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Assessment Of Managed Lanes Options

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ASSESSMENT OF MANAGED LANES OPTIONS

by

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A THESIS

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ABSTRACT

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 aiming at reducing traffic demand or spreading 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 the recent years, application of such operational policies is evolving into the notion of "managed lanes." This study examines the potential role of managed lanes 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 reviews the state of practice and summarizes best practices and lessons learned from earlier deployment efforts. An investigation of the potential operational impacts of managed lanes implementation along selected Birmingham facilities follows. This is done through traffic modeling and analysis using sophisticated simulation modeling tools. 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.

Keywords: Managed Lanes, HOV Lanes, Truck-only Lanes, CORSIM, Birmingham, AL I-65.

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LIST OF ABBREVIATIONS

AADT	average annual daily traffic
AADTT	average annual daily truck traffic
ALDOT	Alabama Department of Transportation
AVO	average vehicle occupancy
CALTRANS	California Department of Transportation
DMS	dynamic message signs
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
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

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 by only 0.3% *(3)*. 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 managing-lanes concept. Such lanes serve selected types, and 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 manage option. Managed lanes help to increase the efficiency of roads and thus reduce congestion and decrease travel delay.

Urban areas in Alabama face challenges with respect to flow management and congestion mitigation similar to those identified nationwide. In 2003, for example, 9.7 million person-hours were wasted in Birmingham alone due to congestion. This translates to a cost of congestion in the area of $165 million dollars, or three times the figure reported a decade ago ($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 *(1)*.

1.1. 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 managed lanes, and traffic modeling and analysis of appropriate HOV and truck-only lane design features along local freeways.

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

- Identifying key issues related to planning, implementation, and operation of managed lanes;
- Examining the feasibility of managed lanes implementation in the Birmingham, AL area.

This thesis is organized into five chapters:

- Chapter 1 discusses the scope and objectives of the research.
- Chapter 2 summarizes the review of literature related to the implementation of managed lanes.

- Chapter 3 presents the design of the study and the features of the simulation model used in the analysis, along with model requirements and functions.
- Chapter 4 summarizes the results obtained from the simulation runs.
- Chapter 5 presents conclusions drawn from the results, along with recommendations for future research.

2. LITERATURE REVIEW

With the growing uncontrollable traffic demand on U.S. roads, transportation professionals have been trying to find new ways to more effectively operate the existing transportation networks. 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 use freeway 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 lanes was introduced and referred to a managed lane strategy which offered dedicated lanes for vehicles with 3 or more occupants. By the mid-1980s, federal legislation changed this requirement to 2 or more people. In the mid-1990s, a pricing strategy was considered on several HOV lanes, and the HOT lane term was coined. Today there are more than 2,900 lane-miles of managed lanes on U.S. freeways *(21)*. A comprehensive list of managed lanes projects is shown in Table 1, and a summary of lane management operation is available in Figure 1.

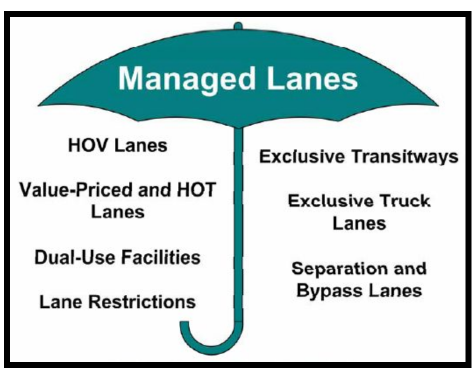

Figure 1. Lane Management Operations *(22)*

Table 1. Comprehensive List of Managed Lanes Projects *(37)*

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 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” *(2)*. 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" *(3)*.

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 *(21)*.

Three different lane management strategies exist, namely vehicle eligibility, access control, and pricing. These strategies can be used alone or be combined with each other *(3)*. Figure 2 shows these relations between strategies.

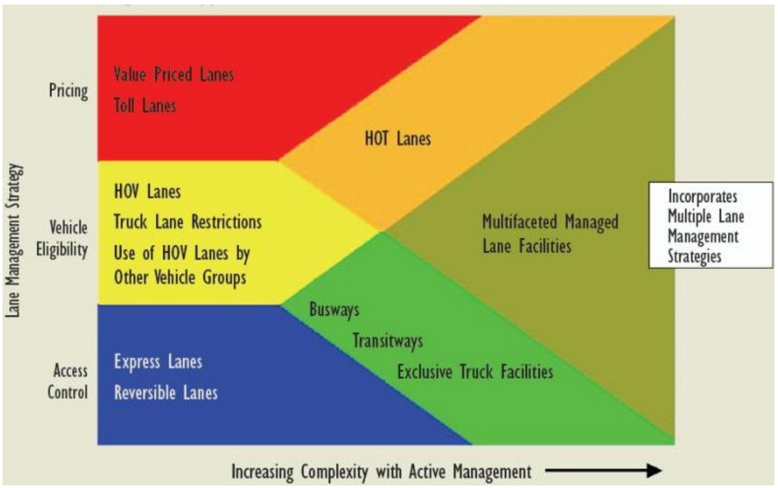

Figure 2. Managed Lane Applications *(3)*

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, and paratransit vehicles, etc. Vehicle eligibility on managed lanes may be in effect 24 hours or vary by time of day or day of the week. Especially during peak hours, vehicle occupancy can be set to a minimum of 3 or more per vehicle on HOV lanes, whereas lower occupancy vehicles may be allowed to enter HOV lanes during off-periods or weekends *(3, 21)*. Figure 3 shows an example of lane designation based on vehicle eligibility from New Jersey Turnpike.

Figure 3. New Jersey Turnpike Truck/Bus Lane *(38)*

Access control regulates entry and exit movements on the facility according to the congestion level of the corridor, without any restrictions by user type. The main idea is to ensure that the lanes do not become oversaturated *(3)*. 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 the free flow speed *(21)*.

Another 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 summarizes all lane management strategies.

Table 2. Lane Management Strategies *(38)*

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 before, 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 *(22)*.

2.1. High Occupancy Vehicle Facilities

2.1.1. HOV Facilities Overview

HOV lanes have been used widely in many parts of the United States since the 1970s, *(10)*. 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 *(11)*.

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 in peak hours. Figure 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 less 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 use lanes.

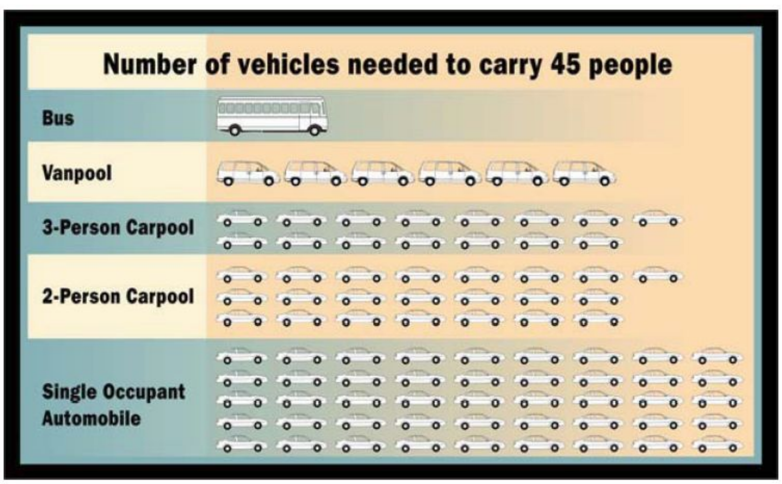

Figure 4. Number of Vehicles Needed to Carry 45 People *(27)*

In order to ensure that HOV lanes are effective in traffic management and 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, the travel patterns of the area, current vehicle and truck volumes, passenger vehicle person capacity, the 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 *(10)*.

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.

2.1.2. Types of HOV Facilities

HOV lanes are implemented on freeways or arterial streets *(14)*. HOV lanes on arterial streets are not as popular as HOV lanes on freeways. There are only 32 arterial HOV lane projects throughout the U.S. *(40)*, compared to more than 100 freeway HOV lane projects *(11)*. There are three types of HOV facilities on freeways *(22)*, namely concurrent-flow lanes, contraflow lanes, or separated roadways.

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

Figure 5. Concurrent flow, Buffer-Separated HOV Lane, Dallas, TX *(22)*

Contraflow HOV lanes (Figure 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.

Figure 6. Contraflow HOV lane, IH-45 North, Houston, TX *(19)*

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 7 illustrates a *two-way barrier separated* HOV lane in Los Angeles, CA.

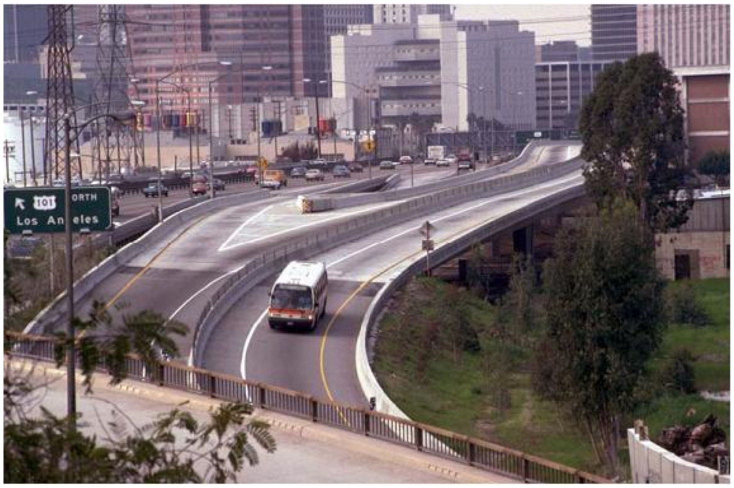

Figure 7. Two-Way, Barrier Separated HOV Lane, Los Angeles, CA *(22)*

Reversible separated HOV lanes (Figure 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 *(22)*.

2.1.3. HOV Lanes 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.

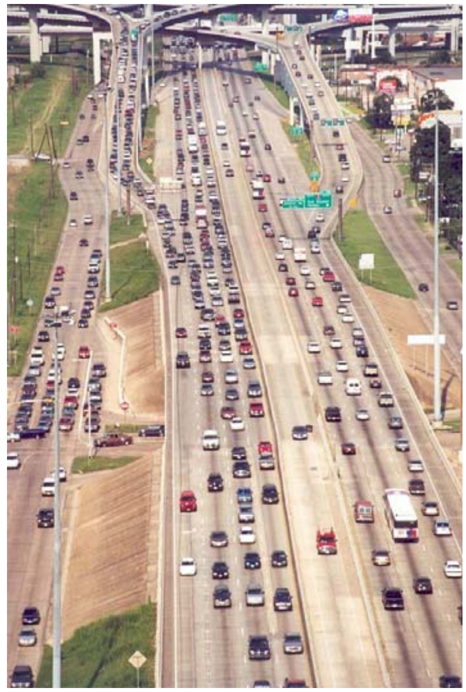

Figure 8. Reversible, Barrier Separated HOV lane, Houston, TX *(22)*

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 9 *(24)*.

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, and access is limited. Figure 10 illustrates a typical example of two-way barrier separated HOV lanes *(24)*.

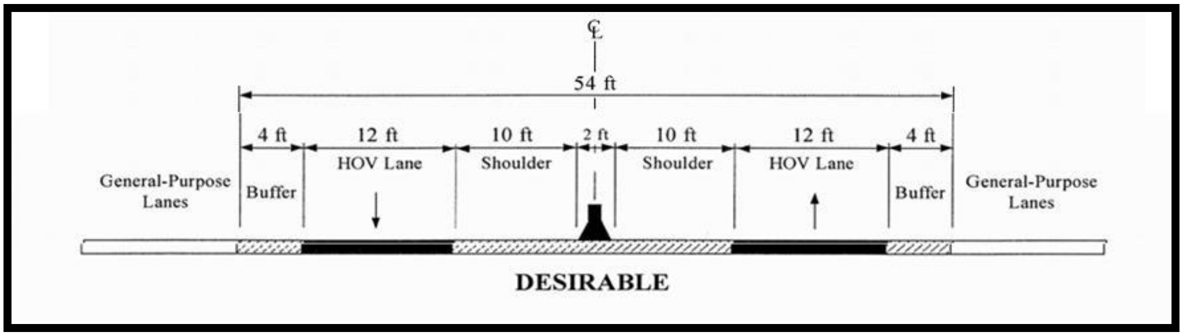

Figure 9. Cross Section of Buffered Separated Concurrent Flow HOV Lanes *(24)*

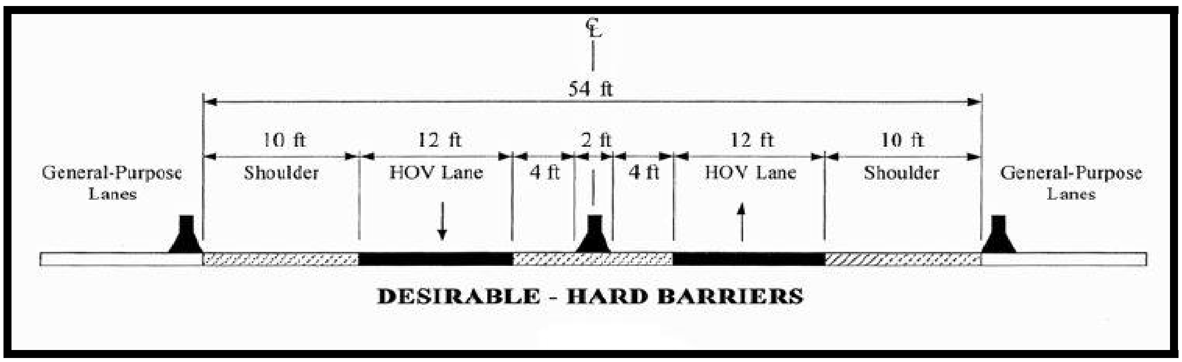

Figure 10. Cross Section of Two-Way Barrier Separated HOV Lanes *(24)*

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 11 *(24)*.

