA, which implemented a reversible, barrier-separated HOV lane on I-93/Southeast Expressway and a southbound, buffer-separated lane on I-93 North. In 1987, the I-93 North HOV lane was initially made available to buses and carpools with occupancy of at least three persons, but a year later this created "empty lane syndrome" and led to a change of the HOV lane occupancy requirement to two or more people. In four years, the I-93 North HOV lane almost reached capacity with an average of 1,100 vehicles during the morning peak hour. In 2004, the I-93 North HOV lane in the Boston metropolitan region carried an average of 13,800 HOVs per lane. Between 2004 and 2007, there were 18,000 HOVs per lane, a 30% increase in four years. When the Southeast Expressway HOV lane opened in 1995, the 3+ occupancy requirement resulted in maximum volumes of 375 and 400 vehicles per hour for the morning and afternoon peak periods, respectively. In 1998, these volumes increased to a maximum of 550 and 525 vehicles per hour for the morning and afternoon peak periods with the introduction of two-or-more occupancy sticker program. Later in 1999, the HOV lane was opened to all vehicles with two or more occupants, no sticker required. With these improvements on the corridor, lane use increased to 1,300 vehicles per hour during the morning peak period and 1,000 during the afternoon peak period. During 2006 and 2007, an average of 1,000 to 1,100 vehicles per hour per lane were observed on northbound of 1-93/Southeast Expressway HOV Lane with an average of three or more occupants and between 6:00 AM and 10:00 AM (Boston RMPO 2009).

According to an occupancy count survey that was done in 2007 by the Central Transportation Planning Staff (CTPS), 21,142 vehicles traveled northbound on I-93/Southeast Expressway in the four general-purpose lanes, with a ratio of 1.11 occupants per vehicle, and 4,193 vehicles traveled in the HOV lane, with a ratio of 2.97 occupants per vehicle, between 6:00 AM and 10:00 AM. For I-93 North southbound traffic, the travel time savings in the HOV lane have improved between 2002 and 2003, whereas in the general lanes travel times increased during the same time period. The observations show that HOV lanes provide more travel-time savings compared to general-purpose lanes, especially during morning peak-hours for northbound traffic and afternoon peak-hours for traffic headed southbound from Boston (Boston RMPO 2007).

Minneapolis, MN. In 1993, I-394 opened in Minneapolis with three miles of two-lane, reversible, barrier-separated HOV lanes and eight miles of concurrent flow HOV lanes. Based on a 1994 study, the HOV lanes along I-394 averaged 3.28 occupants per vehicle during the morning rush, more than triple that of the general-purpose lanes (average vehicle occupancy of 1.01) (Turnbull, *et al.* 2006). The facility is an 11-mile long corridor with two general-purpose lanes in each direction; 8 miles of concurrent flow HOV lanes; 3 miles of two-lane, reversible, barrier-separated HOV lanes; park-and-ride lots; expanded bus service; and three parking garages on the edge of downtown Minneapolis. In May 2005, the I-394 HOV lane was converted to a MnPASS HOT lane (Turnbull 2006).

Atlanta, GA. Another noteworthy HOV implementation project is in Atlanta, GA. HOV lanes in metro Atlanta were opened in 1994 along an 18-mile section of I-20, east of I-75/85. In 1996, 60 lane miles were added on I-75/85 inside I-285 to reduce air-pollution and traffic congestion and to provide time savings (GDPS 2007). Another addition was made on I-85 in 2004. According to a fact sheet prepared by the Atlanta Regional Commission in November 2006, the Atlanta region has over 90 miles of HOV lanes on roadways I-20, I-75, and I-85. In 2005, HOV lanes were used by more than 28,000 commuters, which is 8% greater than the 2004 traffic volumes (ARC 2006). The Georgia Department of Transportation (GDOT) reports that travel time savings of 15 to 20 minutes are due to HOV use for travel to or from work (GDPS 2007). Plans are in place to further expand the HOV lane system over the next 20 years (ARC 2006).

Los Angeles, CA. Los Angeles County has an impressive system of HOV facilities, with 14 HOV corridors covering over 485 HOV lane miles, or approximately 34% of the total 1,410 HOV lane miles in California. These facilities serve an average of 1,300 vehicles or 3,300 people per hour during peak hours, or approximately 331,000 vehicle trips and 780,000 person trips per day. Between 1992 and 2007, the increase in the total number of carpools on freeways with HOV lanes for the two-hour morning peak was 77%. A significant increase was also observed in the two-hour afternoon peak. It is also specified that each HOV facility in Los Angeles County carries 80 qualifying hybrid vehicles during both morning and afternoon peak hour (CALTRANS 2009). Moreover, it is predicted that by the year 2015, the Los Angeles County HOV system will serve more than one million person trips each day (LA CMTA 2007).

Seattle, WA. Washington State has implemented approximately 200 lane miles of a planned 300-mile freeway HOV lane and ramp system since 1970 (WSDOT 2007). Today, the HOV facilities in Seattle, WA, move more than 100,000 persons per day (Fuhs and Obenberger 2002). HOV facilities are located on the I-5, I-90 (east of I-405), I-90 (west of I-405), I-405, SR 167, SR 520 (east of I-405), and SR 520 (west of I-405) corridors. All corridors have direct access ramps 24 hours a day. With respect to operations, the I-5, I-90 (west of I-405), and SR 520 (west of I-405) corridors operate 24 hours a day, while the rest operate between 5 AM and 7 PM. HOV lanes carry nearly 35% of the commuters and 18% of the vehicles on freeways during rush hours. It was reported that HOV lanes carry more people than the general-purpose lanes during peak hours and the time savings on each HOV facility were documented (WSDOT 2007). Among the concurrent flow HOV lanes in the US, the I-5 facility carries the second largest number of bus riders in the peak morning hours (Turnbull, *et al.* 2006).

New Jersey, NJ. While most HOV lane projects reported in the literature may be considered successful, public opposition resulted in the closing of HOV lanes on two corridors in New Jersey (I-287 and I-80) (Skowronek, *et al.* 1999). New Jersey began using HOV lanes in 1969 with the Exclusive Bus Lane (XBL) on Route 495. This was a short, 2.5-mile lane segment that was taken from the off-peak direction. It cost less than $200,000 to implement, and it served more than 700 buses with more than 30,000 commuters during the peak hour (Fuhs and Obenberger 2002). In New Jersey, concurrent flow HOV lanes were implemented along I-80 in March 1994 and on I-287 in January 1998. The peak hour HOV demand on I-80 was an average of 1,200 vehicles per hour, while HOV lanes on I-287 were clearly underutilized, with an average of 480 vehicles per hour. The vehicle occupancy threshold on both facilities was 2+ persons per vehicle during the morning and afternoon peak hours (Turnbull and Dejohn 2000). Although the I-80 HOV lane was well-used, with more than 1,000 vehicles per hour per lane, both HOV facilities were closed due to strong political opposition. The public was also not in favor of this strategy when they first opened. Consequently, inadequate services and facilities, as well as policies and poor marketing, contributed to the failure and subsequent closure of the HOV lanes in New Jersey (Martin, *et al.* 2005).

Birmingham, AL. In recent years, interest in managed lanes as a tool to address congestion and air quality problems grew in Birmingham, AL. In 2006, the Regional Planning Commission of Greater Birmingham (RPCGB) conducted an initial feasibility analysis (fatal flaws analysis) of highway and/or transit capacity improvements along 45 miles of the I-65 corridor, which is the main corridor serving metropolitan Birmingham, AL, on a north-south route. Transportation options screened for fatal flaws included HOV lanes, as well as other strategies, such as express bus lanes, HOT lanes, and bus rapid transit. This initial feasibility analysis was intended to identify potential opportunities and challenges from the implementation of various highway and transit lane management options. Such issues could include physical, environmental, financial, and operability constraints as well as political and public perception challenges (PBS&J 2007).

The fatal flaws study recommended further consideration of HOV lanes on the I-65 corridor and indicated that a 12.5 mile-long segment of I-65 extending from Valleydale Rd to I-20/59 had the best potential and greater need for immediate implementation. Figure 2-20 shows the study site for the fatal flaws analysis in the Birmingham area, and Figure 2-21 summarizes the daily traffic volumes in 2005 (PBS&J 2006).

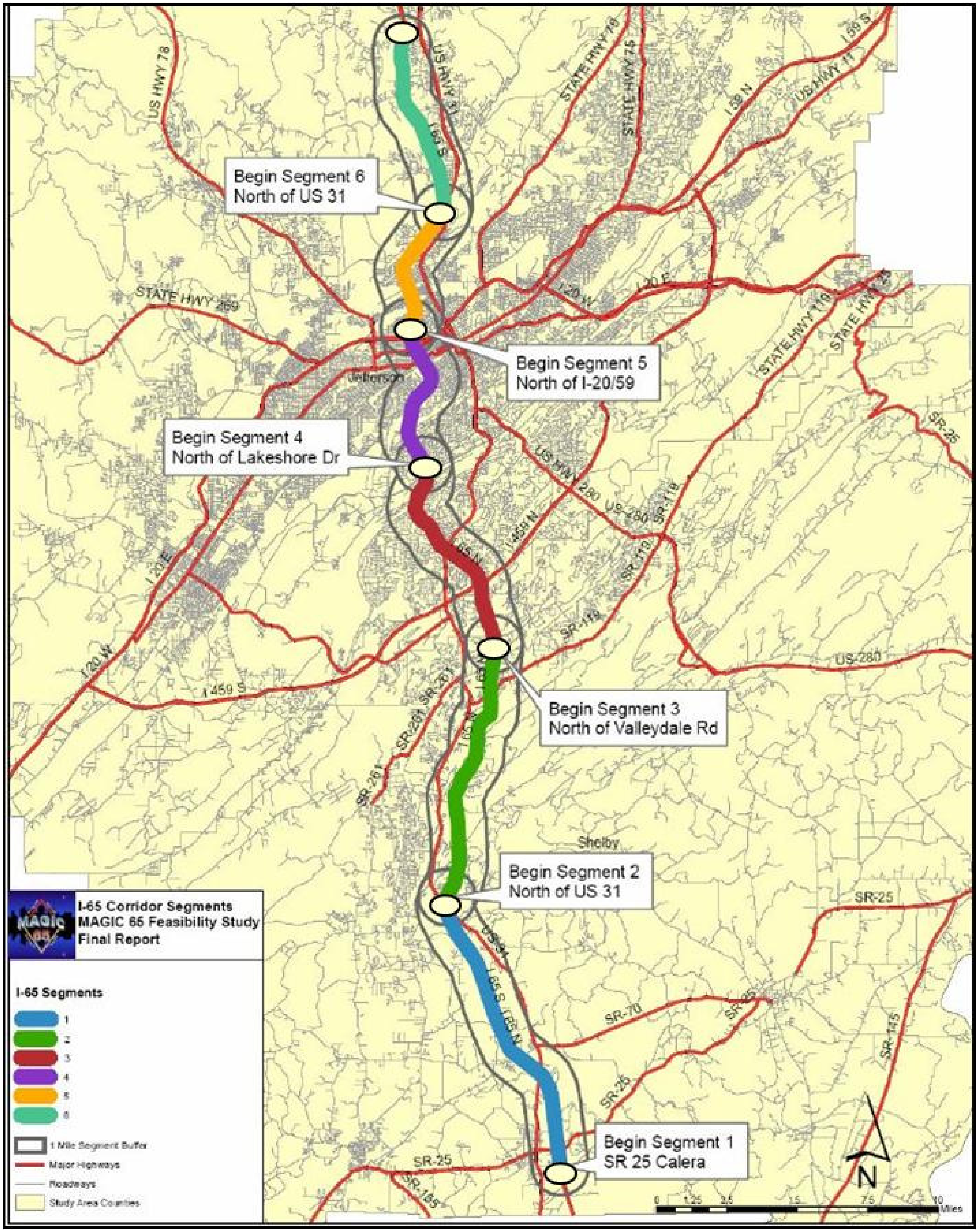

Figure 2-20. Segments on I-65 corridor (PBS&J 2006)

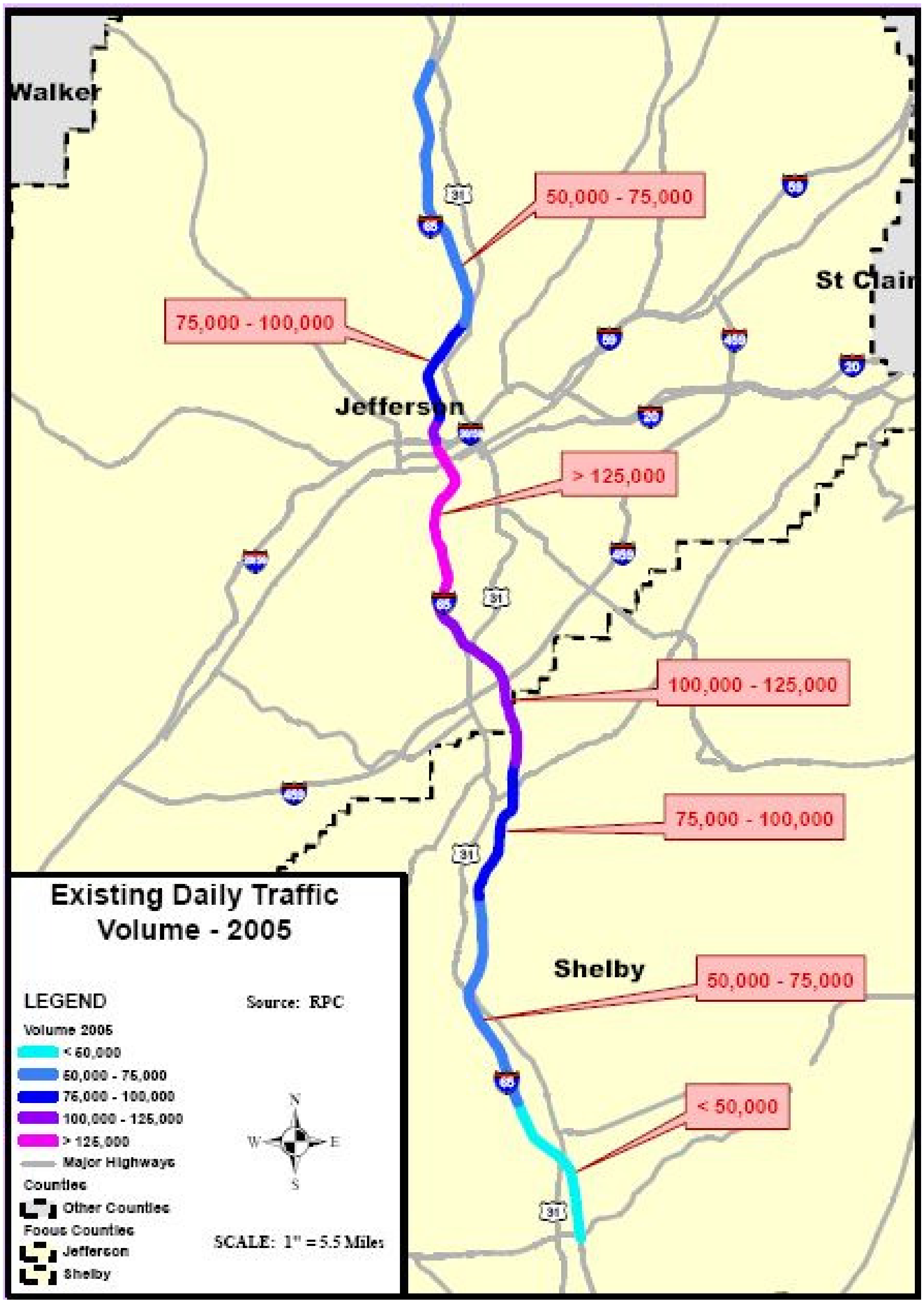

Figure 2-21. Daily traffic volumes in 2005 (PBS&J 2006)

Discussion

While HOV lanes prove to be generally effective in managing travel demand along congested urban corridors, they are not a cure-all solution. The lesson learned by the review of the state-of-practice is that localized studies are needed to determine if HOV lanes are indeed a desirable and viable option for implementation, taking into consideration the congestion level of the corridor, regional travel patterns, current vehicle volumes for single and high occupancy vehicles, projected demand of the HOV lane, enforcement option, operational and environmental issues, and public support.

Truck Lane Facilities

Truck Lane Facilities Overview The continuing increase of truck traffic across the nation creates new challenges and new opportunities for traffic management. Additionally, trucks have different acceleration and deceleration rates and weaving capabilities than passenger cars, which may compromise operational efficiency and traffic safety and affect the comfort of passenger car drivers, especially when roads are congested. For facilities that service large numbers of trucks, a dedicated lane for trucks may be considered. The main purpose of this strategy is separating trucks from general traffic to increase safety and throughput (CALTRANS 2008). Truck-only lane facilities may reduce travel time or increase time reliability, which is often very important in freight transportation. Truck facilities also have a positive impact on the environment. The literature review suggests that the implementation of truck facilities may reduce air and noise pollution, as well as fuel consumption. According to a study done by TTI (Middleton 2003), if the average annual daily truck traffic (AADTT) reaches 5,000 trucks per day, a truck facility should be considered.

Types of Truck Lane Facilities According to a 1985 study by TTI (Middleton, *et al.* 2003), there are seven types of truck lane facilities. The first type is a minimum median truck lane. It consists of a 12-ft inside truck lane with 5-ft inside shoulders. The non-truck traffic uses the outside lanes, and the lanes are not barrier-separated. The second type has a similar configuration to the first except for the presence of 10- to 12-ft shoulders (Figure 2-22). The third type refers to a truck lane that is located on a 12-ft outside lane with 12-ft outside shoulders. These lanes are also non-barrier-separated, as shown in Figure 2-23. The next type is a four-lane facility. The two 12-ft inside lanes are designated for trucks with 5-ft-long inside shoulders. This type also is not barrier-separated from the outside car lanes. Figure 2-24 illustrates a two-way truck lane cross-section.

The fifth type of truck lane design is similar to the second. The only difference is a depressed median. Trucks travel on 12-ft lanes with 10-ft shoulders, as shown in Figure 2-25.

Another option is a protected lane with a passing lane. In this configuration, 12-ft lanes are used with a 4-ft inside shoulder and a 10-ft outside shoulder. This type of truck facility is barrier-separated. Figure 2-26 shows the configuration of the protected truck lane with a passing lane.

The last type is an elevated truck lane, with a configuration similar to the previous one (Figure 2-26), as shown in the cross section in Figure 2-27.

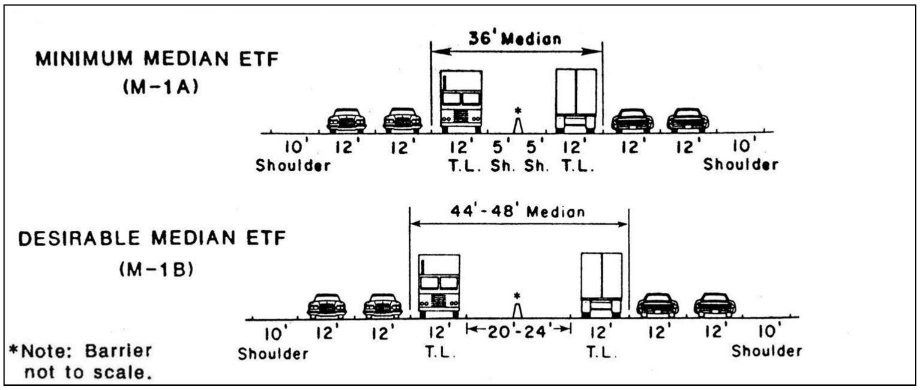

Figure 2-22. Minimum median truck lane (Middleton, *et al.* 2003)

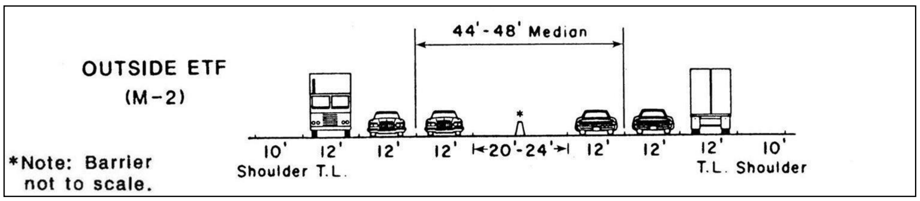

Figure 2-23. Outside truck lane (Middleton, *et al.* 2003)

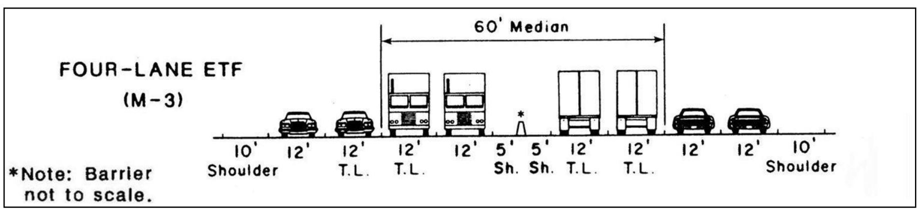

Figure 2-24. Two-way inside truck lane (Middleton, *et al.* 2003)

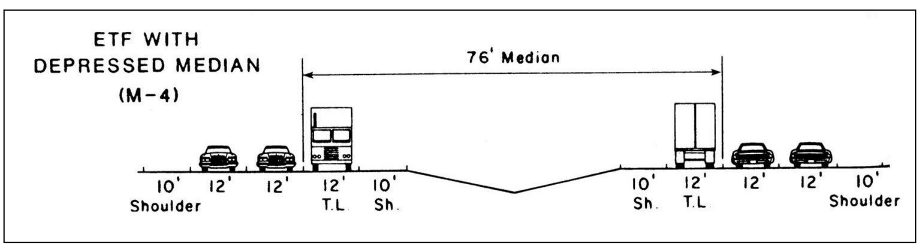

Figure 2-25. Depressed median truck lane (Middleton, *et al.* 2003)

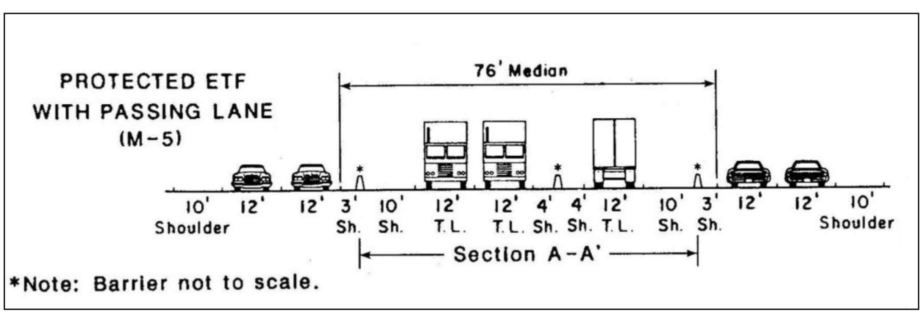

Figure 2-26. Protected truck lane with passing lane (Middleton, *et al.* 2003)

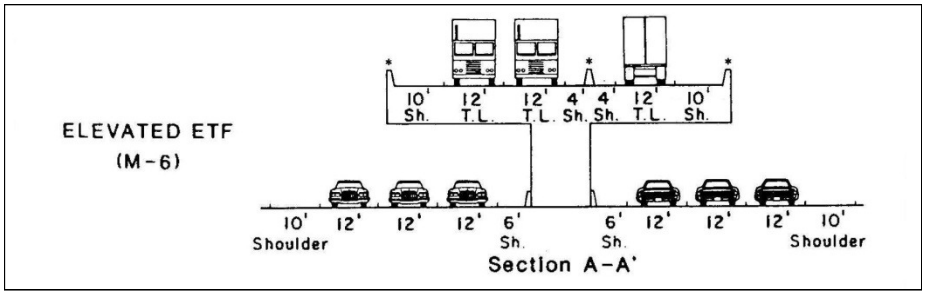

Figure 2-27. Elevated truck facility (Middleton, *et al.* 2003)

The best option is chosen according to the availability of ROW, travel patterns, geometric characteristics of the roadway of interest, and capital and operational cost considerations.

Traffic Control Devices for Truck Lane Facilities On a truck facility, trucks tend to follow each other closely, causing signs to be blocked by the lead vehicle. For that reason, the placement of traffic signs should be considered carefully to enhance visibility. Oversize and overhead signs should be preferred. Figure 2-28 shows an example of sign placement on the New Jersey Turnpike. The signs were placed overhead on the dual-dual roadway, both on inner and outer roadways (Middleton 2003).

Figure 2-28. Overhead truck sign on New Jersey Turnpike (Middleton, *et al.* 2003)

Detailed traffic control guidelines are also available for truck facilities in the MUTCD. An overhead sign, which is recommended in MUTCD, is shown in Figure 2-29. Traffic signs can be used to inform truck drivers about safe passing, merging, and diverging movements (Figure 2-30), as well as weight limits (Figure 2-31) (FHWA 2003).

Intelligent Transportation Systems (ITS) applications are also used to enhance safety and control on truck lane facilities. Figure 2-32 shows an example of an active warning system on Capital Beltway in Washington, DC. The technology has the capability of measuring truck height, speed, and weight, and warning the truck driver about potentially unsafe speeds for the given conditions (Middleton, *et al.* 2003).

Figure 2-29. Overhead truck sign recommended in MUTCD (FHWA 2003)

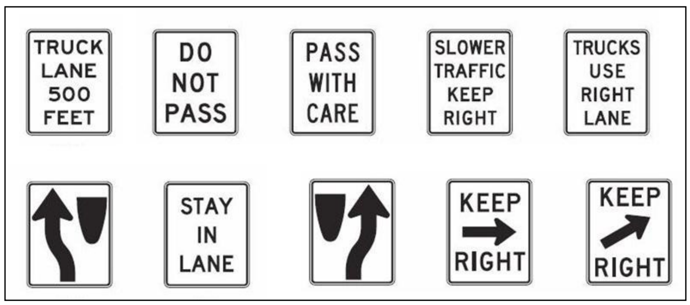

Figure 2-30. MUTCD recommended truck facility signs (FHWA 2003)

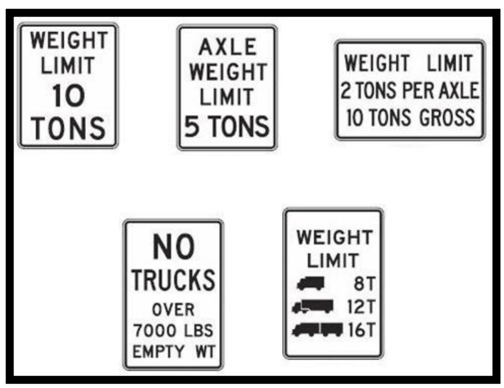

Figure 2-31. Weight limitation signs of trucks (FHWA 2003)

Figure 2-32. Warning system on Capital Beltway (Middleton 2003)

Operation Strategies and Enforcement of Truck Lane Facilities Acceleration rates, stopping distances, weaving capabilities, and roll stability are special characteristics of trucks that cause them to operate differently than other modes. Separating trucks from other traffic can be done spatially or by time of day. Spatial separation can be performed by placing trucks on exclusive truck lanes. Truck lane restrictions can also be applied to certain hours of the day. For example, trucks are not allowed on I-10 Highway in Texas on weekdays and during daylight hours when traffic flows are heaviest.

Two types of operation strategies are commonly used for truck traffic management. The first strategy allows trucks to remain in the mixed traffic stream but restricts them to or from certain lanes. There should be at least three lanes on each side to apply truck lane restrictions. While trucks are restricted from the far left or right lane, they are allowed to use the other two lanes in mixed traffic.

According to a study done by TTI (Middleton, *et al.* 2003), truck lane restrictions improve traffic operations and reduce the potential truck-car conflicts by separating low-speed vehicles from faster-moving ones. An example of a successful implementation of truck traffic management is in Broward County, FL. Vehicles with three or more axles were restricted from the far left lane on I-95 on a 25-mile segment during the morning and afternoon peak hours (Reich, *et al.* 2002).

The second truck traffic management strategy involves truck roadways or truck-only facilities that are separated with barriers from other traffic. Cars are not allowed on truck roadways. Such treatment is particularly beneficial when the number of trucks and the crash rates involving trucks are high. With the introduction of truck facilities, the roadway section turns to a dual facility where there is an inner and outer roadway in each direction. One example of a truck-only facility is the New Jersey Turnpike. While the inner roadway in the New Jersey Turnpike is reserved for non-trucks, the outer roadway is a truck-preferred facility, which allows passenger vehicles as well, as shown in Figure 2-33. Generally speaking, truck-only facilities are not widely used due to high cost and mixed public perception (Middleton, *et al.* 2003).

Implementation of Truck Lane Facilities No universally accepted implementation criteria exist for truck facility implementation. For example, TxDOT has developed specific criteria for lane restrictions for trucks, e.g. the facility should have at least three lanes in each direction and an engineering study should be conducted before implementation (Middleton, *et al.* 2003). A cost-effectiveness analysis should be performed before implementation as well.

Evaluation of Truck Lane Facilities The literature review indicates that truck traffic management in the US primarily involves truck lane restrictions or dedicated truck lanes on shared-traffic facilities (Reich, *et al.* 2002). Several states are considering the implementation of truck lanes. The Missouri State 2007 Long Range Transportation Plan, for instance, includes dedicated truck lanes on I-70 as a potential strategy to meet future needs. The expected cost of the investment is approximately $7.2 billion (MoDOT 2007). The GDOT conducted a preliminary study in 2007 that includes the construction of truck-only lanes on I-75 North, I-85 North, I-75 South, I-20 West, and I-285 in Metro Atlanta. The first phase includes the construction of truck-only lanes on I-75 North, I-285 West, and I-75 South (HNTB 2008). Examples of truck management facilities in operation are provided as follows.

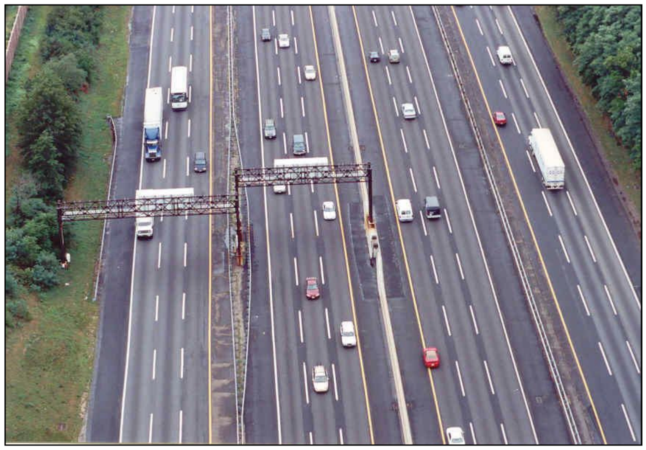

Figure 2-33. New Jersey Turnpike dual facility (Middleton, *et al.* 2003)

Figure 2-34. Truck facility in Los Angeles (Middleton, *et al.* 2003)

Figure 2-35. Truck bypass lanes on I-5 at I-405 north of LA (Middleton, *et al.* 2003)

Los Angeles, CA. The State of California has operated a 2.42-mile truck roadway near Los Angeles since the 1970s. To provide a truck roadway, the California Department of Transportation (CALTRANS) used an old roadway parallel to I-5 north of Los Angeles and just north of the I-5/I-405 interchange. Cars are allowed to use all of the truck facilities, as shown in Figure 2-34 (Middleton, *et al.* 2003).

Another truck traffic management strategy implemented in the Los Angeles area is truck bypass lanes at high volume interchanges. Truck bypass lanes are considered at locations where safety is a concern due to speed differentials or where weaving capacity is exceeded. Lane restrictions on bypass truck facilities in California make trucks remain in the right lanes to avoid weaving maneuvers. There are three truck bypass lanes at interchanges in the Los Angeles area to reduce or remove weaving trucks: I-5 at I-405 north of Los Angeles (Figure 2-35), I-5 at I-405 in Orange County, and I-405 at I-110/SR-91. The trucks exit the main lanes upstream of the first exit ramp and they reenter the main lanes downstream of the interchange. After the implementation of truck facilities on I-5, the number of crashes involving trucks decreased by 85% (Middleton, *et al.* 2003).

Newark, New Jersey. The New Jersey Turnpike has a dual-dual roadway configuration between Interchange 8A and Interchange 14, a distance of 32 miles. Only cars are allowed to use the inside roadway of the dual-dual facility while cars, trucks, and buses use the outer roadway (Figure 2-36) (Middleton, *et al.* 2003). Only 40% of total traffic uses the outer roadways. The total annual truck traffic volume on the New Jersey Turnpike was 27,649,048 vehicles in 2001. According to New Jersey Turnpike managers, the estimated growth of truck traffic on the facility is 7% per year. Turnpike authorities stated that safety concerns and congestion on New Jersey roads led to the implementation of the dual-dual facility. Figure 2-37 shows the injury crash rates on the New Jersey Turnpike between the years 1999-2001 (Reich, *et al.* 2002).

