Evaluation of the Effectiveness of High Occupancy Vehicle Lanes

Peter T. Martin, Associate Professor
Joseph Perrin, Research Assistant Professor
Pen Wu and Rob Lambert, Research Assistants
University of Utah

May 2004

Acknowledgements

The research presented in this paper was supported by finding from the Mountain-Plains Consortium (U.S. Department of Transportation) and the Utah Department of Transportation through the Utah Transportation Center.

Disclaimer

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ATMS	Advanced Traffic Management System
AVO	Average Vehicle Occupancy
FHWA	Federal Highway Administration
GP	General Purpose Lanes
HOV	High Occupancy Vehicle
ITS	Intelligent Transportation System
MOE	Measure of Effectiveness
SOV	Single Occupancy Vehicle
TMS	Traffic Monitoring Station
TOC	Traffic Operations Center
UDOT	Utah Department of Transportation
USDOT	United States Department of Transportation
VPH	Vehicles Per Hour
VPLH	Vehicles Per Lane Per Hour
WFRC	Wasatch Front Regional Council

EXECUTIVE SUMMARY

In May of 2001, 16 miles of high-occupancy vehicle (HOV) lane opened on the re-constructed Interstate 15 (I-15). The HOV lanes operate between 600 North and 10600 South in the Salt Lake Valley. A single northbound HOV lane and a single southbound HOV lane are separated from the four general-purpose freeway lanes in both directions by striping that allows HOV lane entrance and exit. The HOV lanes operate twenty-four hours a day and allow vehicles with two or more occupants, motorcycles, and transit vehicles. The only HOV-specific access to an arterial is located at 400 South and allows HOV-only direct access to the I-15 southbound on-ramp and the I-15 northbound off-ramp. This paper reports on a two-year study evaluating HOV lane performance. The analysis assesses the freeway operations before the HOV lanes opened with continued assessment throughout the first year of operation. It looks at automatic data from traffic monitoring stations and manual data from roadside and travel time surveys.

The findings indicate that during the afternoon peak period, the HOV lane moves the same number of people as each general-purpose (GP) lane with only 44 percent of the vehicles. However, the HOV lane moves fewer people than its GP lane counterparts throughout the rest of the day during times of little or no congestion. HOV lanes show travel time savings for HOV users. According to measures of travel time between 400 South and 10600 South, relative to the adjacent GP lanes, the HOV lanes provide a 30 percent travel time savings during the afternoon peak period and a 13 percent travel time savings during the morning peak time. Furthermore, unlike the higher variation of travel times on GP lanes, HOV lanes provide a more consistent and predictable travel time because of lower rates of congestion and incidents. The HOV lanes' violation rates range from 5 percent to 13 percent along the I-15 corridor, which is slightly higher than the 5 to 10 percent expected by national averages. At the 400 South HOV on /off ramp the violation rates increase to 20 percent. Recurring surveys during the initial year of HOV operations show that violation rates initially reduced after the HOV lane opening and have since stabilized. Average vehicle occupancy on I-215 and non-HOV portions of I-15 have remained the same before and since the HOV lane opening. Vehicle occupancy on the I-15 corridors with HOV lanes experienced a 17 percent increase, from 1.1 persons per vehicle to 1.3. Therefore, public support of HOV lanes has resulted in carpooling. Though HOV lanes are successful and anticipated to be increasingly valuable as the congestion in the Salt Lake Valley increases, this report offers recommendations to improve the HOV lanes' performance.

1. INTRODUCTION

High Occupancy Vehicle (HOV) lanes exist throughout North America to maximize the person-carrying capacity of a facility by offering travel time savings as well as reliable and predictable travel times. HOV lanes in several states, including New Jersey, California, and Virginia, have recently received criticism for what is termed the "empty lane syndrome," or perceived underutilization of HOV lanes. Two facilities in New Jersey, I-80 and I-287, were decommissioned in November 1998 due to political pressure. In these particular cases the facilities lacked some of the fundamental design and operational characteristics common to successful HOV lanes and local users deemed the lanes wasteful (1,2,3).

In May of 2001, UDOT completed its I-15 reconstruction in Salt Lake City, incorporating sixteen miles of HOV lanes. The reconstruction increased I-15 from three General Purpose (GP) lanes in each direction to four GP lanes and one HOV lane in both directions. This report documents a two-year research study regarding the operation and usage of I-15 one year prior to the HOV lane opening and during the first year of HOV operations. Volume, speeds, vehicle occupancy, and violation rates for HOV and GP lanes are compared to one another. In addition, these variables are compared between pre-HOV I-15 and reconstructed HOV I-15.

Figure 1.1 shows the I-15 HOV lanes located from 600 North to 10600 South in the Salt Lake Valley. A solid white stripe separates the single HOV lane from the four northbound and southbound GP lanes. The open-access stripe allows maximum flexibility for users, however it also provides easy access for Single Occupancy Vehicles (SOVs) to misuse the HOV lane for queue jumping. Exclusive HOV on-ramps are located at 400 South, near the CBD of Salt Lake City. In regard to the current operating policies, the HOV lanes are enforced 24 hours a day, seven days a week and reserve usage to vehicles with two or more passengers (carpools, vanpools and buses) and motorcycles. The question of continuous enforcement or operation during peak hours is being assessed nationwide.