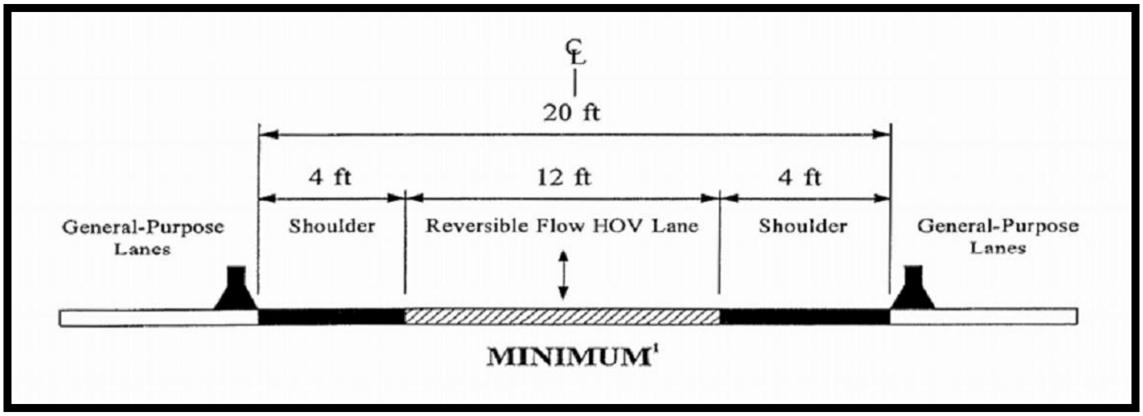

Figure 11. Cross Section of Reversible Separated HOV Lanes *(24)*

2.1.4. Traffic Control Devices at 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. It is recommended in the Manual of Uniform Traffic Control Devices (MUTCD) that a diamond symbol or the word “HOV LANE” is used as a pavement marking to identify HOV lanes, as shown in Figure 12, along with traffic signs that inform travelers about the minimum allowable vehicle occupancy requirements and vehicle eligibility. Figure 13 provides examples of HOV lane signs as presented in MUTCD-Section 2B *(18)*.

Sign placement is another important consideration of HOV facilities. Signs should be place 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, but it is costly to install and maintain them. An example of an overhead HOV lane sign is shown in Figure 14. Detailed guidelines for traffic control at HOV facilities are available in the MUTCD and should be adopted when HOV facilities are introduced *(18)*.

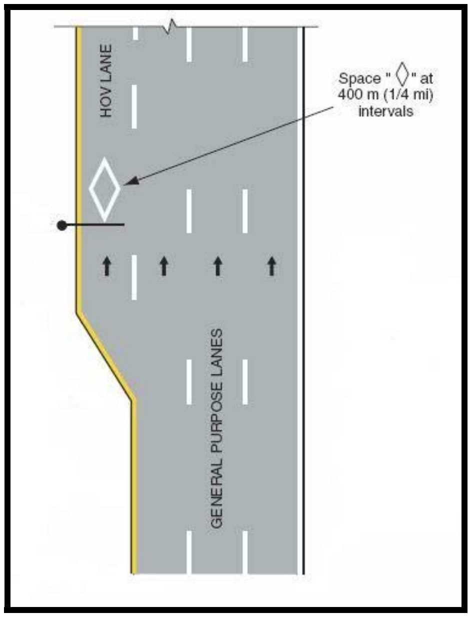

Figure 12. HOV Lane Markings *(18)*

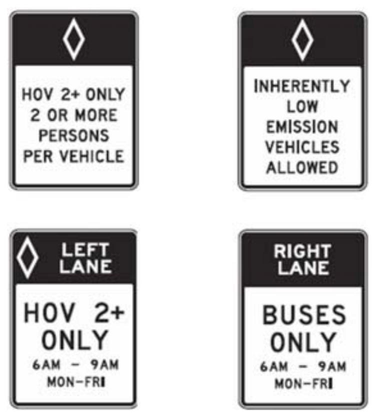

Figure 13. Ground-Mounted HOV Lane Signs *(18)*

Figure 14. Overhead HOV Lane Sign *(18)*

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 0.5 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 15, 16, and 17 *(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. Nowadays it is also possible to display a diamond symbol on DMSs and other HOV management information, such as restrictions, and tolls (Figure 18) *(23)*.

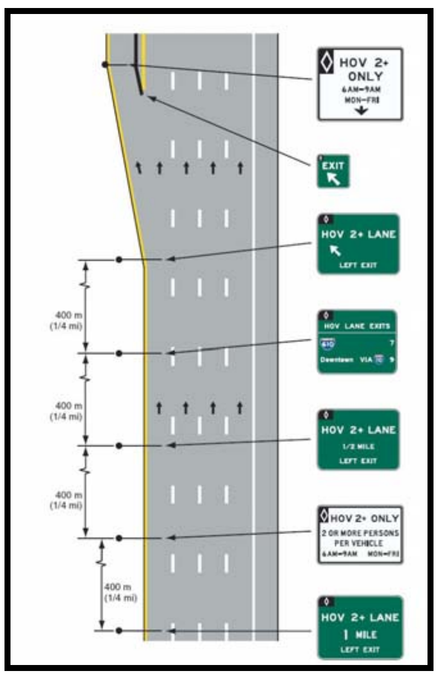

Figure 15. Recommended Controls at the Start of an HOV Lane Added on the Left of the Roadway *(18)*

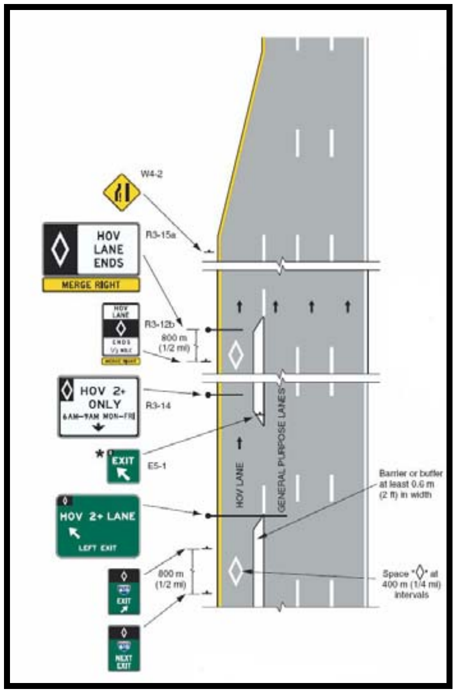

Figure 16. Example of Signing for the Intermediate Entry to and Exit From Barrier- or Buffer-Separated HOV Lanes *(18)*

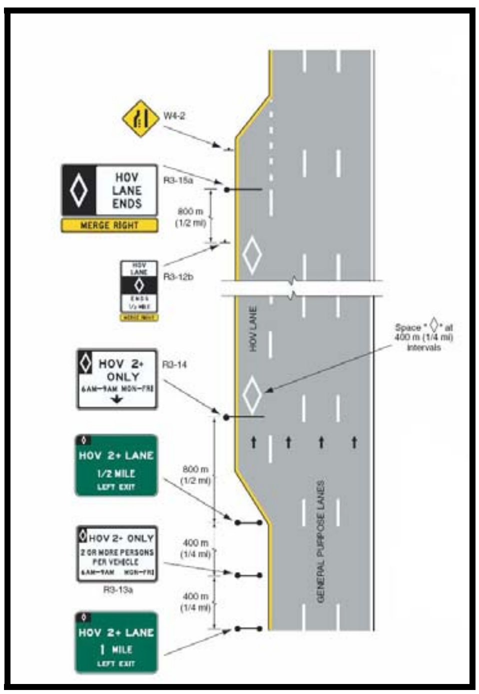

Figure 17. Example of Signing for the Entrance to and Exit From an Added HOV Lane, Planning for HOV Facilities *(18)*

Figure 18. Overhead Dynamic Message Sign, SR 91, CA *(23)*

2.1.5. Planning for HOV Facilities

As in all transportation planning, a number of agencies should be involved in the planning and implementation of HOV facilities *(10),* in order 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 go 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 for implementation. The *corridor stage,* on the other hand, focuses on more detailed analyses, such as alternative designs 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 approach. 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.

2.1.6. 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 and/or operation flexibility allows for effective use of the facility even when traffic conditions change in the future *(3)*. 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 be different by the time of the day or the day of the week. While the HOT lane strategy is based on both pricing and vehicle eligibility, the HOV lane strategy is based only on vehicle eligibility. 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 *(14)*. Today, most of the HOV lanes on freeways meet the 2+ occupancy requirement *(5)*. In heavily populated cities such as Washington, DC, and Los Angeles, the 3+ occupancy requirement is enforced *(25, 26)*. Transit service on HOV lanes introduces additional challenges to the operation of HOV facilities. The volumes 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-hrs per day), operation during most part of the day or operation limited to peak-hour 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.

2.1.7. 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 a good 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; and
- Demonstrated feasibility and cost effectiveness.

2.1.8. HOV Lanes Evaluation

Several states have implemented or are currently in the process of introducing HOV lanes 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, D.C.; 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 lanes case studies around the U.S.

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, D.C., region there are three interstate HOV lane corridors in operation *(7)*. One of them is the I-95/I-395 corridor, which is a 30-mile long, 2-lane HOV facility in the highway median *(25)* with an average of 10,400 person trips and 2,800 vehicles 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 D.C.) in the morning and southbound in the evening. The lanes are also available on the weekends, without the HOV restriction *(25)*. 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 *(5)*. The other HOV facilities in the region are on the corridors 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 D.C.) in the morning and westbound in the evening. I-270 has one HOV lane in each direction. While motorcycles are using the HOV lanes, hybrid vehicles are not. On weekends and other times, the I-270 HOV facility is open to all traffic *(25)*. 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 *(7)*.

Dallas and Houston, TX

Studies also show an increase in person-carrying ability of HOV lanes. For example, according to a study done by the TTI, by implementing a barrier-separated contraflow HOV lane on I-30 and buffer-separated concurrent flow HOV lanes on I-35E North and I-635 freeways in the Dallas area, person trips were increased by 14% in these corridors. 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% *(15)*.

There are 6 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 had 74,867 occupants in one day. Moreover, an average of 407 motorcycles used the lanes daily. During the morning peak-hour, volumes are 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 carry 40% of the morning peak hour total person movement of these three freeways. Studies 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 4 and 2 minutes. Moreover, HOV lane users have more reliable trip times. These reliable travel times and savings led commuters not to drive alone but on the contrary, led them 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 has as the effect of increasing 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 *(19)*.

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. Before 1999, an average daily traffic of 3,500 HOVs per lane was carried on lanes in the Boston Metropolitan region. This volume increased to a daily average of 8,700 high occupancy vehicles per lane in the period between 2001 and 2003. According to an occupancy count survey that was done in 2003 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 travelled 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 *(9)*.

Minneapolis, MN

In Minneapolis, the design of I-394 included three miles of two-lane, reversible, barrier-separated HOV lanes and eight miles of concurrent flow HOV lanes, which opened in 1993. Based on a 1994 study, the HOV lanes average vehicle occupancy for AM peak-hour carpool, vanpool, and bus use lanes along I-394 was 3.28, more that triple that of the general purpose lanes (average vehicle occupancy of 1.01) *(17)*. The facility is an 11-mile long corridor with two general purpose lanes in each direction; 3 miles of two-lane, reversible, barrier separated HOV lanes; 8 miles of concurrent flow 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 *(27)*.

Atlanta, GA

Another successful HOV implementation project is in Atlanta, GA. HOV lanes in the 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 75/85 inside I-285 to reduce air-pollution and traffic congestion, and to provide time savings *(6)*. 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 currently 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 *(4)*. The Georgia Department of Transportation (GDOT) reports that the travel time savings of 15 to 20 minutes are due to HOV use for a trip to or from work *(6)*. Plans are currently in place to further expand the HOV lane system over the next 20 years *(4)*.

Los Angeles, CA

Los Angeles County has an impressive system of HOV facilities with 14 HOV corridors covering over 470 HOV lane miles, which is approximately 36% of the total 1320 HOV lane miles in the State of California. These facilities serve an average of 1,350 vehicles or 3,200 people per hour during peak hours or approximately 330,000 vehicle trips and 750,000 person trips per day. Between the years 1992 and 2007, the increase in the total number of carpools on freeways with HOV lanes for the morning peak 2-hour period was 79%. A significant increase was also observed in the afternoon peak 2-hour period. It is also specified that each HOV facility in Los Angeles County carry 70 qualifying hybrid vehicles during both morning and afternoon peak hour *(26)*. 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 *(8)*.