The New Jersey Turnpike Authority works with the state police and contracted towing and emergency response services for incident management on the turnpike. Wreckers, ambulances, and fire-fighting equipment and personnel are available for emergencies 24 hours a day. A specialist is also on call for any emergency involving trucks that carry hazardous materials. The Turnpike Authority also sponsors a program called "Sharing the Road with Truckers" to inform the public about how difficult it is to control a large vehicle and discuss safety practices related to sharing the road, including blind spots (Middleton, *et al.* 2003).

Atlanta, Georgia. The first attempt to restrict trucks to right lanes (except to pass or to make a left-hand exit) was made in Georgia in 1986 (Neudorff, *et al.* 2003). In 2006, Georgia's State Road and Tollway Authority (SRTA) considered constructing separate truck-only lanes as a measure to ease traffic congestion in the Metro Atlanta region, and a statewide truck lane needs identification study was completed. It was found that, with the introduction of truck-only lanes and the shift of truck traffic to those lanes from general-purpose lanes, the congestion experienced by trucks, and the percentage and number of trucks in the general purpose (GP) lanes would be reduced. Moreover, a reduction in the number of crashes was projected (HNTB 2007).

Figure 2-36. New Jersey Turnpike dual-dual facility (Middleton, *et al.* 2003)

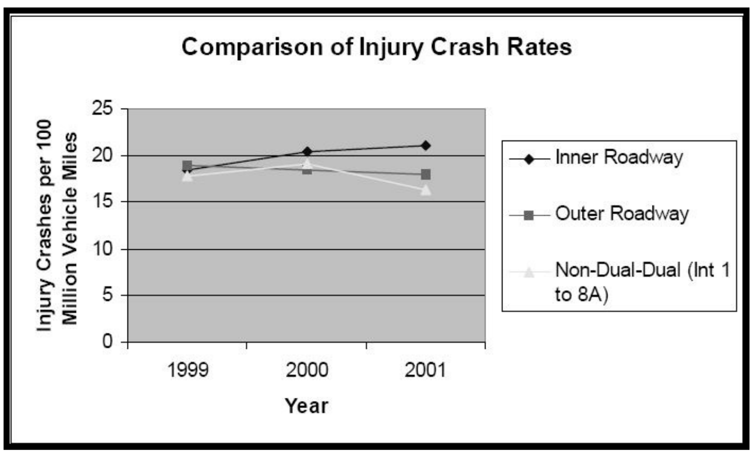

Figure 2-37. Injury crash rates on the New Jersey Turnpike (Reich, *et al.* 2002)

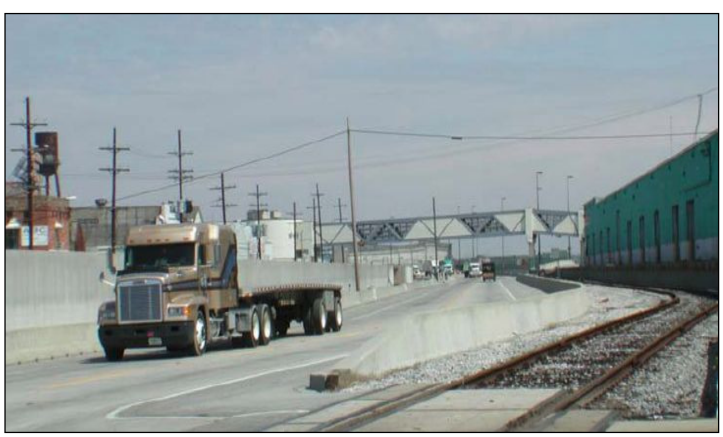

Figure 2-38. The Tchoupitoulas Truckway (Reich, *et al.* 2002)

New Orleans, Louisiana. The Port of New Orleans, LA (Port NOLA) receives 70% of the cargo arriving in Louisiana, and 80% of this freight is carried by trucks. In 1983, the city restricted trucks from the historic area. The Tchoupitoulas Truckway, with one 12-ft lane in each direction and 8-ft shoulders on both sides, was built as an exclusive truck facility to handle 2,000 trucks per day. Figure 2-38 shows the Tchoupitoulas Truckway at the Port NOLA (Reich, *et al.* 2002).

Examples of Other Systems. In the Netherlands, unmanned trucks carry sea containers on a Combi-Road Driverless Truck Guideway. Trucks are driven on dedicated tracks with active longitudinal guidance from seaports to inland terminals. Figure 2-39 illustrates this system (Neudorff, *et al.* 2003).

Figure 2-39. Combi-Road Driverless Truck Guideway (Neudorff, *et al.* 2003)

Section 3
Study Design

Study Area

As mentioned earlier, the objective of this case study is to determine the impact of managed lane implementation in the Birmingham, AL, region. The section of I-65 extending from Valleydale Road to I-20/59 was chosen for further analysis. The section is within the area that shows greater promise for HOV implementation as per the recommendations of the 2006 fatal flows study (RPCGB 2006).

The following paragraphs provide information about the geometric design, demand, and operational characteristics of the study site.

Geometric Characteristics The I-65 freeway is an interstate highway of major importance to the mobility of Alabamians and also a north-south route of national significance for the movement of people and goods. Extending as far north as Lake Michigan, I-65 connects the city of Birmingham with Nashville, TN, and Indianapolis, IN, to the north, and Montgomery and Mobile, AL, to the south. It also provides direct access to the Birmingham freeway system, including interstates I-20, I-59, and I-459, which serve local mobility needs as well as connect the city of Birmingham to Atlanta, GA, to the east and Tuscaloosa, AL, and New Orleans, LA, to the west and south.

The study site is an approximately 10-mile long median-divided freeway section and extends from Valleydale Road (Exit 247) to I-20/59 (Exit 261). The mainline has typically three 12-ft lanes of traffic per direction with auxiliary lanes added near ramp locations. The posted limit on the I-65 study corridor is 60 mph and 45 mph on the ramps. The main transportation facilities in the Birmingham metropolitan area are depicted in Figure 3-1.

Birmingham Area Travel Patterns Among US metropolitan areas with populations greater than 500,000, Birmingham ranks third in the number of vehicle miles driven per day per capita (34.8 miles per day) (Schrank and Lomax 2005). Between 1995 and 2000, the total travel vehicle miles in Jefferson County increased by 8.5%, while the increase in Shelby County was 18.8%.

In the Birmingham metropolitan area, 83.5% of commuters drive to work alone, and work trips that are made by using public transit are less than 1% of all work trips. The average travel time to work in the year 2000 was 26.2 minutes. During the morning peak (i.e. 7:00 to 8:00 AM), 92.1% of all vehicles traveling northbound on I-65 and 93.4% of all vehicles traveling southbound are single-occupant vehicles. As roadway capacity becomes more constrained, alternatives to single-occupant travel will be needed to keep pace with personal travel demand (RPCGB 2006).

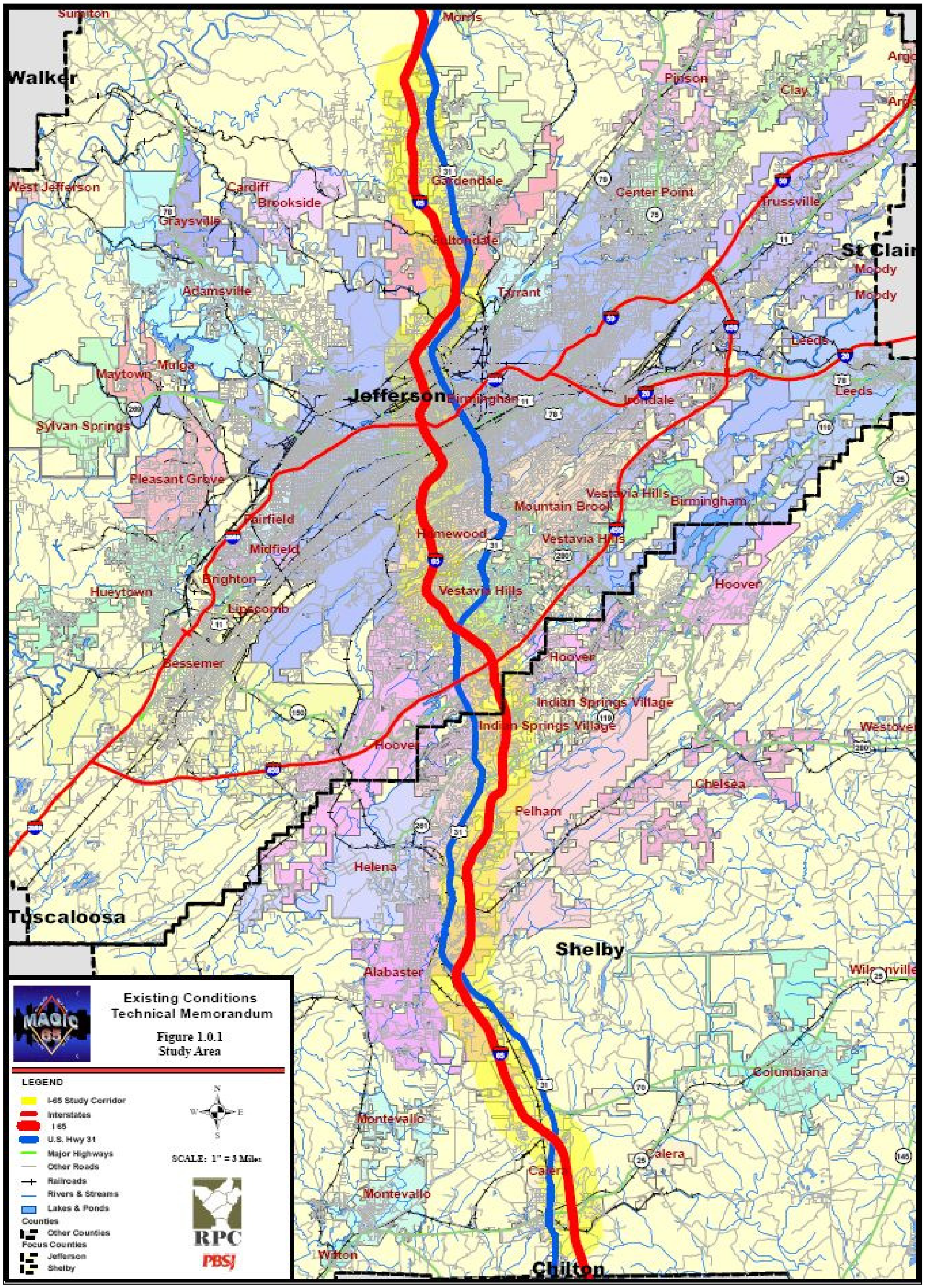

Figure 3-1. Transportation facilities in the Birmingham region (PBS&J 2006)

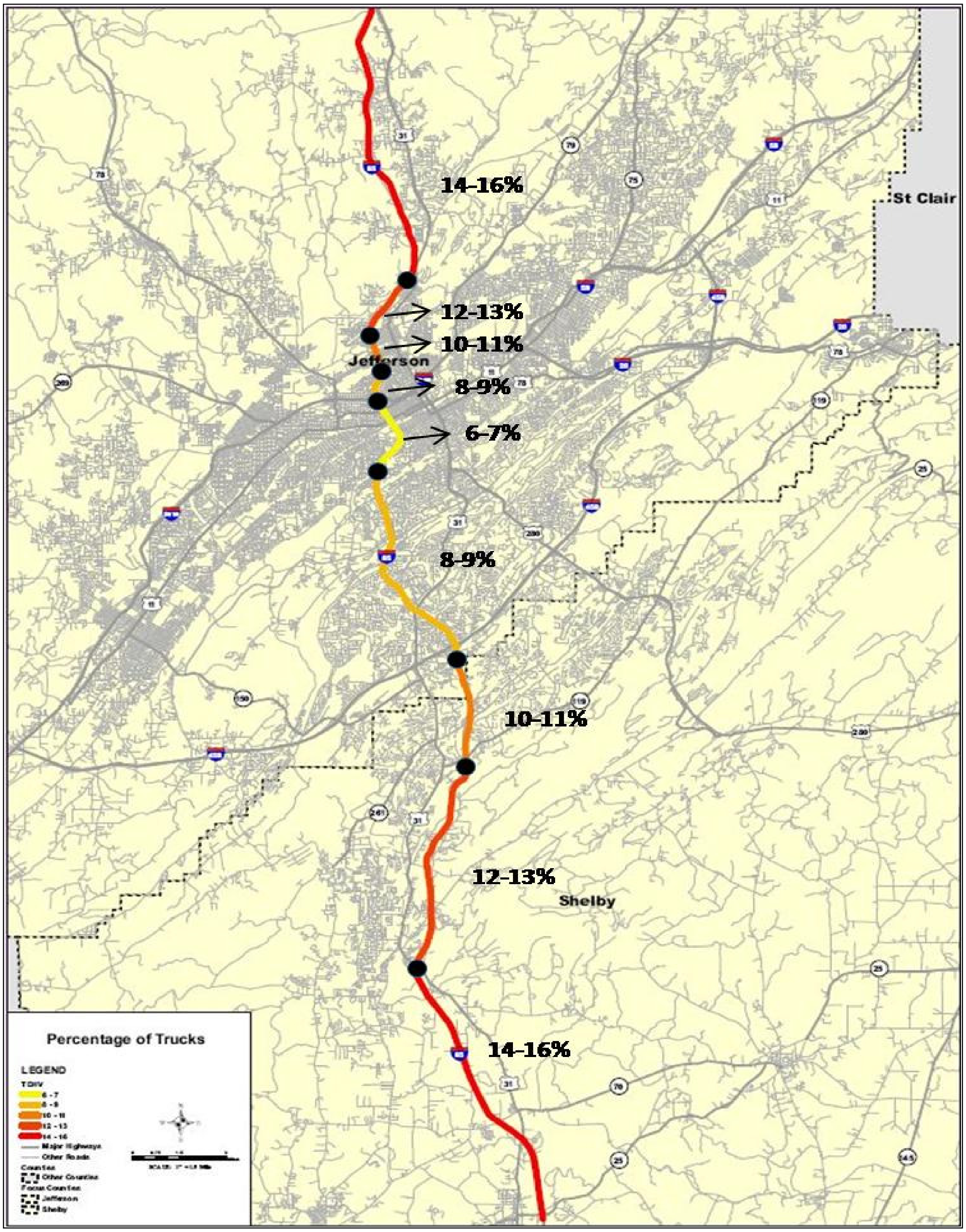

Figure 3-2. Percentages of truck volumes along I-65 (PBS&J 2006)

Operational Characteristics of I-65 Corridor Based on traffic counts reported by ALDOT, the 2005 daily traffic volumes along the study segment of I-65 ranged from 75,000 to 125,000. By 2030, daily traffic volumes are expected to exceed 125,000 along the entire I-65 study section (Figure 3-1). Table 3-1 summarizes the operational characteristics of the study site based on local studies performed in 2005 to 2006 (PBS&J 2006).

Table 3-1. Operational characteristics of the I-65 study corridor NB direction (PBS&J 2006)

Segments	LOS	v/c Ratio
Valleydale Road to I-459	F	1.55
I-459 to US 31	E	0.99
US 31 to Alford Avenue	F	1.47
Alford Ave to Lakeshore Dr	F	1.47
Lakeshore Dr to Oxmoor Rd	F	1.42
Oxmoor Rd to Greensprings Ave	F	1.50
Greensprings Ave to University Blvd	F	1.26
University Blvd to 3rd-4th Ave S	D	0.84
3rd-4th Ave S to 3rd-6th Ave	C	0.67
3rd-6th Ave to I-20/59	C	0.64

Figure 3-2 illustrates the percentages of truck volumes on I-65 during peak hours based on 2005 traffic count data collected by the ALDOT. The percentage of truck traffic on I-65 is nearly 10% of all vehicle traffic (PBS&J 2006).

Designing HOV Lanes on I-65 Two typical HOV design configurations were considered for I-65 in this study: a median concurrent-striped lane and a median concurrent-barrier lane in each direction. Figures 3-3 and 3-4 show median concurrent-striped lane and median concurrent-barrier lane configurations, respectively.

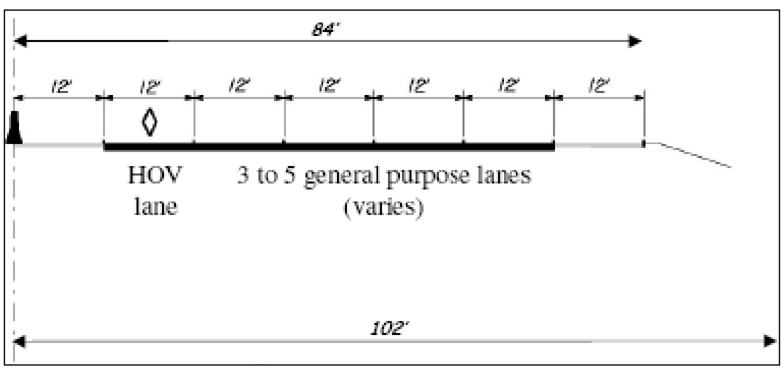

Figure 3-3. Median concurrent-striped HOV lane configuration (PBS&J 2006)

It is recommended that the median concurrent striped HOV design be applied to the I-65 corridor except at interchanges with other interstate highways where elevated structures should be considered (RPCGB 2006). Figure 3-5 illustrates a typical section of these elevated lanes.

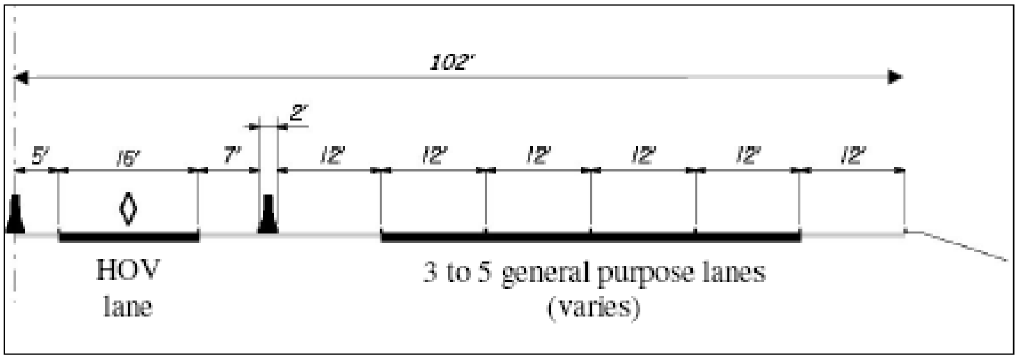

Figure 3-4. Median concurrent-barrier HOV lane configuration (PBS&J 2006)

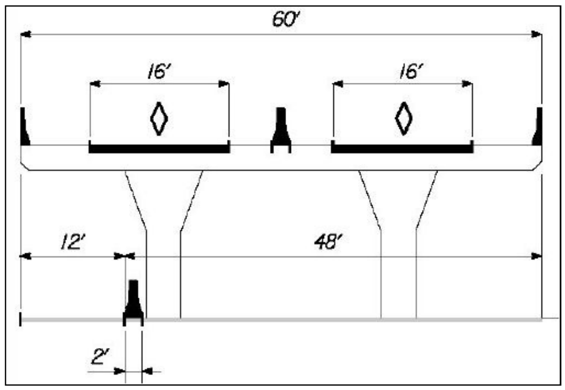

Figure 3-5. Typical section of elevated HOV lane configuration (PBS&J 2006)

Alternatives Analysis Prior to a potential implementation of HOV lanes and truck-only lanes along the I-65 corridor, a detailed alternatives analysis should be performed that uses traffic analysis tools to predict the impact of these strategies on traffic operations in the Birmingham area. Such analysis is the main objective of this study and requires the following steps:

1. *Model Selection*. Model selection refers to the selection of appropriate traffic analysis tools with the ability to model a variety of managed lane strategies, including high occupancy lanes (HOV) and truck-only lanes.
2. *Data Collection and Processing*. Collection of required data (such as traffic volumes, lane geometry, and Origin-Destination [O-D] Matrices) and development of a model of I-65 and selected transportation facilities in the Birmingham area using the simulation tool identified in Step 1.
3. *Data Analysis.* The simulation model developed in Step 2 should be used to examine traffic operations with and without the presence of HOV and truck lanes strategies as well as assess different configurations of designs. The impact from implementation could be measured using selected measures of effectiveness (MOEs), such as travel speeds, travel times, delays, and fuel consumption.

The following sections provide details on simulation model selection, data collection and processing, and data analysis for the Birmingham case study.

Simulation Model Selection

A detailed review of the candidate simulation model approaches, capabilities, and limitations, along with the availability of models and other resources led to the selection of the Visual Interactive System for Transport Algorithms (VISTA) as the simulation tool for this study. VISTA utilizes a mesoscopic simulator called RouteSim and a dynamic traffic assignment (DTA) routine to emulate the behavior of individual drivers and how they distribute themselves into the transportation network. RouteSim is based on an extension of Daganzo's cell transmission model introduced by Ziliaskopoulos and Lee (Ziliaskopoulos and Lee 1996). In this model, the road is divided into small cells that are adjustable in length; larger cells are used for a mid-section of a long highway segment, and smaller cells are used for intersections and interchanges. Vehicles are considered to be moving from one cell to another in platoons. The simulator keeps track of the flow in each cell and at every time step calculates the number of vehicles that are transmitted between adjacent cells.

Initially, the RouteSim simulator in VISTA is run with vehicles assigned to the free flow shortest paths. The link travel times resulting from that assignment pattern are then used to calculate a new set of shortest paths, and the simulation is repeated with vehicles assigned to a combination of the paths in the previously calculated path set. At first, the link flows generated by the free flow shortest paths vehicle assignment can be different from the link flows generated by the simulation using the new set of calculated paths. Thus, iterations continue between the mesoscopic simulation and vehicle assignment until the link flows converge. This procedure accounts for vehicle path choice with changes in traffic conditions.

VISTA simulation model can be used for a wide range of applications in transportation engineering and planning. Some of the capabilities of VISTA follow (Sisiopiku, *et al.* 2009):

- VISTA runs over a cluster of Unix/Linux machines and is easily accessible to authorized users via Internet/Intranet. This allows access to and use of the model by a variety of users and eliminates the need to install new software and software upgrades.
- VISTA uses a universal database model that can be accessed through a web interface or GIS interface. The GIS interface enables users to edit on the network.
- VISTA has enormous capacity for handling large networks.
- The model provides DTA capabilities. Dynamic User Equilibrium (DUE) is the main traffic assignment technique employed in VISTA. As a result, no user can switch path to decrease his/her travel time.
- VISTA can meet the functional needs of various areas by multiple types of DTA capabilities (descriptive vs. normative).
- VISTA is capable of distinguishing between informed and non-informed road users, as well as user classes, such as normal passenger cars, buses, and trucks in terms of operational characteristics.

- Congestion management strategies such as incident management, ITS technologies, and work zone management activities can be modeled easily.
- VISTA offers a number of pre-confined reports to provide information on various types of MOEs such as travel time, delays, and VMT.
- VISTA also offers other customized outputs by running query to database directly in the web interface.

As a mesoscopic simulation-based DTA model, VISTA can meet the requirements of the study tasks by modeling the route choice of individual drivers and other important driver behaviors but limiting the level of detail when modeling driver interactions with the infrastructure and other drivers. This is accomplished by using various modules, a brief description of which follows. Additional details are available at *www.vistatransport.com*.

Cell Generator This module is used for converting the network of links and nodes into the networks of cells. The RouteSim simulator employed in VISTA uses the cell transmission model to propagate vehicles in the cells. Links are divided into multiple cells of length equal to the distance traveled in one time step by a vehicle moving at free-flow speed. In other words, vehicles can move one cell in one time step given that there is no congestion present. In fact, the number of vehicles that moves depends upon the space available on the downstream cell and the maximum flow permitted. In case of space constraints, vehicles do not move forward and queues will develop (Mouskos, *et al.* 2006).

Prepare Demand Although Origin-Destination (O-D) demands refer to the whole simulation period, time dependent simulation or dynamic demand requires exact percentage of vehicle departures. Hence each interval in the simulation can assign different weight using Prepare Demand Module (Abro 2007).

DTA-Path Generation In the DTA–Path generation module, traffic assignment is done by calculating the time dependent shortest path at every iteration. This process is a simulation-based process of dynamic traffic assignment; hence RouteSim simulator is automatically called in this module. Simulation process starts when DTA-Path generation is started (VISTA 2005). Hence this process generates dynamic least cost path for all vehicles in O-D demand depending upon shortest path algorithm.

DTA-Dynamic User Equilibrium (DUE) The DTA-Dynamic User Equilibrium module does not calculate paths for the vehicles but it reshuffles the vehicles among the existing set of paths. It should be noted that DTA–Path Generation should be performed before employing DTA–Dynamic User Equilibrium. In the process of DUE, vehicles are redistributed until the desirable cost gap factor is reached (Abro 2007). Cost gap is the percentage error for the convergence of traffic assignment to equilibrium condition. Generally a cost gap of 5% or less is considered acceptable.

Simulation The simulator used in VISTA can also simulate vehicles without DTA. RouteSim simulator is active in doing traditional simulation process without carrying Dynamic Traffic

Assignment. In case of simulation-only runs vehicles are assigned according to originally assigned path, and real time conditions (such as information provision) do not affect the users' route choices (VISTA 2005).

Development of Simulation Model for the Birmingham Case Study

The study network of the Birmingham region was built in VISTA using background geometric and AADT volume data from the TRANPLAN (TRANsportation PLANning) model provided by the RPCGB. The simulation network included a segment of I-65 beginning from the I-459 interchange in the south and extending to the I-20/59 interchange to the north. The US 31, Alford Ave, Lakeshore Dr, Oxmoor Blvd, and Green Springs Ave interchanges were also coded to reflect traffic entering to and/or exiting from the study network. Figure 3-6 shows the Birmingham region network that was coded in VISTA.

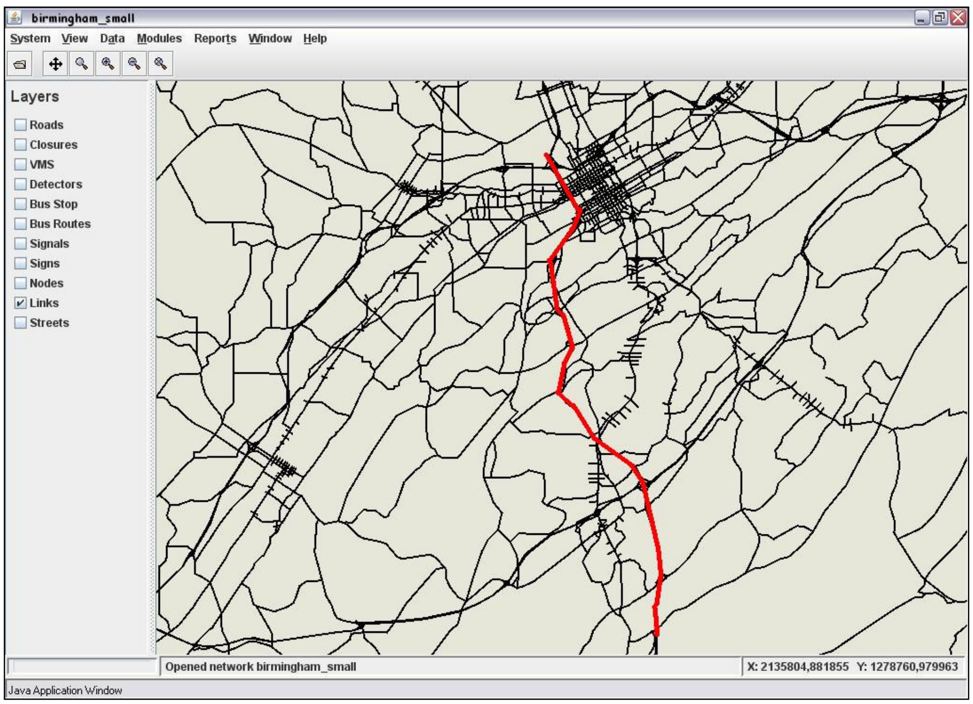

Figure 3-6. Birmingham case study network coded in VISTA for alternatives analysis

Birmingham Case Study Scenarios

HOV Lanes Scenarios Three scenarios were designed for the Birmingham VISTA network to analyze the operational effectiveness of HOV lanes.

- *Scenario 1-HOV* described network operations under current conditions (i.e. no HOV lane presence, just general-purpose lanes) and provided the baseline for comparisons (Figure 3-7).
- *Scenario 2-HOV* assumed that the innermost general-purpose lane was converted to an HOV lane as shown in Figure 3-8. This scenario was designed for a sensitivity analysis

by varying the percentage of drivers using an HOV lane (from 10% up to 25% in increments of 5%) and observing the relative changes in model response.

- *Scenario 3-HOV* assumed that an HOV lane was added to the current design configuration and performed a sensitivity analysis similar to that of Scenario 2 where the percentage usage was varied incrementally. The lane configuration of the third HOV scenario is shown in Figure 3-9.

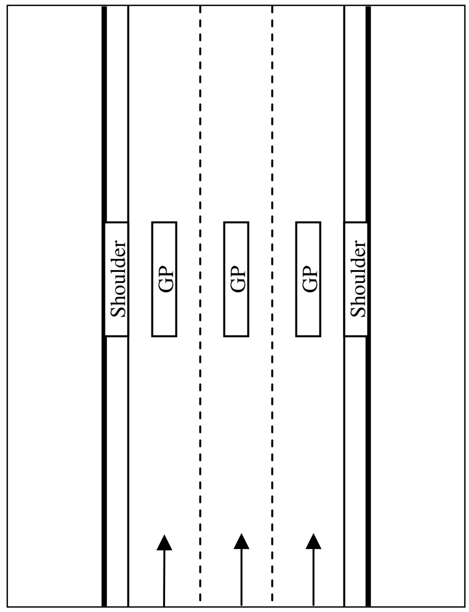

Figure 3-7. Typical lane configuration for scenario 1-HOV

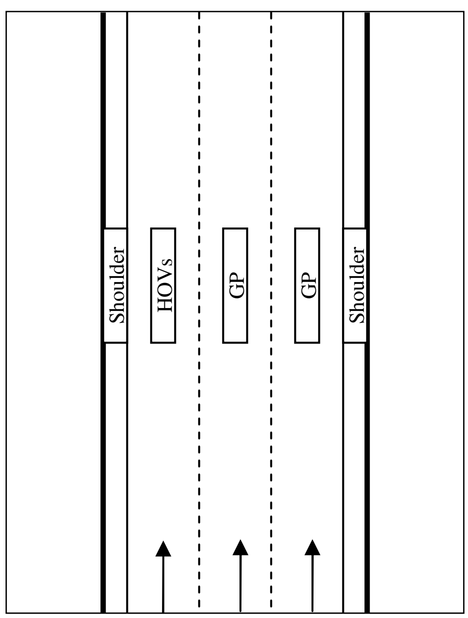

Figure 3-8. Typical lane configuration for scenario 2-HOV

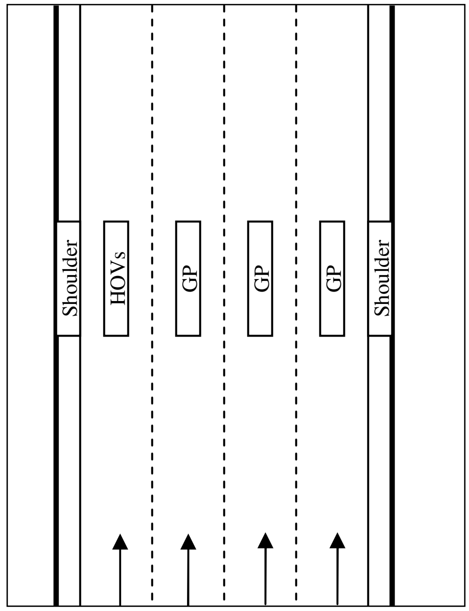

Figure 3-9. Typical lane configuration for scenario 3-HOV

Two different demands are considered as inputs in Scenarios 2-HOV and 3-HOV. More specifically, simulations were run first with *vehicle demand equal to the baseline conditions*. Under this assumption, the same numbers of vehicles are placed on the network when HOV lanes are introduced, but because of the higher occupancy of the HOV vehicles a larger number of travelers could be accommodated. To provide a fair comparison between baseline and HOV operations, a second case study was performed that adjusted the demand used in the HOV scenarios to result in *equal people carrying capacity*. Using a 1.3-person occupancy for a regular vehicle and a 2-person occupancy for an HOV vehicle, one can get 5%, 8%, 11% and 13% reductions in total vehicle trips for 10%, 15%, 20%, and 25% HOV use.

The data analysis allowed a comparison of results from Scenarios 2-HOV and 3-HOV with the baseline conditions (Scenario 1-HOV), as well as comparison between the two HOV designs. Finally, the sensitivity analysis was performed to gain insights on HOV lane use and its impact on traffic operations.

