Analysis of Operational and Economic Impacts from the Implementation of High Occupancy Vehicle Lanes Strategies

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Abstract: Lane management is a promising approach for congestion management through demand regulation, separation of traffic streams to reduce turbulence, and better utilization of available capacity. In response to the continually growing problem of urban congestion in the Birmingham, Alabama metropolitan area, this study examined the potential introduction of High Occupancy Vehicle Lanes (HOV) as a managed lanes strategy for improving traffic operations and assisting in congestion mitigation. More specifically, the study first reviewed lane management options and lessons learned from earlier HOV deployments efforts. Then micro-simulation modeling was employed to quantify the potential operational impacts of implementation of HOV along a segment of I-65 freeway. Different design scenarios were considered and compared on the basis of measures of effectiveness including travel time, delay, travel speed, and emissions. Moreover, a detailed cost-benefit analysis was performed to estimate economic impacts from possible deployment and determine the most economically efficient investment alternative in the short- and long term.

Key Words: Managed lanes, High Occupancy Vehicle Lanes, Freeway Operations, Congestion

1. Introduction

The U.S. highway system is a critical component of American life that provides extensive and flexible personal mobility to American citizens and efficient freight movement to support the domestic economy. Both of these services are affected by investment and location decisions that governmental entities across the country make in their planning processes (Mirshahi et al., 2007). However, an increase in travel, congestion, and environmental and financial constraints interfere with the system's ability to provide these services. The 2007 Texas Transportation Institute (TTI) study of urban mobility reports that congestion amounts to a cost of $710 per traveler per year and causes the average peak-period traveler to spend an extra 38 hours of travel time on the road annually and consume an additional 26 gallons of fuel (Schrank and Lomax, 2007). On the other hand, the growth in vehicle miles traveled (VMT) continues to outpace lane mile growth across the country. Between 1993 and 2000, VMT increased 2.7 percent annually while the number of U.S. lane miles grew only 0.2 percent annually. This growth in travel places a strain on an already-overburdened transportation system (U.S. DOT, 2002).

Urban areas in Alabama face similar challenges to those experienced 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 as one of the medium-sized urban areas with higher congestion or faster increases in urban congestion than their counterparts (Schrank and Lomax, 2005). Based on 2005 data, the average annual hours of delay per traveler in the Birmingham area was 33 hrs, which is more than 50% higher to the figure reported in 1995 (i.e., 21 hrs) and significantly higher than the average reported in the 2005 TTI study for comparable size cities (28 hrs average). As a result, congestion in Birmingham resulted in 12.41 million hours of travel delay and 8.21 million gallons in excess fuel consumption in 2005 alone.

In order to address the continually growing problem of urban congestion at the national and the local level agencies consider various operational and management strategies including the use of managed lanes. Managed lanes, a component of congestion management, are defined as interstate or high speed expressway travel lanes that manage traffic flow through access restrictions or pricing in response to changing travel conditions. 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 lane option (Charmeck, 2007).

Managed lane projects have the potential to improve mobility while reducing the increase in pollution and minimizing the impact on the environment. They also have the potential to better use existing facilities and reduce the impact of the increase in travel. They may lend themselves to alternative funding mechanisms, thereby reducing financial constraints and allowing projects to be completed sooner than under traditional funding schemes (Mirshahi et al., 2007). The potential of lane management strategies that fall into the broad definition of managed lanes is illustrated in Figure 1 (Collier and Goodin, 2004).