Seattle, WA

Washington State has implemented approximately 200 lane miles of a planned 300-mile freeway HOV lane and ramp system since 1970 *(20)*. Today, the HOV facilities in Seattle, WA, move more than 100,000 persons per day *(5)*. 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), 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 a.m. and 7 p.m. the HOV facility on SR 520 (west of I-405) requires 3+ persons per vehicle. HOV lanes carry nearly 35% of the commuters and 18% of the vehicles during rush hours on freeways. It is reported that HOV lanes carry more people than the general purpose lanes during peak hours and the time savings on each HOV facility are documented *(20)*. Among the concurrent flow HOV lanes in the U.S., the I-5 facility carries the second largest number of bus riders in the AM peak hours *(17)*.

New Jersey, NJ

While most HOV lane projects reported in the literature may be considered as successful, public opposition resulted in the closing of HOV lanes on two corridors in New Jersey (I-287 and I-80) *(15)*. New Jersey began using in 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 peak-off direction. Its implemented cost was less than $200,000, and it was serving more than 700 buses with more than 30,000 commuters during the peak hour *(5)*. 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 *(16)*. 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 ready to use them 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 *(28)*.

Birmingham, AL

In the recent years, interest was generated in Birmingham, AL, in managed lanes as a tool to address congestion and area quality problems. 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 *(12)*.

The fatal flows 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 19 shows the study site for the fatal flows analysis in the Birmingham area, and Figure 20 summarizes the daily traffic volumes in 2005 *(13)*.

Discussion

While HOV lanes prove to be generally effective in managing travel demand along congested urban corridors, they are not a cure-all. 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 of the facility, operational and environmental issues, and public support.

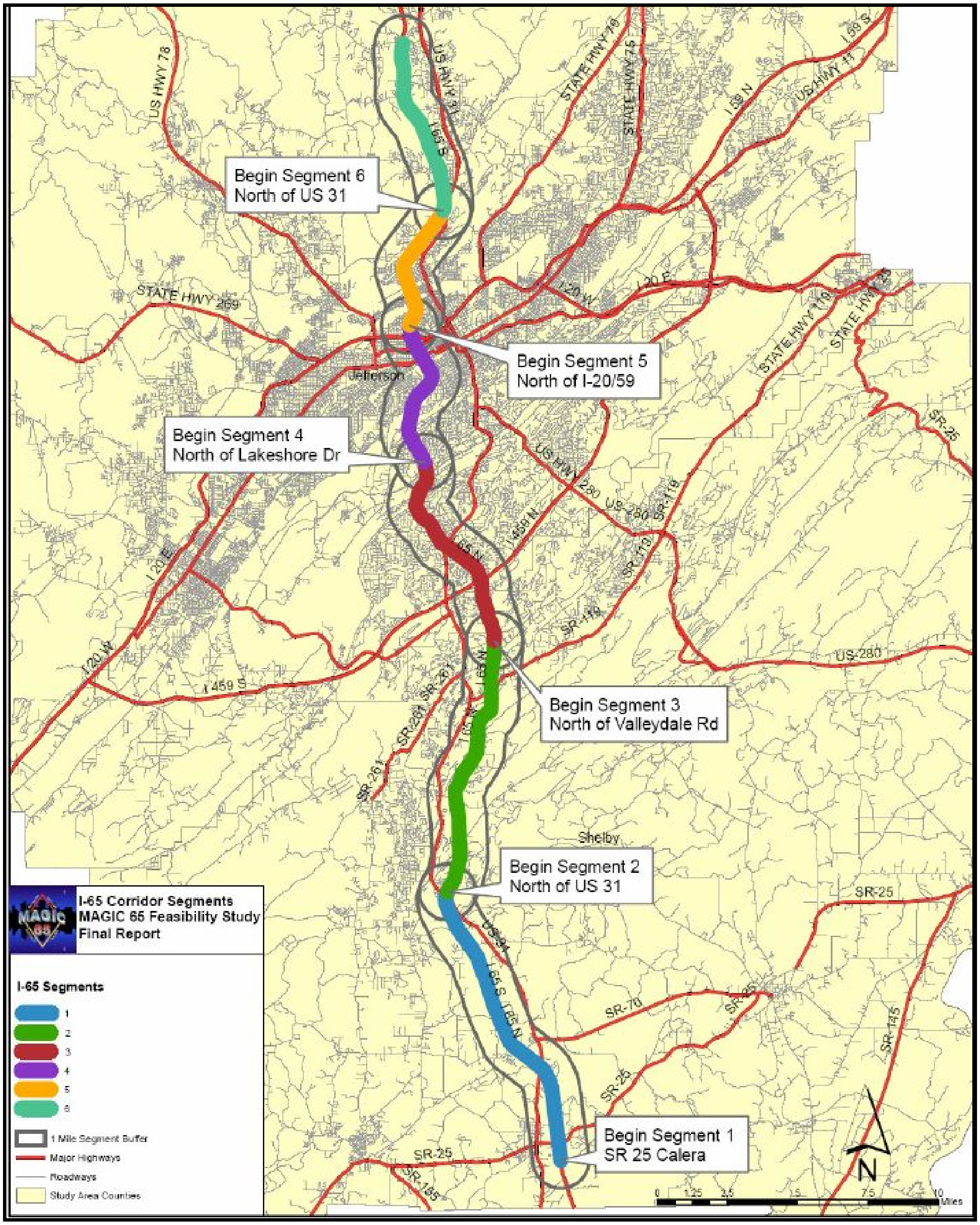

Figure 19. Segments on I-65 Corridor *(13)*

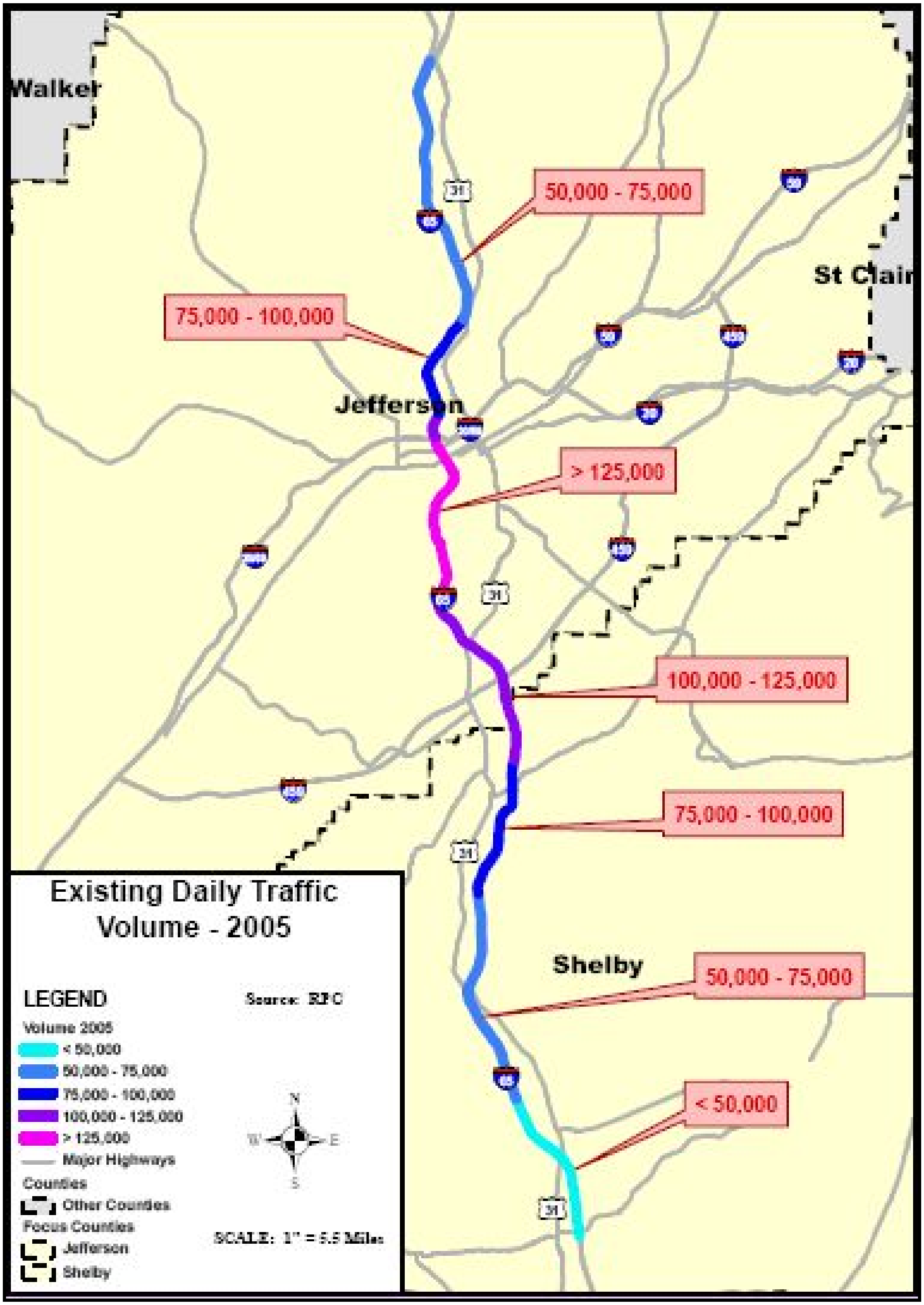

Figure 20. Daily Traffic Volumes in 2005 *(13)*

2.2. Truck Lane Facilities

2.2.1. 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 compromise 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 *(30)*. Truck-only lane facilities may reduce travel time or increase time reliability, which is often very important in freight transportation. Truck facilities have also some positive impacts 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 the TTI *(29)*, if the average annual daily truck traffic (AADTT) reaches 5,000 trucks per day, a truck facility should be considered.

2.2.2. Types of Truck Lane Facilities

According to a study done by TTI in 1985 *(32)*, 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 type except from the presence of 10- to 12-ft long shoulders, (Figure 21). The third type refers to a truck lane that is on a 12-ft *outside lane* with 12-ft outside shoulders. These lanes are also non-barrier separated, as shown in Figure 22. 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 23 illustrates a two-way truck lane cross-section.

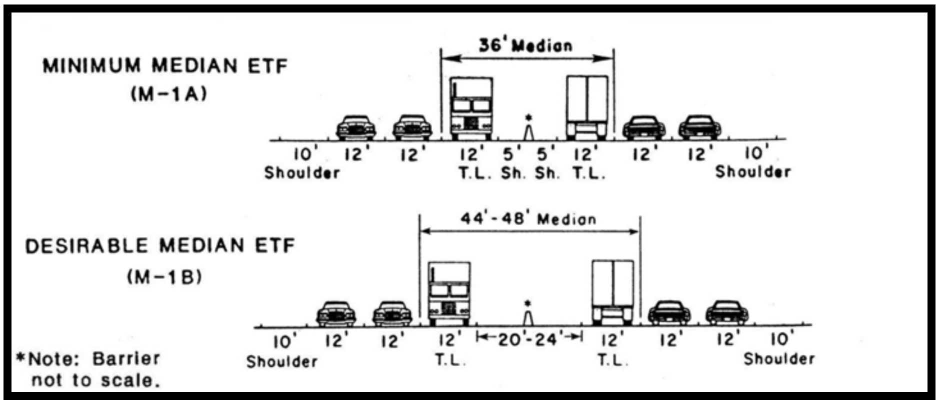

Figure 21. Minimum Median Truck Lane *(32)*

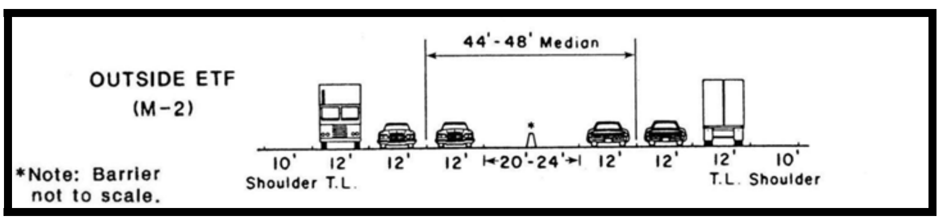

Figure 22. Outside Truck Lane *(32)*

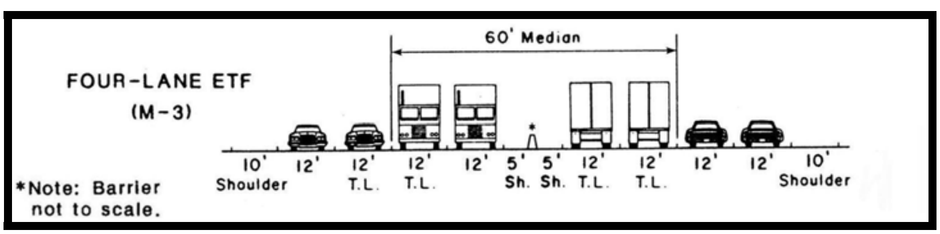

Figure 23. 2-way Inside Truck Lane *(32)*

The fifth type of truck lanes design is similar to the second type. The only difference is a depressed median. Trucks travel on 12-ft lanes with 10-ft shoulders as shown in Figure 24.