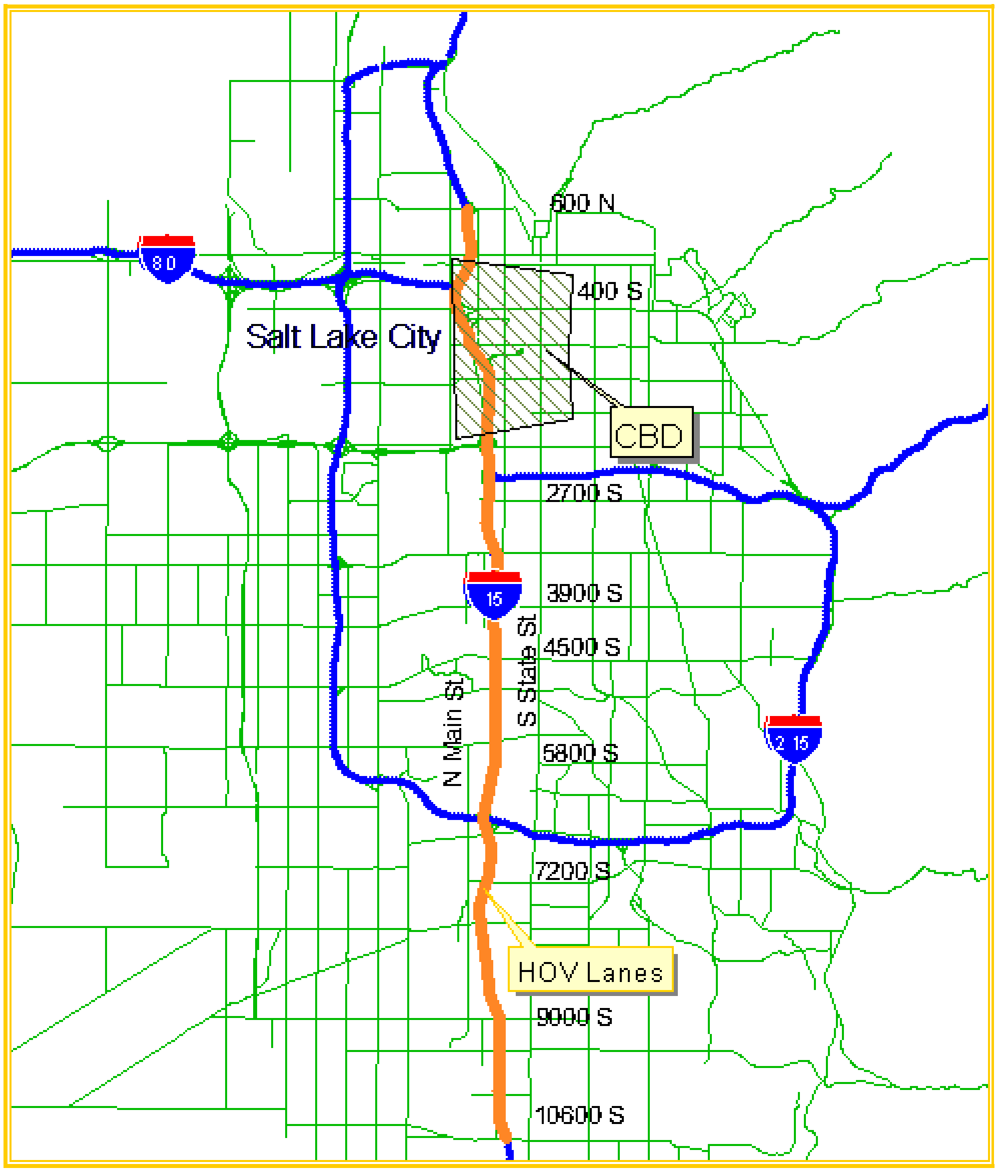


Figure 1.1 HOV Lanes along 1-15 Corridor in Salt Lake Valley

Transportation is the movement of people or goods from where they are to where they are of more value or want to be. Therefore, moving vehicles is not an inherent goal of transportation. However, if more people can be moved in fewer vehicles, congestion is reduced and the transportation system is more efficient. One of the main objectives of the I-15 HOV lanes, and HOV lanes in general, is to increase the average number of persons per vehicle. Knowing the effectiveness of the I-15 HOV lanes is important for policy-making decisions, including whether to implement HOV lanes on other freeways in the area and whether the minimum passenger level should be raised. HOV lane violation rates indicate the degree of public acceptance of HOV lanes and also measure the risks versus the benefits of violation. While this report documents the assessment of the first year of HOV operation, ongoing assessment and monitoring is the key to continued acceptance and successful operation of HOV lanes. This continuous monitoring allows decisions to be made about HOV operations and benefits as freeway congestion increases. The success and benefit of HOV lanes should continue to increase as congestion in the Salt Lake Valley increases.

The Utah Department of Transportation (UDOT), in conjunction with the University of Utah and Mountain Plains Consortium, a federally supported ITS program, conducted a two-year study. The project sought to measure HOV lane effectiveness. The study's research objectives are:

1. Evaluate the impact of HOV lanes on I-15 and alternate routes.
2. Measure the effectiveness of HOV lanes by comparing before-HOV-lane statistics with after-HOV-lane statistics.
3. Recommend changes to existing HOV operations policies or procedures.
4. Review and recommend educational programs for improving HOV lane acceptance and compliance.

It is important to assess the HOV lane's performance because the recent increase in capacity of I-15 may actually promote a decrease in occupancy by increasing available travel opportunities. To meet the research objectives mentioned above and determine whether the HOV lane is successful, the following tasks were completed:

1. Review of success and failures in other metropolitan areas
2. Determine measure of effectiveness (MOEs)
3. Collect field data with and without the HOV lanes operating
4. Evaluate effectiveness and acceptance
5. Measure the benefits provided by HOV lanes

2. LITERATURE REVIEW

2.1 Review of Other Evaluations

Many other transportation systems have incorporated and evaluated HOV systems and components similar to those used in the Salt Lake system. This section features individual discussions of several related HOV evaluations.

2.1.1 Houston System

The I-10W Katy Transitway is an eleven-mile radial corridor originally built as a transit expressway. When it opened, vehicles with at least two occupantswere allowed in addition to transit vehicles. Presently, the corridor allows vehicles with three or more occupants during peak hours and two or more at regular hours. About 45 percent of Katy's users ride buses. The success of Katy has helped pave the way for a growing network of HOV lanes in Houston, now totaling 74 miles (4).

2.1.2 Oregon Evaluation

The Oregon Department of Transportation evaluated I-5 before and after the introduction of a HOV lane (5). Four follow-up evaluations were conducted and the results from the last evaluation indicate:

- HOV lane drivers save an average of eight to ten minutes when they drive the entire length of the corridor.
- The number of persons using the HOV lane is greater than the number of persons using a GP lane. The HOV lane carries approximately 2,600 people per hour and a typical general-purpose lane in the same area carries about 1,700 people per hour.
- Occupancy compliance rates are at about 92 percent. This percentage is average compared to HOV lanes nationwide.