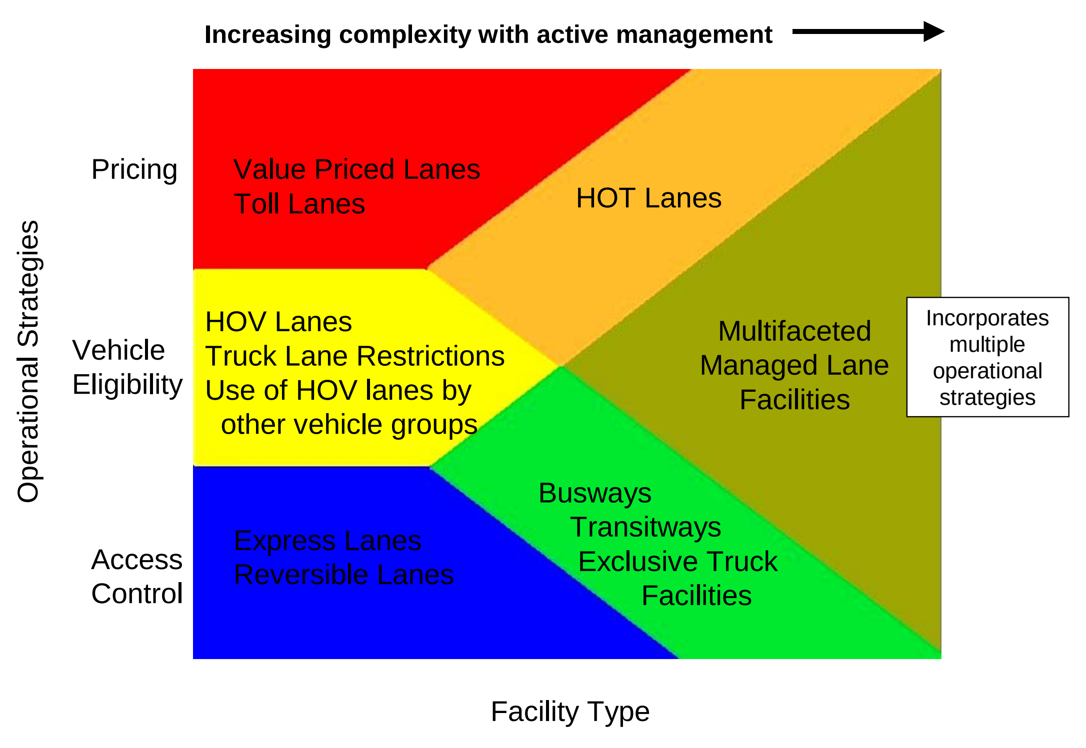


Figure 1- Typical U.S. Managed Lane Facilities and Applications (Collier and Goodin, 2004).

There are numerous references that review in detail lane management options, implementation requirements, case studies, and lessons learned. Due to the scope of this study, the following paragraphs discuss lessons learned from earlier deployments of HOV strategies, which is the main focus of this paper.

1.1 HOV Literature Review

HOV lanes have been used widely in many parts of the United States since the 1970s (NCHRP, 1998). Today there are over 125 HOV lanes projects in 30 cities operating over 2,500 lane-miles of HOV facilities and carrying more than 3 million persons everyday (NCDOT, 2007). Examples of states that operate HOV systems include Houston and Dallas, TX; Seattle, WA; Los Angeles, Orange County, and San Francisco Bay, CA; New York City, NY; Northern Virginia, VA; Washington, D.C.; Atlanta, GA; and Boston, MA (Sisiopiku and Cavusoglu, 2008).

Many studies available in the literature confirm that the implementation of HOV lanes resulted in delay savings and more predictable travel times. For example, the Washington, D.C. region where three interstate HOV lane corridors are in operation reported travel time savings due to HOV operation range from 5 to 36 minutes for morning rush hours and 36 minutes for the evening rush (Fuhs and Obenberger, 2002, and HTHW, 2007).

Studies also confirm an increase in person-carrying ability of lanes operating as HOV in Dallas and Houston, TX. According to a study performed 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 increased by 14% and the HOV lane carried twice the number of people compared to an adjacent general-purpose lane during the peak hour. Automobile occupancy also increased from 8 to 12%, while the average automobile occupancy on that route, without an HOV lane, has decreased by 2% (TTI, 1999). Furthermore, morning peak hour travel time savings from approximately 2 to 22 minutes were realized in HOV lanes. It is worth noting that periodic surveys of HOV lane users show that nearly 45% of current carpoolers and 46% of bus riders previously drove alone (FHWA, 2003).

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 than triple that of the general purpose lanes averaging just 1.01 persons per vehicle (TCRP, 2006).

The Los Angeles County has an impressive system of HOV facilities with 14 HOV corridors covering over 470 HOV lane miles, or approximately 36% of the total 1,320 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 during the morning 2-hour peak was 79% (CALTRANS, 2007). 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 (LACMTA, 2007).

Washington State has implemented approximately 200 lane miles of a planned 300-mile freeway HOV lane and ramp system since 1970. Today, HOV lanes carry nearly 35% of the commuters and 18% of the vehicles during rush hours on freeways. It is reported that the average HOV lane is carrying more than 1½ times as many people as the average “regular” lane during the peak commuting periods and HOV use results in significant time savings (WSDOT, 2007). 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 (TCRP, 2006).

While most HOV lane projects reported in the literature are success stories, public opposition resulted in the closing of HOV lanes on two corridors in New Jersey (I-287 and I-80) in 1999 (TTI, 1999). Concurrent flow HOV lanes were implemented along I-80 and I-287 in 1994 and 1998 respectively but were forced to closure due to strong political opposition. Although many of the elements associated with successful HOV projects were present to some extent with the I-80 and I-287 HOV lanes, some critical factors were missing, modified, or not implemented during the course of the projects. These elements focus primarily on the changes in the policy and regulatory environment and the lack of supporting facilities, services, and programs. 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 (Martin et al., 2005).

1.2 Study Scope

This study focuses on quantification of impacts from potential implementation of HOV lanes in the Birmingham, AL region as a tool to address local congestion and environmental related concerns. HOV is a strategy used to maximize capacity by increasing the number of passengers per vehicle and is one among a number of potential managed lanes options that the Regional Planning Commission of Greater Birmingham (RPCGB) considered as part of its congestion mitigation program.

More specifically, in 2006, 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 north-south corridor serving metropolitan Birmingham. Transportation options screened for fatal flaws included HOV lanes, 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. Issues considered include physical, environmental, financial, and operability constraints as well as political and public perception challenges (HTHW, 2007).