Two sets of runs were performed for each HOV scenario (namely 2-HOV and 3-HOV). The first set assumed that the drivers are unfamiliar with the new implementation and thus can use the information on the VMS to make informed decisions about their options. Under these assumptions the Simulation Module of VISTA was run (2-HOV-S and 3-HOV-S scenarios). The second set of runs assumed that after a certain time drivers became familiar with the operation of HOV lanes and thus planned their travel accordingly. This involved utilization of the VISTA DTA/DUE Modules (2-HOV-D and 3-HOV-D scenarios). Results from both options are summarized and discussed in Section 4.

Truck-Lane Scenarios Three scenarios were designed to analyze operational effectiveness of truck lanes. A consistent naming scheme was devised for easy reference. The name of each test scenario starts with three letters referring to the type of truck lane strategy considered (BNT=Baseline-No Truck lane, ETL=Exclusive Truck Lane-no passenger cars allowed, and STL=Shared Truck Lane-passenger cars allowed), followed by the number of lanes per direction (3=3 lanes, or 4=4 lanes). More specifically:

- *Scenario BNT3* describes network operations under current conditions to provide the baseline for comparisons.
- *Scenario BNT4* assumes that a lane is added to the current network, and all lanes are available to be used by mixed traffic.
- *Scenario STL3* assumes that a lane is converted to a truck lane. The lane configuration is shown in Figure 3-10. Trucks are required to use the truck lane, while passenger cars may elect to use it as well.
- *Scenario ETL3* assumes that a lane is converted to a dedicated truck lane to be used exclusively by truck traffic (Figure 3-10).
- *Scenario ETL4* assumes that a dedicated truck lane is added to the network to be used exclusively by truck traffic (Figure 3-11).

A sensitivity analysis was performed in all scenarios to consider the impact of various percentages of truck traffic in the traffic stream. Truck traffic considered ranged from 4%, to 12% in increments of 4%. Table 3-2 summarizes details of the scenarios tested in this project.

Table 3-2. Case study scenarios

Scenario	Total Number of Lanes per Direction	Number of Truck Lanes	Truck Lane Type	Sensitivity Analysis Performed (%trucks)
BNT3	3	0	-	Yes (4%, 8%, 12%)
BNT4	4	0	-	Yes (4%, 8%, 12%)
STL3	3	1	Shared	Yes (4%, 8%, 12%)
ETL3	3	1	Exclusive	Yes (4%, 8%, 12%)
ETL4	4	1	Exclusive	Yes (4%, 8%, 12%)

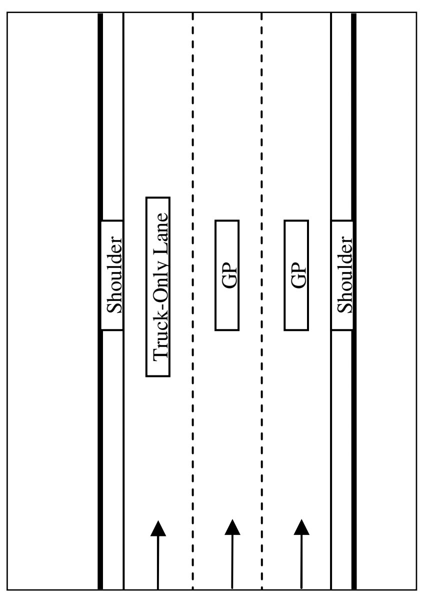

Figure 3-10. Typical lane configuration for scenarios STL3 and ETL3

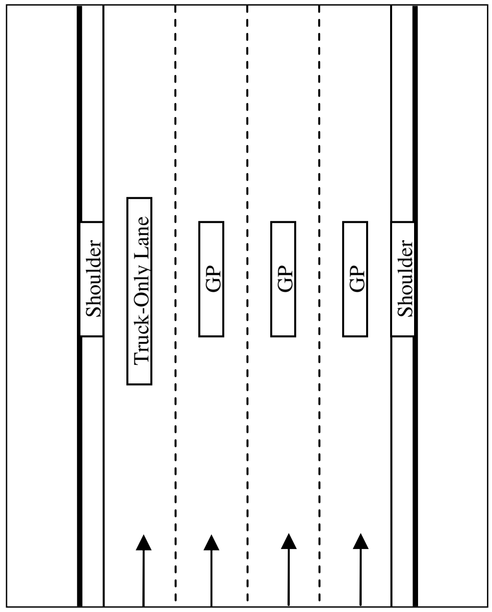

Figure 3-11. Typical lane configuration for scenario ETL4

Data Analysis

The scenarios presented reflect two operational strategies: HOV lane and designated truck lane. Simulations were performed for these scenarios within the VISTA environment. In the HOV and truck lane networks, a series of links were added in parallel to the general-purpose links to represent the HOV and designated truck lane. When a scenario called for lane addition such links represented the added lanes. When a scenario simulated lane conversion to HOV or designated truck lane operations, the general-purpose lanes along the I-65 mainline were reduced by one lane to accurately model the proper number of lanes. This approach was followed to overcome a difficulty created by the fact that the mesoscopic simulator RouteSim's working principle is based on links and not lanes, and thus a lane-by-lane analysis is not feasible.

Ten Variable Message Signs (VMS) were also added to specific locations throughout the study corridor to inform drivers about the HOV/truck lane option and let them choose the shortest path during their journey as in real life. For the purpose of choosing the shortest path some routes were defined as HOV/truck lane and others as general-purpose routes and comparisons between their operational characteristics were allowed. Four of the VMS were located on the southbound direction, and six VMSs were on the northbound direction of the study corridor. More specifically, the VMSs on the southbound are north of I-20/59, between University Blvd and Green Springs Ave S, between Alford Ave S and Montgomery Highway, and between I-459 and Valleydale Rd interchanges. In the northbound I-65 VMSs are available between University Blvd and I-20/59, Green Springs Ave S and University Blvd, Lakeshore Dr and Oxmoor Rd, Montgomery Highway and Alford Ave S, Valleydale Rd and I-459, and south of Highway 119.

Section 4
Results

HOV Lanes Simulation Results

As mentioned in Section 3, three scenarios were defined for the Birmingham VISTA network to analyze the operational effectiveness of HOV lanes.

Scenario 1-HOV: Baseline Scenario Results This scenario assumed 2006 AADT volumes increased by 15% to account for demand increase in the near future. Three 12-ft lanes in each direction were considered along I-65. The results from the simulation are summarized in Table 4-1 and reflect baseline conditions.

Table 4-1. Results of scenario 1-HOV: Baseline

Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
133,559.50	11,420.80	44.643	0.141	1.447

According to the results, vehicles travel an average of 44.643 mph and experience an average of 0.141 minutes of delay per mile traveled.

Scenario 2-HOV: Converting Lane Case Scenario Results As mentioned in the methodology section, two assumptions were considered in Scenario 2-HOV:

- *Assumption A*: Equal Vehicle Demand. The number of vehicles on the network when HOV lanes are introduced is the same as in the baseline (Scenario 2A-HOV).
- *Assumption B*: Equal Person-carrying ability. The number of travelers on the network when HOV lanes are introduced is the same as in the baseline (Scenario 2B-HOV).

Furthermore, two assumptions were made regarding the familiarity of the users with the HOV operation:

- *Option S:* Unfamiliar users who based their routes on guidance from VMS.
- *Option D:* Familiar users who took into consideration the presence of the treatment in their selection of optimal routes.

The results from these options are summarized next and details are provided in Appendix 1.

Results from Scenario 2A-HOV-S and 2A-HOV-D. Both in Scenario 2A-HOV-S and 2A-HOV-D, the percentages of users using the converted HOV lane are assumed to vary from 10%

to 25% of all traffic. Traffic volumes assumed in this scenario represent future traffic demand conditions (i.e. 2006 AADT increased by 15%).
Currently, 10% of vehicles in the network carry two persons or more. The results presented in Table 4-2 summarize the network performance with the conversion of an existing traffic lane to HOV assuming the current ridesharing percentage (10%) in the short- (S) and long-term (D).

Table 4-2. Comparison of scenarios 2A-HOV-S and 2A-HOV-D: Converting lane case scenario (10%)

Scenarios	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
2A-HOV-S (10%)	121,237.40	11,408.93	44.480	0.132	1.444
2A-HOV-D (10%)	129,493.87	7,810.72	45.136	0.102	1.410

Negligible gains in delay and travel speed are observed in the near term (2A-HOV-S) when an HOV lane conversion is implemented, as compared to the baseline conditions (Table 4-1). This is expected due to the small percentage of HOV users and their unfamiliarity with the available options. On the other hand, as drivers realize the potential time savings from using HOV lanes, more significant gains are realized from the use of HOV lane in the future. This is evident from the decrease in total delay time under 2A-HOV-D (10%) conditions by 32% as compared to the baseline (7,810.72 versus 11,420.80 in 1-HOV).

Further analysis was performed to test the impact of higher HOV lane utilization on traffic operations and the results from the 2A-HOV-D (10% through 25%) are shown in Table 4-3. From Table 4-3 it can be seen that small improvements in performance should be expected from an HOV lane conversion for 10% to 25% HOV presence. Gains ranging from 1% to 2% are expected in average travel speed while the delay time improves 28% to 35%. It should be noted that under the study conditions in these scenarios, optimal system performance can be achieved when the HOV lane carries 25% of the facility's traffic. This finding indicates that, for best performance, a major campaign will be needed to increase the existing ridesharing proportion during peak hours, HOT lanes should be considered to populate the HOV lanes, or both.

Table 4-3. Scenario 2A-HOV: Converting lane case, sensitivity analysis results

Scenario	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Baseline	133,559.50	11,420.80	44.643	0.141	1.447
2A-HOV-S (10%)	121,237.40	11,408.93	44.480	0.132	1.444
2A-HOV-S (15%)	121,661.01	11,554.26	44.479	0.133	1.445
2A-HOV-S (20%)	121,789.17	11,339.17	44.521	0.131	1.443
2A-HOV-S (25%)	122,004.01	11,266.58	44.546	0.131	1.442
2A-HOV-D (10%)	129,493.87	7,810.72	45.136	0.102	1.410
2A-HOV-D (15%)	128,538.13	7,272.74	45.321	0.099	1.404
2A-HOV-D (20%)	128,113.76	6,714.27	45.455	0.095	1.400
2A-HOV-D (25%)	127,359.42	6,354.92	45.582	0.093	1.397

However, one should also acknowledge that as vehicle occupancy increases with increased HOV usage, the actual person-carrying ability of the network increases as well. In other words, under the HOV scenario, a larger number of travellers can be accommodated by the same number of vehicles, which in turn creates an advantage that is not easily detected by the operational analysis results documented in Table 4-3. These impacts are discussed in detail when the 2B-HOV scenarios are reviewed.

Results from Scenario 2B-HOV-S and 2B-HOV-D. These scenarios are similar to 2A-HOV scenarios except for the fact that the traffic volumes assumed in 2B-HOV scenarios are adjusted to represent equal number of travelers (rather than vehicles) as compared to the baseline. Table 4-4 shows the comparison of unfamiliar (2B-HOV-S) and familiar (2B-HOV-D) drivers for 10% HOVs. As drivers become familiar with the treatment, the realized benefits increase. For example, delay time of familiar drivers is found to be 12% less than unfamiliar ones (0.094 versus 0.107).

Table 4-4. Comparison of scenarios 2B-HOV-S and 2B-HOV-D: Converting lane case scenario (10%)

Scenario	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
2B-HOV-S (10%)	111,573.79	7,431.42	44.986	0.107	1.418
2B-HOV-D (10%)	121,240.82	6,334.98	45.420	0.094	1.400

The sensitivity analysis results of familiar drivers (2B-HOV-D) are summarized in Table 4-5.

Table 4-5. Comparison of results from scenario 2B-HOV: Converting lane case and baseline

Scenario	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Baseline	133,559.50	11,420.80	44.643	0.141	1.447
2B-HOV-S (10%)	111,573.79	7,431.42	44.986	0.107	1.418
2B-HOV-S (15%)	107,442.65	5,830.58	45.257	0.096	1.407
2B-HOV-S (20%)	103,747.43	4,748.08	45.490	0.088	1.399
2B-HOV-S (25%)	100,392.17	4,038.00	45.665	0.083	1.394
2B-HOV-D (10%)	121,240.82	6,334.98	45.420	0.094	1.400
2B-HOV-D (15%)	116,456.98	5,340.49	45.696	0.088	1.393
2B-HOV-D (20%)	112,809.39	4,910.34	45.789	0.087	1.391
2B-HOV-D (25%)	108,559.83	4,413.33	45.954	0.084	1.386

Under the equal people carrying ability assumption in Scenario 2B-HOV-D the results from the sensitivity analysis show operational benefits from the conversion of a freeway lane to HOV. For example, Scenario 2B-HOV-D (25%) leads to an increase in the average travel speed to 45.954 mph (3% higher than in the baseline) and significant savings in travel delay and travel times (nearly 43% and 4% respectively). As expected such benefits are greater than those observed under the 2A-HOV-D scenarios.

Overall, the results from the sensitivity analyses in Scenarios 2A-HOV and 2B-HOV confirm that the conversion of a freeway lane to HOV is justified on the basis of operational benefits regardless of the percentage of HOVs of all traffic. While the benefits are not dramatic, they constitute an improvement over current operations, which appear to increase as HOV lane utilization increases.

Scenario 3-HOV: Adding Lane Case Scenario Results

Results from Scenario 3A-HOV-S and 3A-HOV-D. As mentioned before, Scenario 3A-HOV assumes that an HOV lane is added to the current design configuration. A sensitivity analysis similar to that of Scenario 2A-HOV is performed where the percentage usage is varied incrementally, and the results are summarized in Table 4-6.

Table 4-6. Comparison of results from scenario 3A-HOV: Adding lane and baseline

Scenario	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Baseline	133,559.50	11,420.80	44.643	0.141	1.447
3A-HOV-S (10%)	116,016.55	5,202.45	45.459	0.089	1.400
3A-HOV-S (15%)	130,875.10	17,863.79	44.022	0.156	1.491
3A-HOV-S (20%)	116,492.08	5,179.65	45.491	0.089	1.399
3A-HOV-S (25%)	116,681.16	5,164.59	45.505	0.089	1.399
3A-HOV-D (10%)	127,181.39	5,888.39	45.711	0.091	1.394
3A-HOV-D (15%)	126,073.19	5,563.41	45.863	0.088	1.390
3A-HOV-D (20%)	127,365.60	6,133.91	45.680	0.091	1.395
3A-HOV-D (25%)	127,602.55	6,397.44	45.644	0.092	1.396

As expected, the addition of an HOV lane leads further improvement of traffic conditions. With the shift of HOV traffic to the new lane, the average delay time decreases from 0.141 in the baseline to 0.089 min/veh-mile in Scenario 3A-HOV-S and 0.091 min/veh-mile in Scenario 3A-HOV-D, a savings of 35%. Although these results are positive, they do not necessary justify the implementation of an HOV lane, but they clearly show that when HOV vehicles shift to the new lane, the overall system performance improves.
Results from Scenario 3B-HOV-S and 3B-HOV-D. Adding lane case scenarios are also run with demand adjustments to represent equal people carrying ability of the network. The results are summarized in Table 4-7.

Table 4-7. Comparison of results from scenario 3B-HOV: Adding lane and baseline

Scenario	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Baseline	133,559.50	11,420.80	44.643	0.141	1.447
3B-HOV-S (10%)	116,009.38	5,197.04	45.458	0.089	1.400
3B-HOV-S (15%)	106,269.81	4,175.56	45.677	0.083	1.394
3B-HOV-S (20%)	103,392.33	3,933.72	45.742	0.082	1.392
3B-HOV-S (25%)	100,335.17	3,711.07	45.784	0.081	1.391
3B-HOV-D (10%)	119,453.85	5,041.16	45.885	0.086	1.389
3B-HOV-D (15%)	115,623.42	4,706.80	45.943	0.085	1.387
3B-HOV-D (20%)	111,873.28	4,413.43	46.013	0.083	1.385
3B-HOV-D (25%)	108,062.45	4,141.04	46.070	0.082	1.384

The results obtained under the assumptions of Scenario 3B-HOV also show the benefits on traffic operations from introducing a new dedicated HOV lane. When compared to the baseline, a 3% (or approximately 1.5 mph) increase in speed and 42% reduction in delay time is observed under Scenario 3B-HOV-D (25%). Still, under the study assumptions the differences in operational performance measures are not large enough to determine the best solution for implementation. Additional considerations should be made, including a detailed cost-benefit analysis to assist in the determination of the best option for possible deployment.

Truck Lane Simulation Results

The simulations for the truck-only lane scenarios were completed with VISTA software using future traffic volumes. The next paragraphs summarize and discuss the truck lane simulation results for each scenario.

Baseline Results (BNT3 and BNT4 Scenarios) Table 4-8 presents results from the sensitivity analysis performed under the current configuration (BNT3). Consideration of the network total delay time shows that the network performs optimally for 8% truck traffic. When a general-purpose lane is added (BNT4) significant savings in delay time (43%) and total travel time (4%) are realized as expected, along with a slight increase in average travel speed.

Table 4-8. Results of truck lane baseline scenarios

Scenario	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
BNT3 (4%)	131,715.14	10,328.23	45.426	0.129	1.434
BNT3 (8%)	131,947.14	9,832.21	45.321	0.126	1.432
BNT3 (12%)	136,938.75	14,627.06	45.159	0.166	1.473
BNT4 (4%)	126,051.90	5,941.87	45.761	0.094	1.395
BNT4 (8%)	126,123.11	5,883.47	45.714	0.094	1.396
BNT4 (12%)	126,663.44	6,363.93	45.631	0.098	1.401

Converting Lane Case Results (STL3 and ETL3)

Unfamiliar Results. Table 4-9 summarizes the results obtained when converting an existing general-purpose lane into a truck lane for shared (STL3) or exclusive (ETL3) use. The results are from simulation studies performed in VISTA assuming the users continue to use their regular paths when the truck lanes are first implemented and demonstrate the network performance soon after the implementation of the truck lane scenarios.

Table 4-9. Converting lane case – simulation results (STL3 and ETL3 Scenarios) - unfamiliar users

Scenario	Total Travel Time (veh-hrs)	Total Delay Time (veh-hrs)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
STL3 (4%)	135,030.45	14,091.21	44.426	0.155	1.468
STL3 (8%)	131,261.44	11,156.70	44.447	0.134	1.452
STL3 (12%)	128,917.38	10,494.17	44.440	0.139	1.461
ETL3 (4%)	128,883.84	14,782.31	44.064	0.162	1.479
ETL3 (8%)	126,101.80	11,915.19	44.087	0.141	1.463
ETL3 (12%)	124,199.39	11,858.29	44.081	0.149	1.475

Several observations can be made from the analysis of the results. First, it becomes apparent that for the same percentage of truck traffic the dedicated truck lane works better under the shared traffic option (i.e. when cars are allowed to use the truck lane) rather than the exclusive truck-use option. For instance, for 12% trucks in the traffic stream, the shared truck lane option yielded total network delay time of 10,494 veh-hrs, or 13% less than the exclusive truck lane option (11,858 veh-hrs). A likely reason for this is that in the ETL3 scenario the dedicated truck lane is underutilized for the percentage of trucks considered in the analysis. It should be noted that the performance of the exclusive truck lane option improves as the percentage of truck users increases (from 14,782 veh-hrs of total delay in ETL3 [4%] to 11,858 in ETL3 [12%], or a 20% improvement). The comparison of the converting lane case results to the baseline (BNT3) in Table 4-8 further indicates that the conversion of a general-purpose lane to a truck lane can only be justified for the 12% truck option.

Familiar Results. Table 4-10 summarizes the results obtained when converting an existing general-purpose lane into a truck lane for shared (STL3) or exclusive (ETL3) use, assuming that the users are now familiar with the treatment. The results are from optimization studies performed in VISTA using its DTA capability assuming the users have been considering new path options to further optimize their travel in the presence of the truck lanes. These results demonstrate the network performance in the long term, when the users become familiar with the implementation and impact of the truck lanes on local traffic operations.

Table 4-10. Converting lane case – Optimization results (STL3 and ETL3 scenarios) - familiar users

Scenario	Total Travel Time (veh-hrs)	Total Delay Time (veh-hrs)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
STL3 (4%)	127,124.26	5,963.21	45.649	0.092	1.396
STL3 (8%)	128,216.35	6,365.45	45.480	0.097	1.403
STL3 (12%)	129,229.16	7,218.21	45.329	0.105	1.412
ETL3 (4%)	131,310.41	9,313.17	44.899	0.119	1.429
ETL3 (8%)	131,005.33	8,914.61	44.964	0.118	1.428
ETL3 (12%)	131,749.71	9,385.40	44.958	0.123	1.433

The results in Table 4-10 show that the conversion of an existing lane to a truck lane yields best results under the shared traffic mode of operation as compared to exclusive truck traffic use. The total travel time and total delay are lower in STL3 scenario and travel speeds as slightly higher than in ETL3 for similar percentages of truck traffic. The results in Tables 4-8 and 4-10 further demonstrate that both lane conversion options (STL3 and ETL3) improve network performance compared to the baseline (BNT3) for any percentage of truck traffic considered. Among the two-lane conversion options tested, STL3 is preferable as it leads to greater gains in network operational performance (up to a 50% reduction in total delay for 12% truck traffic). Furthermore, comparison of findings in Tables 4-9 and 4-10 indicate that, while no to moderate improvement in network performance should be expected soon after the implementation of the lane-conversion strategy, significant gains will be realized in the long run as users learn to optimize their travel routes.

Adding Lane Case Scenario Results (DTL4) Scenario DTL4 assumed a lane is added to the network to serve truck traffic. A sensitivity analysis was performed where the percentage truck usage was varied incrementally to evaluate short- and long-term performance measures (i.e. unfamiliar and familiar users). The results from the analysis are summarized in Table 4-11.

Table 4-11. Add lane case – simulation and optimization results (DLT4)

Scenario	Modeling Option	Total Travel Time (veh-hrs)	Total Delay Time (veh-hrs)	Avg. Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
DTL4(4%)	Simulation	120,984.90	6,392.01	44.957	0.103	1.420
DTL4(8%)	Simulation	119,349.74	6,483.14	44.923	0.107	1.426
DTL4 (12%)	Simulation	117,101.70	6,572.37	44.832	0.111	1.433
DTL4 (4%)	Optimization	126,724.59	6,052.51	45.689	0.095	1.398
DTL4 (8%)	Optimization	126,515.50	5,847.69	45.676	0.094	1.398
DTL4(12%)	Optimization	128,551.25	6,872.44	45.388	0.102	1.408

The comparison of total delays and speeds in Table 4-8 (BNT4) and Table 4-11 (DLT4) reveals that in the case of a lane addition no improvement in system performance is achieved by designating the lane as a truck lane for any percentage of truck traffic within the study range. In other words, the added capacity serves the needs of all users well and no further improvement is expected by separating truck traffic from the rest of the traffic stream. Thus, a designated truck lane is not justified under the study assumptions when a lane is added to the study facility.

Section 5
Cost-Benefit Analysis (CBA)

Introduction

Cost-benefit analysis (CBA) considers life-cycle costs and benefits of the project alternatives under study. The analysis reveals the economically efficient investment alternative, i.e. the one that maximizes net benefits from an allocation of resources. The life-cycle costs include design and engineering costs, right-of-way procurement costs, and construction and maintenance costs. Life-cycle benefits include Vehicle Operating Cost Savings, travel time savings, safety benefits, and emission reduction benefits. A detailed CBA was conducted to quantify the costs and gains from potential implementation of the HOV strategies considered earlier and to determine the most economically efficient alternative. The scenarios considered and the options within these scenarios follow:

Scenario 1: Baseline – do nothing.
Scenario 2: Convert one lane in each traveling direction of I-65 to an HOV lane.
Scenario 3: Add one HOV lane in each traveling direction of I-65.

Similar to the traffic impact analysis, a sensitivity analysis was performed to determine the potential impact of HOV lane utilization on the study results. More specifically, Scenario 2 was designed to have four options:

Option 2: HOV 10% - Assuming 10% of traffic would travel by the HOV lane.
Option 3: HOV 15% - Assuming 15% of traffic would travel by the HOV lane.
Option 4: HOV 20% - Assuming 20% of traffic would travel by the HOV lane.
Option 5: HOV 25% - Assuming 25% of traffic would travel by the HOV lane.

Scenario 3 considered five options:

Option 6: All four lanes in each direction are general-purpose lanes.
Option 7: HOV 10% - One of four lanes in each direction is a designated HOV lane, and 10% of the traffic will use the HOV lane.
Option 8: HOV 15% - One of four lanes in each direction is HOV lane, and 15% of the traffic will use the HOV lane.

Option 9:	HOV 20% - One of four lanes in each direction is HOV lane, and 20% of the traffic will use the HOV lane.
Option 10:	HOV 25% - One of four lanes in each direction is HOV lane, and 25% of the traffic will use the HOV lane.

As with the traffic-impact analysis presented earlier, there are two important demand-related assumptions in the analysis. Under the first assumption (i.e. Equal Volume Assumption) similar volumes are considered in the study networks with or without HOV presence. However, this assumption does not take under consideration the fact that as the percentage of HOV vehicles increases, fewer vehicles are needed to carry the same person demand. The second assumption (i.e. Equal Person Assumption) accounts for this reality by adjusting the vehicle demand for different percentage of HOV lane use.

With two assumptions and three scenarios consisting of ten options, a detailed CBA was performed to measure the worthiness of the proposed investment to identify the best option.

Methodology

A common methodology has been adopted for analyzing the costs and benefits of each option stated above. It includes:

(i) Analysis of infrastructure cost for each option.
(ii) Analysis of user benefits for each option.

The infrastructure cost has two components: investment cost and operation and maintenance cost. Investment cost of the project includes design and engineering cost, land acquisition cost, and construction cost.

The benefits of highway improvement projects are estimated as a function of the speed and volume of traffic with and without the project. Speeds and traffic volumes along the specific segment of I–65 were estimated from the TRANPLAN regional planning model for the base year 2006 and for the future year 2030. For future projection of traffic, data provided by ALDOT were considered.

There are four primary categories of user benefits that result from highway projects:

- Vehicle operating cost savings
- Travel time savings
- Safety benefits (accident cost savings)
- Emission reductions

The analysis period in this study was from 2010 through 2030. In order to conduct the analysis the Integrated Development Assessment System (IDAS) was used. In the following sections a brief overview of IDAS is provided following the IDAS manual (Cambridge Systematics 2009) and the methodology is discussed in greater detail.

Integrated Development Assessment System (IDAS)

The Integrated Development Assessment System (IDAS) is an ITS sketch-planning analysis tool that can be used to estimate the impact, benefits, and costs resulting from the deployment of ITS components (Cambridge Systematics 2009). IDAS operates as a post-processor to travel demand models, used by metropolitan planning organizations (MPO) and by state departments of transportation (DOT) for transportation planning purposes. IDAS, although a sketch-planning tool, implements the modal split and traffic assignment steps associated with a traditional planning model. These steps are of key importance to estimating the changes in modal, route, and temporal decisions of travelers resulting from implementation of ITS technologies.

The set of impacts evaluated by IDAS include changes in user mobility, travel time/speed, travel time reliability, fuel costs, operating costs, accident costs, emissions, and noise. The performance of selected ITS options can be viewed by market sector, facility type, and district. IDAS also provides cost-benefit comparison of various ITS improvements individually or in combination. IDAS comprises five analysis modules:

- Input/Output Interface Module (IOM)
- Alternatives Generator Module (AGM)
- Benefits Module
- Cost Module
- Alternatives Comparison Module (ACM)

The Benefits Module further comprises four submodules: i) Travel Time/Throughput, ii) Environment, iii) Safety, and iv) Travel Time Reliability. Within each of these sub-modules, traditional benefits of ITS deployment (e.g. improvement in average travel time) and non-traditional benefits (e.g. reduction in travel time variability) are estimated.

IDAS Data In the following paragraphs the input data required for analysis using IDAS are described.

Travel Demand Model Data The travel demand model data required by IDAS form the building blocks of information to derive the benefits analysis of the various ITS deployments. Input files can be in fixed format or space, tab, or comma delimited ASCII text with each column of data separated by the delimiter. IDAS contains a data translator that allows the user to define column variables of the input data. The data translator automatically parses the data upon input.

There is, however, a minimum amount of information that must be input into IDAS to test any ITS deployment:

- Node coordinate file
- Network link file
- Trip origin-destination (trip table) data files
- Zone to district equivalence (optional)
- Turn prohibitor file (optional)
- Trip in-vehicle travel time origin-destination tables (optional for vehicle market sectors)
- Trip out-of-vehicle travel time origin-destination tables (optional for vehicle market sectors)

An important concept within IDAS is the use of market sectors to describe discreet segments of the traveling population of a study area. Market sectors are analogous to trip purposes or modes of travel. For example, single-occupant vehicle trips can be classified as one market sector or could be classified by work trip and non-work trip single-occupant vehicle trips in two market sectors, as the two sectors could have different sensitivities to transportation improvements. The user can provide the most appropriate level of detail when defining the number of total market sectors (up to 99 can be defined).

IDAS requires detail-coded networks of freeway mainlines and ramps, with mainline freeway links coded in their separate directions. Such detailed coding is required to test freeway management systems such as ramp metering. Trip data required by IDAS are actually matrix data. Matrix data are two-dimensional array data structures that describe information for origin and destination zone pairs. This information can consist of trips, travel times, travel costs, or any other zonal pair data.

Other Input Data requirement. For Cost Module the analyst may use the default data available in IDAS. If the default cost data are not sufficient to conduct an analysis, the analyst need to feed in required cost data.

Creating a Project, Alternative, and ITS Option IDAS reads data prepared by a typical regional travel demand model (such as TRANPLAN) to construct the basic supply and demand characteristics of the transportation system being analyzed. Defining and reading in transportation planning data is the first step required to run IDAS. These data are organized within IDAS under a predefined hierarchy of projects, alternatives, and ITS options.

- A project is the highest level of the data hierarchy, and it describes the overall project of interest. The project contains the most general level of information, such as the project name, the year of the analysis, and zone to district equivalence import data file.

- An alternative is the second level in the data hierarchy and contains more specific information, such as the time period of analysis, network node, link data, and travel demand information (market sectors).
- The last level of data hierarchy in IDAS is an ITS option. ITS options are generated when the user creates a dataset that contains one or more of the various ITS elements being deployed on the networks.

ITS Options IDAS can assess impacts and costs for 12 types of ITS element categories:

- Arterial traffic management systems
- Freeway traffic management systems
- Advanced public transit systems
- Electronic payment collection
- Commercial vehicle operations
- Incident management systems
- Railroad grade crossings
- Emergency management services
- Regional multimodal traveler information systems
- Advanced vehicle control and safety systems
- Supporting deployments
- Generic deployments

Input Data for Case Study Analysis

The node coordinate data, link data, and trip table data (trips from origin to destination) for the base year were acquired from the TRANPLAN regional planning model maintained by RPCGB for the Birmingham region. The node coordinate data consist of the x and y coordinates of the nodes. The link data include A node and B node numbers, number of lanes, traffic volume, transportation facility/infrastructure type, traffic speed, length of the link, etc. The Generic Link Deployment option of IDAS was used in the analysis.

With the feed-in input data IDAS constructed the full network, where the facility types along with their attributes – i.e. volume, speed, number of lanes etc. – were well defined. In the IDAS analysis, the mode choice and traffic assignment steps of the four-step UTPS model were executed for the analysis period (2010 – 2030).

Figure 5-1 shows part of the Birmingham roadway transportation infrastructure constructed by IDAS using the node coordinates and link data. In this figure the study section of I-65 is highlighted, whereas the rest of the roadways are opaque for display purposes.