2.1.3 New Jersey Failure

New Jersey recently closed two HOV lanes, I-80 and I-287, and re-opened the lanes to all vehicles. The HOV lane on I-287 was used very little with fewer than 400 vehicles per lane-hour (vplh). This flow was not nearly high enough to alleviate the high congestion problem on this corridor. The I-80 HOV lane, however, was used heavily with more than 1,000 vplh. However, political opposition spilled over from the I-287 closure and encouraged the closure of I-80's HOV. Neither of these HOV facilities carried much transit service nor was the public prepared for the initial opening of lanes. They therefore lacked a sufficient HOV market (4).

2.1.4 Virginia Success

In Northern Virginia I-66 extends west from downtown Washington, D.C. The HOV lane on this corridor was originally designated for vehicles with at least three occupants but was changed to vehicles with at least two occupants. This relaxation of restrictions produced a 60 percent increase in ridership (1,700 vplh) (4).

2.1.5 California Evaluation

Caltrans operate 1,061 miles of HOV lanes and is constructing an additional 162 miles. On average, California's HOV lanes carry 2,518 persons per hour during peak hours — substantially more people than a congested mixed-flow lane and roughly the same number of people as a typical mixed-flow lane operating at maximum capacity. In terms of vehicles carried, however, California's HOV lanes are operating at only two-thirds of their capacity. There has been some political discussion that HOV lanes encourage alternative fuel vehicles to utilize the HOV lanes as a way to increase alternative vehicle attractiveness. Transportation engineers are slow to accept this idea as they are trying to focus on the purpose of transportation: to move people. There are some locations where dual occupancy is being implemented. This includes two or more occupants during off-peak times and three or more during peak-times. Some bridges in the San Francisco Bay area eliminate tolls for HOV vehicles during peak times. Regional data indicate that HOV lanes do encourage people to carpool, but the statewide impact on carpooling is unknown due to lack of data. The exact impact of HOV lanes on air quality is also unknown (3,6).

2.1.6 Seattle HOV Evaluation

In the Puget Sound area of Seattle, Washington there are 205 miles of HOV lanes with 330 lane-miles planned by 2010 and 500 more planned by 2030. More than 100 of these lane-miles are arterial. According to the Washington State Department of Transportation (WSDOT) HOV study (7, 8), congestion occurs for nearly fourteen hours per day. HOV lanes average between 700 and 900 vehicles per hour during the midday periods with HOV lanes carrying as many people as the GP lanes. In a public survey, 95 percent of the HOV users thought HOV lanes were a "good idea" while only 72 percent of HOV users agreed. The top five options to improve HOV lane usage were determined to be:

1. Better enforcement
2. Inside access ramps
3. HOV lanes to inside lanes
4. Employer subsidies
5. Increased bus service

The Washington State Patrol (WSP) wrote 3,500 warnings and issued 9,000 tickets during 2000. This was a 49 percent increase in violation citations. The increased enforcement was coupled with the new HERO program. HERO allows motorists to self monitor the HOV lanes by reporting violators via web or phone. Upon first offense violators are sent educational material on HOV lanes. For a second offense WSDOT sends a personalized letter emphasizing the proper use of the HOV system. For a third reported offense the WSP sends a personalized letter noting the date, time, and location of the reported violation. The HERO program received 43,879 reports of violation in 2000, a 6 percent increase from 1999. Less than 6 percent of those reported were second time offenders and less than 1 percent had three offenses or more. The program is credited with reducing repeat HOV violators.

2.1.7 Performance Summary

Nationwide, there are 22 cities with HOV lanes and more than 2000 HOV lane-miles. Approximately 52 percent of the HOV lanes are enforced 24 hours a day, seven days a week. Approximately 86 percent HOV lanes require two or more facilities with the remainder requiring three or more ridership. More than eighty percent of HOV lane users have two riders in the vehicle. When HOV user requirements increase to three or more occupants, 80 percent of HOV lane use is reverted back into the GP lanes. HOV lane violation averages 10 to 15 percent nationally. The purpose of HOV lanes is to increase vehicle occupancy and reduce travel time for private vehicles as well as for transit service. MOEs typically include volume, vehicle occupancy, speeds/travel times, violations and public attitudes. Both continued monitoring and informing the public of system benefits are key to the nationwide success of the programs. Southern California has forty sample locations monitoring 400 of its 1061 lane-miles.

2.2 Review of Other Agencies' Educational Programs

2.2.1 Marketing HOV Lane in Long Island

A HOV lane on the Long Island Expressway underwent an extensive marketing effort. The HOV lane opened in 1994 but the marketing of the lane began much earlier. The marketing program had two major objectives:1) to promote the HOV project to stakeholders as a highway improvement project to gain support for the project, and 2) to build a constituency among potential HOV lane travelers to encourage usage. This marketing program consisted of three parts. First, to provide factual information to stakeholders about the Long Island HOV system and other HOV lanes around the country. Second, to expand the planning process outside of the traditional departments and cooperate with other agencies. And third, to bring together a diverse collection of private and public interests early in the project to encourage support for the HOV concept (9).

2.2.2 Gaining Public Acceptance in Tennessee

The Tennessee Department of Transportation (TDOT) implemented a HOV lane in 1993. Due mostly to a collective marketing effort by TDOT, the Regional Transportation Authority, and other state and local jurisdictions, the lane achieved a high level of support. The campaign utilized free media and paid television and newspaper advertising. It sent information by mail to 38,000 residents and provided newsletters to public policy makers. In addition, outdoor billboards, bus bench boards, and signs on buses were used. The campaign cost approximately $100,000 (10).