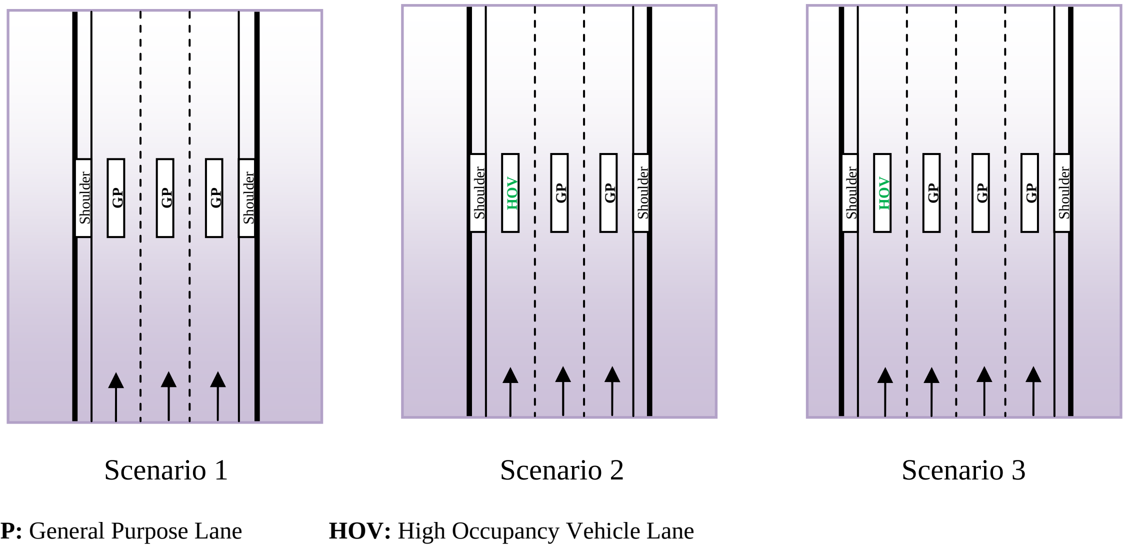
The fatal flows study recommended further consideration of HOV lanes on the I-65 corridor and indicated that a 12.5 mile-long segment of I-65 extending from Valleydale Rd to I-20/59 had the best potential and greater need for immediate implementation (RPCGB, 2006). Based on traffic counts reported by the Alabama Department of Transportation (ALDOT), the daily traffic volumes in 2005 along this segment of I-65 ranged from 75,000 to 125,000 with a 10% truck volume. Table 1 summarizes the operational characteristics of the study site based on local studies performed in 2005 and 2006 (RPCGB, 2006).

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

Table 1- Operational Characteristics of the I-65 Study Corridor-NB Direction (RPCGB, 2006)

Based on the considerations above, this study focused on a segment of I-65 that extends from the I-459 interchange on the south end to the I-20/59 interchange on the north. The study segment traverses the cities of Hoover, Vestavia Hills, Homewood and Birmingham and is one of the backbones of the Birmingham's transportation system. The section currently consists of three 12-ft general purpose lanes with shoulder in each direction of travel with a posted speed limit of 60 mph.

First, the study considered current conditions as the baseline for comparison purposes (Scenario 1). To improve the traffic congestion situation two major development alternatives were assumed. One alternative was to convert one lane in each direction to an HOV lane (Scenario 2) and the other alternative was to add a new lane in each direction designated for HOV usage (Scenario 3). All HOV lanes considered were concurrent flow without buffer separation. A schematic of typical lane configurations under the three scenarios is shown in Figure 2.



Scenario 1 Scenario 2 Scenario 3

GP: General Purpose Lane **HOV:** High Occupancy Vehicle Lane

Figure 2- Typical Lane Configurations for HOV Scenarios- Birmingham Case Study

1.3 Study Objective and Approach

The objective of the Birmingham HOV study reported herein is twofold:

a. Determine the impacts of various HOV strategies on traffic operations especially as they related to mobility and the environment, and
b. Quantify costs and benefits from potential implementation and identify strategies with the highest potential return for the investment.

To achieve these objectives, the study performed a detailed alternatives analysis using traffic simulation tools and cost-benefit analysis to predict the impact of HOV implementation along the I-65 corridor on traffic operations in the Birmingham area.

The **simulation analysis** was performed using the Traffic Software Integrated System (TSIS). TSIS is a suite of simulation models developed by the Federal Highway Administration (FHWA) that has been used extensively by transportation agencies and practitioners in the U.S. and abroad for over three decades. The CORSIM simulator in TSIS has the ability to simulate fairly complex geometric conditions and realistic driver behavior and offers the capability to analyze a variety of lane management strategies, including HOV. Like most of the currently available microscopic traffic simulation models, TSIS requires detailed geometric, traffic, and control data as inputs. Geometric data (such as number of lanes, lane widths, turning pockets, grades, etc) were gathered and incorporated into the model. Moreover, vehicle volumes were determined using 2006 Average Annual Daily Traffic (AADT) data. The simulation model was run for the project alternatives under study (Scenarios 1 through 3). For Scenarios 2 and 3 a sensitivity analysis was performed by varying the percentage of vehicles using the HOV lane (from 10% up to 25% in increments of 5%) and observing the relative changes in model response. For each scenario and each strategy considered a set of 5 runs was performed using 5 different seeds to account the randomness and average results were reported throughout the study. The same 5 seed numbers were used for all scenarios in order to enable a comparison of the results. Additional details about the simulation study approach, assumptions, and summary findings are presented in Section 2.

The **cost-benefit analysis** considered life-cycle costs and benefits of the project alternatives under study in order to identify the most economically efficient investment alternative, i.e., the one that maximizes the net benefits from an allocation of resources. The life-cycle costs considered in the analysis included design and engineering costs, right-of-way procurement costs, construction and maintenance costs. Life-cycle benefits included vehicle operating cost savings, travel time savings, safety benefits, and emission reduction benefits. The analysis quantified costs and benefits for all study scenarios and strategies described above. Details on the methodology and summary findings from the cost-benefit analysis are described in Section 3.