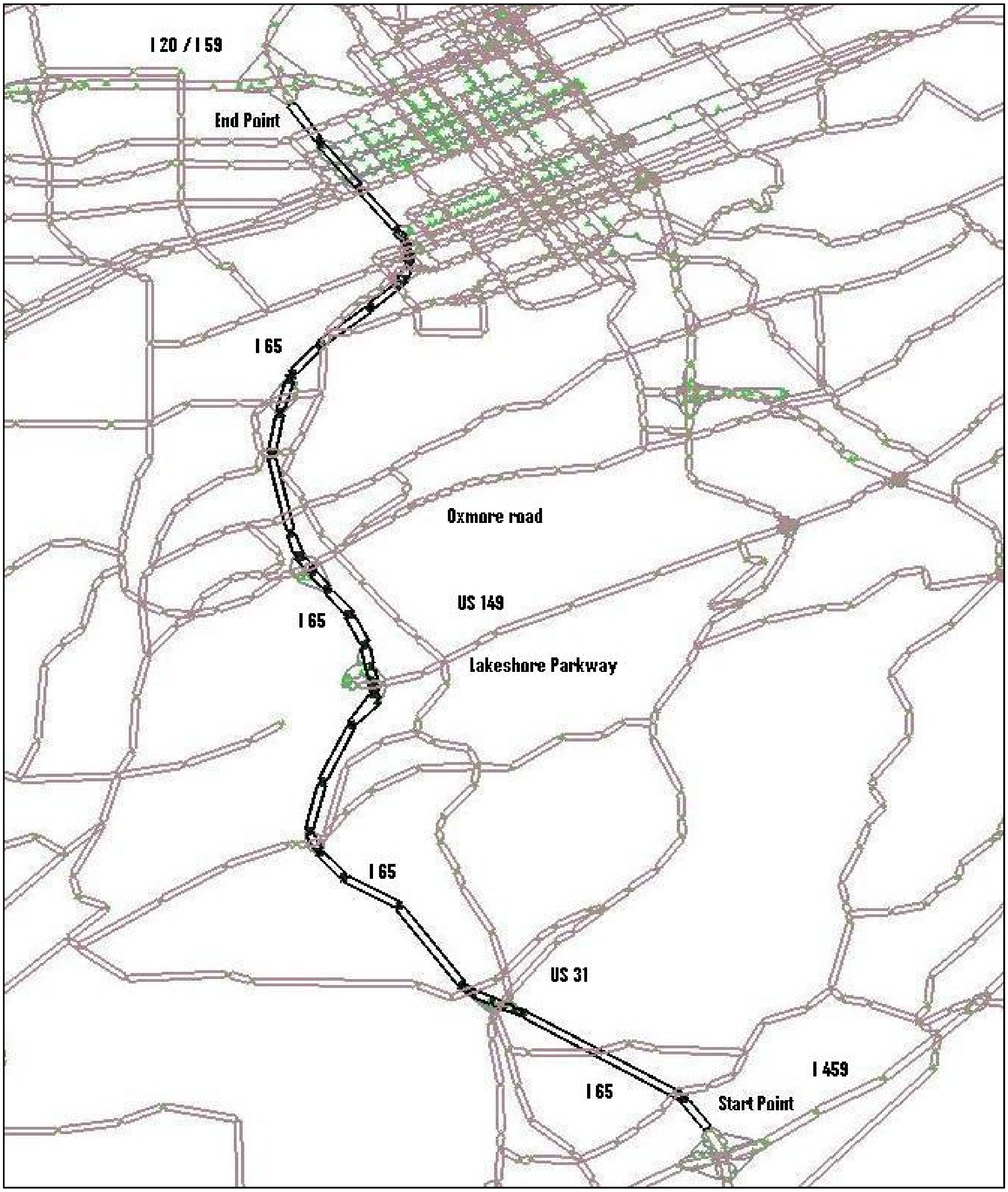

Figure 5-1. Partial view of the Birmingham network in IDAS showing the study segment of I-65

Similar to the traffic impact analysis, the CBA analysis conducted in this study considered two different assumptions, i.e.

(i) Equal Vehicle Assumption
(ii) Equal Person Assumption

For each assumption, two different analysis procedures were applied:

(i) Analysis that considers induced demand
(ii) Analysis that does not consider induced demand

Under the Equal Vehicle Assumption, a reduction in the number of vehicles due to an increase in vehicle occupancy resulted from HOV lane usage is not considered. Under the Equal Person Assumption, this decrease in number of vehicles is considered. Therefore, the Equal Person Assumption better approximates reality. Moreover, any improvement in existing transportation infrastructure or service is expected to induce new traffic in the improved infrastructure. As a result there would be an increase of traffic in the improved roadway along with redistribution of traffic throughout the network. Therefore, it was found necessary to consider induced demand in the analysis. The software IDAS has an Induced/Foregone Demand module that contains an Induced Demand estimation model. The IDAS default values of the Induced Demand model ($\alpha = -0.50$, $\beta = -0.44$, and $\varepsilon = -0.88$) were used in the analysis as described in the Benefit Module of the IDAS User's Manual (Cambridge Systematics 2009).

Discount Rate The discount rate, or interest rate, is one of the variables necessary to complete a CBA utilizing the Net Present Value (NPV) method. The US Office of Management and Budget (OMB) requires US Federal agencies to use a 7% real discount rate to evaluate public investments and regulations (FHWA 2003 and USDOT 2004). OMB reported a 10-year real discount rate of 2.5% and a 30-year rate of 3.2% in January 2003, based on current Federal borrowing costs. However, Federal agencies may use lower rates (based on inflation-adjusted Federal borrowing costs) for life-cycle cost analysis (FHWA 2003). The Federal Highway Administration (FHWA) suggests using a discount rate between 3% and 5% (Walls and Smith 1998). ALDOT uses a 4% discount rate on its life-cycle cost analyses (Lindly and Clark 2003). In this analysis a 4% discount rate was used.

Infrastructure Costs In the analysis performed in this study concerning Scenario 2 it was assumed that the lane conversion construction work begins in 2010 and lasts one year. The facility would open for regular operation from 2011. For Scenario 3, i.e. the Lane Addition Scenario, it was assumed that the project would start in 2008 and end in 2010. The facility would open for operation in 2011.

The construction costs and maintenance costs are estimated on the basis of ALDOT cost estimates and the *I–65 Corridor Feasibility Study Final Report* (PBS&J 2007). The lane conversion (Scenario 2) works involve the conversion of one lane in each traveling direction to an HOV lane. The construction cost for this scenario includes resurfacing of existing pavement and striping costs. The estimated construction cost is $21.42M (million) for the 12.5-mile lane. The estimated annual maintenance cost is $0.11M, with a provision of $21.42M for major rehabilitation costs every fifth year.

The lane addition (Scenario 3) works include the purchase of right-of-way and physical construction – i.e. new lane and shoulder construction, widening of bridges, pavement marking, and necessary highway features. The estimated cost is $116.553M for the 12.5-mile long segment under study. The estimated annual maintenance cost is $0.15M, after the construction is completed in five years. The estimated major rehabilitation cost is $27.90M, which would incur every fifth year after the regular maintenance work would start.

The construction and maintenance costs for different options are summarized in Table 5-1.

Table 5-1. Construction and maintenance costs for different options for analysis period (2010 – 2030)

Scenarios	Construction Cost	Maintenance Cost	Until Year
Scenario 1: Lane Conversion	$ 21.42 Million	$ 43.75 Million $ 87.50 Million	2020 2030
Scenario 2: Lane Addition	$ 116.55 Million	$ 28.95 Million $ 85.95 Million	2020 2030

Benefits of Different Scenario Analysis The major benefits of highway improvement works arise from i) vehicle operating cost savings, ii) value of travel time saving, iii) accident cost saving, and iv) emission cost saving. In the output module of IDAS, these benefits are addressed. However, the IDAS output does not return the Vehicle Operating Cost Savings and Value of Time Saving directly. The other two benefits are directly returned in the IDAS output. The output module (Alternative Comparison Module) returns the following item-specific benefits that include the mentioned major sources of benefit:

- Vehicle miles of travel [million miles]
- Vehicle hours of travel [million hours]
- Average speed [miles/hour]
- Person hours traveled [million hours]
- Number of person trips
- Number of fatality accidents
- Number of injury accidents
- Number of PDO accidents
- Hours of unexpected delay [Hours]
- Fuel consumption [Gallons]
- Hydrocarbon emissions [tons]

- Carbon monoxide emissions [tons]
- Oxides of nitrogen emissions [tons]

These benefits are displayed in accordance with market-sector (mode of transportation) type, facility type, and district type. In order to convert the physical benefits into dollars, IDAS uses default values based on contemporary rates and prices.

Cost-Benefit Analysis Cost-benefit analysis (CBA) attempts to estimate and summarize the equivalent money value of the benefits and costs of projects to society in order to establish whether the projects are economically efficient. The results of the CBA reveal the alternative that maximizes the net benefits to the public from an allocation of resources. The economic outcome parameters obtained from a CBA are the following:

- Net present value (NPV)
- Benefit-cost ratio (BCR)
- Internal rate of return (IRR)

The IDAS Comparison Module returns the average annual benefit, average annual cost, and the benefit-cost ratio. It also returns the net benefit, which is the difference between annual benefit and annual cost and which may be considered an indicator of the net present value (NPV). However, the IRR is not possible to calculate through IDAS.

The economic analyses are carried out over the time span 2010–2030 for each option under study. The cash flow of each option under study is discounted at the FHWA-recommended and ALDOT-practiced discount rate of 4%. Discounting the cash flow of the project options is required to take care of time value of money.

Results of Analysis and Discussion

The detailed results of cost-benefit analysis are presented in Appendix 2 according to Table 5.2.

Table 5-2. Sequence of detail results of cost-benefit analysis presented in Appendix 2

	Scenario	Assumption	Consideration for induced demand
A2.1	Lane Conversion	Equal Vehicle	Considered
A2.1	Lane Conversion	Equal Vehicle	Not Considered
A2.2	Lane Conversion	Equal Person	Considered
A2.2	Lane Conversion	Equal Person	Not Considered
A2.3	Lane Addition	Equal Vehicle	Considered
A2.3	Lane Addition	Equal Vehicle	Not Considered
A2.4	Lane Conversion	Equal Person	Considered
A2.4	Lane Conversion	Equal Person	Not Considered

The results are reported for both the specific I-65 freeway segment and for the network as a whole. These results are summarized in Appendix 2. In the following sections, the results for major elements of cost-benefit analysis are discussed.

Vehicle Operating Cost Savings

As stated in the previous section (cost-benefit analysis), the IDAS analysis does not return the vehicle operating cost savings directly. However, it is possible to determine the vehicle operation cost savings from the 'vehicle miles of travel,' 'fuel consumption,' and 'speed' outputs.

Vehicle Miles Traveled (VMT) Figures 5-2 and 5-3 show the variability in Vehicle Miles Traveled (VMT) in millions of miles along the study segment of I-65 for different scenarios with and without consideration for induced demand. In these figures, 0% HOV of Lane Conversion Scenario is the baseline.

From Figure 5-2 and Figure 5-3 it can be seen that the Lane Addition Scenario results in higher VMT. But with the increased rate of HOV lane usage, VMT under the Lane Addition Scenario and the Equal Person Assumption gradually decreases and converges to that of the Baseline Scenario.

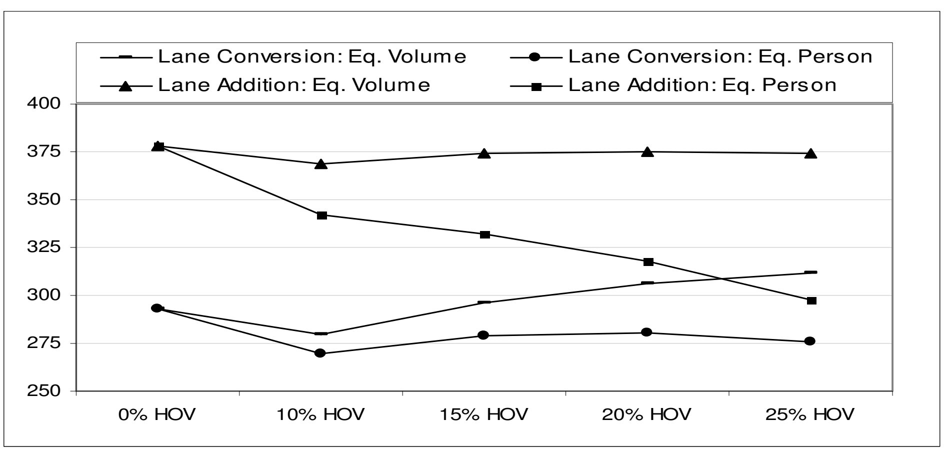

Figure 5-2. Variability in vehicle miles traveled for different scenarios with consideration for induced demand

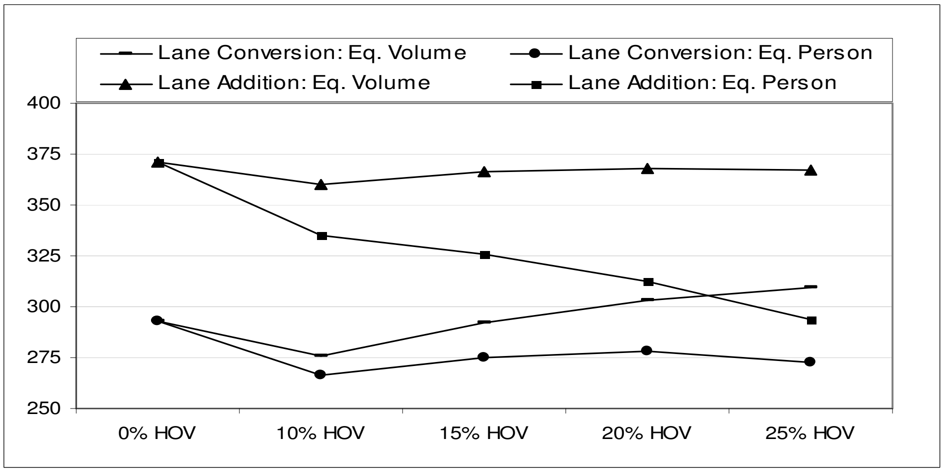

Figure 5-3. Variability in vehicle miles traveled for different scenarios without consideration for induced demand

Average Speed The improvement along the study section of I-65 results in changes in average speed of the vehicles both traveling along the specific section of I-65 and along the whole network. Figures 5-4 and 5-5 show the variability in average speed along the study segment of I-65 for different scenarios with different assumptions and with different levels of induced demand.

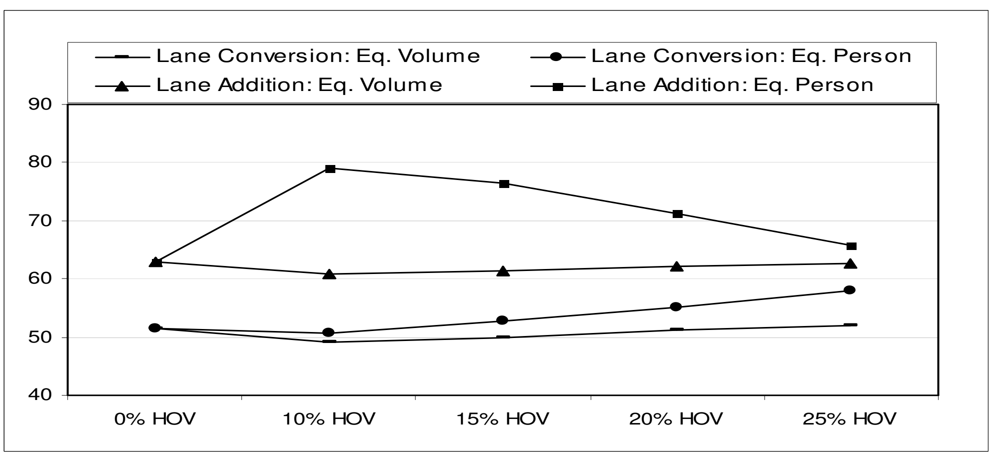

Figure 5-4. Variability in average speed for different scenarios with consideration for induced demand

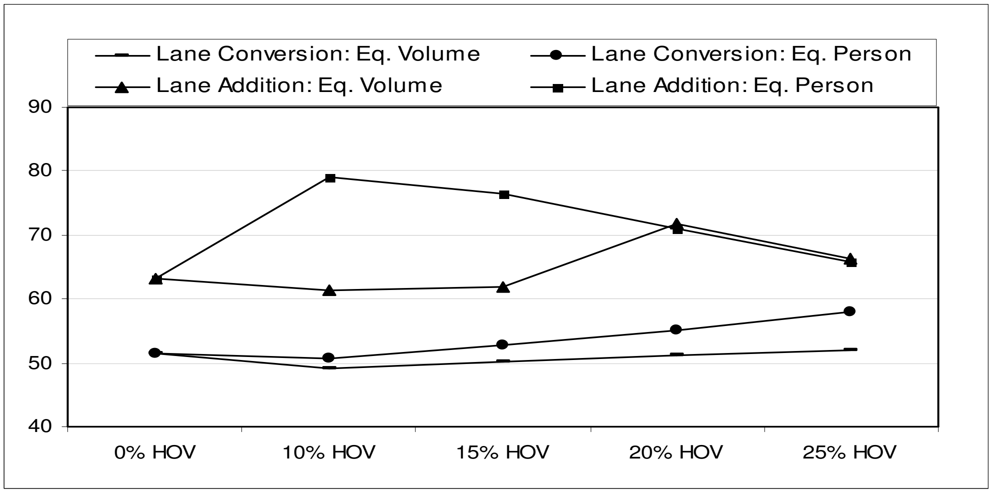

Figure 5-5. Variability in average speed for different scenarios without consideration for induced demand

The analysis shows that the Lane Addition Scenario results in higher average speed than the Lane Conversion Scenario. The Lane Addition Option, an Equal Person Assumption, and 10% of vehicles using the HOV lane resulted in highest average speed. The average speed decreases afterward; however, as expected, average speed in the Lane Addition Scenario always remains higher than that of the Lane Conversion Scenario. The results of the analysis are depicted in Figures 5-4 and 5-5.

Fuel Consumption The analysis reveals that fuel consumption varies with different options, scenarios, and assumptions. Figures 5-6 and 5-7 represents the variability in fuel consumption.

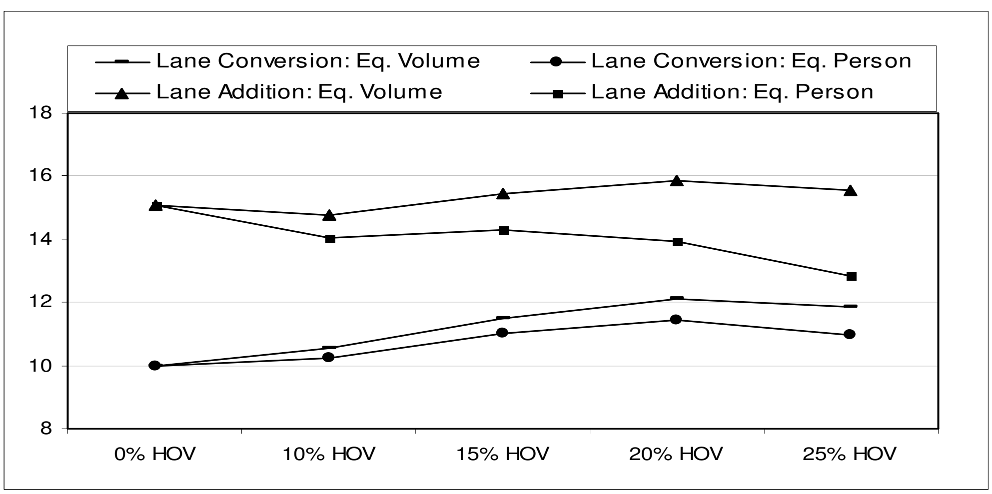

Figure 5-6. Variability in fuel consumption for different scenarios with induced demand

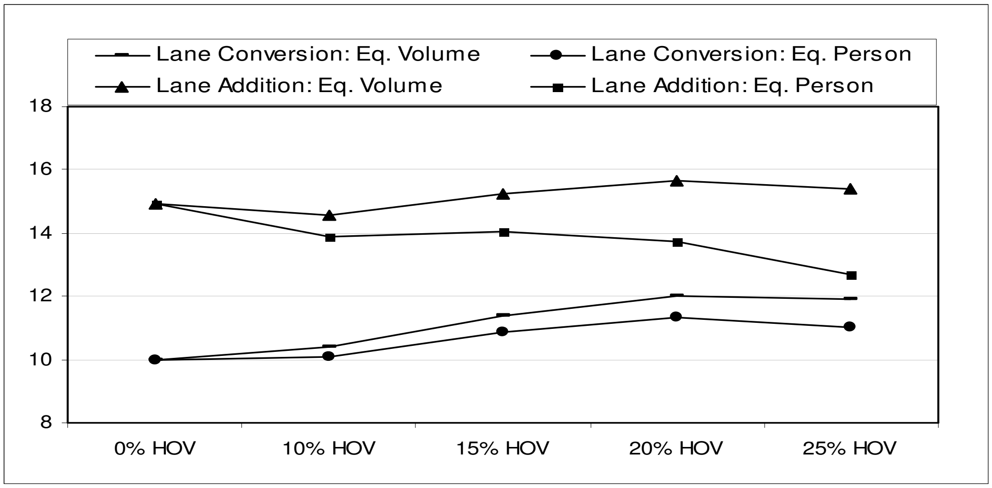

Figure 5-7. Variability in fuel consumption for different scenarios without consideration for induced demand

From Figures 5-6 and 5-7 it may be observed that fuel consumption is highest in the Lane Addition Scenario under an Equal Vehicle Assumption. The Lane Addition Scenario with Equal Person Assumption – which considers the decrease in vehicle number with the increase in vehicle occupancy – shows relatively higher fuel consumption values compared to the Lane Conversion Scenario. The fuel consumption rate decreases gradually as HOV lane use increases.

General Discussion on VOC Savings Figures 5.2 through 5.7 present the variability in vehicle miles of travel, fuel consumption, and vehicle speed due to the conversion of a general-purpose lane into HOV with different HOV shares along the study section of I-65.

Under the Equal Vehicle Assumption, a decline in VMT was observed for 10% HOV usage for both Lane Conversion and Lane Addition Scenarios compared to the baseline. After this HOV usage a gradual increase is observed in Lane Conversion Scenario along with the increase in average speed and fuel consumption. In the Lane Addition Scenario with the Equal Vehicle Assumption, VMT, average speed, and fuel consumption are higher given 0% HOV lane usage compared to the baseline. They decline with 10% HOV usage but increase and remain rather steady for higher rates of HOV lane usage.

Under the Equal Person Assumption the Lane Conversion Scenario results in increasing VMT, average speed, and fuel consumption as HOV lane usage increases. Given the Lane Addition Scenario, Equal Person Assumption, and 0% HOV lane usage, VMT, average speed and fuel consumption are higher than the baseline and the Lane Conversion Scenario. However, VMT and fuel consumption gradually decline as HOV lane use increases. Average speed increases significantly for 10% HOV usage but decreases gradually with an increase in HOV lane use. This implies that, although the Lane Addition Scenario results in higher VMT and fuel consumption (compared to the baseline and the Lane Conversion Scenario), it is better because it has a higher average speed.

Value of Travel Time (VOT) Savings

IDAS does not return the Vehicle Operating Cost Savings directly. However, it is possible to assess the value of time saving for different options given 'vehicle hours of travel,' 'person hours of travel,' and 'hours of unexpected delay.' The following subsections discuss these parameter values.

Figures 5-8 and 5-9 show the variability in vehicle hours traveled (VHT) in millions of hours along the study segment of I-65 for different scenarios with and without induced demand. In these figures, 0% HOV use in the Lane Conversion Scenario is the baseline.

As shown in Figures 5-8 and 5-9, vehicle hours of travel decrease when 10% of vehicles use the HOV lane in the Lane Conversion Scenario under an Equal Vehicle Assumption. VHT then increases as HOV lane use increases. Compared to the baseline, VHT decreases in the Lane Addition Scenario under the 10% HOV assumption. Afterward, VHT remains rather similar to other percentages of HOV lane usage.

Under the Equal Person Assumption, VHT decreases as HOV lane use increases. The rate of decrease is higher in the Lane Addition Scenario. The VHT is lower than in the baseline. Reduction in VHT may be considered an indicator of improvement in traffic congestion.

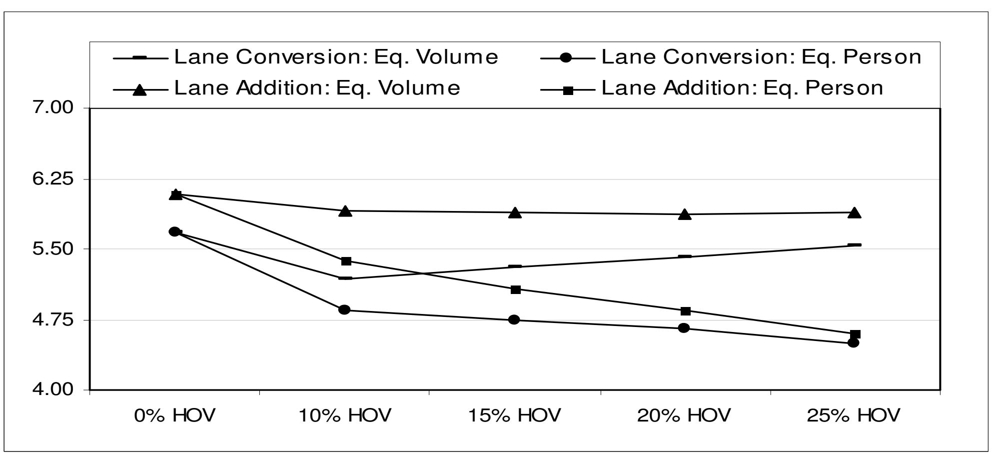

Figure 5-8. Variability in vehicle hours of travel (VHT) for different scenarios with consideration for induced demand

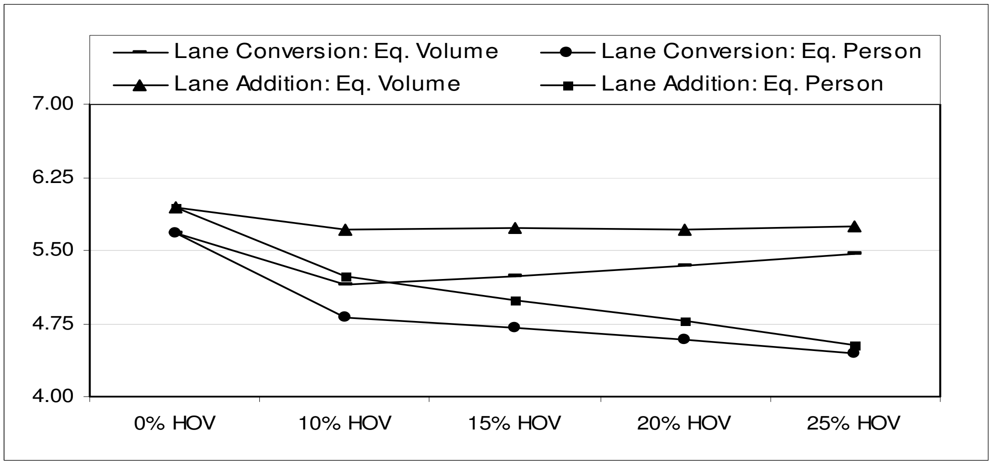

Figure 5-9. Variability in vehicle hours of travel (VHT) for different scenarios without consideration for induced demand

Person Hours Traveled Figures 5-10 and 5-11 show hours traveled (in millions of hours) along the study segment of I-65 for different scenarios with and without induced demand.

Figures 5-10 and 5-11 reveal that person hours traveled gradually decreases as HOV lane usage increases under the Lane Addition Scenario and an Equal Person Assumption, even as vehicle miles of travel increases (see the previous section). This indicates the Lane Addition Scenario improves traffic congestion.

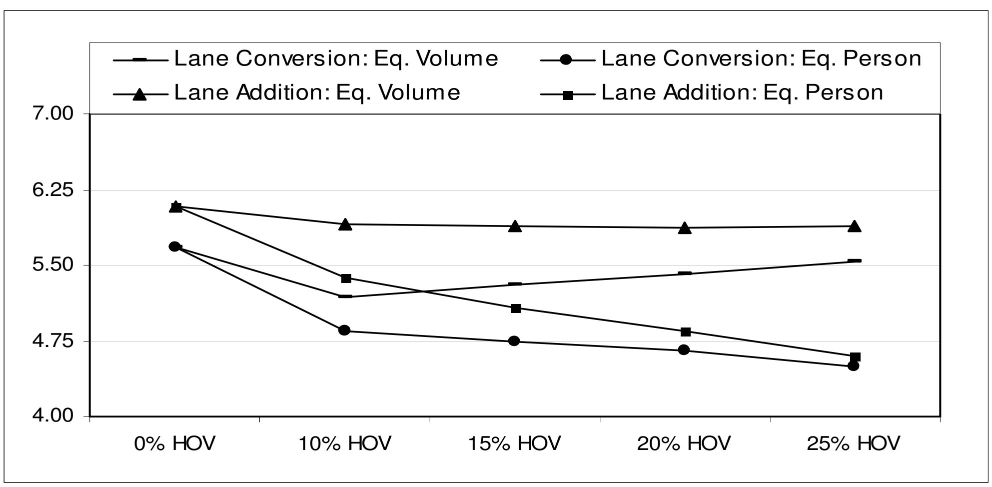

Figure 5-10. Variability in vehicle hours of travel (VHT) for different scenarios with consideration for induced demand

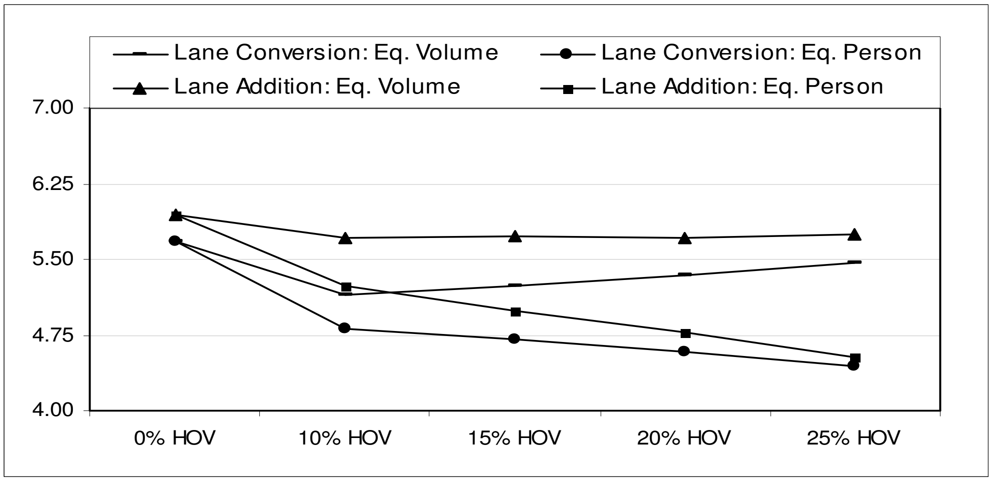

Figure 5-11. Variability in vehicle hours of travel (VHT) for different scenarios without consideration for induced demand

Hours of Unexpected Delay Figures 5-12 and 5-13 show the hours of delay (in millions of hours) due to improvements along the study segment of I-65 for different scenarios with and without induced demand.

Figures 5-12 and 5-13 show hours of unexpected delay increase in the Lane Addition Scenario when 10% of the vehicles use the HOV lane. As HOV lane use increases, delay decreases. It may also be observed that delay in the Lane Addition Scenario is lower than in the Lane Conversion Scenario.

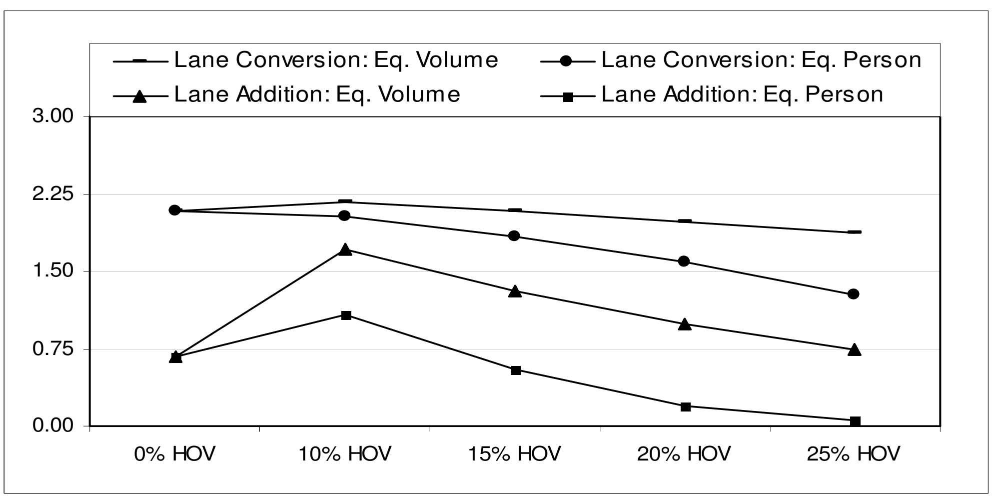

Figure 5-12. Variability in hour of delay for different scenarios with consideration for induced demand

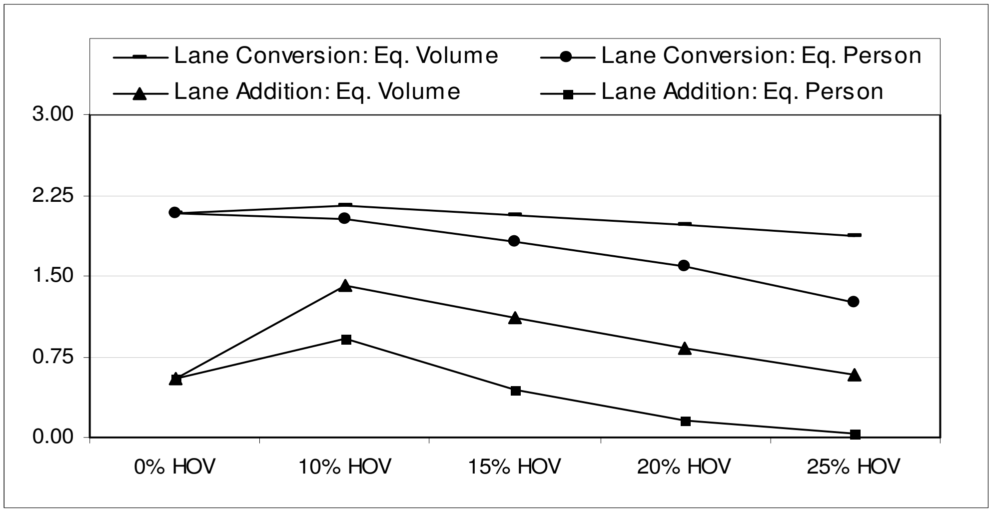

Figure 5-13. Variability in hour of delay for different scenarios without consideration for induced demand

General Discussion on VOT Savings Although the Lane Addition Scenario results in more vehicle miles, vehicle hours traveled, and person hours traveled as well as higher fuel consumption, it also results in higher average speed and fewer hours of unexpected delay. Therefore, the Lane Addition Scenario may result in higher Value of Time (VOT) savings than the Lane Conversion Scenario. It contributes more to improving the baseline's traffic congestion than the Lane Conversion Scenario.