2.2.3 Marketing in New Jersey

While the New Jersey HOV lane failure was a transportation setback, the exclusive bus lane serving the Lincoln Tunnel remains a successful HOV facility. Based on the failure of one HOV project and the success of the other, New Jersey implemented a $2.5 million marketing campaign to promote a new HOV lane on I-80 in Morris County. The marketing campaign had six goals:

- Heighten public awareness of the HOV mission
- Build constituencies and partnerships with employers and elected officials at the local, county, and state level
- Increase public confidence
- Develop accurate expectations
- Encourage HOV facility use and mode shift
- Enhance future HOV project planning

The campaign first sought to create good relations with the print media. Briefings were held with newspapers and reporters who were given status reports throughout the project. The campaign also provided information to television and radio stations and numerous press conferences were held. In addition, one million people were contacted through direct mailings, windshield fliers, and notices accompanying license renewal forms (11).

2.2.4 Marketing Features and Benefits of Carpool Lanes

Donna Carter, an expert in marketing carpool lanes shared some of her marketing experiences at the Seventh International Conference on HOV systems in 1994 (12). According to Carter, because HOV lanes are implemented as a part of a major highway reconstruction, it is best to present the entire transportation system as a whole and provide information on HOV lanes as part of that system. Carter found that motorists find the name HOV confusing and are further confused when the statistical benefits of HOV lanes are presented in miles instead of in time. Carter also noted that research indicates that people overestimate the HOV violation rate. In some areas travelers thought that violation rates were as high as 70 percent when in reality the violation rate was under 10 percent. Commuters must be educated about HOV lanes to dispel misconceptions. Carter says the safety of HOV lanes must be emphasized; the benefits must be presented in terms of time saved driving; and the public must learn that HOV lane violators will be fined. In closing, Carter noted that marketing efforts must continue after the HOV lane is opened. Continuous communication is critical to increasing and maintaining public HOV lane usage.

3. METHODOLOGY AND DATA COLLECTION

3.1 Purpose of Evaluation

Evaluations of transportation projects have three main purposes: to compare alternatives, to measure a project's worth, and to determine if a project's goals are being met. Researchers often use evaluation results to identify areas of improvement and to select alternatives that ensure a project meets intended goals. The Federal Highway Administration suggests four reasons to evaluate an ITS system and places each on a timeline as shown in Figure 3.1.

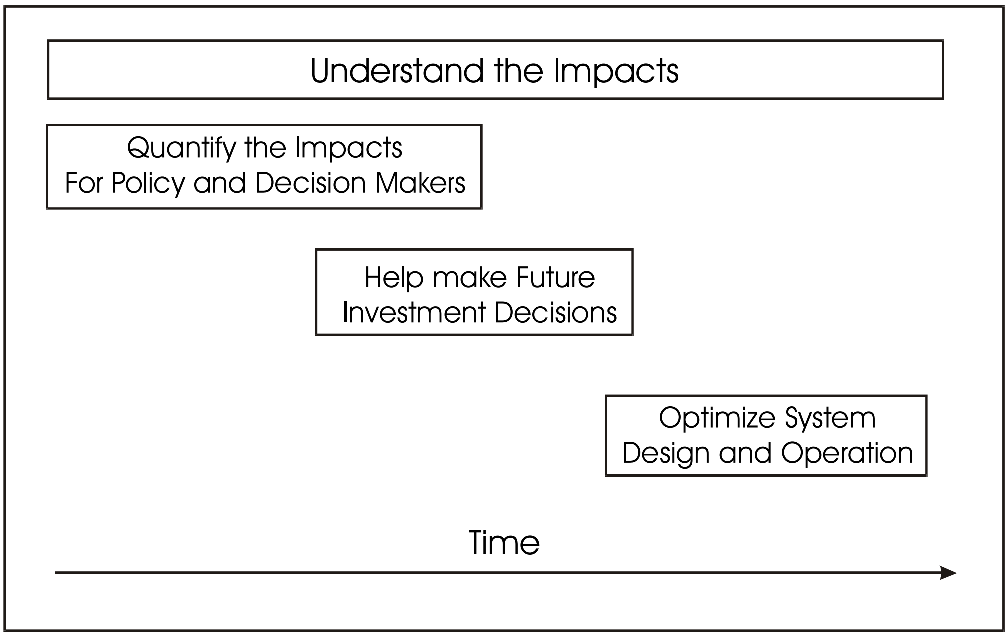


Figure 3.1 Four Reasons to Evaluate ITS Systems – Adapted from Federal Highway Administration (13).

The Federal Highway Administration (13) also hypothesizes that evaluations often focus on the first step of quantifying the impacts of a project. Less often, system evaluations are compared to other evaluations to provide a matrix of choices that may help make future investment decisions. ITS systems in particular are only occasionally evaluated for system optimization and operation refinement purposes. To understand the full impacts of a system, evaluations should be designed for all three purposes.

3.2 Data Collection

Data collection for Salt Lake City's I-15 followed the measure of effectiveness (MOE) analysis method. The measures of effectiveness incorporated into the analysis were based on typical HOV evaluation measures including: volume, speed, travel time, violation, and vehicle occupancy. The freeway TMS sites provided large automated data for volume and speed. Travel time, violations, and vehicle occupancy were based on manual field surveys. Data collection included time periods before the HOV lanes opened, after they opened in May of 2001, and recurring measures throughout the first year of operation.

3.2.1 Location of Data Collection

To investigate the effectiveness of the HOV system, person and vehicle volumes are analyzed at specific sites along the HOV corridor. The results are compared with those of GP lanes during a.m. and p.m. peak periods in the peak travel direction. These measures determine whether the HOV lane is enhancing the person-carrying capacity of the system and the extent to which a HOV lane is being utilized. The locations and data collected include:

Vehicle Occupancy

- four locations along I-15 to provide data representative of the corridor
- one location at I-215 East (4500 South)
- one location at I-215 West (3100 South)

Travel-times / Volume Counts / Speeds

- I-15 (five morning and five afternoon peaks)
- I-215 East (five morning and five afternoon peaks)
- I-215 West (three morning and three afternoon peaks)
- Traffic monitoring stations (TMSs)

Volume Counts / Speeds

- I-15 (3 morning and 3 afternoon peaks)
- I-215 East (3 morning and 3 afternoon peaks)
- I-215 West (3 morning and 3 afternoon peaks)
- Traffic monitoring stations (TMSs)