2. Simulation Study

2.1 Background

Using CORSIM and TSIS tools a simulation model of the I-65 facility was developed extending from the I-459 interchange in the south to the I-20/59 interchange to the north. The demands used were based on 2006 data that were increased by 15% to account of future increases in traffic volumes. Trucks accounted for 15% of the total volume. Vehicle occupancy of 1.3 persons/veh was considered in the general purpose lanes and 2.0 persons/veh in HOV lanes. To provide a fair comparison between current and HOV operations, the study assumed that the facility should serve the same number of travelers with or without HOV lanes. Thus the demand used in the HOV scenarios was adjusted accordingly to account for the impact of higher vehicle occupancies. As a result the number of vehicles in the network decreased with the increase of HOV usage, which is indeed the main objective of the HOV implementation.

As indicated in Section 1 three scenarios were studied as follows:

- **Scenario 1-HOV** described network operations under current conditions (i.e., no HOV lane presence, general purpose lanes only) and provided the baseline for comparisons.
- **Scenario 2-HOV** assumed that the innermost general purpose lane was converted to an HOV lane.
- **Scenario 3-HOV** assumed that an HOV lane was added to the current design configuration.

Scenario 2 considered four options with varying high occupancy lane usage, namely HOV 10%, HOV 15%, HOV 20% and HOV 25%. Similarly Scenario 3 considered five options based on HOV lane usage ranging from 0% (no HOV) to 25%. Every option was run for 2 hrs of simulation time and for 5 replications, the results of which were averaged as discussed in Section 1.3. Comparisons were based on the Measures of Effectiveness (MOEs) shown below and summary results from the simulation study are presented next.

- Total network travel time (veh-hrs);
- Total network delay (veh-hrs);
- Average travel speed (mph);
- Delay time (min/veh-mile);
- Travel time (min/veh-mile);
- Total HC emissions (grams/mile);
- Total CO emissions (grams/mile);
- Total NO emissions (grams/mile); and
- Total fuel consumption (gallons).

2.2 Simulation Study Results

2.2.1 Operational Performance

The results for all scenarios and for various levels of HOV lane usage are summarized in Table 2. Comparison of findings from Scenarios 1 and 2 shows that the conversion of a freeway lane to HOV is not justified on the basis of operational benefits. This is evident from the higher travel times and delays and the lower speeds reported under the converted lane scenario (Scenario 2) in comparison to the baseline results (Scenario 1). A possible explanation is that the remaining general purpose lanes are unable to handle the non-HOV demand, a fact that leads in increased congestion under the lane conversion scenario, as compared to the baseline.

Scenario 1: Base case, no HOV lanes on I – 65					
Alternative	**Total Travel Time (veh-hrs)**	**Total Delay Time (veh-hrs)**	**Avg. Travel Speed (mph)**	**Delay Time (min/veh-mile)**	**Total Time (min/veh-mile)**
Option 1: HOV 0%	5,363	1,744	40.38	0.48	1.49
Scenario 2: Conversion of one lane in each traveling direction of I – 65 to HOV lane					
Option 2: HOV 10%	5,450	2,782	29.22	1.05	2.05
Option 3: HOV 15%	5,149	2,433	31.49	0.90	1.91
Option 4: HOV 20%	4,674	1,861	36.01	0.66	1.67
Option 5: HOV 25%	4,800	1,953	35.47	0.69	1.69
Scenario 3: Addition of one lane in each travelling direction of I – 65 and use as HOV lane					
Option 6: no HOV	5,079	1,421	44.08	0.36	1.36
Option 7: HOV 10%	3,553	338	54.19	0.11	1.11
Option 8: HOV 15%	3,491	314	54.52	0.10	1.10
Option 9: HOV 20%	3,456	297	54.74	0.09	1.10
Option 10: HOV 25%	3,459	294	54.80	0.09	1.09

Table 2- Summary of Simulation Results-Operational MOEs over the Simulation Period

On the other hand, addition of an extra lane in Scenario 3 (Option 6) improves speeds (by nearly 10%) and reduces delays (by 25%) compared to the baseline (Option 1). Furthermore, the use of the new lane as an HOV lane brings considerable benefits, even when the HOV lane utilization is small. For example, comparison of Options 6 and 7 shows that when the added lane is designated as HOV even a moderate HOV lane usage of 10% leads to significant increase in average travel speeds (over 10 mph) compared to the addition of a general purpose lane. In other words, should a lane be added to the facility, the addition of an HOV would be far more beneficial than an extra general purpose lane and is fully justifiable based on operational considerations, even under the current ride sharing patterns in the region. In summary, and based on the results of the operational analysis, the HOV lane addition strategy (Scenario 3) is the recommended strategy for implementation.

2.2.2 Environmental Impacts

Table 3 summarizes annual environmental impacts of the various scenarios and options considered in the simulation analysis. The findings support the conclusions derived from the operational analysis (Section 2.2.1). More specifically, the lane conversion to HOV operation results in increase of annual emissions and fuel consumption, and thus is not viewed as an environmental friendly approach. On the other hand, under the study assumptions, the addition of a designated HOV lane is expected to result in HC, CO, and NO emission savings as well as reduction in annual total fuel consumption. As seen in Table 3, the environmental benefits increase as a higher percentage of travelers shifts to ride sharing options (i.e., as HOV lane utilization increases). Thus Scenario 3 is the most favorable strategy for adoption as far as environmental impacts are concerned.