Accident Cost Savings

The IDAS Alternative Comparison Module returns the average number of accidents per year. The detailed accident statistics for all options are given in Appendix 2. The percentage change in annual accidents compared to the baseline for study options are summarized in Table 5-3.

From Table 5-3 it is evident that the average number of accidents per year is lowest in the Lane Addition Scenario with the Equal Person Assumption. As a result options 7 through 10 of the Lane Addition Scenario using the Equal Person Assumption would have higher accident cost savings.

Emissions Costs Savings

The IDAS Alternative Comparison Module returns the average quantity of hydrocarbon and reactive organic emissions, carbon monoxide emissions, and oxides of nitrogen emissions in tons per year. Detailed emission statistics for all options are given in Appendix 2. From the Emission Output section of the Alternative Comparison Module, all nine options produce higher emissions than the baseline. Table 5-4 summarizes the percentage increase in annual total emissions for different options against the baseline.

Close observation of Table 5-4 reveals that the smallest emissions increase occurs in the Lane Conversion Scenario with an Equal Person Assumption. Since the increase in fuel consumption and average speed is higher in the Lane Addition Scenario than in the Lane Conversion Scenario, emissions would also be higher in Lane Addition Scenario. Therefore, Emission Cost Savings would be higher in the Lane Conversion Scenario than in the Lane Addition Scenario.

Table 5-3. Percent change in average number of accidents per year along I-65 segment

	0% HOV	10% HOV	15% HOV	20% HOV	25% HOV
Equal Vehicle Assumption	**Lane Conversion Scenario: Options 2 – Option 5**				
Induced Demand Considered	-	-8.4	-0.6	5.4	7.4
Induced Demand NOT Considered	-	-9.4	-2.9	4.0	6.4
Equal Person Assumption					
Induced Demand Considered	-	-12.6	-9.1	-6.4	-9.3
Induced Demand NOT Considered	-	-13.4	-11.2	-7.7	-10.3
Equal Vehicle Assumption	**Lane Addition Scenario: Options 6 – Option 10**				
Induced Demand Considered	7.6	-1.2	-1.1	2.0	4.6
Induced Demand NOT Considered	4.8	-5.4	-3.7	-0.4	1.6
Equal Person Assumption					
Induced Demand Considered	7.6	-11.0	-15.8	-17.2	-18.1
Induced Demand NOT Considered	4.8	-13.5	-18.1	-18.3	-19.0

Table 5-4. Percent increase in average annual emissions along I-65 segment

	% Increase in Average Annual Emissions				
	0% HOV	10% HOV	15% HOV	20% HOV	25% HOV
Equal Vehicle Assumption	**Lane Conversion Scenario: Options 2 – Option 5**				
Induced Demand Considered	-	38	48	45	37
Induced Demand NOT Considered	-	35	48	46	38
Equal Person Assumption					
Induced Demand Considered	-	34	45	42	33
Induced Demand NOT Considered	-	32	43	43	35
Equal Vehicle Assumption	**Lane Addition Scenario: Options 6 – Option 10**				
Induced Demand Considered	84	87	98	100	94
Induced Demand NOT Considered	83	86	96	99	92
Equal Person Assumption					
Induced Demand Considered	84	81	88	80	63
Induced Demand NOT Considered	83	81	85	77	61

Cost-Benefit Analysis (CBA) Results

The CBA results are summarized in Table 5-5 below and refer to the network as a whole.

From Table 5-5 it can be observed that the investment costs for the Lane Addition Scenario (Scenario 2) are almost twice as high as for the Lane Conversion Scenario (Scenario 2). However, compared to existing operations, much larger benefits are achievable through the implementation of the Lane Addition Scenario than those expected from the Lane Conversion Scenario. Overall, the highest average annual benefits may be achieved through additional lanes with 20% or 25% HOV use of the newly added lane in either travel direction.

Table 5-5. Network-wide average annual costs and benefits for the analysis period [in $ million]

Options	Costs	Equal Vehicle Assumption		Equal Person Assumption	
		Benefits With Induced Demand	Benefits Without Induced Demand	Benefits With Induced Demand	Benefits Without Induced Demand
Scenario 1: Baseline Scenario, ***Other Scenarios are compared to this Scenario***					
Scenario 2: Conversion of one lane in each traveling direction of I–65 to HOV lane					
Option 2: HOV 10%	5.53	2.12	7.04	8.17	11.00
Option 3: HOV 15%	5.53	4.17	8.72	8.34	19.70
Option 4: HOV 20%	5.53	1.92	8.30	8.89	20.09
Option 5: HOV 25%	5.53	4.99	9.65	5.38	20.33
Scenario 3: Addition of one HOV lane in each traveling direction of I–65					
Option 6: HOV 0%	11.55	29.23	39.02	29.23	39.02
Option 7: HOV 10%	11.55	16.79	34.65	30.12	46.04
Option 8: HOV 15%	11.55	24.58	40.04	43.06	52.48
Option 9: HOV 20%	11.55	30.08	42.03	50.55	55.88
Option 10: HOV 25%	11.55	35.49	44.93	50.26	55.27

The benefit-cost ratios (BCR) for different study options and for the network as a whole are summarized in Table 5-6. The BCRs represent the impact that the studied option has, as compared to the baseline. BCRs greater than 1 are desirable, and the higher the BCR, the better.

The BCRs summarized in Table 5-6 indicate that an additional lane along each direction of the study segment of I-65 results in higher monetary benefits. Figure 5-6 is constructed from the calculated BCRs.

Table 5-6. Network-wide benefit–cost ratios for different options and with different assumptions

Options	Equal Vehicle Assumption		Equal Person Assumption	
	B/C Ratio With Induced Demand	B/C Ratio Without Induced Demand	B/C Ratio With Induced Demand	B/C Ratio Without Induced Demand
Scenario 1: Baseline Scenario, ***Other Scenarios are compared to this Scenario***				
Scenario 2: Conversion of one lane in each traveling direction of I–65 to HOV lane				
Option 2: HOV 10%	0.38	1.27	1.48	1.99
Option 3: HOV 15%	0.75	1.58	1.51	3.56
Option 4: HOV 20%	0.35	1.50	1.61	3.63
Option 5: HOV 25%	0.90	1.74	0.97	3.68
Scenario 3: Addition of one HOV lane in each traveling direction of I–65				
Option 6: HOV 0%	2.53	3.38	2.53	3.38
Option 7: HOV 10%	1.45	3.00	2.61	3.99
Option 8: HOV 15%	2.13	3.47	3.73	4.54
Option 9: HOV 20%	2.60	3.64	4.38	4.84
Option 10: HOV 25%	3.07	3.89	4.35	4.78

Figure 5-14 provides further evidence that the highest benefit-cost ratios are achievable through additional lanes with 20% to 25% HOV usage of the newly added lane along each travel direction of the I-65 study segment.

It should be noted that the analyses based on the Equal Person Assumption and account for induced travel demand are expected to yield the most appropriate results. Given this consideration, the Lane Addition Scenario with 20% HOV usage is the most economically efficient option. In this option both the average annual benefit ($50.55 Million) and the benefit-cost ratio (4.38) are highest given the Equal Person Assumption and induced demand.

From the results summarized in Tables 5-5 and 5-6 and Figure 5-14, it may be observed that the Lane Addition Scenario yields better economic results than the Lane Conversion Scenario. Both the average annual benefit and benefit-cost ratio are higher under the Lane Addition Scenario than the Lane Conversion Scenario. Therefore, it may be concluded that the lane addition option could be the best option from the economic perspective.

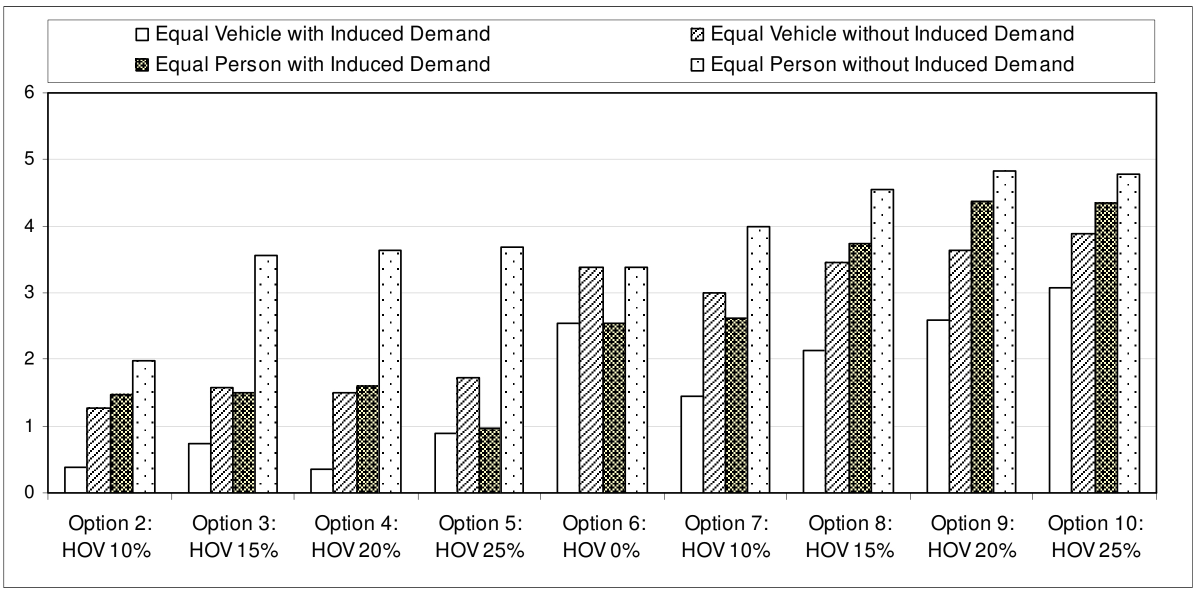

Figure 5-14. Benefit–cost ratios for different options under different assumptions

Sensitivity Analysis

A sensitivity analysis was carried out for all options under Scenarios 2 and 3 using a simultaneous 20% cost overrun and 20% benefit reduction. The results are summarized in the following sections.

Analysis with Higher Costs and Lower Benefits Sensitivity analysis was performed for all eight options (Options 2 through 9) with 20% increased costs and 20% reduced benefits. The discount factor considered was 4%. The results are summarized in Tables 5-7 and 5-8.

Table 5-7. Summary of costs and benefits for all study scenarios

Scenario 1: Baseline Scenario, Other Scenarios are compared to this Scenario					
		Equal Vehicle Assumption		**Equal Person Assumption**	
Options	**Costs**	**Benefits With Induced Demand**	**Benefits Without Induced Demand**	**Benefits With Induced Demand**	**Benefits Without Induced Demand**
Scenario 2: Conversion of one lane in each traveling direction of I–65 as HOV lane					
Option 2: HOV 10%	6.64	2.10	3.97	4.02	6.99
Option 3: HOV 15%	6.64	3.53	4.88	3.42	13.29
Option 4: HOV 20%	6.64	1.24	4.50	3.71	13.44
Option 5: HOV 25%	6.64	1.81	6.14	1.19	13.98
Scenario 3: Addition of one HOV lane in each traveling direction of I–65					
Option 6: HOV 0%	13.86	19.16	28.02	19.16	28.02
Option 7: HOV 10%	13.86	9.73	25.29	19.97	33.79
Option 8: HOV 15%	13.86	15.78	29.36	30.46	38.95
Option 9: HOV 20%	13.86	20.05	30.63	36.47	41.62
Option 10: HOV 25%	13.86	24.20	32.73	36.95	41.60

Table 5-8. Benefit-cost analysis results

Scenario 1: Baseline Scenario, Other Scenarios are compared to this Scenario				
	Equal Vehicle Assumption		**Equal Person Assumption**	
Options	**BC ratio With Induced Demand**	**BC ratio Without Induced Demand**	**BC ratio With Induced Demand**	**BC ratio Without Induced Demand**
Scenario 2: Conversion of one lane in each traveling direction of I–65 as HOV lane				
Option 2: HOV 10%	0.32	0.60	0.61	1.05
Option 3: HOV 15%	0.53	0.73	0.52	2.00
Option 4: HOV 20%	0.19	0.68	0.56	2.03
Option 5: HOV 25%	0.27	0.92	0.18	2.11
Scenario 3: Addition of one HOV lane in each traveling direction of I–65				
Option 6: HOV 0%	1.38	2.02	1.38	2.02
Option 7: HOV 10%	0.70	1.82	1.44	2.44
Option 8: HOV 15%	1.14	2.12	2.19	2.81
Option 9: HOV 20%	1.45	2.22	2.63	3.00
Option 10: HOV 25%	1.75	2.36	2.67	3.00

The results of the analysis show that although the absolute values of average annual benefit and benefit-cost ratio have changed, the relative position of the options remains almost the same as that of the main analysis. Using the Equal Person Assumption and including induced demand, the Lane Addition Scenario with 25% HOV usage assumes the highest average annual benefit and B-C ratio. The Lane Addition Scenario remains the economically most efficient scenario.

Overall the sensitivity analysis shows that the absolute values of the key economic parameters – i.e. average annual benefit and benefit-cost ratio for different options – are sensitive to cost increases and benefit reductions. However, the relative position of these economic parameters is not significantly sensitive to cost increases or benefit decreases.

Section 6
Conclusions and Recommendations

This study performed an in-depth examination of the potential of managed lane strategies in improving traffic operations and assisting in congestion mitigation in the Birmingham region. This was accomplished through an extensive literature and state-of-the practice review, traffic modeling and analysis using sophisticated simulation modeling tools, and estimation of costs and benefits from HOV and truck lanes.

HOV Lanes Case Study Conclusions

The study analyzed a number of alternative scenarios to determine the operational, environmental, and economic impacts of HOV lanes on traffic operations along the I-65 corridor in Birmingham, AL. These included estimation of near- and long-term benefits from conversion of a general-purpose lane to HOV or addition of an HOV lane for various HOV utilization rates. The VISTA environment was employed to construct the models. VISTA allowed for consideration of near- and long-term impacts from potential implementation as it allows for both simulation and DTA/DUE optimization.

The main findings follow:

- The comparison of the base and HOV scenarios results indicate that the conversion of an existing general-purpose lane to an HOV lane is justified on the basis of operational benefits. While the benefits were not dramatic, they constitute an improvement over current operations and they become more evident as HOV lane utilization increases.
- Adding lanes improves network performance, and greater benefits are achieved when the new lane is a designated HOV lane.
- As far as operational benefits are concerned, the additional lane yields somewhat greater benefits compared to HOV lane conversion. Still, under the study assumptions, the differences in operational performance measures were not large enough to clearly justify the expense for implementation.
- Further investigation took place to determine the best option for possible deployment on the basis of a cost-benefit analysis. The results confirmed that the best, most economically efficient alternative to improve existing traffic congestion is to add a lane in each traveling direction of the I-65 corridor segment under study.

Truck Lanes Case Study Conclusions

First we investigated the impact from converting a freeway lane to a truck lane for shared or exclusive use by trucks along a testbed in Birmingham, AL. Then we considered the addition of a lane with the added lane being a general-purpose lane or a lane designated for truck use. Analysis revealed the following:

- In the short term, a general-purpose lane conversion to a truck lane is justified only for 12% truck traffic and above. However, in the longer term, significant gains in delays and travel time are to be realized as drivers become familiar with the new treatment and seek alternative routes to optimize their travel. Thus the lane conversion to a truck lane is justified, on the basis of operational impact.
- Should a general-purpose lane be converted to a truck lane, shared use of the truck lane would lead to greater benefits in network performances compared to those expected from exclusive use of the truck lane by trucks.
- An additional lane on the study network further improves the overall network performance; however, designation of the added lane as a truck lane has little to no impact on traffic operations and thus is not justified.
- The study was not comprehensive as to the use of the additional lane and further scenarios could be explored such as: a) use of the truck lane only for certain hours of the day or days of the week, b) use of the truck lane also by buses, and c) exclusion of trucks during certain hours of the day and day of the week while implementing designated truck lanes at other specific hours of the day.
- Also, all potential scenarios should be evaluated at the end with a calibrated microscopic traffic simulator that will represent more realistically the traffic flow propagation.

Overall the study showcased a methodology that can be used to assess the operational, environmental, and financial impacts of managed lanes deployment in local settings in order to assist decision makers in determining the best option for implementation.

Recommendations

It is recommended that further calibration and validation studies be performed to improve modeling accuracy and the confidence in the model findings. Specifically the following methodology is proposed in the future to gain more accurate and continuously updated results:

1. Create a consortium of stakeholders that will be responsible for visioning and overseeing the development and continuous enhancement of a strategic Transportation Planning and Operations Model (TPOM) including:
    a. Public agencies
    b. Private sector
    c. Universities/research entities

2. Install and operate a comprehensive traffic flow characteristics monitoring system:
    a. Install traffic count/speed/classification detectors at strategic locations.
    b. Implement a vehicle location based system (e.g. GPS plus wireless communication) to collect vehicle trajectories in real time. This can be done through collaboration with taxis, commercial vehicles, buses, and private citizens.
    c. Implement an OD survey system that will be updated in a semi-automated fashion through various means – online surveys, commercial and public entity collaborations.
3. Implement a continuously calibrated TPOM as follows:
    a. Develop a demand model to produce the first origin-destination matrix using the latest models available.
    b. Produce estimates of the dynamic OD matrix using the OD matrix estimated and the latest traffic counts available.
    c. Implement a DTA model using the dynamic OD matrix.
    d. Implement a Traffic Control Optimization model on the selected network.
    e. Implement a Microscopic Traffic Simulator using the DUE paths from the DTA. This will produce the most accurate state of the system in terms of the traffic flow propagation. This is needed as macroscopic and mesoscopic models do not have the capability to emulate actual traffic conditions especially in signalized/unsignalized surface street systems.
    f. Develop a procedure that will update the model automatically based on real time data.
    g. Develop a systematic procedure that will update the model periodically every 3 months based on additional data from studies conducted in the region.
    h. Develop a systematic procedure to upgrade the TPOM once new models are available from the research community.
4. Create a procedure to validate the model by an independent entity once a year.

Additional analysis can be performed to explore alternative congestion management strategies that may be more appropriate to address current and future travel needs in the Birmingham area. Examples include speed harmonization, temporary shoulder use, and dynamic signing and rerouting.

It should also be recognized that successful HOV facilities are also accompanied by robust rideshare programs such as the one that exists in the Birmingham area. It is recommended that the benefits of additional investment in the rideshare program and its impact/influence on the HOV scenarios be quantified in a follow-up study and considered along with cost and benefits directly associated with the HOV implementation.

Moreover, the success of managed lane implementation greatly depends on public support for the project and positive public perception. Thus, the role of public education in the early planning stage is critical and should not be overlooked. Focus groups, open public discussion forums, public information sessions, and media coverage are useful tools that can assist local agencies to obtain input from the public and other local stakeholders and educate the road users about their rights and responsibilities.

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Appendix A
Detailed Results of Network Links

Table A-1. Scenario 1-HOV: Baseline scenario link flow chart

GP SB Links	1-HOV	GP NB Links	1-HOV
2401	33716	**2402**	63093
2421	23293	**2419**	69913
4572	25138	**4561**	58682
5500	21805	**5629**	66566
5502	28629	**5797**	54966
5795	29118	**5994**	57809
5992	22896	**6913**	41383
6217	8619	**6995**	61912
6219	11400	**7003**	76288
6229	23535	**7063**	78060
6915	16159	**7069**	68424
6996	42399	**9038**	34845
7004	39201	**9046**	43871
7062	31142	**9070**	56482
7070	39114	**9078**	56465
9036	11426	**9081**	46134
9048	8289	**9090**	71605
9079	8883	**10307**	58679
9083	8884	**12131**	84934
9091	7765	**12132**	72305
10293	31090	**12299**	62759
10306	21804	**12749**	64445
12135	38404	**20189**	14760
12136	42433	**20191**	14846
12750	27786		

Table A-2. Scenario 1A-HOV: Baseline scenario vehicle type network results

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
1-HOV	HOV	19,966.58	1,705.91	44.668	0.141	1.447
	Car	113,592.92	9,714.88	44.639	0.141	1.447

Table A-3. Scenario 2A-HOV-S: Converting lane case scenario SB link flow charts

HOV Lane SB Links	2A-HOV-S (10%)	2A-HOV-S (15%)	2A-HOV-S (20%)	2A-HOV-S (25%)
20041	601	715	860	1014
20042	601	715	860	1015
20045	601	715	860	1015
20046	602	715	860	1015
20051	283	353	407	499
20052	283	353	407	499
20071	1744	1857	2002	2156
20079	845	958	1103	1257
20084	601	715	860	1014
20085	845	959	1104	1258
20094	603	716	861	1016
20095	602	715	860	1015
20102	603	716	861	1016
20103	283	353	407	499
20112	283	353	407	499
20113	283	353	407	499
20118	283	353	407	499
20124	283	353	407	499
20195	284	353	407	499

GP Lane SB Links	2A-HOV-S (10%)	2A-HOV-S (15%)	2A-HOV-S (20%)	2A-HOV-S (25%)	1-HOV
2401	31032	31069	31074	31081	33716
2421	22148	22139	22161	22143	23293
4572	23732	23723	23745	23727	25138
5500	20399	20389	20411	20394	21805
5502	27223	27213	27235	27218	28629
5795	27712	27702	27724	27707	29118
5992	21490	21480	21502	21485	22896
6217	7211	7202	7223	7207	8619
6219	9992	9983	10004	9988	11400
6229	22128	22118	22140	22124	23535
6915	13976	14010	14017	14025	16159
6996	39719	39753	39760	39768	42399
7004	36521	36556	36563	36570	39201
7062	28463	28497	28504	28512	31142
7070	36430	36467	36472	36479	39114
9036	8992	9027	9034	9042	11426
9048	5856	5891	5898	5906	8289
9079	9155	9301	9455	9617	8883
9083	7411	7446	7453	7461	8884
9091	6291	6326	6334	6341	7765
10293	28411	28445	28452	28460	31090
10306	20398	20388	20410	20393	21804
12135	35720	35757	35762	35769	38404
12136	39752	39787	39793	39800	42433
12750	25354	25388	25395	25403	27786

Table A-4. Scenario 2A-HOV-S: Converting lane case scenario NB link flow charts

HOV Lane NB Links	2A-HOV-S (10%)	2A-HOV-S (15%)	2A-HOV-S (20%)	2A-HOV-S (25%)
20005	757	1059	1406	1656
20008	757	1059	1406	1656
20010	1289	1761	2356	2788
20012	1288	1760	2355	2787
20016	1856	2434	3175	3824
20022	2191	2783	3541	4195
20024	2190	2782	3540	4195
20025	2189	2781	3539	4194
20026	2743	3334	4093	4748
20125	757	1059	1406	1656
20138	1288	1760	2355	2786
20145	1856	2434	3175	3824
20146	1855	2432	3175	3824
20150	1855	2432	3175	3824
20156	2190	2782	3540	4195
20168	2743	3334	4093	4748
20171	2743	3333	4093	4748
20174	2741	3332	4092	4746
20194	4049	4640	5399	6052

GP Lane NB Links	2A-HOV-S (10%)	2A-HOV-S (15%)	2A-HOV-S (20%)	2A-HOV-S (25%)	1-HOV
2402	50228	50241	50282	50206	63093
2419	57048	57062	57102	57026	69913
4561	47566	47580	47619	47530	58682
5629	54897	54912	54952	54862	66566
5797	43296	43311	43351	43260	54966
5994	49248	49263	49303	49212	57809
6913	31517	31510	31493	31571	41383
6995	53346	53356	53327	53394	61912
7003	63485	63461	63519	63411	76288
7063	65195	65208	65250	65173	78060
7069	56218	56190	56251	56144	68424
9038	28818	28752	28764	28888	34845
9046	34000	33994	33976	34057	43871
9070	56683	56687	56687	56684	56482
9078	50173	50108	50117	50238	56465
9081	42455	42377	42443	42505	46134
9090	65317	65250	65260	65381	71605
10307	47564	47578	47617	47527	58679
12131	72134	72106	72167	72060	84934
12132	59502	59477	59536	59428	72305
12299	51090	51105	51144	51054	62759
12749	54583	54576	54559	54636	64445
20189	10451	10458	10496	10409	14760
20191	10537	10544	10582	10495	14846

Table A-5. Scenario 2A-HOV-S: Converting lane case scenario vehicle type network results

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
1-HOV	HOV	19,966.58	1,705.91	44.668	0.141	1.447
	Car	113,592.92	9,714.88	44.639	0.141	1.447
2A-HOV-S (10%)	HOV	12,781.55	1,171.86	44.813	0.131	1.436
	Car	108,455.85	10,237.07	44.442	0.132	1.445
2A-HOV-S (15%)	HOV	19,034.28	1,736.68	44.796	0.131	1.436
	Car	102,626.72	9,817.57	44.421	0.133	1.446
2A-HOV-S (20%)	HOV	25,255.81	2,283.68	44.783	0.131	1.437
	Car	96,533.37	9,055.49	44.455	0.131	1.444
2A-HOV-S (25%)	HOV	31,688.13	2,824.36	44.801	0.129	1.435
	Car	90,315.88	8,442.23	44.458	0.131	1.444

Table A-6. Scenario 2A-HOV-D: Converting lane case scenario SB link flow charts

HOV Lane SB Links	2A-HOV-D (10%)	2A-HOV-D (15%)	2A-HOV-D (20%)	2A-HOV-D (25%)
20041	498	719	936	1229
20042	498	719	936	1229
20045	498	719	936	1229
20046	492	705	915	1197
20051	1960	2912	3839	4822
20052	1951	2901	3811	4800
20071	497	718	936	1228
20079	497	718	936	1228
20084	498	719	936	1228
20085	498	719	936	1228
20094	2069	3138	3962	5026
20095	2074	3144	3965	5031
20102	1979	2941	3878	4880
20103	1960	2912	3839	4822
20112	921	1417	1793	2310
20113	921	1417	1793	2310
20118	914	1404	1773	2291
20124	914	1404	1774	2292
20195	800	1250	1570	2023

GP Lane SB Links	2A-HOV-D (10%)	2A-HOV-D (15%)	2A-HOV-D (20%)	2A-HOV-D (25%)	1-HOV
2401	33692	32671	31767	30760	33716
2421	22674	21731	20798	19838	23293
4572	24707	23781	22808	21916	25138
5500	21158	20230	19316	18409	21805
5502	29494	28981	28651	28137	28629
5795	30002	29460	29143	28603	29118
5992	23487	22992	22620	22087	22896
6217	8319	7856	7541	7082	8619
6219	11279	10809	10493	10034	11400
6229	24168	23669	23311	22767	23535
6915	16933	16818	16370	16164	16159
6996	44397	44169	43903	43600	42399
7004	41067	40861	40612	40349	39201
7062	30870	29767	28968	27913	31142
7070	39240	38155	37350	36304	39114
9036	12595	12503	12352	12162	11426
9048	8702	8551	8384	8151	8289
9079	9264	9165	9202	9170	8883
9083	12309	12294	12030	11831	8884
9091	9148	8998	8778	8524	7765
10293	30807	29720	28908	27866	31090
10306	21157	20229	19315	18409	21804
12135	40066	39835	39638	39369	38404
12136	44360	44120	43928	43639	42433
12750	29895	29725	29311	29076	27786

Table A-7. Scenario 2A-HOV-D: Converting lane case scenario NB link flow charts

HOV Lane NB Links	2A-HOV-D (10%)	2A-HOV-D (15%)	2A-HOV-D (20%)	2A-HOV-D (25%)
20005	4788	6910	8288	10192
20008	3021	4492	5780	7361
20010	3727	5608	7171	9062
20012	3612	5434	7012	8850
20016	5764	8660	10952	13549
20022	5865	8651	10903	13313
20024	5259	7895	9932	12124
20025	4606	6977	8787	10816
20026	1335	2068	2543	3167
20125	4339	6245	7351	9037
20138	3690	5508	7139	8992
20145	5539	8329	10523	12996
20146	5964	8954	11341	13911
20150	5210	7783	9901	12222
20156	5154	7787	9830	12046
20168	1335	2068	2543	3167
20171	1335	2068	2543	3167
20174	1335	2068	2543	3167
20194	1332	2068	2543	3166

GP Lane NB Links	2A-HOV-D (10%)	2A-HOV-D (15%)	2A-HOV-D (20%)	2A-HOV-D (25%)	1-HOV
2402	56648	56468	55327	54547	63093
2419	66027	64362	63139	61727	69913
4561	56787	55176	53782	52294	58682
5629	68801	68711	68664	68468	66566
5797	57191	56887	56717	56420	54966
5994	60278	59969	59802	59513	57809
6913	35347	35733	34071	33487	41383
6995	55307	56447	54303	54068	61912
7003	65625	66315	63650	63189	76288
7063	70861	69772	68684	67566	78060
7069	59660	58909	58347	57353	68424
9038	32880	32329	31599	30738	34845
9046	41000	40160	39079	38053	43871
9070	58121	58623	59477	60303	56482
9078	60015	59332	59184	58792	56465
9081	48812	48367	48378	48335	46134
9090	71825	70846	70481	69958	71605
10307	56784	55174	53779	52291	58679
12131	73924	73448	72595	71671	84934
12132	46804	48466	49002	49603	72305
12299	64670	64587	64520	64362	62759
12749	57735	58816	56754	56469	64445
20189	16959	16863	16200	16018	14760
20191	17059	16964	16298	16116	14846

Table A-8. Scenario 2A-HOV-D: Converting lane case scenario vehicle type network results

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
1-HOV	HOV	19,966.58	1,705.91	44.668	0.141	1.447
	Car	113,592.92	9,714.88	44.639	0.141	1.447
2A-HOV-D (10%)	HOV	12,806.57	646.67	45.710	0.096	1.396
	Car	116,687.30	7,164.05	45.072	0.103	1.411
2A-HOV-D (15%)	HOV	19,005.02	928.56	45.737	0.094	1.395
	Car	109,533.12	6,344.18	45.247	0.099	1.406
2A-HOV-D (20%)	HOV	25,289.77	1,197.15	45.757	0.092	1.394
	Car	102,823.99	5,517.12	45.380	0.095	1.402
2A-HOV-D (25%)	HOV	31,623.85	1,463.96	45.782	0.091	1.393
	Car	95,735.57	4,890.96	45.515	0.093	1.398

Table A-9. Scenario 2B-HOV-S: Converting lane case scenario SB link flow charts

HOV Lane SB Links	2B-HOV-S (10%)	2B-HOV-S (15%)	2B-HOV-S (20%)	2B-HOV-S (25%)
20041	562	704	824	1011
20042	563	704	824	1011
20045	563	704	824	1011
20046	563	704	824	1011
20051	256	307	396	487
20052	256	307	396	487
20071	1704	1845	1966	2153
20079	805	947	1067	1254
20084	561	703	824	1011
20085	805	947	1068	1255
20094	564	705	825	1012
20095	563	704	824	1011
20102	564	705	825	1012
20103	256	307	396	487
20112	256	307	396	487
20113	256	307	396	487
20118	256	307	396	487
20124	256	307	397	487
20195	256	307	397	487