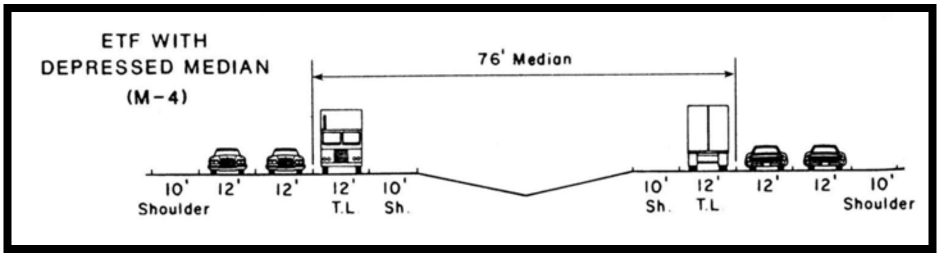

Figure 24. Depressed Median Truck Lane *(32)*

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 a barrier-separated facility. Figure 25 shows the configuration of the protected truck lane with a passing lane.

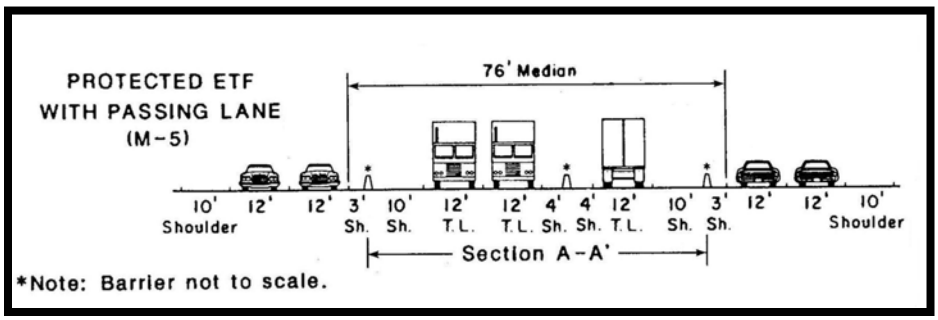

Figure 25. Protected Truck Lane with Passing Lane *(32)*

The last type is an elevated truck lane, which has the same configuration as the previous one (Figure 25), as shown in the cross section in Figure 26.

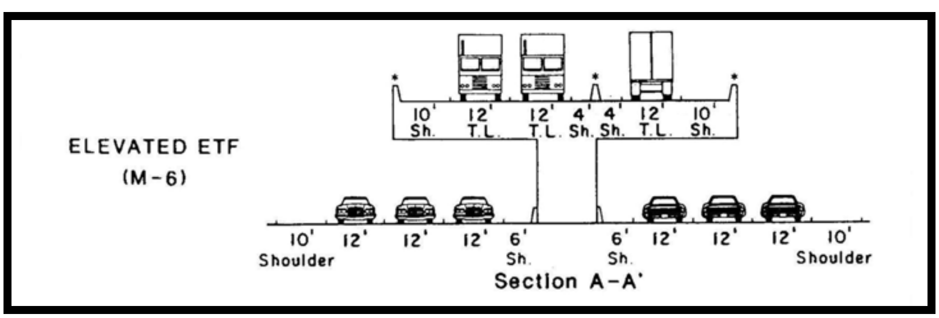

Figure 26. Elevated Truck Facility *(32)*

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.

2.2.3. 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 27 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 *(29)*.

Figure 27. Overhead Truck Sign on New Jersey Turnpike *(32)*

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 28.

Figure 28. Overhead Truck Sign Recommended in MUTCD *(18)*

It is also important to inform truck drivers about safe passing, merging, and diverging movements (Figure 29), as well as weight limits (Figure 30) *(18)*.

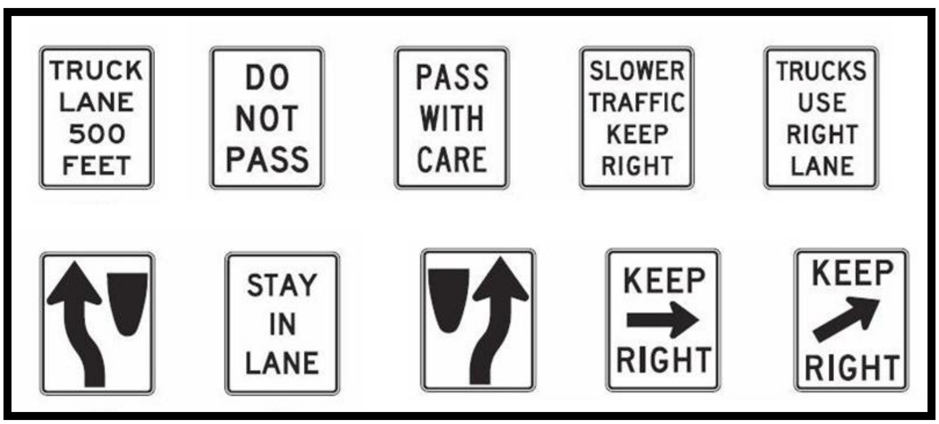

Figure 29. MUTCD recommended truck facility signs *(18)*

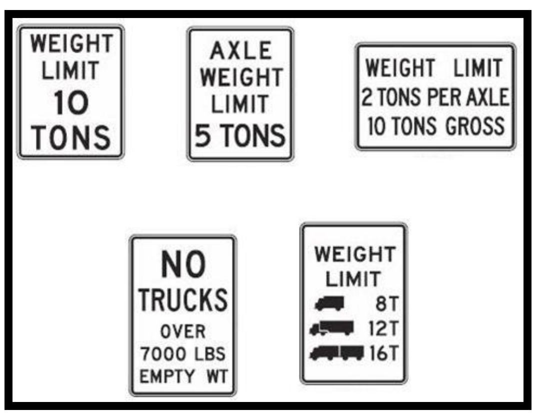

Figure 30. Weight Limitation Signs of Trucks *(18)*

Intelligent Transportation Systems (ITS) applications are also used to enhance safety and control on truck lane facilities. Figure 31 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 *(32)*.

Figure 31. Warning System on Capital Beltway *(29)*

2.2.4. 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 be operated differently than other modes. Separating trucks from other traffic can be done spatially and/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 truck 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 lane or right lane, they are allowed to use the other two lanes in mixed traffic.

According to a study done by TTI *(32)*, 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 3 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 *(31)*.

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 32. Generally speaking, truck-only facilities are not widely used due to high cost and mixed public perception *(32)*.

2.2.5. Implementation of Truck Lane Facilities

No universally accepted implementation criteria exist for truck facilities 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 *(32)*. A cost effectiveness analysis should be performed before implementation as well.

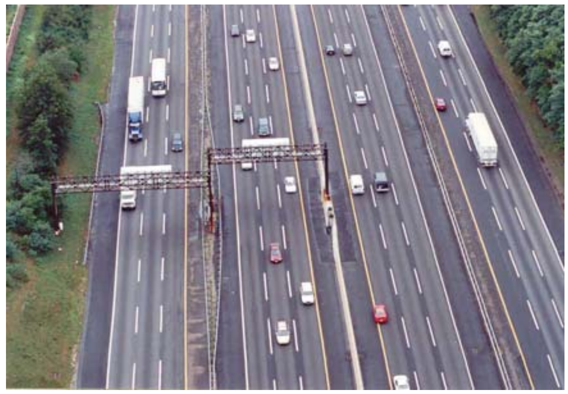

Figure 32. New Jersey Turnpike Dual Facility *(32)*

2.2.6. Evaluation of Truck Lane Facilities

The literature review indicates that truck traffic management in the U.S. primarily involves truck lane restrictions or dedicated truck lanes on shared-traffic facilities *(31)*. Several states are currently considering the implementation of truck-only 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 *(33)*. 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 *(34)*. Examples of truck management facilities currently in operation are provided as follows.

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 33 *(32)*.

Figure 33. Truck Facility in Los Angeles *(32)*

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 number of weaving trucks: I-5 at I-405 north of Los Angeles (Figure 34); 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% *(32)*.

Figure 34. Truck by-pass lanes on I-5 at I-405 north of LA *(32)*

Newark, New Jersey

The New Jersey Turnpike has a dual-dual roadway configuration between Interchange 8A and Interchange 14 a distance of 32 mile. While only cars are allowed to use the inside roadway of the dual-dual facility; cars, trucks, and buses use the outer roadway (Figure 35) *(32)*. 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 36 shows the injury crash rates on the New Jersey Turnpike between the years 1999-2001 *(31)*.

Figure 35. New Jersey Turnpike Dual-Dual Facility *(32)*

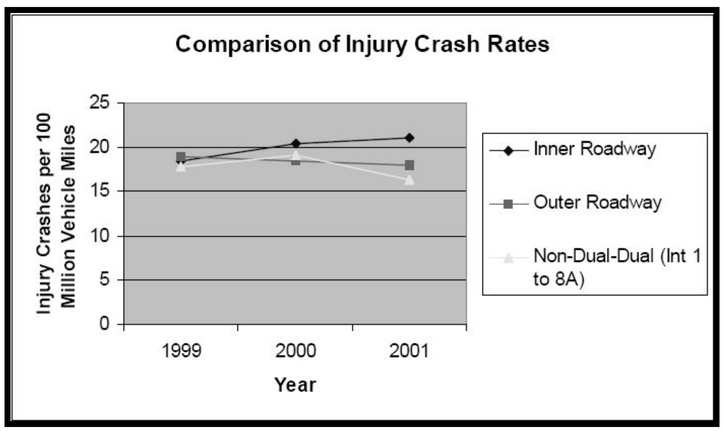

Figure 36. Injury Crash Rates on the New Jersey Turnpike *(31)*

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 *(32)*.

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 *(36)*. 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 *(35).*

New Orleans, Louisiana

The Port of New Orleans, Louisiana (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 37 shows the Tchoupitoulas truckway at the Port NOLA *(31)*.

Examples of Other Systems

Another example of truck lanes is from Europe. In 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 38 illustrates this system *(36).*

Figure 37. The Tchoupitoulas Truckway *(31)*

Figure 38. Combi-Road Driverless Truck Guideway *(36)*

3. STUDY DESIGN

3.1. 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 I-459 to I-20/59 was chosen for further analysis in this thesis. The section is within the area that shows greater promise for HOV implementation as per the recommendations of the 2006 fatal flows study *(13)*.

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

3.1.1. 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 connecting 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 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 39.

3.1.2. Travel Pattern of Birmingham Area

Among U.S. 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) *(1)*. 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 the work trips that are made by using public transit are less than 1% of all work trips. The average travel time to work in 2000 was 26.2 minutes. During the morning peak (i.e., 7:00 to 8:00 a.m.), 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 *(13).*

3.1.3. Operational Characteristics of I-65 Corridor

Based on traffic counts reported by the Alabama Department of Transportation (ALDOT), the daily traffic volumes in 2005 along the study segmented 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 39). Table 3 summarizes the operational characteristics of the study site based on local studies performed in 2005 to 2006 *(13)*.

Table 3. Operational Characteristics of the I-65 Study Corridor-NB Direction *(13)*

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

Figure 40 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 *(13)*.