<table>
<tr><td colspan="5">Scenario 1: Base case, no HOV lanes on I – 65</td></tr>
<tr><th>Alternative</th><th>Total HC Emissions (Tons)</th><th>Total CO Emissions (Tons)</th><th>Total NO Emissions (Tons)</th><th>Total Fuel Consumption (Million Gallons)</th></tr>
<tr><td>Option 1: HOV 0%</td><td>285.45</td><td>2174.20</td><td>567.55</td><td>13.45</td></tr>
<tr><td colspan="5">Scenario 2: Conversion of one lane in each traveling direction of I – 65 to HOV lane</td></tr>
<tr><td>Option 2: HOV 10%</td><td>352.66</td><td>3061.56</td><td>461.77</td><td>18.30</td></tr>
<tr><td>Option 3: HOV 15%</td><td>298.56</td><td>2413.54</td><td>446.45</td><td>15.63</td></tr>
<tr><td>Option 4: HOV 20%</td><td>280.88</td><td>2261.05</td><td>426.16</td><td>14.59</td></tr>
<tr><td>Option 5: HOV 25%</td><td>263.19</td><td>2109.07</td><td>405.88</td><td>14.89</td></tr>
<tr><td colspan="5">Scenario 3: Addition of one lane in each traveling direction of I – 65 and use as HOV lane</td></tr>
<tr><td>Option 6: no HOV</td><td>269.71</td><td>1720.85</td><td>589.35</td><td>13.89</td></tr>
<tr><td>Option 7: HOV 10%</td><td>248.24</td><td>1579.97</td><td>451.91</td><td>12.71</td></tr>
<tr><td>Option 8: HOV 15%</td><td>237.13</td><td>1509.69</td><td>509.76</td><td>12.15</td></tr>
<tr><td>Option 9: HOV 20%</td><td>226.04</td><td>1439.08</td><td>486.55</td><td>11.59</td></tr>
<tr><td>Option 10: HOV 25%</td><td>214.95</td><td>1368.80</td><td>463.35</td><td>11.02</td></tr>
</table>

Table 3- Summary of Simulation Results-Annual Environmental MOEs

3. Cost-Benefit Analysis

The Cost-Benefit analysis considered life-cycle costs and life-cycle benefits of the project alternatives under study. The life-cycle costs include design and engineering costs, right-of-way procurement costs, construction costs, and maintenance costs. Life-cycle benefits include vehicle operating cost savings, travel time savings, safety benefits, and emission reduction benefits. Similar to the simulation analysis, three scenarios with various options were designed in order to conduct a thorough Cost-benefit Analysis and to determine the economically efficient alternative. The three scenarios considered in the analysis are the following:

- **Scenario 1:** Base case (no HOV on I-65).
- **Scenario 2:** Conversion of one lane in each travelling direction of I – 65 to HOV lane.
- **Scenario 3:** Addition of one HOV lane in each travelling direction of I – 65.

Scenario 2 has four options with varying High Occupancy Lane usage, namely HOV 10%, HOV 15%, HOV 20% and HOV 25%. Similarly Scenario 3 has five options based on HOV lane usage. With these three scenarios consisting of ten options, a detail Cost-Benefit analysis (CBA) was performed to measure the worthiness of the proposed investment in order to identify the best option.

3.1 Methodology

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

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

The infrastructure cost has two components, namely investment cost, and operation and maintenance cost. Investment cost of the project includes design and engineering costs, land acquisition costs and construction costs. The benefits of highway improvement projects are estimated as a function of the MOEs obtained from the CORSIM simulation analysis. The four primary categories of user benefits that were considered are:

- Vehicle Operating Cost Savings
- Travel Time Savings
- Safety Benefits (Accident Cost Savings)
- Emission Reductions.

Following the cost-benefit analysis procedure, the costs and benefits were discounted on year-to-year basis, and projected for the analysis period 2010 -2020 and 2010– 2030.

3.1.1 Traffic Data

The benefits of highway improvement projects were estimated as a function of the speed and volume of traffic with and without the project. The required data such as Vehicle Miles Traveled, Travel Time, Delay Time, Person Time etc. are estimated based on existing traffic condition and using a simulation model CORSIM. The relevant traffic data along the specific 12.5 miles long segment of I – 65 were estimated for the base year 2010 through 2030. For future projection of traffic the historical traffic data along I – 65 Corridor provided by the ALDOT website were reviewed and considered (ALDOT, 2009).

3.1.2 Discount Rate

The discount rate, or interest rate, is one of the variables necessary to complete a Cost Benefit Analysis utilizing the Net Present Value (NPV) method. The Federal Highway Administration (FHWA) suggests using a discount rate between 3 and 5 percent (Smith and Walls, 1998). ALDOT currently uses a 4 percent discount rate on its life-cycle cost analyses (Lindly and Clark, 2003). In this analysis a 4% discount rate is considered.