GP Lane SB Links	2B-HOV-S (10%)	2B-HOV-S (15%)	2B-HOV-S (20%)	2B-HOV-S (25%)	1-HOV
2401	29370	28572	27868	26951	33716
2421	20908	20383	19804	19209	23293
4572	22386	21840	21175	20553	25138
5500	19256	18748	18183	17674	21805
5502	25711	25023	24262	23554	28629
5795	26178	25465	24706	24006	29118
5992	20299	19762	19185	18601	22896
6217	6840	6661	6447	6238	8619
6219	9486	9192	8929	8642	11400
6229	20901	20341	19750	19144	23535
6915	13303	12905	12676	12165	16159
6996	37589	36538	35712	34444	42399
7004	34555	33633	32809	31681	39201
7062	26959	26236	25575	24738	31142
7070	34470	33561	32721	31631	39114
9036	8596	8340	8169	7845	11426
9048	5630	5442	5349	5124	8289
9079	8863	8818	8815	8735	8883
9083	7159	6973	6849	6583	8884
9091	6100	5947	5834	5622	7765
10293	26912	26186	25526	24690	31090
10306	19255	18747	18182	17673	21804
12135	33798	32910	32086	31025	38404
12136	37614	36599	35684	34492	42433
12750	24017	23349	22751	21949	27786

Table A-10. Scenario 2B-HOV-S: Converting lane case scenario NB link flow charts

HOV Lane NB Links	2B-HOV-S (10%)	2B-HOV-S (15%)	2B-HOV-S (20%)	2B-HOV-S (25%)
20005	752	1020	1301	1734
20008	752	1020	1301	1734
20010	1306	1780	2224	2777
20012	1306	1779	2222	2776
20016	1734	2326	2839	3430
20022	2074	2679	3200	3798
20024	2074	2679	3200	3798
20025	2073	2677	3198	3796
20026	2627	3231	3752	4350
20125	752	1021	1301	1734
20138	1306	1779	2222	2775
20145	1734	2326	2839	3430
20146	1733	2326	2839	3430
20150	1733	2326	2839	3430
20156	2074	2679	3200	3798
20168	2627	3231	3752	4350
20171	2627	3231	3752	4350
20174	2625	3230	3751	4349
20194	3933	4538	5059	5657

GP Lane NB Links	2B-HOV-S (10%)	2B-HOV-S (15%)	2B-HOV-S (20%)	2B-HOV-S (25%)	1-HOV
2402	48339	46052	46052	44999	63093
2419	54794	52150	52150	50909	69913
4561	45899	43830	43830	42890	58682
5629	52820	50343	50343	49170	66566
5797	41846	39974	39974	39130	54966
5994	47636	45603	45603	44716	57809
6913	29760	28145	28145	27246	41383
6995	50415	47649	47649	46267	61912
7003	60932	57853	57853	56270	76288
7063	62503	59481	59481	58004	78060
7069	54084	51452	51452	50182	68424
9038	27239	25722	25722	24903	34845
9046	32134	30370	30370	29374	43871
9070	53627	50533	50533	49058	56482
9078	47377	44701	44701	43397	56465
9081	40080	37838	37838	36724	46134
9090	61759	58218	58218	56425	71605
10307	45896	43828	43828	42886	58679
12131	69102	65578	65578	63843	84934
12132	57156	54282	54282	52867	72305
12299	49202	46926	46926	45888	62759
12749	51526	48683	48683	47254	64445
20189	10864	10862	10862	10909	14760
20191	10947	10932	10932	10987	14846

Table A-11. Scenario 2B-HOV-S: Converting lane case scenario vehicle type network results

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
1-HOV	HOV	19,966.58	1,705.91	44.668	0.141	1.447
	Car	113,592.92	9,714.88	44.639	0.141	1.447
2B-HOV-S (10%)	HOV	12,283.89	771.21	45.272	0.104	1.411
	Car	99,289.91	6,660.21	44.951	0.107	1.419
2B-HOV-S (15%)	HOV	18,096.99	909.81	45.602	0.093	1.397
	Car	89,345.66	4,920.77	45.189	0.096	1.409
2B-HOV-S (20%)	HOV	23,999.04	1,017.99	45.736	0.085	1.392
	Car	79,748.38	3,730.09	45.417	0.089	1.401
2B-HOV-S (25%)	HOV	30,044.31	1,122.07	45.886	0.082	1.389
	Car	70,347.86	2,915.93	45.573	0.084	1.396

Table A-12. Scenario 2B-HOV-D: Converting lane case scenario SB link flow charts

HOV Lane SB Links	2B-HOV-D (10%)	2B-HOV-D (15%)	2B-HOV-D (20%)	2B-HOV-D (25%)
20041	458	685	866	1205
20042	459	685	866	1205
20045	459	685	866	1205
20046	453	673	851	1205
20051	1825	2822	3635	4695
20052	1813	2810	3615	4662
20071	457	683	866	1204
20079	457	683	866	1204
20084	457	684	866	1205
20085	457	684	866	1205
20094	1859	2861	3669	4762
20095	1860	2861	3669	4762
20102	1847	2843	3669	4762
20103	1825	2822	3635	4695
20112	845	1337	1722	2293
20113	845	1337	1722	2293
20118	838	1319	1705	2277
20124	838	1320	1706	2278
20195	728	1153	1514	2009

GP Lane SB Links	2B-HOV-D (10%)	2B-HOV-D (15%)	2B-HOV-D (20%)	2B-HOV-D (25%)	1-HOV
2401	31731	29853	28207	26136	33716
2421	21361	19785	18378	16702	23293
4572	23253	21628	20142	18458	25138
5500	19920	18369	16959	15409	21805
5502	27809	26575	25392	24091	28629
5795	28283	27010	25843	24504	29118
5992	22129	21001	20001	18798	22896
6217	7868	7202	6637	5898	8619
6219	10693	9897	9276	8449	11400
6229	22783	21625	20620	19388	23535
6915	15510	14601	13703	12564	16159
6996	41822	40437	39214	37542	42399
7004	38722	37533	36353	34880	39201
7062	29159	27366	25768	23792	31142
7070	37101	35125	33323	31083	39114
9036	12055	11708	11323	10697	11426
9048	8313	7960	7630	7058	8289
9079	8735	8515	8297	8004	8883
9083	11628	11281	10630	10126	8884
9091	8650	8278	7787	7253	7765
10293	29104	27324	25722	23755	31090
10306	19919	18368	16958	15408	21804
12135	37786	36612	35463	33998	38404
12136	41822	40494	39251	37652	42433
12750	27640	26308	24995	23534	27786

Table A-13. Scenario 2B-HOV-D: Converting lane case scenario NB link flow charts

HOV Lane NB Links	2B-HOV-D (10%)	2B-HOV-D (15%)	2B-HOV-D (20%)	2B-HOV-D (25%)
20005	3894	5647	6522	7008
20008	2787	4262	5402	6335
20010	3449	5208	6533	7734
20012	3369	5101	6441	7650
20016	5381	7819	9625	11356
20022	5324	7627	9286	10677
20024	4853	6983	8532	9849
20025	4294	6255	7706	8971
20026	1159	1814	2265	2576
20125	3448	4971	5613	6004
20138	3429	5162	6564	7801
20145	5184	7520	9261	10850
20146	5584	8019	9803	11406
20150	4844	7039	8761	10223
20156	4783	6948	8532	9849
20168	1159	1814	2265	2576
20171	1159	1814	2265	2576
20174	1158	1814	2265	2576
20194	1158	1814	2265	2576

GP Lane NB Links	2B-HOV-D (10%)	2B-HOV-D (15%)	2B-HOV-D (20%)	2B-HOV-D (25%)	1-HOV
2402	55781	53855	51194	48770	63093
2419	63549	60586	57620	54982	69913
4561	54309	51431	48251	45894	58682
5629	65554	63584	61121	59397	66566
5797	54415	52703	50449	48941	54966
5994	57356	55579	53225	51721	57809
6913	34788	33217	30528	31280	41383
6995	53668	52110	48407	49961	61912
7003	63858	61977	57686	59037	76288
7063	68755	66345	63273	60978	78060
7069	58727	56661	54305	52392	68424
9038	32553	30979	28740	27279	34845
9046	40264	38311	35522	33650	43871
9070	55497	55390	54229	53615	56482
9078	57977	56704	54587	53708	56465
9081	47345	47178	45419	45157	46134
9090	69503	67882	65476	63963	71605
10307	54306	51428	48248	45891	58679
12131	72452	70437	67481	65912	84934
12132	48042	49497	47671	50983	72305
12299	61722	59876	57546	55999	62759
12749	56065	54264	50542	51978	64445
20189	16009	15500	14149	13812	14760
20191	16102	15587	14230	13898	14846

Table A-14. Scenario 2B-HOV-D: Converting lane case scenario vehicle type network results

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
1-HOV	HOV	19,966.58	1,705.91	44.668	0.141	1.447
	Car	113,592.92	9,714.88	44.639	0.141	1.447
2B-HOV-D (10%)	HOV	12,613.15	582.07	45.723	0.090	1.394
	Car	108,627.67	5,752.91	45.384	0.094	1.401
2B-HOV-D (15%)	HOV	18,731.59	795.42	45.936	0.086	1.387
	Car	97,725.39	4,545.07	45.650	0.089	1.394
2B-HOV-D (20%)	HOV	25,047.94	1,045.53	45.895	0.085	1.388
	Car	87,761.45	3,864.81	45.758	0.087	1.392
2B-HOV-D (25%)	HOV	31,401.33	1,250.69	45.979	0.084	1.387
	Car	77,158.51	3,162.64	45.943	0.084	1.386

Table A-15. Scenario 3A-HOV-S: Adding lane case scenario SB link flow charts

HOV Lane SB Links	3A-HOV-S (10%)	3A-HOV-S (15%)	3A-HOV-S (20%)	3A-HOV-S (25%)
20041	550	708	815	971
20042	550	708	815	972
20045	550	708	815	972
20046	550	709	815	972
20051	251	314	384	478
20052	251	314	384	478
20071	1692	1850	1957	2113
20079	793	951	1058	1214
20084	550	708	814	971
20085	794	952	1058	1215
20094	551	710	816	973
20095	550	709	815	972
20102	551	710	816	973
20103	251	314	384	478
20112	251	314	384	478
20113	251	314	384	478
20118	251	314	384	478
20124	251	314	384	478
20195	251	314	384	478

GP Lane SB Links	3A-HOV-S (10%)	3A-HOV-S (15%)	3A-HOV-S (20%)	3A-HOV-S (25%)	1-HOV
2401	31097	33177	31031	31054	33716
2421	22111	23878	22097	22129	23293
4572	23695	25947	23681	23713	25138
5500	20362	18674	20348	20380	21805
5502	27186	23852	27172	27204	28629
5795	27675	25358	27661	27693	29118
5992	21453	17197	21439	21471	22896
6217	7176	6254	7162	7192	8619
6219	9957	9035	9943	9973	11400
6229	22092	17589	22078	22109	23535
6915	14040	17750	13974	13996	16159
6996	39783	43836	39717	39739	42399
7004	36584	39752	36520	36542	39201
7062	28526	30521	28461	28483	31142
7070	36495	40555	36429	36452	39114
9036	9057	10096	8990	9013	11426
9048	5921	6735	5855	5877	8289
9079	9169	9554	9365	9546	8883
9083	7477	7704	7409	7433	8884
9091	6357	6690	6289	6313	7765
10293	28474	30453	28409	28431	31090
10306	20361	18673	20347	20379	21804
12135	35785	39741	35719	35742	38404
12136	39815	44691	39749	39772	42433
12750	25418	29610	25352	25374	27786

Table A-16. Scenario 3A-HOV-S: Adding lane case scenario NB link flow charts

HOV Lane NB Links	3A-HOV-S (10%)	3A-HOV-S (15%)	3A-HOV-S (20%)	3A-HOV-S (25%)
20005	720	148	1438	1714
20008	720	148	1438	1714
20010	1271	879	2381	2744
20012	1271	879	2381	2744
20016	1491	1103	2596	2971
20022	1784	1398	2891	3263
20024	1784	1398	2891	3262
20025	1782	1396	2889	3260
20026	2336	1950	3442	3814
20125	720	148	1439	1716
20138	1271	879	2381	2744
20145	1491	1103	2596	2971
20146	1490	1103	2596	2970
20150	720	148	1438	1714
20156	720	148	1438	1714
20168	1271	879	2381	2744
20171	1271	879	2381	2744
20174	1491	1103	2596	2971
20194	1784	1398	2891	3263

GP Lane NB Links	3A-HOV-S (10%)	3A-HOV-S (15%)	3A-HOV-S (20%)	3A-HOV-S (25%)	1-HOV
2402	53653	58950	53664	53640	63093
2419	60474	65397	60486	60461	69913
4561	50995	54427	51000	50975	58682
5629	58328	62829	58332	58307	66566
5797	46727	49794	46731	46706	54966
5994	52679	55495	52683	52658	57809
6913	31515	31930	31481	31502	41383
6995	53361	58949	53339	53375	61912
7003	66546	71641	66556	66532	76288
7063	68620	74150	68631	68607	78060
7069	59278	64448	59289	59265	68424
9038	28737	26451	28769	28802	34845
9046	34001	34310	33966	33985	43871
9070	56691	39018	56691	56691	56482
9078	50077	38532	50105	50141	56465
9081	42378	35893	42418	42385	46134
9090	65219	58971	65251	65284	71605
10307	50993	54425	50997	50972	58679
12131	75194	80277	75205	75181	84934
12132	62563	67712	62573	62549	72305
12299	54520	58629	54524	54499	62759
12749	54580	60275	54547	54566	64445
20189	13837	18744	13844	13840	14760
20191	13923	18938	13930	13926	14846

Table A-17. Scenario 3A-HOV-S: Adding lane case scenario vehicle type network results

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
1-HOV	HOV	19,966.58	1,705.91	44.668	0.141	1.447
	Car	113,592.92	9,714.88	44.639	0.141	1.447
3A-HOV-S (10%)	HOV	12,007.14	500.98	45.725	0.087	1.394
	Car	104,009.41	4,701.48	45.429	0.089	1.401
3A-HOV-S (15%)	HOV	20,038.49	2,771.12	44.128	0.158	1.487
	Car	110,836.61	15,092.67	44.003	0.156	1.491
3A-HOV-S (20%)	HOV	24,098.95	998.79	45.759	0.087	1.393
	Car	92,393.13	4,180.85	45.423	0.089	1.401
3A-HOV-S (25%)	HOV	29,936.81	1,243.72	45.714	0.087	1.394
	Car	86,744.35	3,920.87	45.434	0.089	1.401

Table A-18. Scenario 3A-HOV-D: Adding lane case scenario SB link flow charts

HOV Lane SB Links	3A-HOV-D (10%)	3A-HOV-D (15%)	3A-HOV-D (20%)	3A-HOV-D (25%)
20041	384	698	689	904
20042	384	698	689	904
20045	384	698	689	904
20046	382	687	688	904
20051	1521	3020	2645	3384
20052	1510	3007	2626	3362
20071	384	697	689	904
20079	384	697	689	904
20084	384	698	689	904
20085	384	698	689	904
20094	1536	3046	2682	3429
20095	1536	3046	2682	3429
20102	1537	3046	2682	3429
20103	1521	3020	2645	3383
20112	710	1431	1316	1679
20113	710	1431	1316	1679
20118	703	1421	1303	1662
20124	703	1421	1303	1662
20195	624	1241	1150	1449

GP Lane SB Links	3A-HOV-D (10%)	3A-HOV-D (15%)	3A-HOV-D (20%)	3A-HOV-D (25%)	1-HOV
2401	34040	31978	32923	32174	33716
2421	23088	21159	21971	21255	23293
4572	25037	23183	23931	23220	25138
5500	21544	19712	20445	19760	21805
5502	29657	28573	29063	28735	28629
5795	30241	29114	29635	29318	29118
5992	23593	22430	23028	22695	22896
6217	8527	7734	7992	7695	8619
6219	11512	10811	10978	10666	11400
6229	24283	23106	23711	23376	23535
6915	16866	16160	16497	16252	16159
6996	44389	43332	44096	43851	42399
7004	41033	39916	40772	40544	39201
7062	31265	29237	30157	29393	31142
7070	39648	37385	38552	37761	39114
9036	12702	12949	12437	12227	11426
9048	8871	8827	8581	8391	8289
9079	9329	9124	9327	9308	8883
9083	11729	12404	11441	11259	8884
9091	8964	9005	8670	8478	7765
10293	31154	28930	30048	29290	31090
10306	21544	19711	20444	19759	21804
12135	40053	38989	39793	39530	38404
12136	44358	43288	44078	43830	42433
12750	29722	28891	29410	29072	27786

Table A-19. Scenario 3A-HOV-D: Adding lane case scenario NB link flow charts

HOV Lane NB Links	3A-HOV-D (10%)	3A-HOV-D (15%)	3A-HOV-D (20%)	3A-HOV-D (25%)
20005	1854	4783	3517	4243
20008	1854	4756	3517	4242
20010	2218	5514	4212	5057
20012	2217	5495	4210	5054
20016	3104	7234	5892	7199
20022	2831	6742	5289	6496
20024	2709	6517	5045	6184
20025	2548	6209	4722	5801
20026	737	2644	1249	1485
20125	1577	4258	2983	3562
20138	2268	5584	4290	5164
20145	2977	6965	5605	6860
20146	2993	7135	5627	6886
20150	2824	6732	5270	6482
20156	2709	6515	5045	6184
20168	737	2644	1249	1485
20171	737	2644	1249	1485
20174	737	2644	1249	1485
20194	737	2613	1249	1485

GP Lane NB Links	3A-HOV-D (10%)	3A-HOV-D (15%)	3A-HOV-D (20%)	3A-HOV-D (25%)	1-HOV
2402	64764	61437	62510	61404	63093
2419	71962	68697	69701	68578	69913
4561	60307	57663	58228	57177	58682
5629	70580	69683	70153	69903	66566
5797	58319	57869	57888	57654	54966
5994	61367	60967	60928	60709	57809
6913	42971	40345	41005	40188	41383
6995	63983	62073	62060	61218	61912
7003	78178	74630	75482	74215	76288
7063	80230	76970	77846	76648	78060
7069	69987	66935	67583	66400	68424
9038	36184	34307	34616	33890	34845
9046	45723	43124	43757	42932	43871
9070	60920	61858	60903	61031	56482
9078	64755	66036	63472	63103	56465
9081	54520	59868	53238	52897	46134
9090	77760	79109	76295	75592	71605
10307	60305	57660	58226	57174	58679
12131	87196	84103	84627	83378	84934
12132	74066	70649	71546	70337	72305
12299	66563	65593	66146	65907	62759
12749	66630	63877	64673	63841	64445
20189	16967	19451	16480	16301	14760
20191	17062	19546	16576	16394	14846

Table A-20. Scenario 3A-HOV-D: Adding lane case scenario vehicle type network results

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
1-HOV	HOV Car	19,966.58 113,592.92	1,705.91 9,714.88	44.668 44.639	0.141 0.141	1.447 1.447
3A-HOV-D (10%)	HOV Car	12,650.09 114,531.30	586.37 5,302.02	45.738 45.708	0.091 0.090	1.394 1.394
3A-HOV-D (15%)	HOV Car	18,781.08 107,292.10	817.92 4,745.49	45.934 45.851	0.087 0.088	1.388 1.390
3A-HOV-D (20%)	HOV Car	25,466.88 101,898.73	1,228.37 4,905.53	45.706 45.673	0.092 0.091	1.394 1.395
3A-HOV-D (25%)	HOV Car	31,678.39 95,924.16	1,586.80 4,810.64	45.640 45.645	0.092 0.092	1.396 1.396

Table A-21. Scenario 3B-HOV-S: Adding lane case scenario SB link flow charts

HOV Lane SB Links	3B-HOV-S (10%)	3B-HOV-S (15%)	3B-HOV-S (20%)	3B-HOV-S (25%)
20041	569	697	822	1015
20042	569	697	822	1016
20045	569	697	822	1016
20046	569	697	823	1016
20051	254	329	374	520
20052	254	329	374	521
20071	1712	1841	1965	2157
20079	813	942	1066	1258
20084	569	697	822	1015
20085	813	942	1066	1259
20094	570	698	824	1017
20095	569	697	823	1016
20102	570	698	824	1017
20103	254	329	374	520
20112	254	329	374	521
20113	254	329	374	521
20118	254	329	374	521
20124	254	329	374	521
20195	254	329	374	521

GP Lane SB Links	3B-HOV-S (10%)	3B-HOV-S (15%)	3B-HOV-S (20%)	3B-HOV-S (25%)	1-HOV
2401	31053	28521	27740	26765	33716
2421	22116	20332	19812	19066	23293
4572	23700	21764	21205	20395	25138
5500	20367	18697	18201	17535	21805
5502	27191	24999	24225	23429	28629
5795	27680	25441	24661	23871	29118
5992	21458	19703	19114	18506	22896
6217	7179	6580	6479	6193	8619
6219	9960	9131	8950	8591	11400
6229	22096	20287	19683	19059	23535
6915	13996	12915	12572	12126	16159
6996	39739	36545	35482	34288	42399
7004	36542	33599	32626	31551	39201
7062	28482	26175	25448	24547	31142
7070	36451	33505	32546	31470	39114
9036	9012	8296	8114	7824	11426
9048	5877	5427	5320	5111	8289
9079	9143	8745	8793	8759	8883
9083	7432	6904	6828	6602	8884
9091	6312	5875	5832	5631	7765
10293	28430	26126	25399	24502	31090
10306	20366	18696	18200	17534	21804
12135	35741	32861	31923	30859	38404
12136	39772	36561	35513	34317	42433
12750	25374	23367	22729	21874	27786

Table A-22. Scenario 3B-HOV-S: Adding lane case scenario NB link flow charts

HOV Lane NB Links	3B-HOV-S (10%)	3B-HOV-S (15%)	3B-HOV-S (20%)	3B-HOV-S (25%)
20005	714	1073	1384	1635
20008	714	1073	1384	1635
20010	1219	1819	2294	2721
20012	1219	1819	2294	2720
20016	1425	2032	2501	2928
20022	1720	2325	2796	3222
20024	1720	2325	2795	3221
20025	1718	2323	2793	3219
20026	2272	2877	3347	3773
20125	714	1073	1384	1638
20138	1218	1819	2294	2720
20145	1425	2032	2501	2928
20146	1425	2031	2501	2928
20150	1425	2031	2501	2928
20156	1720	2325	2796	3222
20168	2272	2877	3347	3773
20171	2272	2877	3347	3773
20174	2271	2876	3346	3772
20194	3579	4184	4654	5080

GP Lane NB Links	3B-HOV-S (10%)	3B-HOV-S (15%)	3B-HOV-S (20%)	3B-HOV-S (25%)	1-HOV
2402	53724	49417	48003	46581	63093
2419	60544	55673	54061	52512	69913
4561	51059	47074	45757	44485	58682
5629	58389	53770	52204	50740	66566
5797	46788	43143	41875	40670	54966
5994	52740	48852	47522	46237	57809
6913	31505	29016	28174	27335	41383
6995	53361	49159	47740	46299	61912
7003	66617	61260	59550	57610	76288
7063	68691	63190	61389	59477	78060
7069	59349	54649	53072	51434	68424
9038	28730	26573	25730	25019	34845
9046	33990	31281	30386	29460	43871
9070	56691	51991	50475	49116	56482
9078	50068	45999	44698	43501	56465
9081	42351	38907	37794	36745	46134
9090	65212	59941	58275	56579	71605
10307	51056	47071	45755	44484	58679
12131	75265	69172	67255	65149	84934
12132	62634	57607	56001	54164	72305
12299	54582	50270	48820	47472	62759
12749	54571	50236	48763	47277	64445
20189	13918	13097	12846	12525	14760
20191	14004	13177	12922	12598	14846

Table A-23. Scenario 3B-HOV-S: Adding lane case scenario vehicle type network results

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
1-HOV	HOV	19,966.58	1,705.91	44.668	0.141	1.447
	Car	113,592.92	9,714.88	44.639	0.141	1.447
3B-HOV-S (10%)	HOV	12,744.87	540.32	45.685	0.088	1.395
	Car	103,264.51	4,656.72	45.430	0.089	1.401
3B-HOV-S (15%)	HOV	17,989.29	649.54	45.921	0.080	1.387
	Car	88,280.52	3,526.02	45.628	0.083	1.395
3B-HOV-S (20%)	HOV	23,878.90	832.42	46.018	0.079	1.384
	Car	79,513.44	3,101.30	45.662	0.082	1.394
3B-HOV-S (25%)	HOV	29,825.36	1,023.19	46.018	0.079	1.385
	Car	70,509.81	2,687.88	45.687	0.081	1.393

Table A-24. Scenario 3B-HOV-D: Adding lane case scenario SB link flow charts

HOV Lane SB Links	3B-HOV-D (10%)	3B-HOV-D (15%)	3B-HOV-D (20%)	3B-HOV-D (25%)
20041	383	613	899	1202
20042	383	613	899	1203
20045	383	613	899	1203
20046	383	612	900	1203
20051	1694	2628	3661	4847
20052	1679	2608	3642	4830
20071	383	613	898	1200
20079	383	613	899	1201
20084	383	613	899	1202
20085	383	613	899	1202
20094	1710	2648	3701	4897
20095	1710	2648	3701	4897
20102	1710	2648	3701	4897
20103	1694	2628	3661	4847
20112	762	1226	1757	2313
20113	762	1226	1757	2313
20118	753	1214	1737	2284
20124	753	1215	1737	2285
20195	659	1075	1498	1993

GP Lane SB Links	3B-HOV-D (10%)	3B-HOV-D (15%)	3B-HOV-D (20%)	3B-HOV-D (25%)	1-HOV
2401	32003	30015	28005	25786	33716
2421	21645	19966	18296	16422	23293
4572	23483	21760	20045	18131	25138
5500	20153	18536	16872	15108	21805
5502	27963	26681	25234	23976	28629
5795	28394	27141	25674	24383	29118
5992	22219	21110	19806	18693	22896
6217	7962	7281	6608	5896	8619
6219	10741	10013	9239	8435	11400
6229	22866	21751	20432	19300	23535
6915	15679	14692	13568	12679	16159
6996	42007	40529	38924	37467	42399
7004	38940	37510	36101	34809	39201
7062	29441	27497	25576	23442	31142
7070	37426	35270	33082	30791	39114
9036	12209	11757	11294	10709	11426
9048	8486	8075	7596	7065	8289
9079	8867	8529	8277	7975	8883
9083	11410	10919	10576	10228	8884
9091	8596	8131	7738	7245	7765
10293	29405	27427	25528	23420	31090
10306	20152	18535	16871	15107	21804
12135	38045	36621	35226	33837	38404
12136	42069	40544	39016	37499	42433
12750	27707	26312	24916	23596	27786

Table A-25. Scenario 3B-HOV-D: Adding lane case scenario NB link flow charts

HOV Lane NB Links	3B-HOV-D (10%)	3B-HOV-D (15%)	3B-HOV-D (20%)	3B-HOV-D (25%)
20005	2092	3083	4273	5762
20008	2092	3083	4273	5762
20010	2505	3641	4984	6731
20012	2504	3636	4982	6727
20016	3456	5052	6863	9145
20022	3106	4520	6119	8214
20024	2955	4296	5907	7933
20025	2777	4061	5554	7489
20026	744	1141	1578	2330
20125	1784	2613	3783	5145
20138	2559	3716	5085	6844
20145	3274	4770	6460	8639
20146	3281	4798	6464	8650
20150	3097	4513	6120	8215
20156	2955	4296	5907	7933
20168	744	1141	1578	2330
20171	744	1141	1578	2329
20174	744	1141	1578	2329
20194	743	1141	1578	2329

GP Lane NB Links	3B-HOV-D (10%)	3B-HOV-D (15%)	3B-HOV-D (20%)	3B-HOV-D (25%)	1-HOV
2402	60917	57926	54633	51134	63093
2419	67730	64569	61009	57433	69913
4561	56795	54071	50947	47822	58682
5629	66751	64516	62279	60037	66566
5797	55271	53482	51559	49666	54966
5994	58173	56330	54349	52395	57809
6913	39949	37892	35366	32843	41383
6995	60397	57787	54751	51661	61912
7003	73705	70239	66412	62232	76288
7063	75670	72296	68620	64634	78060
7069	66006	62904	59439	55729	68424
9038	34235	32568	30492	28328	34845
9046	42538	40457	37882	35285	43871
9070	58073	56812	55465	54219	56482
9078	61640	59618	57498	55394	56465
9081	52036	50623	49058	47222	46134
9090	73942	71539	69054	66202	71605
10307	56792	54069	50944	47820	58679
12131	82361	78758	74921	70716	84934
12132	69911	66656	63091	59127	72305
12299	62909	60841	58721	56618	62759
12749	62736	60029	56851	53628	64445
20189	16243	15770	15358	14627	14760
20191	16330	15858	15442	14709	14846

Table A-26. Scenario 3B-HOV-D: Adding lane case scenario vehicle type network results

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
1-HOV	HOV Car	19,966.58 113,592.92	1,705.91 9,714.88	44.668 44.639	0.141 0.141	1.447 1.447
3B-HOV-D (10%)	HOV Car	12,641.11 106,812.74	534.16 4,507.00	45.836 45.891	0.087 0.086	1.390 1.389
3B-HOV-D (15%)	HOV Car	18,874.02 96,749.40	765.29 3,941.51	45.923 45.946	0.084 0.085	1.388 1.387
3B-HOV-D (20%)	HOV Car	25,014.08 86,859.20	982.92 3,430.51	46.046 46.003	0.083 0.084	1.384 1.386
3B-HOV-D (25%)	HOV Car	31,134.33 76,928.11	1,193.55 2,947.49	46.083 46.065	0.082 0.082	1.384 1.384

Table A-27. Scenario ETL3-S: Converting lane case scenario SB link flow charts

Truck Lane SB Links	ETL3-S (4%)	BNT3 (4%)	ETL3-S (8%)	BNT3 (8%)	ETL3-S (12%)	BNT3 (12%)
20041	354	NO TRUCK LANE	419	NO TRUCK LANE	477	NO TRUCK LANE
20042	354		419		477	
20045	354		419		477	
20046	354		419		477	
20051	172		233		294	
20052	172		233		294	
20071	1498		1562		1619	
20079	599		663		720	
20084	354		419		477	
20085	599		664		721	
20094	355		420		478	
20095	354		419		477	
20102	355		420		478	
20103	172		233		294	
20112	172		233		294	
20113	172		233		294	
20118	172		233		294	
20124	172		234		294	
20195	172		234		294	

GP SB Links	ETL3-S (4%)	BNT3 (4%)	ETL3-S (8%)	BNT3 (8%)	ETL3-S (12%)	BNT3 (12%)
2401	30534	35285	28878	35021	26859	34673
2421	22142	24540	20958	24439	19443	24117
4572	23886	26587	22656	26538	21346	26375
5500	20416	22976	19175	22801	18132	22702
5502	27364	30331	25883	30071	24530	29955
5795	27843	31104	26331	30640	24984	30868
5992	21580	24364	20341	24074	19227	24075
6217	7191	9024	6821	8930	6397	8836
6219	10266	12029	9860	12008	9530	12032
6229	22215	26222	20937	24714	19787	25046
6915	17286	19198	16230	19234	16124	19765
6996	41383	46016	39288	45701	37440	46626
7004	35575	41103	33918	40872	31139	40533
7062	27912	32567	26220	32194	24075	31752
7070	35904	41108	33893	40736	31120	40270
9036	10285	13016	9716	12910	9345	12940
9048	6531	9096	6166	9015	6120	9054
9079	8482	9008	8210	8918	7823	8886
9083	7051	9009	6776	8918	6393	8887
9091	6321	8252	5956	8058	5575	8100
10293	27904	32563	26219	32193	24071	31751
10306	20415	22975	19174	22800	18131	22701
12135	35083	40317	33149	39988	30400	39524
12136	39317	44579	37233	44229	34559	43924
12750	26846	29879	25190	30008	24023	29706

Table A-28. Scenario ETL3-S: Converting lane case scenario NB link flow charts

Truck Lane NB Links	ETL3-S (4%)	BNT3 (4%)	ETL3-S (8%)	BNT3 (8%)	ETL3-S (12%)	BNT3 (12%)
20005	105	NO TRUCK LANE	105	NO TRUCK LANE	105	NO TRUCK LANE
20008	105		105		105	
20010	296		298		296	
20012	296		298		296	
20016	530		537		531	
20022	831		842		831	
20024	831		842		831	
20025	830		841		830	
20026	1384		1395		1384	
20125	105		105		105	
20138	296		298		296	
20145	530		536		531	
20146	530		536		530	
20150	530		536		530	
20156	831		842		831	
20168	1384		1395		1384	
20171	1384		1395		1384	
20174	1383		1394		1383	
20194	2691		2702		2691	