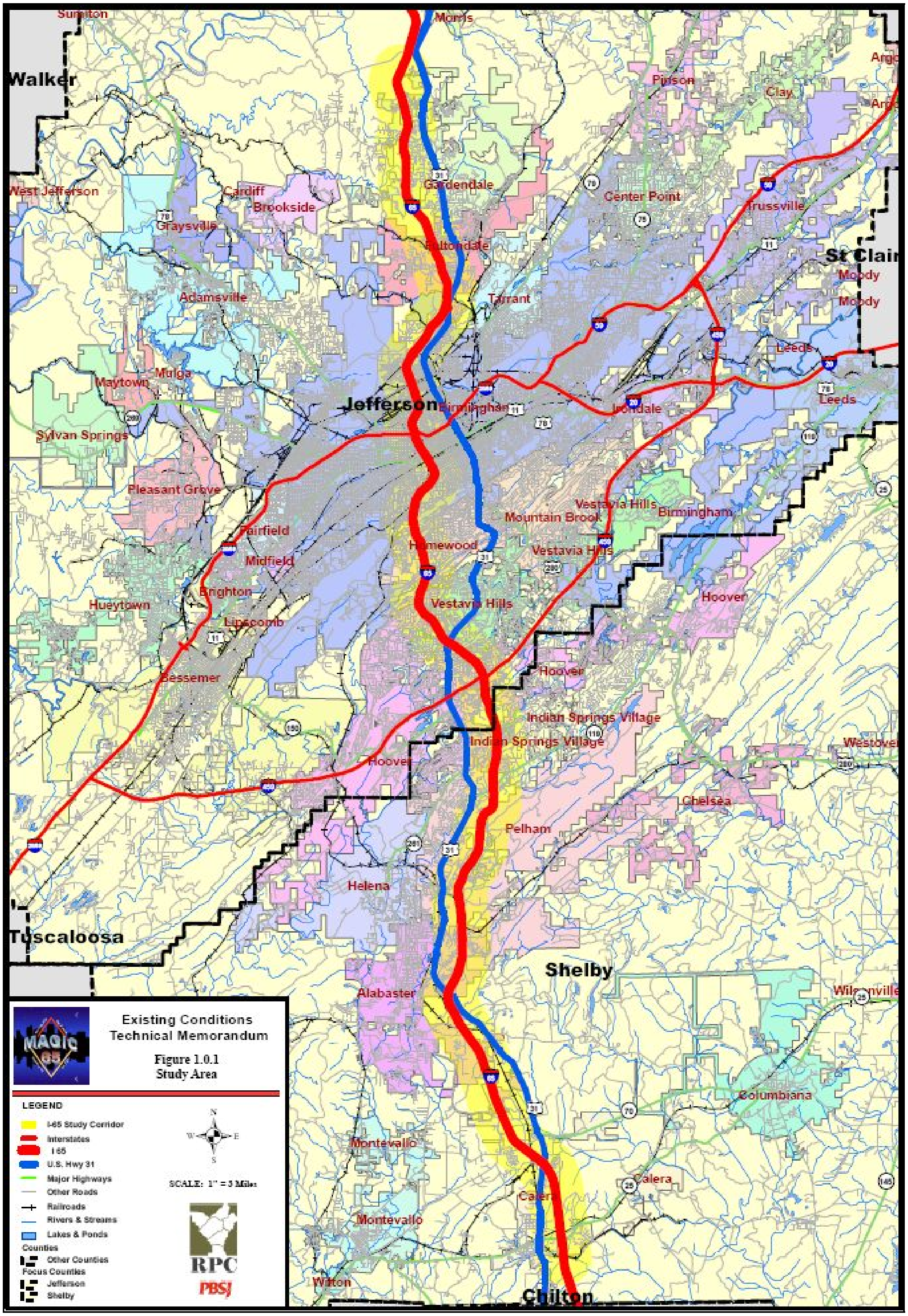

Figure 39. Transportation Facilities in the Birmingham Region *(13)*

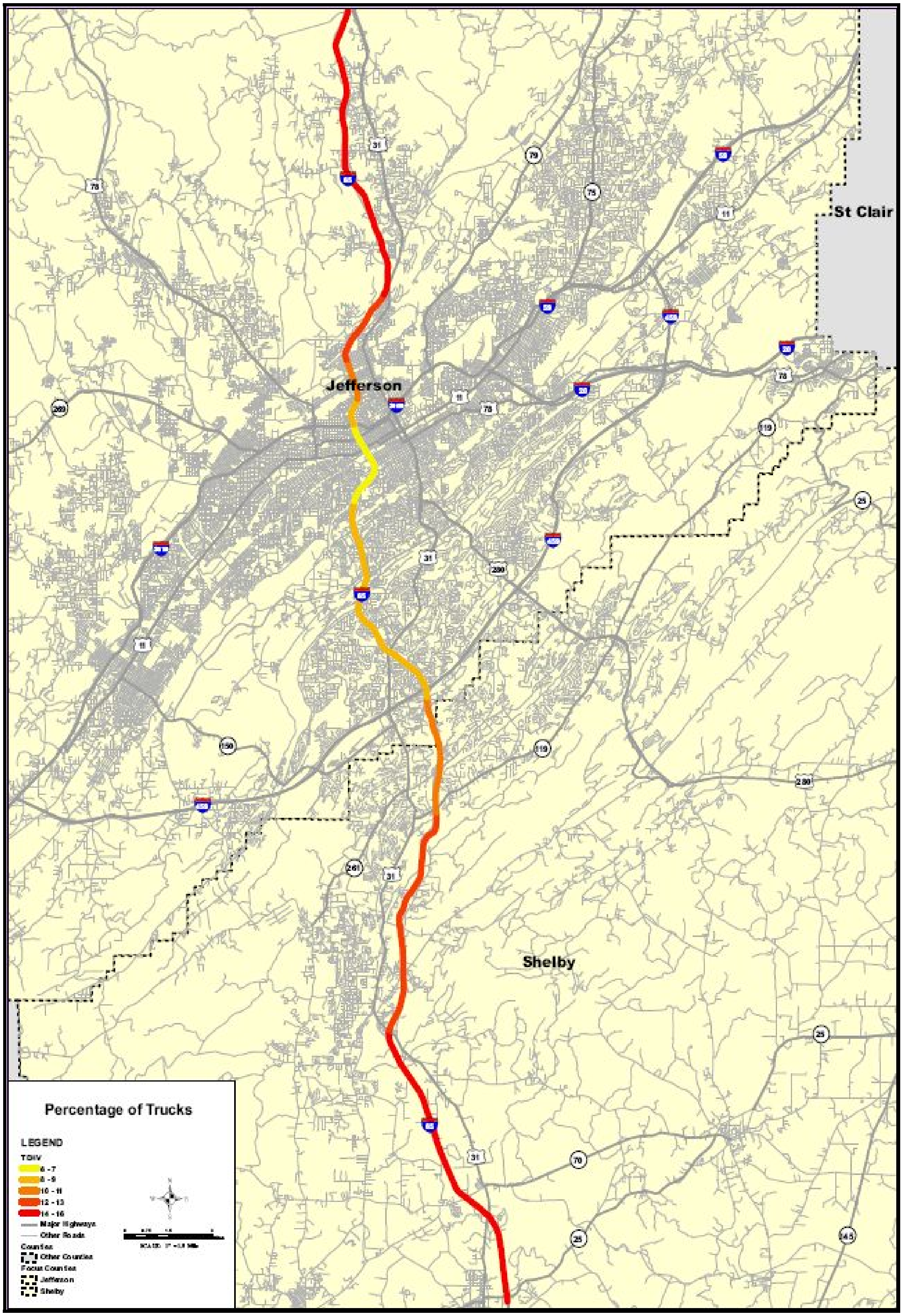

Figure 40. Percentages of Truck Volumes Along I-65 *(13)*

3.1.4. Designing HOV Lanes on I-65

Two typical HOV design configurations are considered for I-65 in this study, namely a Median Concurrent-Striped lane and a Median Concurrent-Barrier lane for each direction. Figure 41 and 42 show Median Concurrent-Striped lane and Median Concurrent-Barrier lane configurations, respectively.

It is recommended that these two designs be applied to I-65 corridor, except at interchanges with other interstate highways where elevated structures should be considered *(13)*. Figure 43 illustrates a typical section of these elevated lanes.

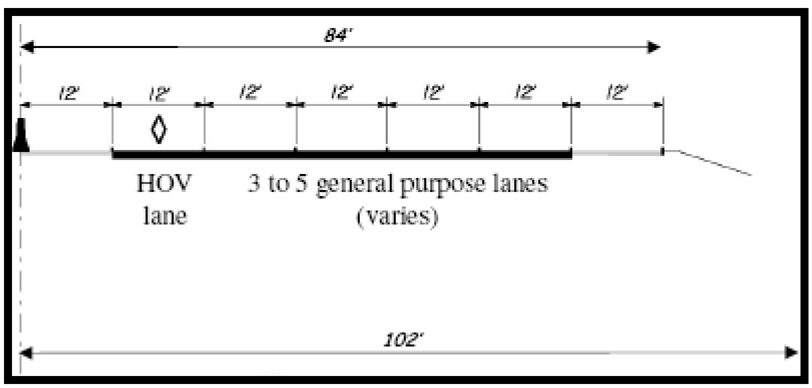

Figure 41. Median Concurrent-Striped HOV Lane Configuration *(13)*

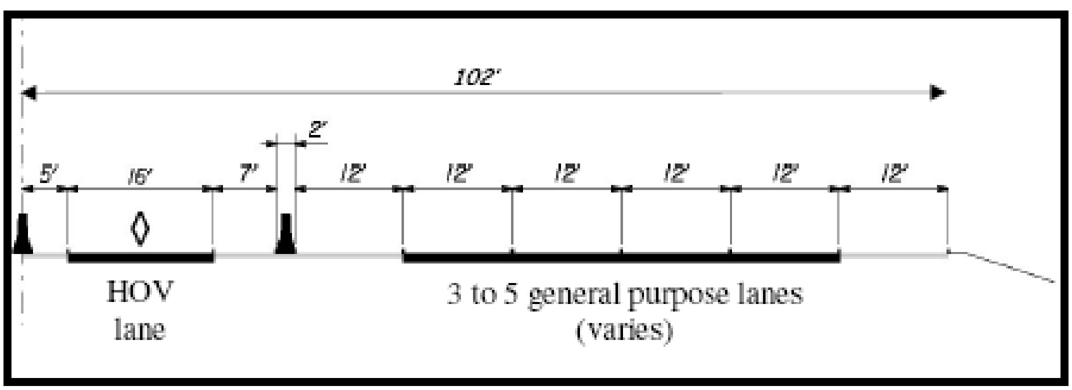

Figure 42. Median Concurrent-Barrier HOV Lane Configuration *(13)*

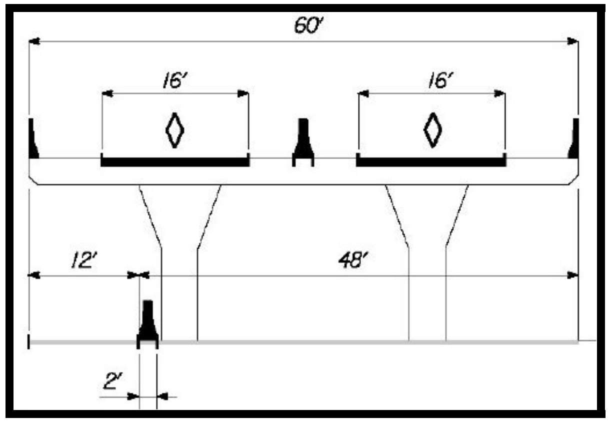

Figure 43. Typical Section of Elevated HOV Lane Configuration *(13)*

3.1.5. Alternatives Analysis

Prior to 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 simulation model of I-65 and selected transportation facilities in the Birmingham area, using the tool identified in Step 1 and,

3. Data Analysis. The simulation model developed in Step 2 will be used to examine traffic operations with and without the presence of HOV lanes strategies and truck-only lanes strategies as well as assess different configurations of designs. The

impact from implementation will be measured using selected measures of effectiveness (MOEs), such as travel speeds, travel times, delays, and fuel consumption.

Sections 3.2 through 3.4 provide details on simulation model selection, data collection and processing, and data analysis for the Birmingham case study.

3.2. Simulation Model Selection

Microscopic computer simulation is one of the most commonly used approaches for predicting the effect of alternative transportation systems management (TSM) strategies on traffic operation. The assessment can be performed on the basis of MOEs such as average vehicle speeds, vehicle stops, delays, vehicle-hours of travel, vehicle-miles of travel, fuel consumption, and pollutant emissions. While the MOEs provide insight into the effect of the applied strategy on the traffic stream, they can also provide the basis for optimizing that strategy. Some MOEs needed in traffic studies cannot be measured in the field precisely or even adequately within reasonable time and cost constraints. In addition, with computer simulation, the disruption of traffic operations caused by field experiments can be completely avoided.

A variety of micro simulation models currently exist that performs traffic analysis and it is important to maintain a proper perspective when making decisions on model selection. Simulation models cannot describe complex dynamic systems with perfect fidelity and this is particularly true for traffic systems. Traffic flow models implement general principles that are extracted from observations and measurements. Such principles (e.g., car following logic or rules for lane changing) are dependant not only on physical laws of traffic flow mechanics but also on driver behavior *(39).*

Driver behavior varies widely with geography, age, time of day, weather, and a host of other variables, and though it is important to capture this variability in the model, it is also important to recognize that the resulting model will always contain some degree of error. Consequently, modeling traffic systems with perfect fidelity is not and should not be the goal. Instead, the goal is to model the system with sufficient detail and to carefully design test scenarios to ascertain critical properties of the system's behavior. Figure 44 presents criteria that should be considered for the selection of a microscopic simulation model.

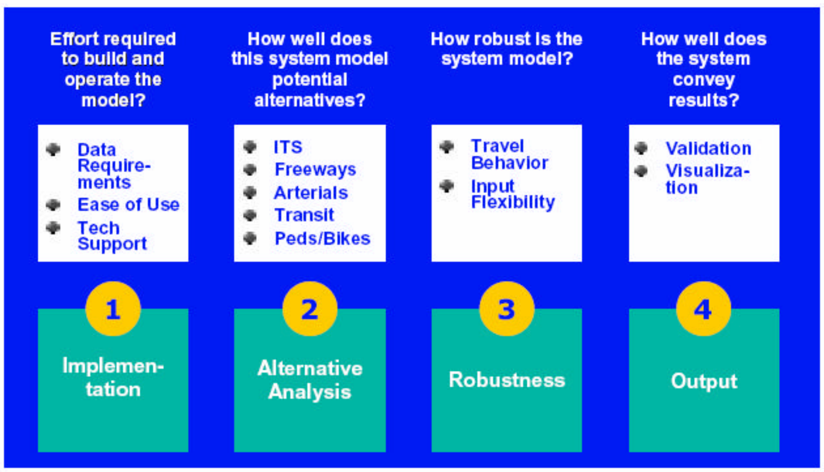

Figure 44. Criteria For Selection of Micro-Simulation Tool *(39)*

This simulation model selection approach was adopted for the evaluation task in this study and the micro simulation tool Traffic Software Integrated System (TSIS) was chosen for this purpose. The TSIS is a suite of simulation models that have been developed by the FHWA and have been used extensively by transportation agencies and practitioners in the U.S for over three decades. It can simulate stochastic individual traffic vehicle operations and control systems on integrated networks containing freeway and surface streets. The model has the ability to simulate fairly complex geometric conditions and realistic driver behavior after it is appropriately calibrated and validated. Moreover, the model offers the capability to analyze a variety of lane management strategies, including HOV and truck-only lanes.