3.1.3 Infrastructure Costs

It was assumed that the construction work begins in year 2010. For Scenario 2, i.e. the HOV lane conversion option, the construction work would be completed in the same year. The facility would open for regular operation from Year 2011. For Scenario 3, i.e. the lane addition scenario, it was assumed that the project would start in Year 2010 and end in Year 2012. The facility would operate with HOV lanes from Year 2013. The construction costs and maintenance costs were estimated on the basis of ALDOT cost estimates and RPCGB (2007). The Lane Conversion (Scenario 2) involves the conversion of one lane in each travelling direction as HOV lane. The construction cost for this scenario includes resurfacing of existing pavement and striping costs. The Lane Addition (Scenario 3) works include purchase of right-of-way (ROW), physical construction of new lane and shoulder, widening of bridges, pavement marking, and placement of necessary highway features. The construction and maintenance costs for different options considered in the study are summarized in Table 3.1.

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

Table 4 - Construction and Maintenance Costs for Different Options and Analysis Periods

3.1.4 Benefits of Different Scenarios

The major benefits of highway improvement works arise from (i) vehicle operating cost saving, (ii) value of travel time saving, (iii) accident cost savings and (iv) emission cost saving. All of these benefits were quantified in dollar values and were used for the analysis.

Vehicle Operating Cost (VOC) Savings

Vehicle Operating Costs were calculated based on the fuel consumption (in gallons) data that generated along with output of the simulation model (CORSIM). To calculate total fuel costs, fuel consumption was multiplied by fuel cost per gallon minus taxes (currently $1.70). Non-fuel costs are not considered in the analysis.

Value of Travel Time Savings

The value of time (VOT) is the opportunity cost of the time that a traveler spends on their journey. In essence, VOT is the amount that a traveler would be willing to pay in order to save time, or the amount they would accept as compensation for lost time. One of the main justifications for transportation improvements is the amount of time that travelers will save. Different agencies are using different monitory (dollar) values for VOT based on different estimation procedures. The VOT used for the analysis is $14.85 per hour for automobiles and $

21.20 for trucks, based on the value used by the Texas Transportation Institute in their annual report on urban traffic congestion (TRIP, 2006).

Safety Benefits – Accident Cost Savings

Reducing the number of vehicle accidents is a primary motivation for many highway capital investments or improvement projects. Reductions in the number or severity of accidents can be converted to an annual benefit, measured in dollars, and included in a benefit-cost analysis. An assessment of accident savings for proposed highway projects requires an examination of the historical accident rates for the area, or historical rates for the roadway type. For these estimation purposes, accident types are divided into three broad categories of severity – fatal, injury, and property damage only (PDO). Two factors were considered in estimating the value of accident costs: (i) frequency of accidents and, (ii) value of an accident. The historical accident statistics of the US and that of the state of Alabama were reviewed and incorporated in the analysis. The unit costs of accidents by severity (as estimated by National Safety Council), is presented in Table 5 and used in the analysis.

Types of Accident	Accident Costs [$]
Fatal	3,460,000
Injury	188,000
Property Damage Only (PDO)	2,100

Table 5- Accident Costs (Source: NSC, 2005)

Emissions Costs Savings

Highway infrastructure projects that increase the capacity of a facility may reduce vehicle emissions by reducing congestion, which is considered as a significant benefit of transportation infrastructure improvement works. In this analysis the simulation model output of Hydro Carbon (HC), Carbon Monoxide (CO) and Nitrogen Oxide (NOx) emissions were used to estimate the health cost of emission. The emission health cost rates as expressed in dollar per ton of emissions are available at the US Environmental Protection Agency (EPA) website.

3.1.5 Cost-Benefit Analysis

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

(i) Net Present Value (NPV),
(ii) Benefit Cost Ratio (BCR), and
(iii) Internal Rate of Return (IRR).

The economic analyses were carried out over two time spans (2010 – 2020 and 2010 – 2030) for each of the options under the study. The cash flow of each of the options under study was discounted at the FHWA recommended and ALDOT practiced discount rate of 4%. Discounting the cash flow of the project options is quite a straightforward exercise and is required to be done in order to take care of time value of money.

3.2 Cost-Benefit Analysis Results

Based on the assumptions discussed in Section 3.1.4 savings obtained from the introduction of HOV operations in Scenarios 2 and 3 were determined in comparison to Scenario 1. These include Vehicle Operating Cost savings, Vehicle Travel Time savings, Accident Cost savings and Emission Cost Savings and were later used to determine benefit/cost ratios. The findings for the study site are summarized next.

Vehicle Operating Cost Savings

The estimated Vehicle Operating Cost (VOC) savings with respect to the base case (Scenario 1, Option 1), for different other Options are given in the Table 6. It can be observed that Vehicle Operating Cost savings are realized by the introduction of HOV operations that increase with the increase in HOV lane usage.