GP NB Links	ETL3-S (4%)	BNT3 (4%)	ETL3-S (8%)	BNT3 (8%)	ETL3-S (12%)	BNT3 (12%)
2402	50782	67456	49340	66748	47948	67245
2419	57601	74549	56057	73966	54391	74467
4561	48300	62255	47013	61844	45840	62140
5629	56124	71834	55168	71264	53861	72721
5797	44522	58663	43945	58703	43521	58965
5994	50425	62559	49879	61783	49394	62373
6913	32016	45325	29458	44285	28958	44597
6995	53096	66870	49286	65587	47359	65714
7003	63248	81087	59965	79557	57611	79654
7063	66155	83526	64146	82666	61981	83139
7069	56940	73106	55051	72177	53232	72606
9038	29682	38830	28887	38873	27125	38775
9046	34650	47992	34015	47702	32761	47996
9070	60320	63498	56728	62583	53525	62569
9078	53380	63480	50104	62564	46793	62549
9081	45568	54920	41698	53695	37679	51253
9090	68905	81665	64525	80700	60031	79691
10307	48297	62252	47012	61842	45838	62138
12131	72614	90184	69878	89228	67475	89649
12132	56688	73249	53753	72567	52383	72849
12299	52141	66821	51299	66893	50102	67398
12749	54204	68417	50762	67235	48916	67228
20189	10270	18495	9985	16917	10289	18162
20191	10384	18906	10099	18133	10388	18547

Table A-29. Scenario ETL3-S: Converting lane case scenario vehicle type data

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
BNT3 (4%)	Truck	5,204.87	394.72	45.525	0.128	1.431
	Car	126,510.27	9,933.51	45.422	0.129	1.434
ETL3-S (4%)	Truck	2,696.90	179.73	42.054	0.124	1.521
	Car	126,186.94	14,602.57	44.122	0.163	1.478
BNT3 (8%)	Truck	10,456.08	778.14	45.387	0.128	1.432
	Car	121,491.06	9,054.07	45.315	0.126	1.432
ETL3-S (8%)	Truck	5,535.98	365.26	42.002	0.124	1.522
	Car	120,565.82	11,549.93	44.211	0.142	1.460
BNT3 (12%)	Truck	16,283.99	1,739.70	45.170	0.166	1.472
	Car	120,654.75	12,887.36	45.157	0.166	1.473
ETL3-S (12%)	Truck	8,379.09	717.02	41.818	0.148	1.548
	Car	115,820.30	11,141.26	44.293	0.149	1.468

Table A-30. Scenario ETL3-D: Converting lane case scenario SB link flow charts

Truck Lane SB Links	ETL3-D (4%)	BNT3 (4%)	ETL3-D (8%)	BNT3 (8%)	ETL3-D (12%)	BNT3 (12%)
20041	1750	NO TRUCK LANE	3523	NO TRUCK LANE	5201	NO TRUCK LANE
20042	1618		3263		4829	
20045	1725		3497		5214	
20046	1591		3268		4833	
20051	1050		2116		3115	
20052	955		1942		2818	
20071	381		802		1102	
20079	519		1095		1517	
20084	674		1359		1938	
20085	1089		2200		3192	
20094	1352		2771		4097	
20095	1671		3447		5089	
20102	1388		2824		4180	
20103	949		1940		2836	
20112	1141		2314		3385	
20113	1155		2331		3417	
20118	939		1897		2787	
20124	1054		2090		3097	
20195	471		908		1371	

GP SB Links	ETL3-D (4%)	BNT3 (4%)	ETL3-D (8%)	BNT3 (8%)	ETL3-D (12%)	BNT3 (12%)
2401	33833	35285	32208	35021	30488	34673
2421	23534	24540	22387	24439	21208	24117
4572	25555	26587	24347	26538	23169	26375
5500	22032	22976	20919	22801	19960	22702
5502	29083	30331	27664	30071	26421	29955
5795	29823	31104	28152	30640	27144	30868
5992	23387	24364	22129	24074	21148	24075
6217	8660	9024	8249	8930	7814	8836
6219	11552	12029	11105	12008	10657	12032
6229	25243	26222	22706	24714	21966	25046
6915	17184	19198	16205	19234	15252	19765
6996	42713	46016	40604	45701	38517	46626
7004	38744	41103	36973	40872	34958	40533
7062	31207	32567	29624	32194	27859	31752
7070	39549	41108	37680	40736	35505	40270
9036	12945	13016	12462	12910	12147	12940
9048	8991	9096	8630	9015	8494	9054
9079	8463	9008	8216	8918	7966	8886
9083	12304	9009	12198	8918	11458	8887
9091	9075	8252	8794	8058	8513	8100
10293	31203	32563	29623	32193	27856	31751
10306	22031	22975	20919	22800	19959	22701
12135	38757	40317	36917	39988	34800	39524
12136	42029	44579	40032	44229	37894	43924
12750	29072	29879	27850	30008	26557	29706

Table A-31. Scenario ETL3-D: Converting lane case scenario NB link flow charts

Truck Lane NB Links	ETL3-D (4%)	BNT3 (4%)	ETL3-D (8%)	BNT3 (8%)	ETL3-D (12%)	BNT3 (12%)
20005	2353	NO TRUCK LANE	4882	NO TRUCK LANE	7144	NO TRUCK LANE
20008	1554		3124		4685	
20010	2180		4418		6551	
20012	2076		4204		6250	
20016	2533		5123		7640	
20022	2974		6101		8799	
20024	2881		6024		8785	
20025	2527		5270		7679	
20026	2627		5511		8049	
20125	1890		3826		5438	
20138	2034		4113		6099	
20145	2460		4911		7341	
20146	2826		5718		8459	
20150	2393		4852		7196	
20156	2637		5535		8048	
20168	2744		5764		8431	
20171	2305		4889		7123	
20174	2472		5187		7535	
20194	953		1876		2824	

GP NB Links	ETL3-D (4%)	BNT3 (4%)	ETL3-D (8%)	BNT3 (8%)	ETL3-D (12%)	BNT3 (12%)
2402	60280	67456	58450	66748	57157	67245
2419	67169	74549	65027	73966	63205	74467
4561	57241	62255	55678	61844	53744	62140
5629	67464	71834	64965	71264	63516	72721
5797	55437	58663	54176	58703	52049	58965
5994	59262	62559	57073	61783	55087	62373
6913	40308	45325	38168	44285	37986	44597
6995	60437	66870	57811	65587	56736	65714
7003	70745	81087	68166	79557	67007	79654
7063	71977	83526	70382	82666	68899	83139
7069	58790	73106	58356	72177	57537	72606
9038	34898	38830	34282	38873	33706	38775
9046	43834	47992	42795	47702	41573	47996
9070	59732	63498	56737	62583	55348	62569
9078	67235	63480	64308	62564	62515	62549
9081	58133	54920	55923	53695	51578	51253
9090	73714	81665	71055	80700	69094	79691
10307	57239	62252	55677	61842	53741	62138
12131	74717	90184	73512	89228	72187	89649
12132	36206	73249	37869	72567	39536	72849
12299	62519	66821	60948	66893	58867	67398
12749	62017	68417	59357	67235	58222	67228
20189	17555	18495	17341	16917	16541	18162
20191	17982	18906	18153	18133	16841	18547

Table A-32. Scenario ETL3-D: Converting lane case scenario vehicle type data

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
BNT3 (4%)	Truck	5,204.87	394.72	45.525	0.128	1.431
	Car	126,510.27	9,933.51	45.422	0.129	1.434
ETL3-D (4%)	Truck	5,276.85	300.40	44.488	0.112	1.438
	Car	126,033.56	9,012.77	44.916	0.120	1.429
BNT3 (8%)	Truck	10,456.08	778.14	45.387	0.128	1.432
	Car	121,491.06	9,054.07	45.315	0.126	1.432
ETL3-D (8%)	Truck	10,561.98	615.65	44.572	0.116	1.439
	Car	120,443.34	8,298.96	44.998	0.119	1.427
BNT3 (12%)	Truck	16,283.99	1,739.70	45.170	0.166	1.472
	Car	120,654.75	12,887.36	45.157	0.166	1.473
ETL3-D (12%)	Truck	15,883.09	1,050.84	44.413	0.123	1.448
	Car	115,866.61	8,334.56	45.032	0.122	1.431

Table A-33. Scenario STL3-S: Converting lane case scenario SB link flow charts

Truck Lane SB Links	STL3-S (4%)	BNT3 (4%)	STL3-S (8%)	BNT3 (8%)	STL3-S (12%)	BNT3 (12%)
20041	2879	NO TRUCK LANE	2726	NO TRUCK LANE	2670	NO TRUCK LANE
20042	2879		2726		2672	
20045	2879		2726		2672	
20046	2881		2727		2674	
20051	1546		1480		1471	
20052	1547		1481		1471	
20071	4020		3868		3813	
20079	3122		2969		2914	
20084	2879		2725		2670	
20085	3124		2970		2914	
20094	2882		2728		2675	
20095	2881		2727		2674	
20102	2882		2728		2675	
20103	1546		1480		1471	
20112	1547		1481		1471	
20113	1547		1481		1471	
20118	1547		1481		1471	
20124	1547		1481		1472	
20195	1547		1482		1473	

GP SB Links	STL3-S (4%)	BNT3 (4%)	STL3-S (8%)	BNT3 (8%)	STL3-S (12%)	BNT3 (12%)
2401	30587	35285	28916	35021	26785	34673
2421	22148	24540	20962	24439	19441	24117
4572	23889	26587	22665	26538	21343	26375
5500	20419	22976	19184	22801	18129	22702
5502	27362	30331	25892	30071	24527	29955
5795	27845	31104	26342	30640	24978	30868
5992	21578	24364	20350	24074	19224	24075
6217	7189	9024	6830	8930	6394	8836
6219	10275	12029	9872	12008	9523	12032
6229	22208	26222	20947	24714	19784	25046
6915	17348	19198	16275	19234	16041	19765
6996	41442	46016	39331	45701	37355	46626
7004	35631	41103	33960	40872	31056	40533
7062	27966	32567	26258	32194	23994	31752
7070	35957	41108	33931	40736	31042	40270
9036	10348	13016	9766	12910	9265	12940
9048	6598	9096	6204	9015	6046	9054
9079	11075	9008	10574	8918	9960	8886
9083	7112	9009	6822	8918	6311	8887
9091	6385	8252	6007	8058	5495	8100
10293	27958	32563	26257	32193	23988	31751
10306	20418	22975	19183	22800	18128	22701
12135	35136	40317	33187	39988	30322	39524
12136	39372	44579	37275	44229	34474	43924
12750	26913	29879	25229	30008	23949	29706

Table A-34. Scenario STL3-S: Converting lane case scenario NB link flow charts

Truck Lane NB Links	STL3-S (4%)	BNT3 (4%)	STL3-S (8%)	BNT3 (8%)	STL3-S (12%)	BNT3 (12%)
20005	6966	NO TRUCK LANE	6635	NO TRUCK LANE	6686	NO TRUCK LANE
20008	6965		6634		6686	
20010	11146		10451		10410	
20012	11142		10447		10407	
20016	14324		12472		12285	
20022	14844		13001		12738	
20024	14842		12997		12735	
20025	14842		12997		12735	
20026	15390		13546		13283	
20125	6968		6639		6691	
20138	11142		10446		10405	
20145	14323		12472		12285	
20146	14321		12472		12284	
20150	14321		12472		12284	
20156	14844		13000		12738	
20168	15388		13545		13283	
20171	15387		13544		13283	
20174	15385		13542		13282	
20194	16669		14834		14574	

GP NB Links	STL3-S (4%)	BNT3 (4%)	STL3-S (8%)	BNT3 (8%)	STL3-S (12%)	BNT3 (12%)
2402	50931	67456	49456	66748	47957	67245
2419	57750	74549	56174	73966	54401	74467
4561	48444	62255	47113	61844	45844	62140
5629	56264	71834	55271	71264	53870	72721
5797	44664	58663	44058	58703	43534	58965
5994	50538	62559	49977	61783	49391	62373
6913	31991	45325	29446	44285	28901	44597
6995	53082	66870	49276	65587	47302	65714
7003	63302	81087	60019	79557	57652	79654
7063	66304	83526	64262	82666	61990	83139
7069	56995	73106	55109	72177	53272	72606
9038	29638	38830	28851	38873	27129	38775
9046	34625	47992	34010	47702	32686	47996
9070	60320	63498	56729	62583	53525	62569
9078	53334	63480	50073	62564	46816	62549
9081	45566	54920	41657	53695	37728	51253
9090	68858	81665	64490	80700	60036	79691
10307	48442	62252	47112	61842	45842	62138
12131	72670	90184	69937	89228	67514	89649
12132	56756	73249	53808	72567	52429	72849
12299	52291	66821	51402	66893	50108	67398
12749	54182	68417	50753	67235	48859	67228
20189	10418	18495	10079	16917	10292	18162
20191	10534	18906	10199	18133	10387	18547

Table A-35. Scenario STL3-S: Converting lane case scenario vehicle type data

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
BNT3 (4%)	Truck Car	5,204.87 126,510.27	394.72 9,933.51	45.525 45.422	0.128 0.129	1.431 1.434
STL3-S (4%)	Truck Car	2,695.93 132,334.52	178.76 13,912.45	42.056 44.493	0.123 0.156	1.520 1.466
BNT3 (8%)	Truck Car	10,456.08 121,491.06	778.14 9,054.07	45.387 45.315	0.128 0.126	1.432 1.432
STL3-S (8%)	Truck Car	5,530.19 125,731.25	359.46 10,797.24	42.014 44.588	0.122 0.135	1.521 1.448
BNT3 (12%)	Truck Car	16,283.99 120,654.75	1,739.70 12,887.36	45.170 45.157	0.166 0.166	1.472 1.473
STL3-S (12%)	Truck Car	8,359.74 120,557.64	697.67 9,796.50	41.827 44.679	0.145 0.138	1.545 1.454

Table A-36. Scenario STL3-D: Converting lane case scenario SB link flow charts

Truck Lane SB Links	STL3-D (4%)	BNT3 (4%)	STL3-D (8%)	BNT3 (8%)	STL3-D (12%)	BNT3 (12%)
20041	6264	NO TRUCK LANE	7158	NO TRUCK LANE	8915	NO TRUCK LANE
20042	6127		6885		8519	
20045	6261		7117		8879	
20046	6048		6781		8342	
20051	17139		16984		17771	
20052	16939		16709		17382	
20071	4330		4369		4722	
20079	4452		4639		5116	
20084	4564		4903		5464	
20085	4964		5705		6697	
20094	17771		17838		18974	
20095	18111		18514		19957	
20102	17797		17889		19039	
20103	17036		16792		17515	
20112	9816		9650		10815	
20113	9156		9364		10311	
20118	8822		8775		9475	
20124	8942		8986		9769	
20195	7105		6933		7122	

GP SB Links	STL3-D (4%)	BNT3 (4%)	STL3-D (8%)	BNT3 (8%)	STL3-D (12%)	BNT3 (12%)
2401	17097	35285	17009	35021	15678	34673
2421	7305	24540	7435	24439	6532	24117
4572	9286	26587	9345	26538	8463	26375
5500	5982	22976	6133	22801	5440	22702
5502	20371	30331	20300	30071	19024	29955
5795	21758	31104	21122	30640	20286	30868
5992	15344	24364	15123	24074	14433	24075
6217	1948	9024	2188	8930	2082	8836
6219	4883	12029	5061	12008	4866	12032
6229	17054	26222	15687	24714	15259	25046
6915	13129	19198	12839	19234	11919	19765
6996	38352	46016	37516	45701	35596	46626
7004	34369	41103	33785	40872	32059	40533
7062	14547	32567	14495	32194	13216	31752
7070	22550	41108	22312	40736	20661	40270
9036	9386	13016	9117	12910	8689	12940
9048	5259	9096	5146	9015	4935	9054
9079	8649	9008	8264	8918	7943	8886
9083	8594	9009	8126	8918	7907	8887
9091	5331	8252	5241	8058	4927	8100
10293	14536	32563	14495	32193	13215	31751
10306	5982	22975	6133	22800	5440	22701
12135	33648	40317	33039	39988	31203	39524
12136	37620	44579	36858	44229	34959	43924
12750	24882	29879	23968	30008	22835	29706

Table A-37. Scenario STL3-D: Converting lane case scenario NB link flow charts

Truck Lane NB Links	STL3-D (4%)	BNT3 (4%)	STL3-D (8%)	BNT3 (8%)	STL3-D (12%)	BNT3 (12%)
20005	24521	NO TRUCK LANE	23636	NO TRUCK LANE	24954	NO TRUCK LANE
20008	23077		21968		22674	
20010	26555		25703		26774	
20012	26399		25474		26495	
20016	29656		28659		29249	
20022	27235		26590		27736	
20024	26511		26056		27278	
20025	25117		24483		25582	
20026	12209		12898		14642	
20125	21968		20760		21845	
20138	27251		26121		26636	
20145	27928		26870		27426	
20146	28385		27538		28546	
20150	26740		25778		26654	
20156	26226		25521		26554	
20168	12340		13137		14985	
20171	11807		12237		13657	
20174	11964		12525		14091	
20194	10286		9505		9402	

GP NB Links	STL3-D (4%)	BNT3 (4%)	STL3-D (8%)	BNT3 (8%)	STL3-D (12%)	BNT3 (12%)
2402	41621	67456	41705	66748	41105	67245
2419	48387	74549	48334	73966	47429	74467
4561	37831	62255	38232	61844	37562	62140
5629	60087	71834	58805	71264	58217	72721
5797	47417	58663	47202	58703	46276	58965
5994	51114	62559	50075	61783	49224	62373
6913	19532	45325	19526	44285	19553	44597
6995	39296	66870	38718	65587	38182	65714
7003	50663	81087	49809	79557	49142	79654
7063	55651	83526	55353	82666	54577	83139
7069	45484	73106	45272	72177	44715	72606
9038	16572	38830	17685	38873	17794	38775
9046	22232	47992	23087	47702	23101	47996
9070	61088	63498	58118	62583	55651	62569
9078	49307	63480	47898	62564	46911	62549
9081	39352	54920	38359	53695	35398	51253
9090	59070	81665	57690	80700	55685	79691
10307	37829	62252	38230	61842	37560	62138
12131	60400	90184	59928	89228	59068	89649
12132	40956	73249	40840	72567	41345	72849
12299	55265	66821	54758	66893	53600	67398
12749	41759	68417	41189	67235	40371	67228
20189	8864	18495	8675	16917	10194	18162
20191	9232	18906	9636	18133	10489	18547

Table A-38. Scenario STL3-D: Converting lane case scenario vehicle type data

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
BNT3 (4%)	Truck Car	5,204.87 126,510.27	394.72 9,933.51	45.525 45.422	0.128 0.129	1.431 1.434
STL3-D (4%)	Truck Car	5,146.75 121,977.52	248.20 5,715.01	44.483 45.697	0.098 0.092	1.426 1.395
BNT3 (8%)	Truck Car	10,456.08 121,491.06	778.14 9,054.07	45.387 45.315	0.128 0.126	1.432 1.432
STL3-D (8%)	Truck Car	10,474.79 117,741.57	541.63 5,823.82	44.423 45.571	0.102 0.097	1.429 1.401
BNT3 (12%)	Truck Car	16,283.99 120,654.75	1,739.70 12,887.36	45.170 45.157	0.166 0.166	1.472 1.473
STL3-D (12%)	Truck Car	15,722.34 113,506.83	923.96 6,294.25	44.361 45.461	0.111 0.104	1.436 1.409

Table A-39. Scenario ETL4-S: Adding lane case scenario SB link flow charts

Truck Lane SB Links	ETL4-S (4%)	BNT4 (4%)	ETL4-S (8%)	BNT4 (8%)	ETL4-S (12%)	BNT4 (12%)
20041	471	4692	675	4467	891	4577
20042	471	4693	675	4468	885	4578
20045	471	4693	675	4468	885	4578
20046	468	4639	668	4434	876	4503
20051	491	19233	851	18537	1307	18948
20052	488	19134	839	18434	1291	18847
20071	1614	4689	1818	4464	2027	4573
20079	715	4690	919	4465	1128	4574
20084	471	4691	675	4466	885	4576
20085	715	4691	919	4466	1129	4576
20094	686	19634	1056	18870	1512	19292
20095	687	19647	1060	18887	1515	19295
20102	686	19448	1056	18751	1512	19162
20103	491	19236	851	18541	1307	18953
20112	488	10995	839	9624	1291	10454
20113	488	9187	839	8812	1291	9132
20118	481	9099	836	8726	1282	8952
20124	481	9102	836	8729	1282	8955
20195	436	8019	746	7679	1135	7882

GP SB Links	ETL4-S (4%)	BNT4 (4%)	ETL4-S (8%)	BNT4 (8%)	ETL4-S (12%)	BNT4 (12%)
2401	31581	16130	30086	16830	28765	16387
2421	22503	5494	21669	6234	20562	5868
4572	24250	7533	23385	8285	22147	7947
5500	20700	4079	19957	4797	18950	4398
5502	27622	19503	26640	20924	25356	20066
5795	28068	21759	27057	22173	25751	21836
5992	21872	15247	21052	15627	20051	15445
6217	7256	1077	7050	1419	6612	1214
6219	10088	4019	9765	4360	9266	4156
6229	22490	15897	21643	16263	20609	16074
6915	14809	13471	14287	13947	14559	14405
6996	40518	41236	38914	41898	38426	42432
7004	37370	36925	35285	37104	33930	37053
7062	29005	13350	27588	14156	26365	13754
7070	37090	21749	35458	22572	33820	22224
9036	10145	9168	10171	9362	9646	9272
9048	6400	4896	6424	5124	6047	5001
9079	8816	9124	8496	9124	8120	9103
9083	11002	8620	10542	8825	10225	8751
9091	7874	5159	7608	5345	7335	5257
10293	28976	13342	27549	14139	26334	13749
10306	20700	4079	19957	4797	18949	4398
12135	36362	35899	34765	36101	33163	36055
12136	40492	40148	38350	40348	36875	40275
12750	27123	25096	25624	25224	24285	25136

Table A-40. Scenario ETL4-S: Adding lane case scenario NB link flow charts

Truck Lane NB Links	ETL4-S (4%)	BNT4 (4%)	ETL4-S (8%)	BNT4 (8%)	ETL4-S (12%)	BNT4 (12%)
20005	622	22217	1088	20855	1467	22310
20008	453	20503	880	19545	1173	20785
20010	930	23849	1681	22865	2272	24150
20012	924	23818	1648	22795	2232	24054
20016	1466	26887	2585	26261	3501	27141
20022	2049	23618	3239	22901	4425	23780
20024	2005	22834	3079	21996	4229	22936
20025	1845	21574	2777	20595	3767	21651
20026	1545	8549	1708	7551	1893	8540
20125	463	20093	754	18458	947	19818
20138	903	24697	1621	23918	2199	24886
20145	1404	24557	2484	23863	3361	24772
20146	1573	24657	2798	23929	3919	24887
20150	1406	23702	2389	22885	3320	23849
20156	1929	22831	3020	21992	4110	22926
20168	1545	8549	1708	7551	1893	8540
20171	1545	8548	1708	7549	1893	8538
20174	1544	8547	1707	7549	1892	8537
20194	2852	8546	3015	7541	3193	8518

GP NB Links	ETL4-S (4%)	BNT4 (4%)	ETL4-S (8%)	BNT4 (8%)	ETL4-S (12%)	BNT4 (12%)
2402	47367	44981	49760	46607	47212	45683
2419	57849	53053	56364	54040	54584	53434
4561	50724	42985	49129	44131	47673	43454
5629	59057	64699	57551	66142	55699	65812
5797	48211	52537	46996	53893	45493	53447
5994	54290	55654	52944	56996	51285	56520
6913	28867	19940	27058	21027	26225	20127
6995	49380	40266	45444	40922	44293	40215
7003	59816	52697	55563	53201	54053	52478
7063	61400	60437	61256	61465	59360	60873
7069	50083	49603	50031	50701	49079	50040
9038	28405	18359	27729	19435	26780	18303
9046	33153	24285	32628	25344	31390	24294
9070	54314	61384	54656	61458	51671	61559
9078	54346	50572	55462	51895	52440	50995
9081	44795	41219	47706	43135	44740	42199
9090	66133	61037	64003	62128	62025	61040
10307	50722	42982	49127	44128	47671	43452
12131	65248	65955	63628	66888	62038	66225
12132	39673	48435	29420	47360	30634	47137
12299	55026	60557	53586	61955	51957	61590
12749	50779	42998	46470	43929	45382	42848
20189	15152	12728	14570	13398	13875	12835
20191	15251	12824	14673	13494	13971	12932

Table A-41. Scenario ETL4-S: Adding lane case scenario vehicle type data

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
BNT4 (4%)	Truck	4,978.96	232.01	45.883	0.094	1.394
	Car	121,072.94	5,709.86	45.756	0.094	1.396
ETL4-S (4%)	Truck	2,791.08	186.07	42.320	0.124	1.512
	Car	118,193.82	6,205.93	45.034	0.102	1.417
BNT4 (8%)	Truck	10,065.02	477.98	45.765	0.095	1.395
	Car	116,058.09	5,405.49	45.710	0.094	1.396
ETL4-S (8%)	Truck	5,789.09	406.83	42.303	0.130	1.517
	Car	113,560.65	6,076.31	45.084	0.105	1.421
BNT4 (12%)	Truck	15,155.05	770.51	45.657	0.100	1.401
	Car	111,508.39	5,593.42	45.628	0.098	1.401
ETL4-S (12%)	Truck	8,566.54	615.37	42.231	0.135	1.524
	Car	108,535.16	5,956.99	45.083	0.109	1.424

A-42. Scenario ETL4-D: Adding lane case scenario SB link flow charts

Truck Lane SB Links	ETL4-D (4%)	BNT4 (4%)	ETL4-D (8%)	BNT4 (8%)	ETL4-D (12%)	BNT4 (12%)
20041	1703	4692	3513	4467	5040	4577
20042	1571	4693	3247	4468	4658	4578
20045	1685	4693	3493	4468	4965	4578
20046	1539	4639	3195	4434	4537	4503
20051	1053	19233	2065	18537	3051	18948
20052	956	19134	1873	18434	2744	18847
20071	381	4689	773	4464	1164	4573
20079	534	4690	1063	4465	1587	4574
20084	606	4691	1254	4466	1915	4576
20085	984	4691	2071	4466	3128	4576
20094	1339	19634	2719	18870	3897	19292
20095	1629	19647	3375	18887	4831	19295
20102	1378	19448	2788	18751	3986	19162
20103	956	19236	1885	18541	2776	18953
20112	1155	10995	2282	9624	3273	10454
20113	1162	9187	2301	8812	3295	9132
20118	930	9099	1855	8726	2619	8952
20124	1033	9102	2057	8729	2879	8955
20195	483	8019	930	7679	1398	7882

GP SB Links	ETL4-D (4%)	BNT4 (4%)	ETL4-D (8%)	BNT4 (8%)	ETL4-D (12%)	BNT4 (12%)
2401	34136	16130	32665	16830	30961	16387
2421	23669	5494	22711	6234	21467	5868
4572	25623	7533	24591	8285	23299	7947
5500	22174	4079	21264	4797	20160	4398
5502	29145	19503	28007	20924	26647	20066
5795	29571	21759	28426	22173	27073	21836
5992	23349	15247	22403	15627	21310	15445
6217	8730	1077	8388	1419	7906	1214
6219	11554	4019	11096	4360	10605	4156
6229	23980	15897	23003	16263	21866	16074
6915	17152	13471	16408	13947	15595	14405
6996	43749	41236	41756	41898	39740	42432
7004	39923	36925	38176	37104	36226	37053
7062	31557	13350	30191	14156	28482	13754
7070	39669	21749	37935	22572	35922	22224
9036	13265	9168	12745	9362	12056	9272
9048	9190	4896	8826	5124	8432	5001
9079	8755	9124	8403	9124	7921	9103
9083	12740	8620	12290	8825	11601	8751
9091	9450	5159	9047	5345	8574	5257
10293	31544	13342	30177	14139	28457	13749
10306	22174	4079	21264	4797	20159	4398
12135	38949	35899	37246	36101	35279	36055
12136	43075	40148	41172	40348	39138	40275
12750	28818	25096	27631	25224	26700	25136

Table A-43. Scenario ETL4-D: Adding lane case scenario NB link flow charts

Truck Lane NB Links	ETL4-D (4%)	BNT4 (4%)	ETL4-D (8%)	BNT4 (8%)	ETL4-D (12%)	BNT4 (12%)
20005	2464	22217	4970	20855	7031	22310
20008	1569	20503	3176	19545	4419	20785
20010	2163	23849	4352	22865	6178	24150
20012	2067	23818	4183	22795	5913	24054
20016	2473	26887	5097	26261	7248	27141
20022	2838	23618	5782	22901	8294	23780
20024	2902	22834	5880	21996	8351	22936
20025	2559	21574	5174	20595	7297	21651
20026	2633	8549	5391	7551	7648	8540
20125	1699	20093	3380	18458	4804	19818
20138	2006	24697	4086	23918	5760	24886
20145	2354	24557	4842	23863	6871	24772
20146	2872	24657	5876	23929	8376	24887
20150	2475	23702	5013	22885	7125	23849
20156	2619	22831	5318	21992	7567	22926
20168	2743	8549	5615	7551	7942	8540
20171	2284	8548	4657	7549	6500	8538
20174	2422	8547	4939	7549	6881	8537
20194	906	8546	1840	7541	2560	8518

GP NB Links	ETL4-D (4%)	BNT4 (4%)	ETL4-D (8%)	BNT4 (8%)	ETL4-D (12%)	BNT4 (12%)
2402	64306	44981	63012	46607	60476	45683
2419	72216	53053	69850	54040	67558	53434
4561	61416	42985	59427	44131	57586	43454
5629	69927	64699	67861	66142	65988	65812
5797	58549	52537	56991	53893	55526	53447
5994	61522	55654	59865	56996	58227	56520
6913	41434	19940	40335	21027	37925	20127
6995	62011	40266	60268	40922	57248	40215
7003	75859	52697	73522	53201	69998	52478
7063	80229	60437	77948	61465	75043	60873
7069	69791	49603	68057	50701	65403	50040
9038	37105	18359	36162	19435	34311	18303
9046	45866	24285	44535	25344	42348	24294
9070	58552	61384	57397	61458	54283	61559
9078	66975	50572	65027	51895	61841	50995
9081	57529	41219	57096	43135	53307	42199
9090	79279	61037	77005	62128	72884	61040
10307	61413	42982	59424	44128	57584	43452
12131	86484	65955	84017	66888	80749	66225
12132	68461	48435	65745	47360	61327	47137
12299	65914	60557	63963	61955	62182	61590
12749	63869	42998	61964	43929	59053	42848
20189	20170	12728	19701	13398	18386	12835
20191	20263	12824	19790	13494	18474	12932

Table A-44. Scenario ETL4-D: Adding lane case scenario vehicle type data

Scenario	Vehicle Type	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Avg. Travel Speed (mph)	Average Delay Time (min/veh-mile)	Average Total Time (min/veh-mile)
BNT4 (4%)	Truck	4,978.96	232.01	45.883	0.094	1.394
	Car	121,072.94	5,709.86	45.756	0.094	1.396
ETL4-D (4%)	Truck	5,197.11	253.30	44.669	0.098	1.422
	Car	121,527.48	5,799.21	45.731	0.095	1.397
BNT4 (8%)	Truck	10,065.02	477.98	45.765	0.095	1.395
	Car	116,058.09	5,405.49	45.710	0.094	1.396
ETL4-D (8%)	Truck	10,422.44	501.54	44.711	0.097	1.420
	Car	116,093.06	5,346.15	45.760	0.094	1.396
BNT4 (12%)	Truck	15,155.05	770.51	45.657	0.100	1.401
	Car	111,508.39	5,593.42	45.628	0.098	1.401
ETL4-D (12%)	Truck	15,983.26	912.73	44.316	0.107	1.435
	Car	112,568.00	5,959.71	45.535	0.101	1.404

Appendix B
Detailed Results of Cost/Benefit Analysis

Table B-1. Lane conversion with induced demand, equal vehicle assumption

Along the Specific Section of I 65 Only					
	Baseline	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	293.33	279.47	295.71	305.90	311.88
Vehicle hours of travel [million hours]	5.68	5.19	5.31	5.41	5.54
Average speed [miles/hour]	51.34	48.99	49.91	51.18	52.09
Person hours traveled [million hours]	8.07	7.53	8.08	8.60	9.15
Number of person trips	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	1.94	1.84	1.95	2.02	2.06
Number of injury accidents	196.57	179.93	195.53	207.17	211.15
Number of PDO accidents	255.83	234.59	254.31	269.77	274.71
Unexpected delay [million hours]	2.09	2.16	2.07	1.98	1.88
Fuel consumption [million gallons]	9.98	10.54	11.52	12.10	11.84
Hydrocarbon emissions [tons]	290.39	307.20	324.58	328.51	326.25
Carbon monoxide emissions [tons]	1,564.89	2391.81	2570.21	2482.70	2286.91
Oxides of nitrogen emissions [tons]	623.83	718.84	777.60	787.54	772.00
Network-Wide					
	Baseline	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	7085.15	7090.43	7094.68	7096.35	7096.58
Vehicle hours of travel [million hours]	173.33	173.29	173.12	173.05	173.03
Average speed [miles/hour]	40.84	40.92	40.98	41.01	41.01
Person hours traveled [million hours]	246.12	245.94	256.07	266.41	276.83
Number of person trips	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	88.93	89.17	89.06	88.93	88.88
Number of injury accidents	8373.95	8389.00	8384.20	8376.74	8372.22
Number of PDO accidents	11982.96	12007.77	11997.48	11984.63	11977.01
Unexpected delay [million hours]	11.32	11.40	11.28	11.28	11.16
Fuel consumption [million gallons]	344.58	346.14	346.51	346.58	346.03
Hydrocarbon emissions [million tons]	0.01	0.01	0.01	0.01	0.01
Carbon monoxide emissions [million tons]	0.05	0.05	0.05	0.05	0.05
Oxides of nitrogen emissions [million tons]	0.02	0.02	0.02	0.02	0.02
Annual benefit [million $]	-	2.114	4.173	1.912	4.994
BC ratio	-	0.39	0.77	0.35	0.92