Like most of the currently available microscopic traffic simulation models, TSIS requires control, geometric, and traffic data as an input. Control data provide information about traffic control at intersections. Geometric data indicate the number of lanes, the length of the lanes, grades, etc. Traffic data should express information about vehicle volumes, vehicle speed, traffic origins and destinations, vehicle types, traffic composition, etc.

3.3. Development of Simulation Model for the Birmingham Case Study

The study network of the Birmingham region was built in TSIS. The simulation network includes a segment of I-65 Highway that begins from the I-459 interchange in the south and extends to the I-20/59 interchange to the north. The U.S. 31, Alford Avenue, Lakeshore Drive, Oxmoor Boulevard, and Green Springs-Avenue interchanges were also coded to reflect traffic entering to and/or exiting from the study network. Figure 45 shows the network of the Birmingham region that was coded in TSIS.

3.4. Data Analysis

Scenarios were developed for two different operational strategies, namely HOV lane and truck-only lane, as follows. The simulations were performed with TSIS software. The morning peak period between 7:00 am to 9:00 am was chosen as the analysis period, and 2006 AADT volumes were incorporated in the study. Additional runs were performed to represent future demand conditions where the 2006 AADT volumes were increased by 15%.

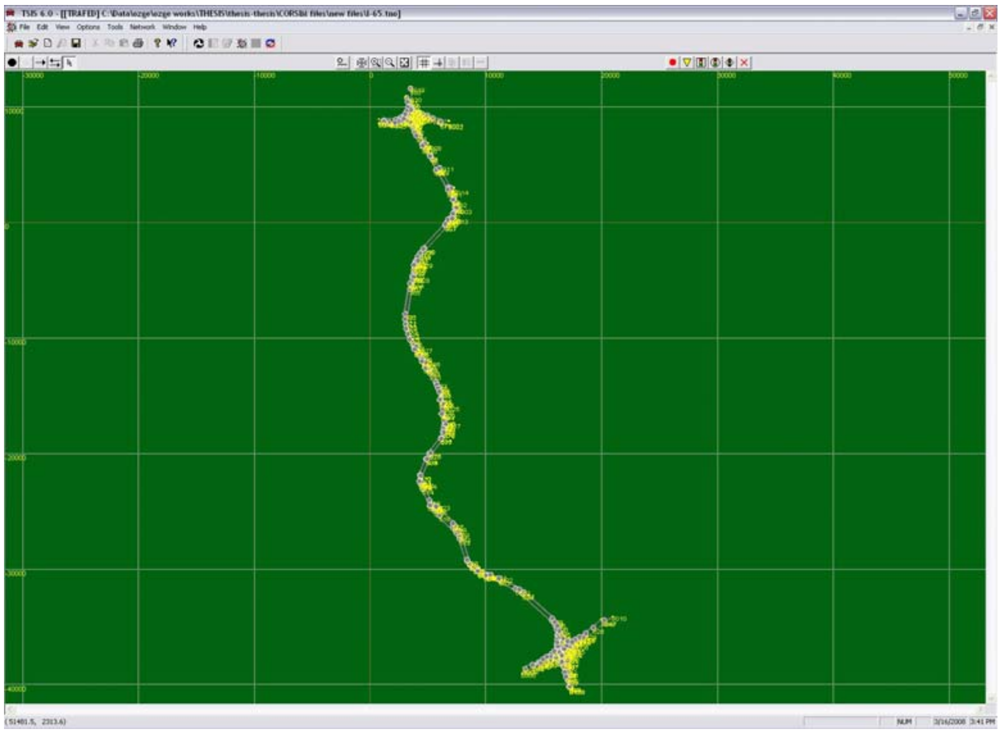

Figure 45. Birmingham Case Study Coded Network for Alternatives Analysis

3.4.1. HOV Lanes Scenarios

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

Scenario 1-HOV describes network operations under current conditions (i.e., no HOV lane presence, just general purpose lanes) and provides the baseline for comparisons (Figure 46).

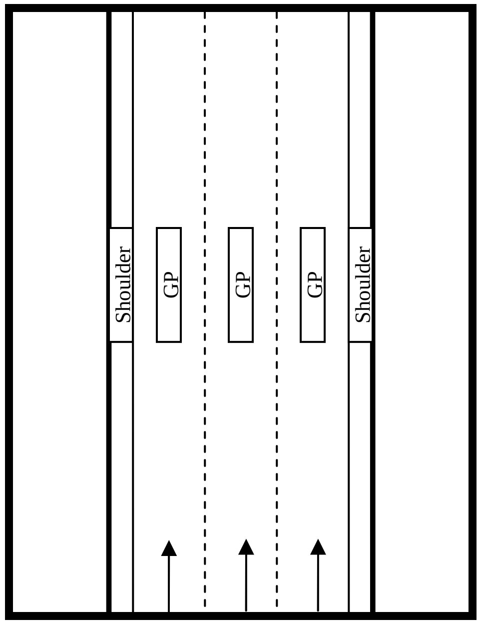

Figure 46. Typical Lane Configuration for Scenario 1-HOV

Scenario 2-HOV assumes that the innermost general purpose lane is converted to an HOV lane as shown in Figure 47. This scenario is designed for a sensitivity analysis by varying the percentage of drivers using an HOV lane (from 10% up to 40% in increments of 10%) and observing the relative changes in model response.

Scenario 3-HOV assumes that an HOV lane is added to the current design configuration and performs a sensitivity analysis similar to that of Scenario 2 where the percentage usage is varied incrementally. The lane configuration of the third HOV scenario is shown in Figure 48.

Two different demands are considered as inputs in Scenarios 2-HOV and 3-HOV as follows. Simulations were run first with *vehicle demand equal to the base line 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 can be accommodated. To provide a fair comparison between baseline and HOV operations a second case study was performed which adjusted the demand used in the HOV scenarios to result in equal people carrying capacity.

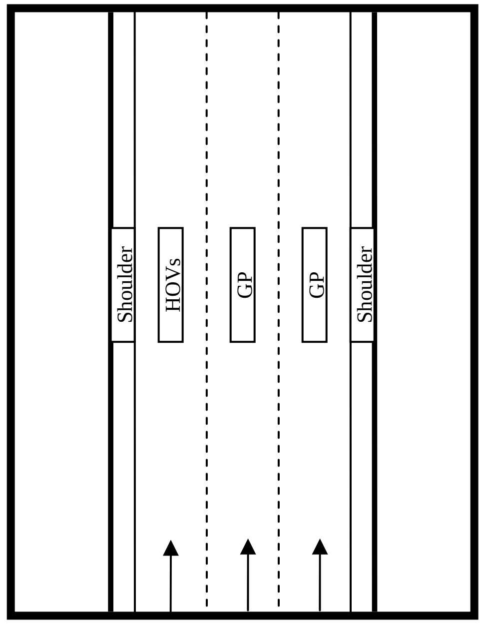

Figure 47. Typical Lane Configuration for Scenario 2-HOV

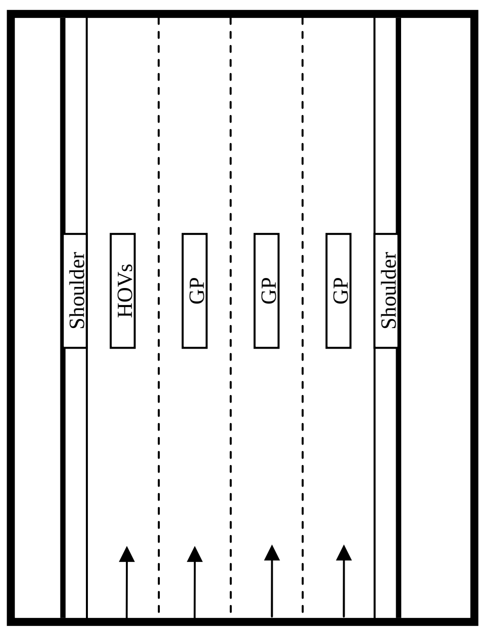

Figure 48. Typical Lane Configuration for Scenario 3-HOV

The data analysis will allow a comparison of results from Scenarios 2-HOV and 3-HOV with the baseline conditions (Scenario 1-HOV), as well as comparison and assessment of the two HOV designs. Finally, the sensitivity analysis will provide insights on HOV lane use and its impact on traffic operations.

3.4.2. Truck-Only Lane Scenarios

Similarly to HOV lane scenarios, three scenarios were designed for truck-only lanes to analyze their operational effectiveness. In all scenarios, passenger cars are allowed to use truck lanes.

Scenario 1-T describes network operations under current conditions to provide the baseline for comparisons, and is identical to Scenario1-HOV of the HOV lanes analysis.

In *Scenario 2-T* it is assumed that the far left lane in each direction is converted to a truck-only lane (Figure 49) and a sensitivity analysis is performed to assign 5% and 10% of traffic to the truck-only lane. Currently truck traffic represents an average of 10% of all traffic along I-65 corridor.

In *Scenario 3-T,* it is assumed that a lane is added to the current design configuration (Figure 50) for the purpose of serving truck traffic. The sensitivity analysis that is performed here is similar to that of Scenario 2-T, where half- and all of truck traffic is considered using the truck-only lane (5% and 10% of all traffic, respectively).

A comparison will be performed again between the results obtained from Scenarios 2-T and 3-T and baseline conditions (Scenario 1). Moreover, the results will be used to access the overall potential of each treatment (i.e., HOV and truck-only lane) and provide recommendations for the best option for implementation.

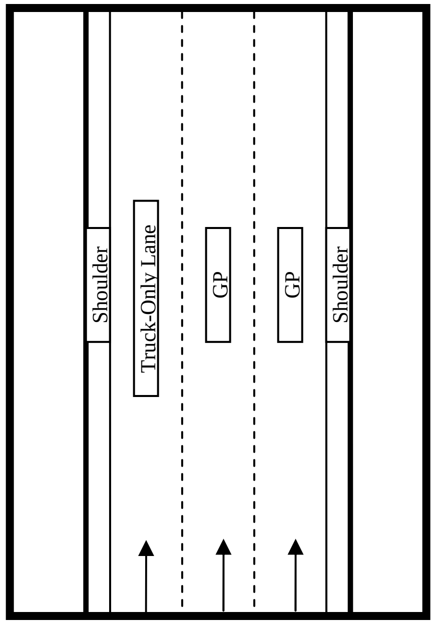

Figure 49. Typical Lane Configuration for Scenario 2-T

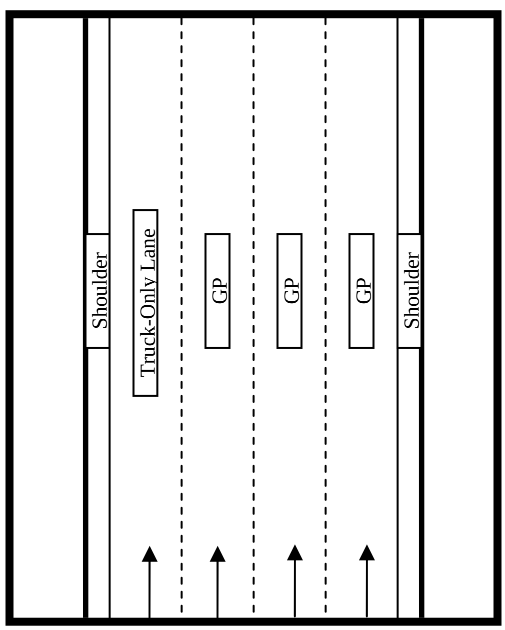

Figure 50. Typical Lane Configuration for Scenario 3-T

4. RESULTS

4.1. HOV Lanes Simulation Results

As mentioned in Section 3, three scenarios were defined for the Birmingham TSIS network to analyze the operational effectiveness of HOV lanes. A set of 5 runs was performed for each scenario using 5 different seeds to account the randomness (See APPENDIX: DETAILED RESULTS OF SIMULATION RUNS) and average results were reported throughout the thesis. The same 5 seed numbers were used for all scenarios in order to enable a comparison of the results. The next paragraphs summarize the HOV lanes simulation results for each scenario obtained from the TSIS runs.

4.1.1. Scenario 1-HOV: Base Case Scenario Results

Initially a simulation run was performed for existing conditions assuming three 12-ft lanes in each direction, 2006 AADT volumes, and 10% trucks. The results from the simulation are summarized in Table 4.

Table 4. Results of Scenario 1-HOV: Base Case with Existing Traffic Volumes

Total Travel Time (veh-hours)	**Total Delay Time** (veh-hours)	**Average Travel Speed** (mph)	**Delay Time** (min/veh-mile)	**Total Time** (min/veh-mile)
2,172.32	381.63	49.17	0.22	1.22

According to the results, vehicles on I-65 are travelling at an average speed of **49.17 mph** and experience an average of **0.22** minutes of delay per mile travelled. If it is assumed that the traffic volumes will increase by 15% and the percentage of trucks will be 15% of all traffic in the near future, then the average delay time will increase to **0.35** minutes and the average speed of overall network will decrease to **44.18 mph** if no countermeasure is taken (Table 5).

Table 5. Future Results Assuming Existing Conditions

Total Travel Time (veh-hours)	**Total Delay Time (veh-hours)**	**Average Travel Speed (mph)**	**Delay Time (min/veh-mile)**	**Total Time (min/veh-mile)**
2,444.73	638.45	44.18	0.35	1.36

4.1.2. Scenario 2-HOV: Converting Lane Case Scenario Results

As mentioned in the methodology section two assumptions were consider in Scenario 2-HOV as follows.