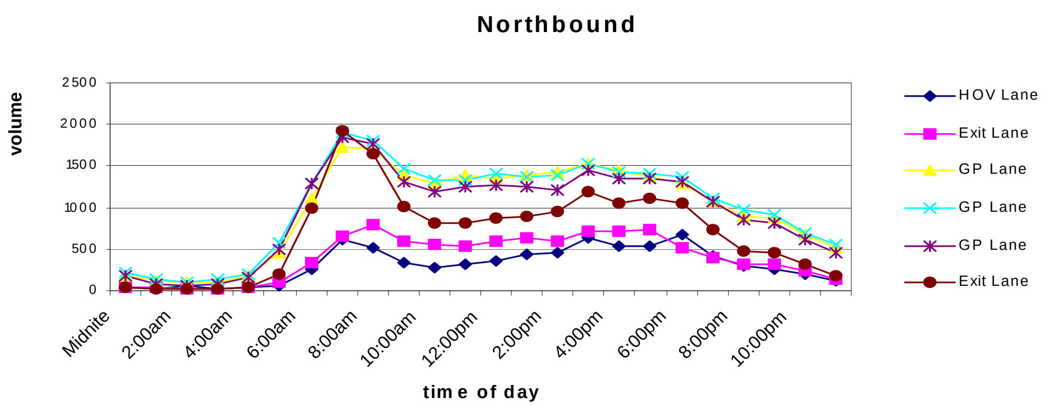
HOV Violation Data

HOV violation data was collected at the 400 South HOV on/off ramp. Vehicle occupancies were collected for traffic entering and exiting I-15 from both directions. It was noted whether or not the vehicles qualified for HOV lane use. Data was collected in fifteen-minute intervals for one and a half hours in the p.m. peak period on a recurring monthly basis. HOV lane violation data was also collected at representative locations along the I-15 corridor.

4. HOV LANE UTILIZATION

4.1 GP Lanes vs. HOV Lanes 24-hour Volume Profile

Throughout the Salt Lake Valley, TMSs are located along the freeways system in 800-meter intervals. The TMSs provide volume, speed, and detector occupancy data. Figure 4.1 displays an example of data collected at the 5800 South TMS site on I-15. This figure illustrates the 24-hour traffic volume profile on a typical weekday. Multiple TMS sites provided the data for the analysis of speed and volume and HOV usage along the I-15 corridor. The a.m. and p.m. peak traffic periods were identified as 6:30 to 8:30 a.m. in the northbound direction and from 4:00 to 6:00 p.m. in the southbound direction. This directional split is consistent with the I-15 HOV corridor connecting downtown Salt Lake City, the dense employment district, with the southern residential suburbs.



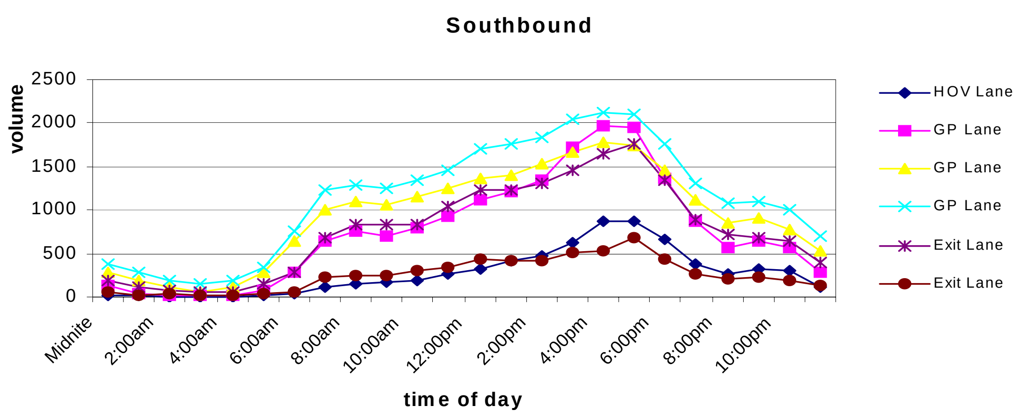
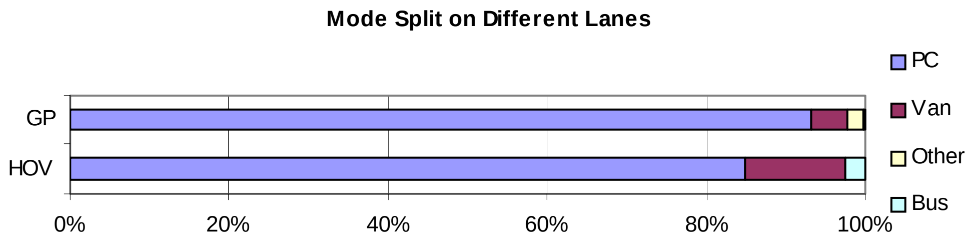


Figure 4.1 24-Hour Traffic Volume Profiles at 5800 South

On a per-lane basis, the HOV lanes carried fewer vehicles in comparison to the GP lanes. During afternoon peak-use times, the traffic volumes in some GP lanes approached 2,200 vplh, the lane's maximum capacity under ideal conditions. Figure 4.1-1 also shows that the utilization of the HOV lane is higher from 3:30 to 6:30 p.m. on the I-15 Southbound, in contrast, the HOV lane volumes on the I-15 Northbound stay relatively constant from 7:00 a.m. to 7:00 p.m.

4.2 GP Lanes vs. HOV Lanes Mode Split

Figure 4.2-1 shows the vehicle classification percentages on I-15 at 3900 South during the peak periods. The percentage of vans and buses on the HOV lane is higher than on the GP lanes. The express buses operated by Utah Transit Authority (UTA) frequently use this HOV facility during peak periods. Buses comprise 2.5 percent of traffic on the HOV lanes, and only 0.1 percent traffic on the GP lanes. Figure 4.2-1 shows the percentages of people that buses, cars, and vans carry on I-15 at a sample 3900 South location during the peak periods. Buses carried 27.6 percent of the people on the HOV lanes.