Table B-2. Lane conversion scenario without induced demand, equal vehicle assumption

Along the Specific Section of I 65 Only					
	Baseline	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	293.33	276.17	292.55	302.93	309.54
Vehicle hours of travel [million hours]	5.68	5.14	5.24	5.34	5.47
Average speed [miles/hour]	51.34	48.99	50.07	51.18	52.08
Person hours traveled [million hours]	8.07	7.43	7.93	8.43	8.98
Number of person trips	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	1.94	1.82	1.93	2.00	2.04
Number of injury accidents	196.57	177.93	190.70	204.46	209.15
Number of PDO accidents	255.83	231.80	248.35	266.02	272.24
Unexpected delay [million hours]	2.09	2.16	2.07	1.98	1.87
Fuel consumption [million gallons]	9.98	10.37	11.37	12.03	11.88
Hydrocarbon emissions [tons]	290.39	302.93	321.64	326.83	325.79
Carbon monoxide emissions [tons]	1,564.89	2340.49	2562.28	2505.19	2332.39
Oxides of nitrogen emissions [tons]	623.83	706.29	772.86	786.76	775.25
Network-Wide					
	Baseline	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	7085.15	7081.23	7083.38	7084.28	7084.98
Vehicle hours of travel [million hours]	173.33	173.03	172.82	172.71	172.69
Average speed [miles/hour]	40.84	40.93	40.99	41.02	41.03
Person hours traveled [million hours]	246.12	245.49	255.55	265.77	276.18
Number of person trips	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	88.93	89.09	88.92	88.80	88.71
Number of injury accidents	8373.95	8381.13	8367.15	8363.01	8356.10
Number of PDO accidents	11982.96	11996.61	11973.79	11965.16	11954.10
Unexpected delay [million hours]	11.32	11.33	11.26	11.21	11.14
Fuel consumption [million gallons]	344.58	345.73	345.92	346.09	345.57
Hydrocarbon emissions [million tons]	0.01	0.01	0.01	0.01	0.01
Carbon monoxide emissions [million tons]	0.05	0.05	0.05	0.05	0.05
Oxides of nitrogen emissions [million tons]	0.02	0.02	0.02	0.02	0.02
Annual benefit [million $]	-	7.038	8.718	8.303	9.651
BC ratio	-	1.27	1.58	1.50	1.74

Table B-3. Lane conversion scenario with induced demand, equal passenger assumption

Along the Specific Section of I-65 Only					
	Baseline	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	293.33	269.20	278.66	280.75	275.41
Vehicle hours of travel [million hours]	5.68	4.84	4.75	4.65	4.50
Average speed [miles/hour]	51.34	50.63	52.85	55.19	57.87
Person hours traveled [million hours]	8.07	7.07	7.32	7.57	7.76
Number of person trips	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	1.94	1.78	1.84	1.85	1.82
Number of injury accidents	196.57	171.72	178.77	183.78	178.28
Number of PDO accidents	255.83	223.48	232.31	239.79	232.01
Unexpected delay [million hours]	2.09	2.03	1.83	1.58	1.26
Fuel consumption [million gallons]	9.98	10.22	11.02	11.46	10.98
Hydrocarbon emissions [tons]	290.39	294.73	306.19	304.27	292.98
Carbon monoxide emissions [tons]	1,564.89	2324.58	2516.02	2450.36	2265.51
Oxides of nitrogen emissions [tons]	623.83	707.40	764.17	770.44	746.23
Network-Wide					
	Baseline	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	7085.15	6450.22	6130.64	5802.74	5486.06
Vehicle hours of travel [million hours]	173.33	155.65	146.69	137.94	129.65
Average speed [miles/hour]	40.84	41.44	41.79	42.07	42.31
Person hours traveled [million hours]	246.12	222.79	221.25	219.94	219.20
Number of person trips	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	88.93	80.47	75.99	71.51	67.24
Number of injury accidents	8373.95	7545.65	7114.22	6684.98	6272.22
Number of PDO accidents	11982.96	10794.72	10171.08	9554.81	8961.09
Unexpected delay [million hours]	11.32	9.63	8.70	7.68	6.77
Fuel consumption [million gallons]	344.58	314.95	299.60	283.87	268.18
Hydrocarbon emissions [million tons]	0.01	0.01	0.01	0.01	0.01
Carbon monoxide emissions [million tons]	0.05	0.05	0.05	0.04	0.04
Oxides of nitrogen emissions [million tons]	0.02	0.01	0.01	0.01	0.01
Annual benefit [million $]	-	8.155	8.337	8.885	5.384
BC ratio	-	1.48	1.51	1.61	0.97

Table B-4. Lane conversion scenario without induced demand, equal passenger assumption

Along the Specific Section of I 65 Only					
	Baseline	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	293.33	266.36	275.27	277.86	273.03
Vehicle hours of travel [million hours]	5.68	4.81	4.70	4.58	4.44
Average speed [miles/hour]	51.34	50.59	52.78	55.19	57.90
Person hours traveled [million hours]	8.07	6.99	7.20	7.41	7.60
Number of person trips	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	1.94	1.76	1.82	1.83	1.80
Number of injury accidents	196.57	170.20	174.13	181.09	176.24
Number of PDO accidents	255.83	221.40	227.44	236.35	229.45
Unexpected delay [million hours]	2.09	2.04	1.83	1.58	1.26
Fuel consumption [million gallons]	9.98	10.07	10.84	11.36	11.01
Hydrocarbon emissions [tons]	290.39	290.92	302.78	302.74	292.19
Carbon monoxide emissions [tons]	1,564.89	2274.86	2492.99	2475.80	2301.43
Oxides of nitrogen emissions [tons]	623.83	695.49	755.80	770.41	748.05
Network-Wide					
	Baseline	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	7085.15	6441.91	6119.51	5791.79	5476.11
Vehicle hours of travel [million hours]	173.33	155.50	146.43	137.66	129.36
Average speed [miles/hour]	40.84	41.43	41.79	42.07	42.33
Person hours traveled [million hours]	246.12	222.51	220.76	219.39	218.62
Number of person trips	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	88.93	80.34	75.87	71.35	67.13
Number of injury accidents	8373.95	7534.77	7099.85	6668.95	6260.56
Number of PDO accidents	11982.96	10778.89	10152.27	9532.44	8944.96
Unexpected delay [million hours]	11.32	9.71	8.64	7.67	6.68
Fuel consumption [million gallons]	344.58	314.46	299.10	283.34	267.86
Hydrocarbon emissions [million tons]	0.01	0.01	0.01	0.01	0.01
Carbon monoxide emissions [million tons]	0.05	0.05	0.05	0.04	0.04
Oxides of nitrogen emissions [million tons]	0.02	0.01	0.01	0.01	0.01
Annual benefit [million $]	-	11.086	19.696	20.090	20.328
BC ratio	-	1.99	3.56	3.63	3.68

Table B-5. Lane addition scenario with induced demand, equal vehicle assumption

Along the Specific Section of I 65 Only						
	Baseline	**HOV 0%**	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	293.33	377.86	369.05	374.55	375.28	374.42
Vehicle hours of travel [million hours]	5.68	6.07	5.90	5.89	5.86	5.89
Average speed [miles/hour]	51.34	62.89	60.84	61.48	62.13	62.71
Person hours traveled [million hours]	8.07	7.90	8.34	8.67	8.98	9.38
Number of person trips	0.00	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	1.94	2.49	2.44	2.47	2.48	2.47
Number of injury accidents	196.57	210.42	192.36	191.54	198.65	204.08
Number of PDO accidents	255.83	276.07	254.28	255.10	262.49	268.68
Unexpected delay [million hours]	2.09	0.67	1.72	1.31	0.99	0.73
Fuel consumption [million gallons]	9.98	15.10	14.78	15.44	15.85	15.56
Hydrocarbon emissions [tons]	290.39	402.32	397.72	409.26	410.90	406.38
Carbon monoxide emissions [tons]	1,564.89	3137.79	3213.74	3441.79	3476.19	3356.30
Oxides of nitrogen emissions [tons]	623.83	1024.16	1025.30	1066.61	1071.66	1051.17
Network-Wide						
	Baseline	**HOV 0%**	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	7085.15	7123.06	7126.32	7127.13	7124.42	7122.41
Vehicle hours of travel [million hours]	173.33	172.82	172.94	172.85	172.73	172.70
Average speed [miles/hour]	40.84	41.22	41.21	41.23	41.24	41.24
Person hours traveled [million hours]	246.12	224.67	245.27	255.44	265.65	276.05
Number of person trips	0.00	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	88.93	88.52	88.68	88.59	88.56	88.55
Number of injury accidents	8373.95	8296.97	8299.68	8287.24	8291.18	8296.52
Number of PDO accidents	11982.96	11868.52	11876.86	11860.12	11863.40	11869.57
Unexpected delay [million hours]	11.32	10.07	11.19	10.81	10.45	10.14
Fuel consumption [million gallons]	344.58	347.21	347.49	347.86	348.14	347.83
Hydrocarbon emissions [million tons]	0.01	0.01	0.01	0.01	0.01	0.01
Carbon monoxide emissions [million tons]	0.05	0.05	0.05	0.05	0.05	0.05
Oxides of nitrogen emissions [million tons]	0.02	0.02	0.02	0.02	0.02	0.02
Annual benefit [million $]	-	29.228	16.786	24.584	30.084	35.485
BC ratio	-	2.53	1.45	2.13	2.60	3.07

Table B-6. Lane addition scenario without induced demand, equal vehicle assumption

Along the Specific Section of I 65 Only						
	Baseline	**HOV 0%**	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	293.33	370.73	360.17	366.49	367.78	366.89
Vehicle hours of travel [million hours]	5.68	5.93	5.71	5.73	5.72	5.75
Average speed [miles/hour]	51.34	63.14	61.34	61.79	71.73	66.21
Person hours traveled [million hours]	8.07	7.71	8.09	8.47	8.79	9.19
Number of person trips	0.00	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	1.94	2.45	2.38	2.42	2.43	2.42
Number of injury accidents	196.57	205.23	183.59	186.69	194.03	198.56
Number of PDO accidents	255.83	268.50	243.90	248.27	255.86	260.50
Unexpected delay [million hours]	2.09	0.55	1.41	1.11	0.83	0.59
Fuel consumption [million gallons]	9.98	14.95	14.59	15.23	15.67	15.37
Hydrocarbon emissions [tons]	290.39	396.25	390.70	402.02	404.41	399.64
Carbon monoxide emissions [tons]	1,564.89	3127.15	3218.83	3417.96	3461.98	3334.57
Oxides of nitrogen emissions [tons]	623.83	1012.05	1012.23	1050.78	1058.13	1036.72
Network-Wide						
	Baseline	**HOV 0%**	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	7085.15	7104.48	7102.28	7105.49	7105.33	7105.15
Vehicle hours of travel [million hours]	173.33	172.33	172.27	172.24	172.20	172.24
Average speed [miles/hour]	40.84	41.23	41.23	41.25	41.26	41.25
Person hours traveled [million hours]	246.12	224.03	244.37	254.59	264.90	275.38
Number of person trips	0.00	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	88.93	88.31	88.39	88.36	88.36	88.34
Number of injury accidents	8373.95	8276.03	8269.35	8265.34	8272.24	8274.76
Number of PDO accidents	11982.96	11838.16	11835.47	11829.03	11836.04	11837.99
Unexpected delay [million hours]	11.32	9.92	10.82	10.51	10.22	9.98
Fuel consumption [million gallons]	344.58	346.49	346.56	347.01	347.43	347.10
Hydrocarbon emissions [million tons]	0.01	0.01	0.01	0.01	0.01	0.01
Carbon monoxide emissions [million tons]	0.05	0.05	0.05	0.05	0.05	0.05
Oxides of nitrogen emissions [million tons]	0.02	0.02	0.02	0.02	0.02	0.02
Annual benefit [million $]	-	39.020	34.654	40.034	42.032	44.925
BC ratio	-	3.38	300	3.47	3.64	3.89

Table B-7. Lane addition scenario with induced demand, equal person assumption

Along the Specific Section of I 65 Only						
	Baseline	**HOV 0%**	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	293.33	377.86	342.34	331.99	317.90	297.80
Vehicle hours of travel [million hours]	5.68	6.07	5.38	5.08	4.85	4.59
Average speed [miles/hour]	51.34	62.89	79.14	76.43	71.33	65.66
Person hours traveled [million hours]	8.07	7.90	7.66	7.62	7.69	7.72
Number of person trips	0.00	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	1.94	2.49	2.26	2.19	2.10	1.97
Number of injury accidents	196.57	210.42	172.83	164.33	162.83	160.94
Number of PDO accidents	255.83	276.07	229.07	216.17	211.29	209.13
Unexpected delay [million hours]	2.09	0.67	1.07	0.55	0.20	0.05
Fuel consumption [million gallons]	9.98	15.10	14.04	14.28	13.96	12.83
Hydrocarbon emissions [tons]	290.39	402.32	373.99	370.49	354.73	328.76
Carbon monoxide emissions [tons]	1,564.89	3137.79	3143.81	3298.14	3157.30	2845.43
Oxides of nitrogen emissions [tons]	623.83	1024.16	974.10	981.22	939.00	862.37
Network-Wide						
	Baseline	**HOV 0%**	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	7085.15	7123.06	6481.21	6150.62	5817.99	5493.66
Vehicle hours of travel [million hours]	173.33	172.82	155.41	146.46	137.75	129.47
Average speed [miles/hour]	40.84	41.22	41.70	42.00	42.23	42.43
Person hours traveled [million hours]	246.12	224.67	222.29	220.68	219.42	218.68
Number of person trips	0.00	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	88.93	88.52	80.06	75.68	71.30	67.13
Number of injury accidents	8373.95	8296.97	7465.48	7039.46	6622.55	6229.59
Number of PDO accidents	11982.96	11868.52	10680.41	10066.50	9464.52	8901.43
Unexpected delay [million hours]	11.32	10.07	8.97	7.60	6.42	5.47
Fuel consumption [million gallons]	344.58	347.21	316.43	301.06	285.17	269.29
Hydrocarbon emissions [million tons]	0.01	0.01	0.01	0.01	0.01	0.01
Carbon monoxide emissions [million tons]	0.05	0.05	0.05	0.05	0.05	0.04
Oxides of nitrogen emissions [million tons]	0.02	0.02	0.01	0.01	0.01	0.01
Annual benefit [million $]	-	29.228	30.118	43.056	50.549	50.258
BC ratio	-	2.53	2.61	3.73	4.38	4.35

Table B-8. Lane addition scenario without induced demand, equal person assumption

Along the Specific Section of I 65 Only						
	Baseline	**HOV 0%**	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	293.33	370.73	335.02	325.92	312.84	294.05
Vehicle hours of travel [million hours]	5.68	5.93	5.23	4.98	4.78	4.54
Average speed [miles/hour]	51.34	63.14	79.08	76.43	71.08	65.66
Person hours traveled [million hours]	8.07	7.71	7.47	7.49	7.60	7.64
Number of person trips	0.00	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	1.94	2.45	2.21	2.15	2.06	1.94
Number of injury accidents	196.57	205.23	168.31	160.04	160.54	159.17
Number of PDO accidents	255.83	268.50	222.67	209.87	208.36	206.83
Unexpected delay [million hours]	2.09	0.55	0.91	0.45	0.16	0.04
Fuel consumption [million gallons]	9.98	14.95	13.91	14.07	13.75	12.67
Hydrocarbon emissions [tons]	290.39	396.25	368.16	364.42	349.07	324.65
Carbon monoxide emissions [tons]	1,564.89	3127.15	3,146.03	3260.39	3106.49	2810.45
Oxides of nitrogen emissions [tons]	623.83	1012.05	963.21	966.64	923.95	851.65
Network-Wide						
	Baseline	**HOV 0%**	**HOV 10%**	**HOV 15%**	**HOV 20%**	**HOV 25%**
Vehicle miles of travel [million miles]	7085.15	7104.48	7102.28	6137.09	5807.04	5485.95
Vehicle hours of travel [million hours]	173.33	172.33	172.27	146.15	137.51	129.30
Average speed [miles/hour]	40.84	41.23	41.23	41.99	42.23	42.43
Person hours traveled [million hours]	246.12	224.03	244.37	220.26	219.06	218.43
Number of person trips	0.00	0.00	0.00	0.00	0.00	0.00
Number of fatality accidents	88.93	88.31	88.39	75.51	71.18	67.06
Number of injury accidents	8373.95	8276.03	8269.35	7021.83	6611.29	6222.63
Number of PDO accidents	11982.96	11838.16	11835.47	10039.99	9448.52	8892.27
Unexpected delay [million hours]	11.32	9.92	10.82	7.45	6.37	5.42
Fuel consumption [million gallons]	344.58	346.49	346.56	300.45	284.65	268.93
Hydrocarbon emissions [million tons]	0.01	0.01	0.01	0.01	0.01	0.01
Carbon monoxide emissions [million tons]	0.05	0.05	0.05	0.05	0.04	0.04
Oxides of nitrogen emissions [million tons]	0.02	0.02	0.02	0.01	0.01	0.01
Annual benefit [million $]	-	39.020	46.040	52.480	55.880	55.270
BC ratio	-	3.38	3.99	4.54	4.84	4.78

Table B-9. Benefit/cost summary, lane addition 6.1 alternative 1

Annual Benefits*	**Weight**	
Change in user mobility	1.00	9,533,654
Change In user travel time		
In-vehicle travel time	1.00	0
Out-of-vehicle travel time	1.00	0
Travel time reliability	1.00	25,404,373
Change in costs paid by users		
Fuel costs	1.00	(2,912,563)
Non-fuel operating costs	1.00	(2,002,736)
Accident costs (internal only)	1.00	4,128,605
Change in external costs		
Accident costs (external only)	1.00	728,567
Emissions		
HC/ROG	1.00	(104,316)
NOx	1.00	(974,153)
CO	1.00	(4,550,800)
PM10	1.00	(0)
CO2	1.00	(0)
SO2	1.00	(0)
Global warming	0.00	(0)
Noise	1.00	(22,982)
Other mileage-based external costs	1.00	(0)
Other trip-based external costs	1.00	(0)
Change in public agencies costs (efficiency induced)	1.00	0
Other calculated benefits	1.00	(0)
User defined additional benefits	1.00	0
Total annual benefits*		**29,227,648**
Annual Costs		
Average Annual Private Sector Cost		0
Average Annual Public Sector Cost		11,550,594
Total Annual Cost		**11,550,594**
Benefit/Cost Comparison		
Net Benefit (Annual Benefit - Annual Cost)		**17,677,054**
B/C Ratio (Annual Benefit/Annual Cost)		**2.53**

*Benefits are reported in 1995 dollars

Table B-10. Lane addition 6.1, alternative 1

By Facility Type	Centroid Connector	Divided Arterial	Expressway
Vehicle miles of travel			
Control Alternative	2,084,277	4,335,812	5,922,949
ITS Option	2,086,354	4,324,639	5,798,352
Difference (%)	2,078 (0.1%)	-11,173 (-0.3%)	-124,597 (-2.1%)
Vehicle hours of travel			
Control Alternative	138,832	103,323	134,991
ITS Option	138,970	103,072	131,819
Difference (%)	138 (0.1%)	-252 (-0.2%)	-3,172 (-2.3%)
Average speed			
Control Alternative	15	42	43.9
ITS Option	15	42	44
Difference (%)	0 (0.0%)	0 (0.0%)	0 (0.3%)
person hours of travel			
Control Alternative	180,481	134,320	175,488
ITS Option	180,661	133,993	171,364
Difference (%)	180 (0.1%)	-327 (-0.2%)	-4,124 (-2.3%)
Number of person trips			
Control Alternative			
ITS Option			
Difference (%)			
Number of fatality accidents			
Control Alternative		7.67E-02	1.05E-01
ITS Option		7.65E-02	1.03E-01
Difference (%)		-1.978E-04 (-0.3%)	-2.205E-03 (-2.1%)
Number of injury accidents			
Control Alternative		7.37E+00	1.01E+01
ITS Option		7.35E+00	9.85E+00
Difference (%)		-1.898E-02 (-0.3%)	-2.117E-01 (-2.1%)
Number of PDO accidents			
Control Alternative		1.07E+01	1.47E+01
ITS Option		1.07E+01	1.43E+01
Difference (%)		-2.764E-02 (-0.3%)	-3.082E-01 (-2.1%)
Travel Time Reliability (hours of unexpected delay)			
Control Alternative			
ITS Option			
Difference (%)			
Fuel consumption (gallons)			
Control Alternative	152,098.89	222,989.69	304,085.09
ITS Option	152,250.52	222,422.77	297,651.91
Difference (%)	151.63 (0.1%)	-566.92 (-0.3%)	-6,433.19 (-2.1%)
Hydrocarbon and Reactive Organic Gases Emissions (tons)			
Control Alternative	4.3126	4.6449	6.251
ITS Option	4.3169	4.6334	6.1164
Difference (%)	0.0043 (0.1%)	-0.0116 (-0.2%)	-0.1346 (-2.2%)
Carbon monoxide emissions (tons)			
Control Alternative	35.7801	25.5521	34.6437
ITS Option	35.8157	25.4912	33.9505
Difference (%)	0.0357 (0.1%)	-0.0609 (-0.2%)	-0.6932 (-2.0%)
Carbon Dioxide Emissions (tons)			
Control Alternative			
ITS Option			
Difference (%)			
Oxides of nitrogen emissions (tons)			
Control Alternative	3.8324	8.2014	11.6083
ITS Option	3.8362	8.1802	11.3877
Difference (%)	0.0038 (0.1%)	-0.0212 (-0.3%)	-0.2205 (-1.9%)
PM10 Emissions (tons)			
Control Alternative			
ITS Option			
Difference (%)			
Sulfur Dioxide Emissions (tons)			
Control Alternative			
ITS Option			
Difference (%)			

Table B-11. Lane addition 6.1, alternative 1

By Facility Type	Expressway	Freeway
Vehicle miles of travel		
Control Alternative	5,922,949	8,805,981
ITS Option	5,798,352	8,841,894
Difference (%)	-124,597 (-2.1%)	35,913 (0.4%)
Vehicle hours of travel		
Control Alternative	134,991	148,009
ITS Option	131,819	149,110
Difference (%)	-3,172 (-2.3%)	1,101 (0.7%)
Average speed		
Control Alternative	43.9	59.5
ITS Option	44	59.3
Difference (%)	0 (0.3%)	0 (-0.3%)
person hours of travel		
Control Alternative	175,488	192,411
ITS Option	171,364	193,843
Difference (%)	-4,124 (-2.3%)	1,432 (0.7%)
Number of person trips		
Control Alternative		
ITS Option		
Difference (%)		
Number of fatality accidents		
Control Alternative	1.05E-01	5.81E-02
ITS Option	1.03E-01	5.84E-02
Difference (%)	-2.205E-03 (-2.1%)	2.37E-04 (0.4%)
Number of injury accidents		
Control Alternative	1.01E+01	4.88E+00
ITS Option	9.85E+00	4.91E+00
Difference (%)	-2.117E-01 (-2.1%)	2.797E-02 (0.6%)
Number of PDO accidents		
Control Alternative	1.47E+01	6.38E+00
ITS Option	1.43E+01	6.41E+00
Difference (%)	-3.082E-01 (-2.1%)	3.35E-02 (0.5%)
Travel Time Reliability (hours of unexpected delay)		
Control Alternative		37,490.33
ITS Option		38,047.84
Difference (%)		557.51 (1.5%)
Fuel consumption (gallons)		
Control Alternative	304,085.09	343,932.84
ITS Option	297,651.91	345,132.44
Difference (%)	-6,433.19 (-2.1%)	1,199.59 (0.3%)
Hydrocarbon and Reactive Organic Gases Emissions (tons)		
Control Alternative	6.251	9.2573
ITS Option	6.1164	9.297
Difference (%)	-0.1346 (-2.2%)	0.0397 (0.4%)
Carbon monoxide emissions (tons)		
Control Alternative	34.6437	68.0769
ITS Option	33.9505	68.2504
Difference (%)	-0.6932 (-2.0%)	0.1735 (0.3%)
Carbon Dioxide Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		
Oxides of nitrogen emissions (tons)		
Control Alternative	11.6083	22.8417
ITS Option	11.3877	22.8794
Difference (%)	-0.2205 (-1.9%)	0.0377 (0.2%)
PM10 Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		
Sulfur Dioxide Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		

Table B-12. Lane addition 6.1, alternative 1

By Facility Type	HOV I-65	I-65
Vehicle miles of travel		
Control Alternative	488,757	773,663
ITS Option	440,294	1,089,486
Difference (%)	-48,463 (-9.9%)	315,823 (40.8%)
Vehicle hours of travel		
Control Alternative	9,297	14,291
ITS Option	7,270	17,324
Difference (%)	-2,027 (-21.8%)	3,032 (21.2%)
Average speed		
Control Alternative	52.6	54.1
ITS Option	60.6	62.9
Difference (%)	8 (15.2%)	9 (16.2%)
person hours of travel		
Control Alternative	12,086	18,579
ITS Option	9,451	22,521
Difference (%)	-2,635 (-21.8%)	3,942 (21.2%)
Number of person trips		
Control Alternative		
ITS Option		
Difference (%)		
Number of fatality accidents		
Control Alternative	3.23E-03	5.11E-03
ITS Option	2.91E-03	7.19E-03
Difference (%)	-3.199E-04 (-9.9%)	2.084E-03 (40.8%)
Number of injury accidents		
Control Alternative	3.44E-01	5.03E-01
ITS Option	3.10E-01	5.42E-01
Difference (%)	-3.426E-02 (-9.9%)	3.907E-02 (7.8%)
Number of PDO accidents		
Control Alternative	4.48E-01	6.57E-01
ITS Option	4.04E-01	7.14E-01
Difference (%)	-4.458E-02 (-9.9%)	5.711E-02 (8.7%)
Travel Time Reliability (hours of unexpected delay)		
Control Alternative		6,839.91
ITS Option		2,723.51
Difference (%)		-4,116.39 (-60.2%)
Fuel consumption (gallons)		
Control Alternative	17,081.81	27,159.54
ITS Option	16,905.56	44,239.94
Difference (%)	-176.25 (-1.0%)	17,080.39 (62.9%)
Hydrocarbon and Reactive Organic Gases Emissions (tons)		
Control Alternative	0.491	0.7727
ITS Option	0.4588	1.1701
Difference (%)	-0.0323 (-6.6%)	0.3973 (51.4%)
Carbon monoxide emissions (tons)		
Control Alternative	2.8497	4.5246
ITS Option	3.3313	9.3723
Difference (%)	0.4816 (16.9%)	4.8477 (107.1%)
Carbon Dioxide Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		
Oxides of nitrogen emissions (tons)		
Control Alternative	1.0759	1.7461
ITS Option	1.1483	2.9981
Difference (%)	0.0724 (6.7%)	1.2520 (71.7%)
PM10 Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		
Sulfer Dioxide Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		

Table B-13. Lane addition 6.1, alternative 1

By: Facility Type	Oneway Arterial	Oneway Ramp
Vehicle miles of travel		
Control Alternative	208,005	473,109
ITS Option	207,629	487,239
Difference (%)	-376 (-0.2%)	14,129 (3.0%)
Vehicle hours of travel		
Control Alternative	6,286	16,794
ITS Option	6,289	17,695
Difference (%)	3 (0.0%)	901 (5.4%)
Average speed		
Control Alternative	33.1	28.2
ITS Option	33	27.5
Difference (%)	0 (-0.2%)	-1 (-2.3%)
person hours of travel		
Control Alternative	8,172	21,832
ITS Option	8,176	23,004
Difference (%)	4 (0.0%)	1,172 (5.4%)
Number of person trips		
Control Alternative		
ITS Option		
Difference (%)		
Number of fatality accidents		
Control Alternative	3.68E-03	8.37E-03
ITS Option	3.68E-03	8.62E-03
Difference (%)	-6.653E-06 (-0.2%)	2.501E-04 (3.0%)
Number of injury accidents		
Control Alternative	3.53E-01	8.04E-01
ITS Option	3.53E-01	8.28E-01
Difference (%)	-6.386E-04 (-0.2%)	2.401E-02 (3.0%)
Number of PDO accidents		
Control Alternative	5.15E-01	1.17E+00
ITS Option	5.14E-01	1.21E+00
Difference (%)	-9.298E-04 (-0.2%)	3.495E-02 (3.0%)
Travel Time Reliability (hours of unexpected delay)		
Control Alternative		
ITS Option		
Difference (%)		
Fuel consumption (gallons)		
Control Alternative	11,256.53	26,886.96
ITS Option	11,245.06	27,934.37
Difference (%)	-11.47 (-0.1%)	1,047.41 (3.9%)
Hydrocarbon and Reactive Organic Gases Emissions (tons)		
Control Alternative	0.2562	0.6359
ITS Option	0.2561	0.6629
Difference (%)	-0.0001 (0.0%)	0.0270 (4.2%)
Carbon monoxide emissions (tons)		
Control Alternative	1.6127	4.2573
ITS Option	1.6144	4.4723
Difference (%)	0.0017 (0.1%)	0.2150 (5.1%)
Carbon Dioxide Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		
Oxides of nitrogen emissions (tons)		
Control Alternative	0.3721	0.8558
ITS Option	0.3714	0.8821
Difference (%)	-0.0007 (-0.2%)	0.0263 (3.1%)
PM10 Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		
Sulfer Dioxide Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		

Table B-14. Project: I-65 lane addition 6.1. Alternative: alternative 1, ITS option, lane addition 6.1

By: Facility Type	Undivided Arterial	Total
Vehicle miles of travel		
Control Alternative	5,612,806	28,705,359
ITS Option	5,562,396	28,838,283
Difference (%)	-50,410 (-0.9%)	132,924 (0.5%)
Vehicle hours of travel		
Control Alternative	129,269	701,092
ITS Option	128,137	699,686
Difference (%)	-1,131 (-0.9%)	-1,405 (-0.2%)
Average speed		
Control Alternative	43.4	40.9
ITS Option	43.4	41.2
Difference (%)	0 (0.0%)	0 (0.7%)
person hours of travel		
Control Alternative	168,049	911,419
ITS Option	166,578	909,592
Difference (%)	-1,471 (-0.9%)	-1,827 (-0.2%)
Number of person trips		
Control Alternative		
ITS Option		
Difference (%)		
Number of fatality accidents		
Control Alternative	9.93E-02	3.59E-01
ITS Option	9.85E-02	3.58E-01
Difference (%)	-8.923E-04 (-0.9%)	-1.05E-03 (-0.3%)
Number of injury accidents		
Control Alternative	9.54E+00	3.39E+01
ITS Option	9.45E+00	3.36E+01
Difference (%)	-8.565E-02 (-0.9%)	-2.602E-01 (-0.8%)
Number of PDO accidents		
Control Alternative	1.39E+01	4.84E+01
ITS Option	1.38E+01	4.81E+01
Difference (%)	-1.247E-01 (-0.9%)	-3.805E-01 (-0.8%)
Travel Time Reliability (hours of unexpected delay)		
Control Alternative		44,330.24
ITS Option		40,771.36
Difference (%)		-3,558.88 (-8.0%)
Fuel consumption (gallons)		
Control Alternative	290,481.75	1,395,973.12
ITS Option	287,935.78	1,405,718.34
Difference (%)	-2,545.97 (-0.9%)	9,745.22 (0.7%)
Hydrocarbon and Reactive Organic Gases Emissions (tons)		
Control Alternative	6.0337	32.6555
ITS Option	5.982	32.8936
Difference (%)	-0.0517 (-0.9%)	0.2381 (0.7%)
Carbon monoxide emissions (tons)		
Control Alternative	35.0919	212.389
ITS Option	34.8283	217.1266
Difference (%)	-0.2636 (-0.8%)	4.7376 (2.2%)
Carbon Dioxide Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		
Oxides of nitrogen emissions (tons)		
Control Alternative	11.2379	61.7716
ITS Option	11.1453	62.8287
Difference (%)	-0.0926 (-0.8%)	1.0571 (1.7%)
PM10 Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		
Sulfer Dioxide Emissions (tons)		
Control Alternative		
ITS Option		
Difference (%)		