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

Results from Scenario 2A-HOV

In Scenario 2A-HOV, the percentages of users using the converted HOV lane are assumed to vary from 10% up to 40% of all traffic. Traffic volumes assumed in this scenario represent future traffic demand conditions. The results summarized in Table 6 represent the conditions where the converted HOV lane will attract 10% of traffic. This represents current ridesharing patterns during peak hours along the study area.

Table 6. Scenario 2A-HOV: Converting Lane Case (HOVs 10%)

Total Travel Time (veh-hours)	**Total Delay Time** (veh-hours)	**Average Travel Speed** (mph)	**Delay Time** (min/veh-mile)	**Total Time** (min/veh-mile)
3,082.65	1,592.12	28.82	1.08	2.09

It is observed that when a lane is converted to an HOV lane, the total system delay increases to over 1,000 veh-hours while the average speed decreases significantly when compared to the basic conditions (from 44.18 to **28.82 mph**). This is expected due to the underutilization of the HOV lane under the assumptions of this scenario.

Further analysis was performed to test the impact of higher HOV lane utilization on traffic operations and the results are shown in Table 7. Under our study assumptions the results from the sensitivity analysis confirm that the conversion of a freeway lane to HOV is not justified on the basis of operational benefits. Should an HOV lane conversion be selected for implementation, the optimal system performance can be achieved when the HOV lane carries 30% of the traffic of the facility. This finding indicates that, for best performance, either a major campaign will be needed to triple the existing ridesharing proportion during peak hours, or HOT lanes should be considered to populate the HOV lanes, or both. 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 which is not easily detected by the operational analysis results documented in Table 7.

Table 7. Scenario 2A-HOV: Converting Lane Case, Sensitivity Analysis Results

	Total Travel Time (veh-hours)	**Total Delay Time** (veh-hours)	**Avg. Travel Speed** (mph)	**Delay Time** (min/veh-mile)	**Total Time** (min/veh-mile)
Base Case Scenario	2,444.73	638.45	44.18	0.35	1.36
Scenario 2A-HOV (10%)	3,082.65	1,592.12	28.82	1.08	2.09
Scenario 2A-HOV (20%)	2,905.55	1,289.88	33.17	0.80	1.81
Scenario 2A-HOV (30%)	2,762.24	1,018.18	37.71	0.59	1.59
Scenario 2A-HOV (40%)	2,923.29	1,146.02	36.33	0.65	1.65

Results from Scenario 2B-HOV

This scenario is similar to Scenario 2A-HOV except from the fact that the traffic volumes assumed in Scenario 2B-HOV are adjusted to represent equal number of travelers (rather than vehicles) as compared to the base case. In other words, in Scenario 2B-HOV the number of people that are served by the network after the introduction of the HOV strategy is assumed to remain the same as in the base case. As a result the number of vehicles in the network decreases, which is indeed the main objective of the HOV implementation. The results are summarized in Table 8.

Under the equal people carrying ability assumption in Scenario 2B-HOV the results from the sensitivity analysis confirm that the conversion of a freeway lane to HOV is justified on the basis of operational benefits when the percentage of HOVs of all traffic is more than 20%. For example, Scenario 2B-HOV (30%) leads to an increase in the average travel speed to **53.57 mph** (from 44.18 mph in Based Case) and significant savings in delay and travel times.

Table 8. Scenario 2B-HOV: Converting Lane Case, Sensitivity Analysis Results with Equal People Carrying Ability

	Total Travel Time (veh-hours)	**Total Delay Time** (veh-hours)	**Avg. Travel Speed** (mph)	**Delay Time** (min/veh-mile)	**Total Time** (min/veh-mile)
Base Case Scenario	2,444.73	638.45	44.18	0.35	1.36
Scenario 2B-HOV (10%)	2,254.53	882.16	36.31	0.65	1.65
Scenario 2B-HOV (20%)	1,947.16	527.25	43.60	0.37	1.38
Scenario 2B-HOV (30%)	1,677.39	229.05	51.65	0.16	1.16
Scenario 2B-HOV (40%)	1,616.18	169.56	53.57	0.12	1.12

4.1.3. Scenario 3A-HOV: Adding Lane Case Scenario Results

Results from Scenario 3A-HOV

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 9.

As expected, the addition of an HOV lane is able to improve traffic conditions. Even with no HOV lane designation (Scenario 3A-HOV [0%]), the new lane will result in an improvement of traffic operations compared to the base case scenario. With the shift of HOV traffic to the new lane, the average delay time decreases from **0.35** in the base case to **0.22 min/veh-mile** in Scenario 3A-HOV (30%), which represents the optimal case. Significant benefits are also observed with respect to average travel speeds, where an average increase of nearly 5 mph can be achieved under Scenario 3A-HOV

(30%) as compared to the base case. 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 until HOV traffic reaches approximately 30%. A further increase in HOV lane usage results in overloading which has a negative effect on traffic operations along the HOV lane and in the network overall. This is evident by the results reported in Table 9 for the case studied under Scenario 3A-HOV (40%).

Table 9. Comparison of Results from Scenario 3A-HOV: Adding Lane and Base Case

	Total Travel Time (veh-hours)	**Total Delay Time** (veh-hours)	**Avg. Travel Speed** (mph)	**Delay Time** (min/veh-mile)	**Total Time** (min/veh-mile)
Base Case Scenario	2,444.73	638.45	44.18	0.35	1.36
Scenario 3A-HOV (0%)	2,450.88	466.81	48.48	0.24	1.24
Scenario 3A-HOV (10%)	2,373.95	477.94	47.74	0.25	1.26
Scenario 3A-HOV (20%)	2,402.29	449.27	48.66	0.23	1.23
Scenario 3A-HOV (30%)	2,442.03	442.52	49.02	0.22	1.23
Scenario 3A-HOV (40%)	2,777.34	843.55	41.70	0.44	1.44

Results from Scenario 3B-HOV

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 10.

The results obtained under the assumptions of Scenario 3B-HOV clearly show the benefits on traffic operations from introducing a new dedicated HOV lane. When compared to the based case, a 10 mph increase in speed is observed under Scenario 3B-HOV case studies, which is significant.

Table 10. Scenario 3B-HOV: Adding Lane Case, Sensitivity Analysis Results with Equal People Carrying Ability

	Total Travel Time (veh-hours)	**Total Delay Time** (veh-hours)	**Avg. Travel Speed** (mph)	**Delay Time** (min/veh-mile)	**Total Time** (min/veh-mile)
Base Case Scenario	2,444.73	638.45	44.18	0.35	1.36
Scenario 3B-HOV (10%)	1,777.27	167.50	54.24	0.11	1.11
Scenario 3B-HOV (20%)	1,726.45	148.91	54.73	0.09	1.10
Scenario 3B-HOV (30%)	1,713.96	143.77	54.86	0.09	1.09
Scenario 3B-HOV (40%)	1,672.46	139.58	54.90	0.09	1.09

4.2. Truck-only Lanes Simulation Results

The simulations for the truck-only lane scenarios were completed with TSIS software using future traffic volumes. The next paragraphs summarize and discuss the truck-only lanes simulation results for each scenario based on the outputs from TSIS.

4.2.1. Scenario 1-T: Base Case Scenario Results

As mentioned before in HOV lane simulation results, the vehicles on I-65 travel at an average of **49.17 mph** where the total delay time in terms of veh-hours, is **381.63**. Assuming future traffic volumes that are 15% higher than 2006 volumes and 15% trucks in the traffic stream, the total delay time and average speed of the overall network for future conditions is found to be **638.45 veh-hours** and **44.18 mph**, respectively (Table 11).

Table 11. Comparison of Base Case Scenarios based on 2006 Traffic Volumes and Future Traffic Demand.

	Total Travel Time (veh-hours)	**Total Delay Time (veh-hours)**	**Avg. Travel Speed (mph)**	**Delay Time (min/veh-mile)**	**Total Time (min/veh-mile)**
2006 Traffic Volumes	2,172.32	381.63	49.17	0.22	1.22
Future Traffic Volumes	2,444.73	638.45	44.18	0.35	1.36

4.2.2. Scenario 2-T: Converting Lane Case Scenario Results

In Scenario 2-T, the assumption is that a dedicated truck lane will be implemented along the study corridor and the percentages of truck traffic that will use this lane will range from 5% to 15% in increments of 5%. Table 12 summarizes the results of scenario 2-T.

Table 12. Scenario 2-T: Converting Lane Case, Sensitivity Analysis Results

	Total Travel Time (veh-hours)	**Total Delay Time (veh-hours)**	**Average Travel Speed (mph)**	**Delay Time (min/veh-mile)**	**Total Time (min/veh-mile)**
Base Case Scenario	2,444.73	638.45	44.18	0.35	1.36
Scenario 2-T (5%)	2,528.37	521.16	47.20	0.26	1.27
Scenario 2-T (10%)	2,547.56	615.64	45.18	0.32	1.33
Scenario 2-T (15%)	2,599.05	717.52	43.22	0.38	1.39

It is observed that when a lane is converted to a dedicated truck lane in the study area and trucks are moved to this lane small positive gains are realized with respect to travel speed, travel time and delay. For example, the comparison of the Base Case and the

2-T (10%) Scenario demonstrates that for the same percentage of truck traffic (i.e., 10%) the presence of the truck lane resulted in a 1 mph speed increase and a **23 veh-hours** total delay savings. Still, the improvements are small and thus a lane conversion to truck lane is not justified based on the findings from the operational analysis.

Furthermore, it is likely that the presence of a designated truck lane may attract additional truck traffic in the future. If it is assumed that the percentage of trucks using the truck lane is 15% (i.e., 5% higher that current) and all trucks are forced to use the designated truck lane, then the total delay time increases to **717.52 veh-hours** and the average speed decreases to **43.22 mph**. Consequently, it is concluded that converting a lane to a truck lane in the current design configuration does not provide any measurable improvements and thus is not recommended.

4.2.3. Scenario 3-T: Adding Lane Case Scenario Results

Scenario 3-T also assumes that a lane is added to the current design configuration for the use of truck traffic. A sensitivity analysis similar to that of Scenario 2 is performed where the percentage usage is varied incrementally, and the results are shown in Table 13.

Adding a lane to the current design decreases the average delay time to **0.11** min/mi for 5% truck traffic. The average speed of the network also increases to **53.81 mph**, an improvement of almost **10 mph** compared to the base case. Reserving an extra lane for truck traffic is also a calming solution for the overall network. This is evident from the comparison of the results from the base case with 4 lanes to that from Scenario 2-T. While in both of these scenarios 4 travel lanes are available and 10% of truck traffic is served, by shifting the truck traffic to the dedicated truck lane a **2.4 mph** increase in the average travel speed is realized coupled with a nearly 20% reduction in total travel time (from **466.81** to **368.44 veh-hours**). The sensitivity analysis further confirms that the lower the percentage of truck traffic, the higher the average speed and the lower the delay time that is observed.

Table 13. Comparison of Results from Scenario 3-T: Adding Lane and Base Case

	Total Travel Time (veh-hours)	**Total Delay Time** (veh-hours)	**Avg. Travel Speed** (mph)	**Delay Time** (min/veh-mile)	**Total Time** (min/veh-mile)
Base Case Scenario (3 lanes)	2,444.73	638.45	44.18	0.24	1.24
Base Case Scenario (4 lanes)	2,450.88	466.81	48.48	0.24	1.24
Scenario 2-T (5%)	2,420.38	231.24	53.81	0.11	1.12
Scenario 2-T (10%)	2,512.43	368.44	50.88	0.17	1.18
Scenario 2-T (15%)	2,595.54	529.97	47.57	0.26	1.26

5. CONCLUSIONS AND RECOMMENDATIONS

This study analyzed a number of alternative scenarios to determine the impact of managed lanes on traffic operations along the I-65 corridor in Birmingham, AL. Both current and future travel demand conditions were analyzed, with future conditions representing an increase of 15% over 2006 AADT values. The modeling was performed in the TSIS environment using the features of the CORSIM model.

For the same demand levels under the base and HOV scenarios the results indicate that the conversion of an existing travel lane to an HOV or truck-only lane is not justifiable based solely on their impacts on traffic operations. On the other hand, moderate gains in travel speeds and delays are realized when adding a new lane and treating it as a managed lane. Under such conditions, an added HOV lane works best for HOV volumes that represent of 30% of total volumes. However, when adjusting the demand to account for the fact that HOV vehicles have greater occupancy and thus can carry more travelers in fewer vehicles, HOV lanes show a clear advantage over current operations. For example, when 30% of vehicles are HOVs the conversion of an existing lane to HOV leads to a 7.47 mph travel speed increase and more than 50% reduction in delay time compared to the base case. When a lane is added, a 10.68 mph speed increase is realized coupled with significant reductions in delay and travel times.

Moreover, when a lane is added, a designated truck lane that serves 10% on truck traffic results in a 2.4 mph increase in the average travel speed and a nearly 20%

reduction in total travel time when compared to a configuration that does not involve truck-lane management.