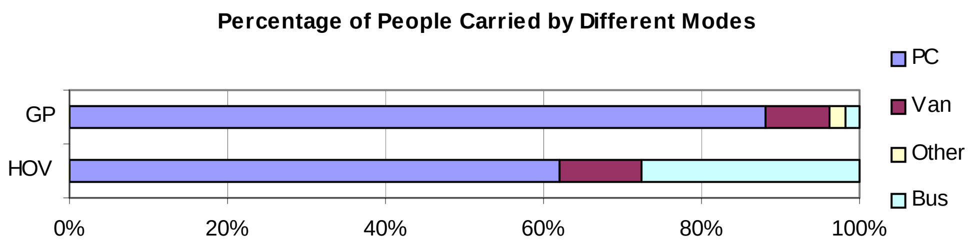


Figure 4.2-1 Passengers by Mode and Lane Type

4.3 GP Lanes vs. HOV Lanes Throughput

Throughput refers to roadway person-movement and/or vehicle-movement on HOV and GP lanes. It is necessary to analyze both person and vehicle throughput in order to evaluate a HOV lane. Three representative I-15 sites located at 2700 South, 3900 South, and 5800 South were selected for detailed manual analysis. Selection was based on points of interest, availability, and usability of manually collected data as well as TMS data.

Figures 4.3-1 through 4.3-2 depict several pieces of throughput information for each representative site. The The Average Vehicle Occupancy (AVO) and the vehicle and person throughput data for GP and HOV lanes are also presented in overall and per-lane statistics in Figure 4.3-3.

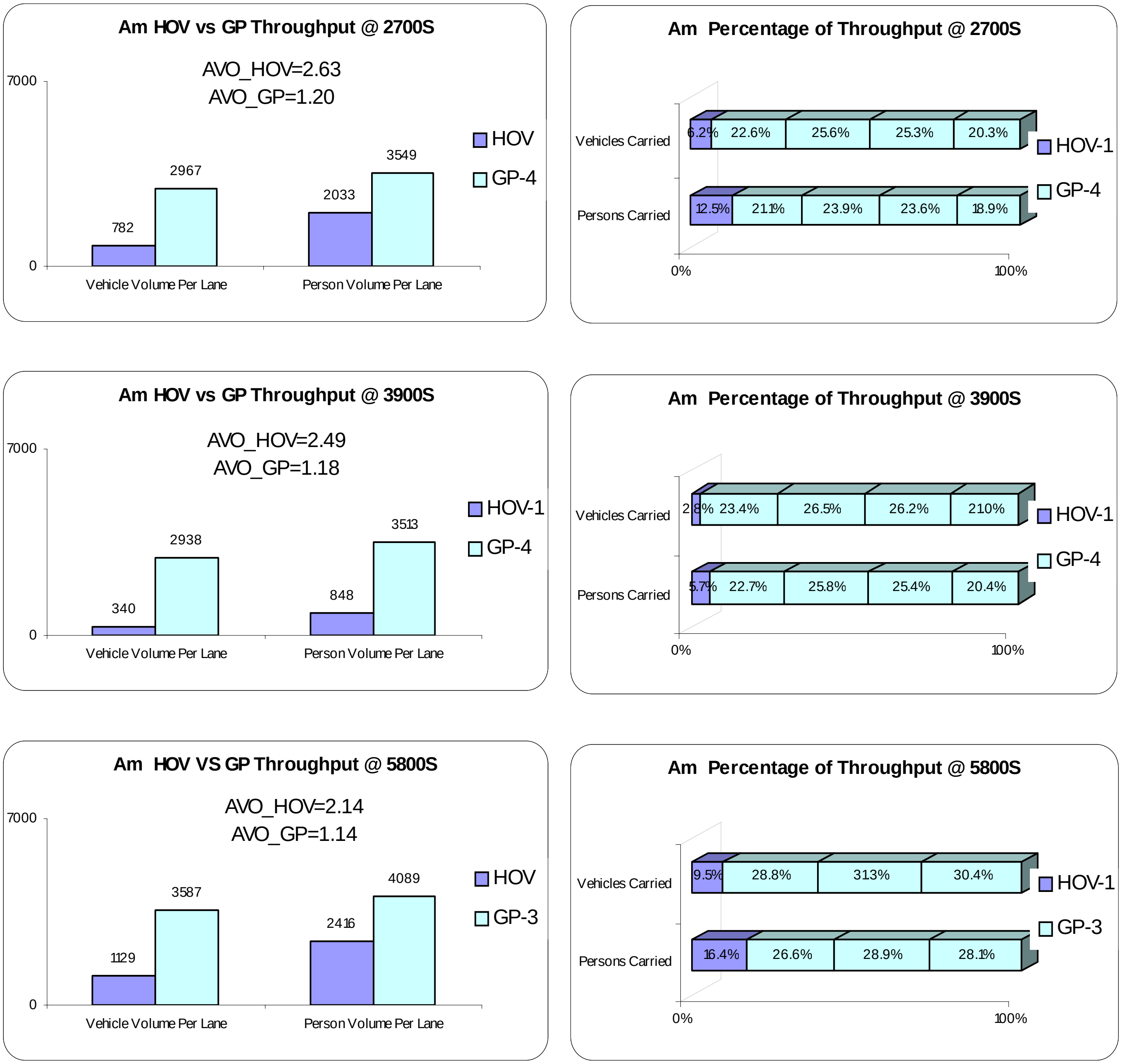


Figure 4.3-1 Throughput Comparisons at Different Locations during Morning Peak Period.