Scenario 1: Base Case Scenario, Other Scenarios are compared to this Scenario		
Scenario 2: Converting One General Purpose Lane into HOV Lane in Each Direction		
Options	VOC Savings [Million $] Analysis Period: 2010 - 2020	VOC Savings [Million $] Analysis Period: 2010 - 2030
Option 2: HOV 10%	92.82	194.53
Option 3: HOV 15%	156.14	327.22
Option 4: HOV 20%	106.48	223.15
Option 5: HOV 25%	151.75	318.02
Scenario 3: Addition of One Lane in Each Direction		
Options	VOC Savings [Million $] Analysis Period: 2010 - 2020	VOC Savings [Million $] Analysis Period: 2010 - 2030
Option 6: HOV 0%	-4.29	-21.11
Option 7: HOV 10%	107.25	244.84
Option 8: HOV 15%	110.39	252.32
Option 9: HOV 20%	116.93	267.92
Option 10: HOV 25%	115.07	263.49

Table 6- VOC Savings for Different Options

Value of Travel Time Savings

The estimated Value of Travel Time (VOT) savings for different options of the I – 65 Corridor project are summarized in Table 7. The lane conversion in Scenario 2 did not yield Value of Travel Time savings for HOV lane usage less than 10% due to underutilization of the HOV lane. Comparison of Scenarios 2 and 3 confirms that significantly higher VOT savings can be realized by the addition of HOV lanes, as compared to the HOV lane conversion. Also comparison of results from Option 6 to those from Options 7 through 10 further highlights the benefit from designation of the added lane as HOV, rather than general purpose lane.

Scenario 1: Base Case Scenario, Other Scenarios are compared to this Scenario		
Scenario 2: Conversion of One General Purpose Lane into HOV Lane in Each Direction		
Options	VOT Savings [Million $] Analysis Period: 2010 - 2020	VOT Savings [Million $] Analysis Period: 2010 - 2030
Option 2: HOV 10%	-10.29	-21.38
Option 3: HOV 15%	82.20	170.78
Option 4: HOV 20%	207.01	430.08
Option 5: HOV 25%	186.74	387.97
Scenario 3: Addition of One HOV Lane in Each Direction		
Options	VOT Savings [Million $] Analysis Period: 2010 - 2020	VOT Savings [Million $] Analysis Period: 2010 - 2030
Option 6: HOV 0%	56.30	93.55
Option 7: HOV 10%	452.76	1031.24
Option 8: HOV 15%	449.98	1024.64
Option 9: HOV 20%	440.63	1002.56
Option 9: HOV 25%	419.62	952.86

Table 7- VOT Savings for Different Options

Accident Cost Savings

The estimated Accident Cost savings in comparison to Scenario 1 (Option 1) for different other options considered in this study are summarized in Table 8.

Scenario 1: Base Case Scenario, Other Scenarios are compared to this Scenario		
Scenario 2: Converting One General Purpose Lane into HOV Lane in Each Direction		
Options	Accident Cost Savings [Million $] Analysis Period: 2010-2020	Accident Cost Savings [Million $] Analysis Period: 2010 - 2030
Option 2: HOV 10%	219.82	440.55
Option 3: HOV 15%	208.73	418.34
Option 4: HOV 20%	186.77	374.31
Option 5: HOV 25%	178.07	356.89
Scenario 3: Addition of One Lane in Each Direction		
Options	Accident Cost Savings [Million $] Analysis Period: 2010-2020	Accident Cost Savings [Million $] Analysis Period: 2010-2030
Option 6: HOV 0%	-51.97	-125.88
Option 7: HOV 10%	81.89	177.54
Option 8: HOV 15%	88.51	192.56
Option 9: HOV 20%	92.00	200.47
Option 9: HOV 25%	90.08	196.12

Table 8- Accident Cost Savings for Different Options

Emissions Costs Savings

The estimated Emission Cost savings in comparison to Option 1 for different other options of the I – 65 Corridor project are summarized in Table 9. As expected increase in ridesharing percentages in the HOV options results in reduction in vehicle volumes and thus in emission cost savings compared to the base case.

Scenario 1: Base Case Scenario, Other Scenarios are compared to this Scenario		
Scenario 2: Converting One General Purpose Lane into HOV Lane in Each Direction		
Options	Accident Cost Savings [Million $] Analysis Period: 2010-2020	Accident Cost Savings [Million $] Analysis Period: 2010-2030
Option 2: HOV 10%	176.55	357.44
Option 3: HOV 15%	191.80	388.33
Option 4: HOV 20%	189.97	384.61
Option 5: HOV 25%	187.07	378.75
Scenario 3: Addition of One Lane in Each Direction		
Options	Accident Cost Savings [Million $] Analysis Period: 2010-2020	Accident Cost Savings [Million $] Analysis Period: 2010-2030
Option 6: HOV 0%	-10.83	-26.33
Option 7: HOV 10%	148.47	337.53
Option 8: HOV 15%	150.16	341.40
Option 9: HOV 20%	141.74	335.87
Option 9: HOV 25%	150.85	342.98

Table 9- Emission Cost Savings for Different Options

3.2.1 Cost-Benefit Analysis Results

The total costs and benefits for the two study analysis periods are summarized in Table 10. It can be seen that total benefits from both HOV lane conversion (Scenario 2) and HOV lane addition (Scenario 3) outweigh total costs which further confirms that the HOV strategy is an economically viable solution for implementation both in the short and long terms.