It is recommended that further calibration and validation studies are performed to improve modeling accuracy and the confidence in the model findings. Moreover, 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 is also recommended that alternative simulation software tools be considered to address some of the limitations of the TSIS software. For example, several studies confirm that TSIS tend to overestimate capacity and show that traffic conditions are better than they actually are. Innovative traffic modeling tools such as VISTA may be more versatile than traditional models such as The Visual Interactive System for Transport Algorithms (VISTA) and offer additional capabilities (such as Dynamic Traffic Assignment, or DTA) which, in turn, may create enhanced modeling opportunities in future work.

Moreover, the success of 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.

Finally, it is recommended that a cost-benefit analysis be performed to estimate potential benefits and costs, including capital, operation, and maintenance costs for the public and private sectors for the implementation of managed lane strategies in the Birmingham region.

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APPENDIX: DETAILED RESULTS OF SIMULATION RUNS

Detailed Results of Simulation Runs

Results of Scenario 1-HOV: Base Case with Existing Traffic Volumes

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,123.76	330.16	50.34	0.19	1.19
Run II	2,154.38	383.23	49.05	0.22	1.22
Run III	2,181.44	392.91	48.91	0.22	1.23
Run IV	2,179.00	377.96	49.30	0.21	1.22
Run V	2,223.03	423.89	48.27	0.24	1.24
Average Results	**2,172.32**	**381.63**	**49.17**	**0.22**	**1.22**

Future Results Assuming Existing Conditions

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,420.03	616.38	44.53	0.34	1.35
Run II	2,335.88	549.97	45.66	0.31	1.31
Run III	2,408.06	602.64	44.80	0.34	1.34
Run IV	2,480.86	670.55	43.62	0.37	1.38
Run V	2,578.83	752.72	42.29	0.41	1.42
Average Results	**2,444.73**	**638.45**	**44.18**	**0.35**	**1.36**

Scenario 2A-HOV: Converting Lane Case Results (HOVs 10%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	3,187.10	1,684.82	28.07	1.13	2.14
Run II	3,006.12	1,534.34	29.17	1.05	2.06
Run III	3,080.55	1,588.23	28.90	1.07	2.08
Run IV	3,022.69	1,528.01	29.46	1.03	2.04
Run V	3,116.78	1,625.20	28.50	1.10	2.11
Average Results	**3,082.65**	**1,592.12**	**28.82**	**1.08**	**2.09**

Scenario 2A-HOV: Converting Lane Case Results (HOVs 20%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,881.27	1,263.68	33.48	0.79	1.79
Run II	2,941.27	1,332.91	32.60	0.83	1.84
Run III	2,864.93	1,244.87	33.75	0.77	1.78
Run IV	2,941.85	1,327.66	32.70	0.83	1.83
Run V	2,898.42	1,280.28	33.30	0.80	1.80
Average Results	**2,905.55**	**1,289.88**	**33.17**	**0.80**	**1.81**

Scenario 2A-HOV: Converting Lane Case Results (HOVs 30%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,802.80	1,056.30	37.23	0.61	1.61
Run II	2,710.99	976.32	38.21	0.57	1.57
Run III	2,791.28	1,040.81	37.46	0.60	1.60
Run IV	2,762.78	1,018.69	37.71	0.59	1.59
Run V	2,743.35	998.76	37.96	0.58	1.58
Average Results	**2,762.24**	**1,018.18**	**37.71**	**0.59**	**1.59**

Scenario 2A-HOV: Converting Lane Case Results (HOVs 40%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,955.25	1,183.85	35.80	0.67	1.68
Run II	2,888.10	1,113.97	36.67	0.63	1.64
Run III	2,906.30	1,123.39	36.66	0.63	1.64
Run IV	2,927.55	1,148.41	36.35	0.65	1.65
Run V	2,939.23	1,160.48	36.16	0.66	1.66
Average Results	**2,923.29**	**1,146.02**	**36.33**	**0.65**	**1.65**

Scenario 2B-HOV: Converting Lane Case Results (HOVs 10%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,245.90	885.05	36.14	0.65	1.66
Run II	2,275.42	895.59	36.16	0.65	1.66
Run III	2,267.92	883.91	36.41	0.64	1.65
Run IV	2,288.74	905.09	36.05	0.66	1.66
Run V	2,194.69	841.15	36.79	0.63	1.63
Average Results	**2,254.53**	**882.16**	**36.31**	**0.65**	**1.65**

Scenario 2B-HOV: Converting Lane Case Results (HOVs 20%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	1,943.66	517.61	43.82	0.36	1.37
Run II	1,950.39	521.81	43.80	0.37	1.37
Run III	1,872.96	452.93	45.33	0.32	1.32
Run IV	1,969.13	551.63	43.03	0.39	1.39
Run V	1,999.68	592.29	42.04	0.42	1.43
Average Results	**1,947.16**	**527.25**	**43.60**	**0.37**	**1.38**

Scenario 2B-HOV: Converting Lane Case Results (HOVs 30%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	1,713.15	270.25	50.34	0.19	1.19
Run II	1,681.49	228.62	51.68	0.16	1.16
Run III	1,645.34	200.35	52.55	0.14	1.14
Run IV	1,643.89	195.96	52.66	0.14	1.14
Run V	1,703.07	250.06	51.03	0.17	1.18
Average Results	**1,677.39**	**229.05**	**51.65**	**0.16**	**1.16**

Scenario 2B-HOV: Converting Lane Case Results (HOVs 40%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	1,642.59	179.60	53.24	0.12	1.13
Run II	1,615.53	165.65	53.74	0.11	1.12
Run III	1,598.54	167.96	53.59	0.12	1.12
Run IV	1,623.76	170.37	53.56	0.12	1.12
Run V	1,600.49	164.20	53.71	0.11	1.12
Average Results	**1,616.18**	**169.56**	**53.57**	**0.12**	**1.12**

Scenario 3A-HOV: Adding Lane Case Results (HOVs 0%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,436.26	454.44	48.67	0.23	1.23
Run II	2,297.05	324.28	51.36	0.16	1.17
Run III	2,467.99	470.57	48.38	0.24	1.24
Run IV	2,598.89	612.55	45.70	0.31	1.31
Run V	2,454.22	472.22	48.30	0.24	1.24
Average Results	**2,450.88**	**466.81**	**48.48**	**0.24**	**1.24**

Scenario 3A-HOV: Adding Lane Case Results (HOVs 10%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,348.53	459.58	48.10	0.24	1.25
Run II	2,381.52	480.76	47.68	0.25	1.26
Run III	2,351.79	457.72	48.14	0.24	1.25
Run IV	2,421.04	521.34	46.87	0.28	1.28
Run V	2,366.88	470.29	47.90	0.25	1.25
Average Results	**2,373.95**	**477.94**	**47.74**	**0.25**	**1.26**

Scenario 3A-HOV: Adding Lane Case Results (HOVs 20%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,419.22	491.05	47.71	0.26	1.26
Run II	2,322.80	371.29	50.23	0.19	1.19
Run III	2,363.18	389.68	49.96	0.20	1.20
Run IV	2,470.44	505.82	47.51	0.26	1.26
Run V	2,435.79	488.51	47.87	0.25	1.25
Average Results	**2,402.29**	**449.27**	**48.66**	**0.23**	**1.23**

Scenario 3A-HOV: Adding Lane Case Results (HOVs 30%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,467.50	465.60	48.53	0.23	1.24
Run II	2,476.22	487.78	48.04	0.25	1.25
Run III	2,447.70	430.85	49.31	0.21	1.22
Run IV	2,326.23	347.75	50.90	0.18	1.18
Run V	2,492.50	480.60	48.30	0.24	1.24
Average Results	**2,442.03**	**442.52**	**49.02**	**0.22**	**1.23**

Scenario 3A-HOV: Adding Lane Case Results (HOVs 40%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,742.01	806.53	42.27	0.42	1.42
Run II	2,862.02	920.12	40.62	0.47	1.48
Run III	2,786.51	857.91	41.45	0.45	1.45
Run IV	2,758.94	826.51	41.91	0.43	1.43
Run V	2,737.20	806.68	42.23	0.42	1.42
Average Results	**2,777.34**	**843.55**	**41.70**	**0.44**	**1.44**

Scenario 3B-HOV: Adding Lane Case Results (HOVs 10%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	1,760.18	163.25	54.31	0.10	1.10
Run II	1,768.65	163.80	54.32	0.10	1.10
Run III	1,778.32	168.86	54.21	0.11	1.11
Run IV	1,800.22	172.13	54.17	0.11	1.11
Run V	1,778.97	169.45	54.17	0.11	1.11
Average Results	**1,777.27**	**167.50**	**54.24**	**0.11**	**1.11**

Scenario 3B-HOV: Adding Lane Case Results (HOVs 20%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	1,725.17	145.66	54.80	0.09	1.09
Run II	1,730.89	152.49	54.70	0.10	1.10
Run III	1,720.47	148.07	54.73	0.09	1.10
Run IV	1,713.80	147.72	54.69	0.09	1.10
Run V	1,741.91	150.60	54.75	0.09	1.10
Average Results	**1,726.45**	**148.91**	**54.73**	**0.09**	**1.10**

Scenario 3B-HOV: Adding Lane Case Results (HOVs 30%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	1,721.03	145.02	54.81	0.09	1.09
Run II	1,697.46	139.97	54.90	0.09	1.09
Run III	1,692.10	139.28	54.91	0.09	1.09
Run IV	1,732.23	151.04	54.71	0.10	1.10
Run V	1,726.96	143.55	54.98	0.09	1.09
Average Results	**1,713.96**	**143.77**	**54.86**	**0.09**	**1.09**

Scenario 3B-HOV: Adding Lane Case Results (HOVs 40%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	1,649.13	125.45	55.34	0.08	1.08
Run II	1,674.64	127.61	55.27	0.08	1.09
Run III	1,681.63	151.29	54.50	0.10	1.10
Run IV	1,692.91	158.85	54.30	0.10	1.11
Run V	1,663.98	134.72	55.11	0.09	1.09
Average Results	**1,672.46**	**139.58**	**54.90**	**0.09**	**1.09**

Scenario 2-T: Converting Lane Case Results (5%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,530.47	525.94	47.07	0.26	1.27
Run II	2,423.06	419.08	49.17	0.21	1.22
Run III	2,545.35	545.47	46.69	0.28	1.28
Run IV	2,551.74	547.82	46.68	0.28	1.29
Run V	2,591.24	567.49	46.38	0.28	1.29
Average Results	**2,528.37**	**521.16**	**47.20**	**0.26**	**1.27**

Scenario 2-T: Converting Lane Case Results (10%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,485.05	564.73	46.08	0.30	1.30
Run II	2,640.56	710.89	43.51	0.37	1.38
Run III	2,561.88	620.52	45.11	0.32	1.33
Run IV	2,507.54	580.10	45.73	0.30	1.31
Run V	2,542.77	601.94	45.47	0.31	1.32
Average Results	**2,547.56**	**615.64**	**45.18**	**0.32**	**1.33**

Scenario 2-T: Converting Lane Case Results (15%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,559.63	675.02	43.94	0.36	1.37
Run II	2,547.94	666.21	44.08	0.36	1.36
Run III	2,659.24	776.08	42.29	0.41	1.42
Run IV	2,575.50	702.96	43.38	0.38	1.38
Run V	2,652.94	767.32	42.41	0.41	1.41
Average Results	**2,599.05**	**717.52**	**43.22**	**0.38**	**1.39**

Scenario 2-T: Adding Lane Case Results (5%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,413.72	232.25	53.79	0.11	1.12
Run II	2,442.15	252.69	53.32	0.12	1.13
Run III	2,401.33	218.70	54.10	0.10	1.11
Run IV	2,440.70	230.54	53.83	0.11	1.11
Run V	2,404.01	222.02	54.00	0.10	1.11
Average Results	**2,420.38**	**231.24**	**53.81**	**0.11**	**1.12**

Scenario 2-T: Adding Lane Case Results (10%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,509.09	356.92	51.15	0.17	1.17
Run II	2,488.14	359.70	50.99	0.17	1.18
Run III	2,450.70	303.06	52.22	0.14	1.15
Run IV	2,561.42	428.31	49.65	0.20	1.21
Run V	2,552.79	394.23	50.39	0.18	1.19
Average Results	**2,512.43**	**368.44**	**50.88**	**0.17**	**1.18**

Scenario 2-T: Adding Lane Case Results (15%)

	Total Travel Time (veh-hours)	Total Delay Time (veh-hours)	Average Travel Speed (mph)	Delay Time (min/veh-mile)	Total Time (min/veh-mile)
Run I	2,570.68	485.66	48.47	0.23	1.24
Run II	2,701.04	640.43	45.55	0.31	1.32
Run III	2,565.14	507.45	47.90	0.25	1.25
Run IV	2,503.45	426.93	49.50	0.21	1.21
Run V	2,637.38	589.39	46.41	0.29	1.29
Average Results	**2,595.54**	**529.97**	**47.57**	**0.26**	**1.26**

BIOGRAPHY

Ms. **Ozge Cavusoglu** is a Research Assistant at the University of Alabama at Birmingham (UAB). She holds a B.S. degree in Urban and Regional Planning from Mimar Sinan University and an M.Sc. degree in Urban and Regional Planning from Gebze Institute of Technology (GIT). She is currently pursing a Master's degree in Civil Engineering with emphasis in Transportation at UAB under the direction of Dr. Virginia Sisiopiku.