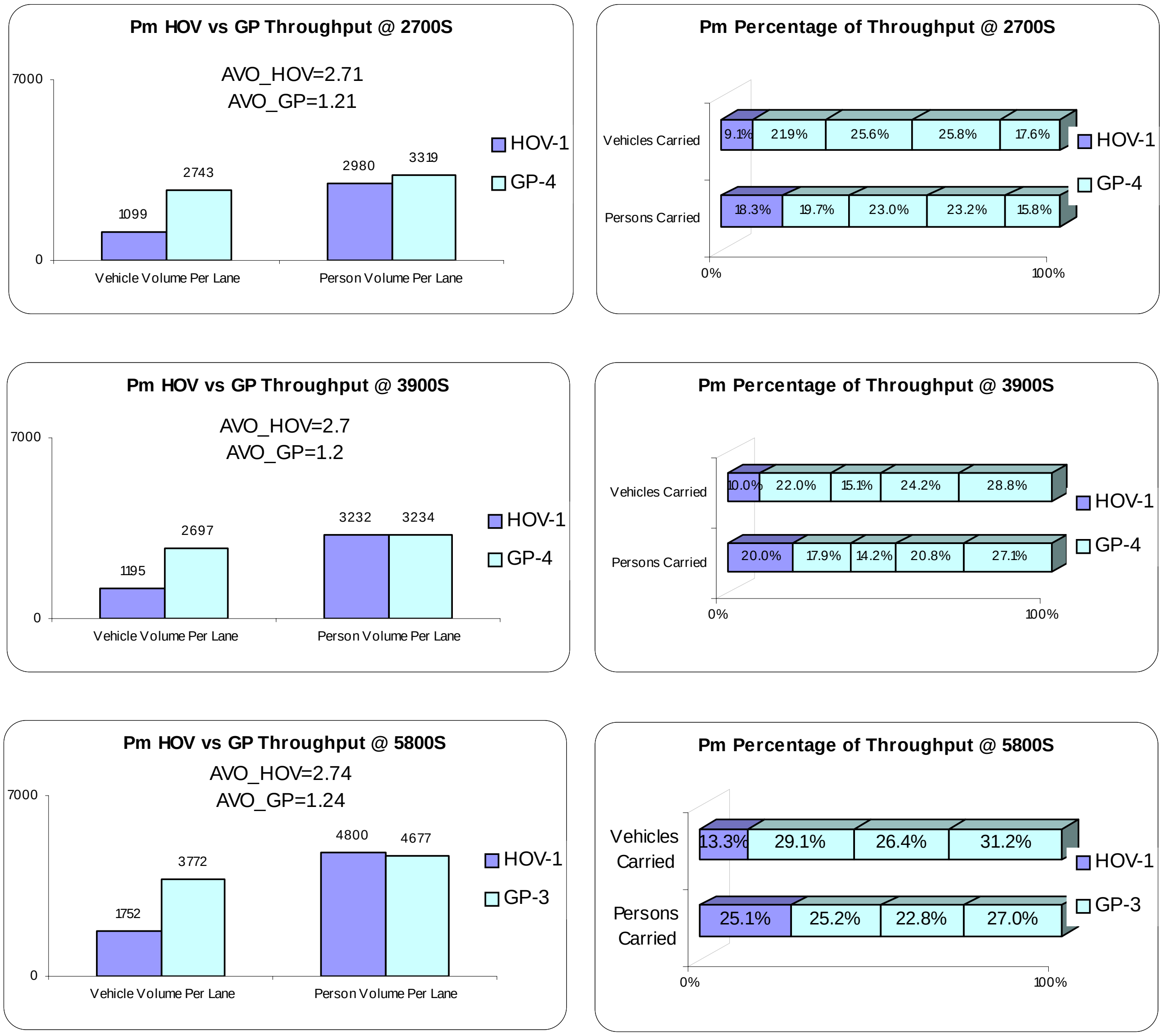


Figure 4.3-2 Throughput Comparisons at Different Locations during Afternoon Peak Period.

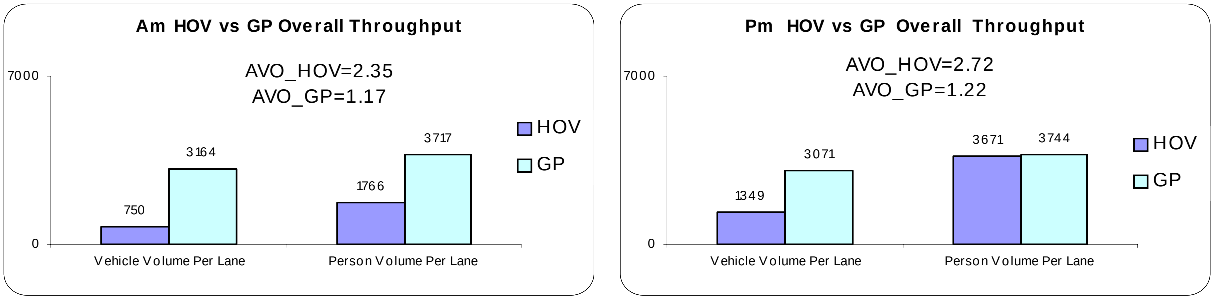


Figure 4.3-3 Overall Throughput Comparisons during Peak Periods.

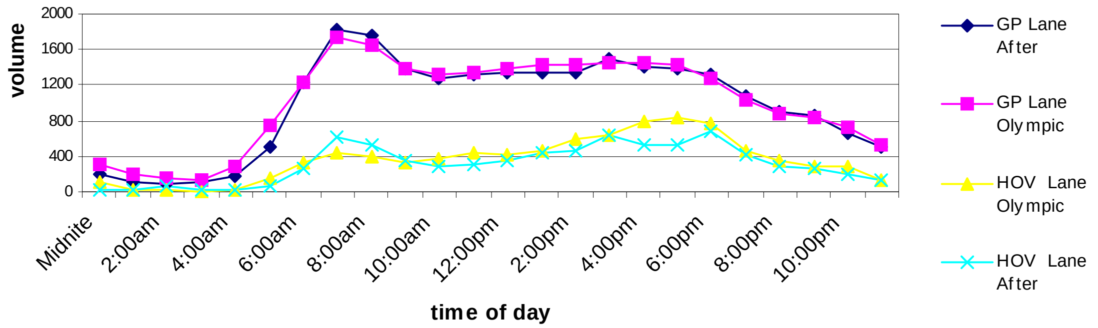
According to Figure 4.3-3 data, on a per-lane analysis, the northbound HOV lane carried 1,766 persons during a two-hour period in the a.m. peak period. Compared with the GP lanes, the HOV lane carried 52.2 percent fewer people and 76.3 percent fewer vehicles. During the two-hour p.m. peak period, the southbound HOV lane carried almost the same number of people as a GP lane, but with 56.2 percent fewer vehicles. As anticipated, the HOV lane displays its value during the more congested periods.