Scenario 1: Base Case Scenario, Other Scenarios are compared to this Scenario					
Scenario 2: Conversion of one lane in each travelling direction of I – 65 as HOV lane					
Analysis Period: 2010-2020			Analysis Period: 2010-2030		
Options	Total Costs [Million $]	Total Benefits [Million $]	Options	Total Costs [Million $]	Total Benefits [Million $]
Option 2: HOV 10%	65.17	478.89	Option 2: HOV 10%	108.92	971.14
Option 3: HOV 15%	65.17	638.88	Option 3: HOV 15%	108.92	1304.67
Option 4: HOV 20%	65.17	690.22	Option 4: HOV 20%	108.92	1412.15
Option 5: HOV 25%	65.17	703.63	Option 5: HOV 25%	108.92	1441.62
Scenario 3: Addition of one HOV lane in each travelling direction of I – 65					
Analysis Period: 2010-2020			Analysis Period: 2010-2030		
Options	Total Costs [Million $]	Total Benefits [Million $]	Options	Total Costs [Million $]	Total Benefits [Million $]
Option 6: HOV 0%	145.50	-10.79	Option 6: HOV 0%	202.50	-79.78
Option 7: HOV 10%	145.50	790.37	Option 7: HOV 10%	202.50	1791.16
Option 8: HOV 15%	145.50	799.05	Option 8: HOV 15%	202.50	1810.95
Option 9: HOV 20%	145.50	797.31	Option 9: HOV 20%	202.50	1806.82
Option 10: HOV 25%	145.50	775.63	Option 9: HOV 25%	202.50	1755.44

Table 10- Total Costs and Total Benefits for the Analysis Periods

The results of cost benefit analysis in terms of NPV, BC Ratio and IRR are summarized in Table 11. It can be seen that both HOV strategies yield great economic benefits, even with percentages of HOV usage as low as 10%. An HOV percentage of 10% is easily attainable given the current ridesharing patterns and future campaigns to inform the public and market the HOV strategy. Additional benefits can be realized as the % of vehicles using HOV lanes continues to increase.

Scenario 1: Base Case Scenario						
Scenario 2: Conversion of one lane in each travelling direction of I – 65 as HOV lane						
	Analysis Period: 2010-2020			Analysis Period: 2010-2030		
Options	NPV	B/C Ratio	IRR %	NPV	B/C Ratio	IRR %
Option 2: HOV 10%	333.83	7.15	> 75	581.14	8.60	> 75
Option 3: HOV 15%	463.23	9.54	> 75	805.39	11.54	> 75
Option 4: HOV 20%	504.75	10.30	> 75	877.59	12.48	> 75
Option 5: HOV 25%	515.56	10.50	> 75	897.15	12.74	> 75
Scenario 3: Addition of one HOV lane in each travelling direction of I – 65						
	Analysis Period: 2010-2020			Analysis Period: 2010-2030		
	NPV	B/C Ratio	IRR %	NPV	B/C Ratio	IRR %
Option 6: HOV 0%	-141.96	-0.06	-	-211.07	-0.27	-
Option 7: HOV 10%	480.46	4.58	50.02	996.18	6.97	51.05
Option 8: HOV 15%	487.20	4.63	50.11	1009.01	7.05	51.09
Option 9: HOV 20%	485.86	4.62	50.09	1006.36	7.04	51.98
Option 10: HOV 25%	469.02	4.49	49.87	973.30	6.84	50.10

Table 11- Summary of Cost-Benefit Analysis Results in Economic Parameters

Examination of the results reveals that the options of the Lane Conversion scenario (Scenario 2) yielded in higher BC ratios and higher IRR comparing to those of the Lane Addition scenario. But, the NPVs of Options 7 through 10 of the Lane Addition scenario (Scenario 3) are higher than those of the Lane Conversion scenario.

It should be stated that among the three parameters considered, NPV is the most relevant as it represents the total present value of a time series of cash flows. In other words, NPV indicates the value or magnitude of the return from the project and since the improvement projects are mutually exclusive, NPV values shall guide the final decision for implementation. On the basis of the NPV perspective, the cost-benefit analysis concludes that Scenario 3 or the HOV lane addition scheme has an advantage over the lane conversion one and is thus the recommended strategy for implementation.

4. Summary and Conclusions

This study analyzed a number of alternative options to determine the impact of HOV use on traffic operations along the I-65 corridor in Birmingham, AL. The modeling was performed in the TSIS environment using the features of the CORSIM model. The analysis considered the possibility of: a. converting an existing general purpose lane to HOV, and b. adding a new lane and potentially designate it as HOV.

Based on the analysis findings and for reasonable HOV lane utilization assumptions (10%-25%), conversion of a general purpose lane into HOV is not the favorite option as it is not expected to improve traffic operations or environmental impacts. On the other hand, the simulation results demonstrate significant operational benefits from the introduction of a new dedicated HOV lane per direction, even when HOV lane utilization is small (10% and higher). Also, it was found that the performance of the network with an HOV lane added in each direction clearly surpasses the performance of the network with a general purpose lane added in each direction. Moreover, the HOV lane addition is the preferred option as far as environmental impacts are concerned.

As expected, the HOV lane addition option is more economically demanding than the lane conversion one. Still, the expansion of the facility to include one HOV lane per direction is expected to result in a 4:1 benefit-to-cost ratio. NPV results also confirm that the HOV lane addition is the best alternative from the economic point of view.

In conclusion, the results from the operational, environmental impacts and cost-benefit analyses confirm that the addition of an HOV lane per direction is the best strategy among those considered for mitigation of traffic congestion along the study section of I-65. Thus, assuming that a lane addition is feasible based on Right-of-Way (ROW) considerations, funding availability, public support etc, the construction of one dedicated HOV lane on each direction of travel is recommended as the most desirable option for future implementation.

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