4.4 HOV Lane Usage During the 2002 Winter Olympic Games

The 2002 Salt Lake City Winter Games were the largest Winter Olympic Games ever held. They included 78 events in 15 disciplines and seven sports. More than 1.5 million tickets were sold for the Olympic events and more than 500,000 visitors attended the Games. These numbers created unprecedented travel needs in Salt Lake City. The I-15 corridor with HOV lanes played an important role during the Olympic Games, providing the greatest amount of freeway capacity in the Salt Lake Valley.

More than one month's worth of continuous traffic monitoring was conducted before, during, and after the Olympic Games (14). HOV lane usage was analyzed based on a comparison between traffic during and after the Olympic Games. The 24-hour overall transportation demand during the Games was only 15 percent higher than after the Games. This is attributed to most people in the Salt Lake area operating with either a working break, a modified schedule, or increased rideshare efforts during the Olympic Games. It resulted from a great effort on the part of engineers, planners, and Olympic coordinators to inform the public of the coming traffic and the need to reduce typical commuter demand during the two-week Olympic period. These preparations were estimated to reduce the background traffic along I-15 by up to 40 percent. In Table 4.4-1 a sample location shows that 24-hour traffic volumes on the HOV lanes during the Olympics were 16 to 18 percent higher than after the Olympics while the GP lanes increased only by 3 to 4 percent. This increase in HOV usage can be attributed to travel behavior changes. More local travelers carpooled, less commuter traffic was on the road due to work schedule shifts, and visitors tended to occupy multi-rider vehicles. The time-saving advantages of the HOV lanes enticed carpoolers to utilize them. Many of the events were held in the downtown area at night. This resulted in a new peak traffic period from 9 to 11 p.m., as shown in Figure 4.4-1. Therefore, the HOV facilities, together with efficient public transportation systems, including the Light Rail TRAX, the Olympic bus, and the regular bus, reduced traffic congestion during the Olympic Games.

Northbound



Southbound

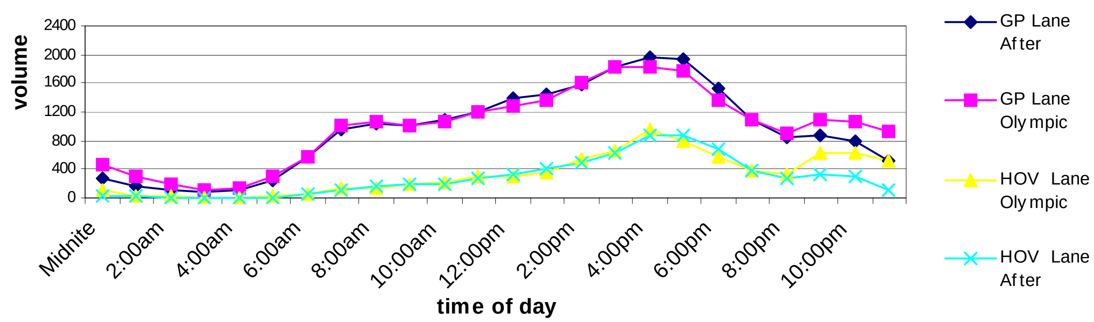


Figure 4.4-1 Traffic Volume Comparison during Olympic Games.

Table 4.4-1 24-hour Traffic Volume Changes at I-15 5800 South between, during, and after Olympic Games

	Northbound			Southbound		
	After Olympics	During Olympics	Volume Change	After Olympics	During Olympics	Volume Change
GP Lane	23659	24399	3.1%	22617	23523	4.0%
HOV Lane	7473	8709	16.5%	6666	7907	18.6%

Traffic volume unit: vehicles/per lane/per day

5. TRIP RELIABILITY AND TRAVEL TIME SAVINGS

Travel speed and reliability serve as the best gauges for measuring HOV system effectiveness. For Los Angeles drivers, trip reliability is the most important factor in driving, followed by travel time. As congestion increases in the Salt Lake Valley, commuters will select routes and modes of transportation based on their reliability. This section discusses speed, reliability, congestion patterns, and travel time of corridor-wide and site-specific HOV facilities. The purpose of these measures is to describe:

- HOV lane travel speeds that can be expected for a range of trip start times throughout the day
- likelihood of an average trip in the HOV lane becoming congested (with a speed of less than 45 miles per hour (mph))
- how traffic conditions change from location to location along a HOV lane and GP lane in different traffic periods
- travel time savings realized when the HOV lane is used

5.1 Corridor–wide Operational Performance

The performance measures used to evaluate the operational characteristics of the entire HOV system along I-15 are described in this section. The operational performance is discussed independently in regard to different direction and different peak periods. The operational performance was assessed with the following measures: speed, trip reliability, and travel time savings. Each measure is discussed below.

5.1.1 Travel Speed

HOV lane performance should reflect higher average speeds than the GP lanes during peak times. Table 5.1-1 assesses the average weekday HOV and GP lane location speed along I-15 from 400 South to 10600 South. The statistical results show that the vehicle speed on the HOV lanes was always higher than the speed of GP lanes throughout the day. During the afternoon peak period, the average speed on the HOV lane was 63.6 mph, significantly greater than the 51.5 mph on the GP lanes.

On I-15, speeds less than 45 mph are considered congested. In the a.m. peak period and off peak period, speeds along the corridor are above 45 mph. During the p.m. peak period, thirty-one percent of the I-15 corridor operates at or below 45 mph in the GP lanes. Only 10 percent of the HOV lane operates at or below 45 mph in the p.m. peak. Table 5.1-1 displays the speed data collected on the multiple travel time runs.

Table 5.1-1 Average Weekday HOV and GP Lane Location Speed

	Morning Peak (Northbound)		Afternoon Peak (Southbound)		Off Peak	
	HOV	GP	HOV	GP	HOV	GP
Mean	74.0	65.7	63.6	51.5	74.2	68.4
Standard Deviation	3.3	4.0	10.8	16.7	2.6	3.8
Percentage < 45 MPH	0	0	10.3%	31.0%	0	0

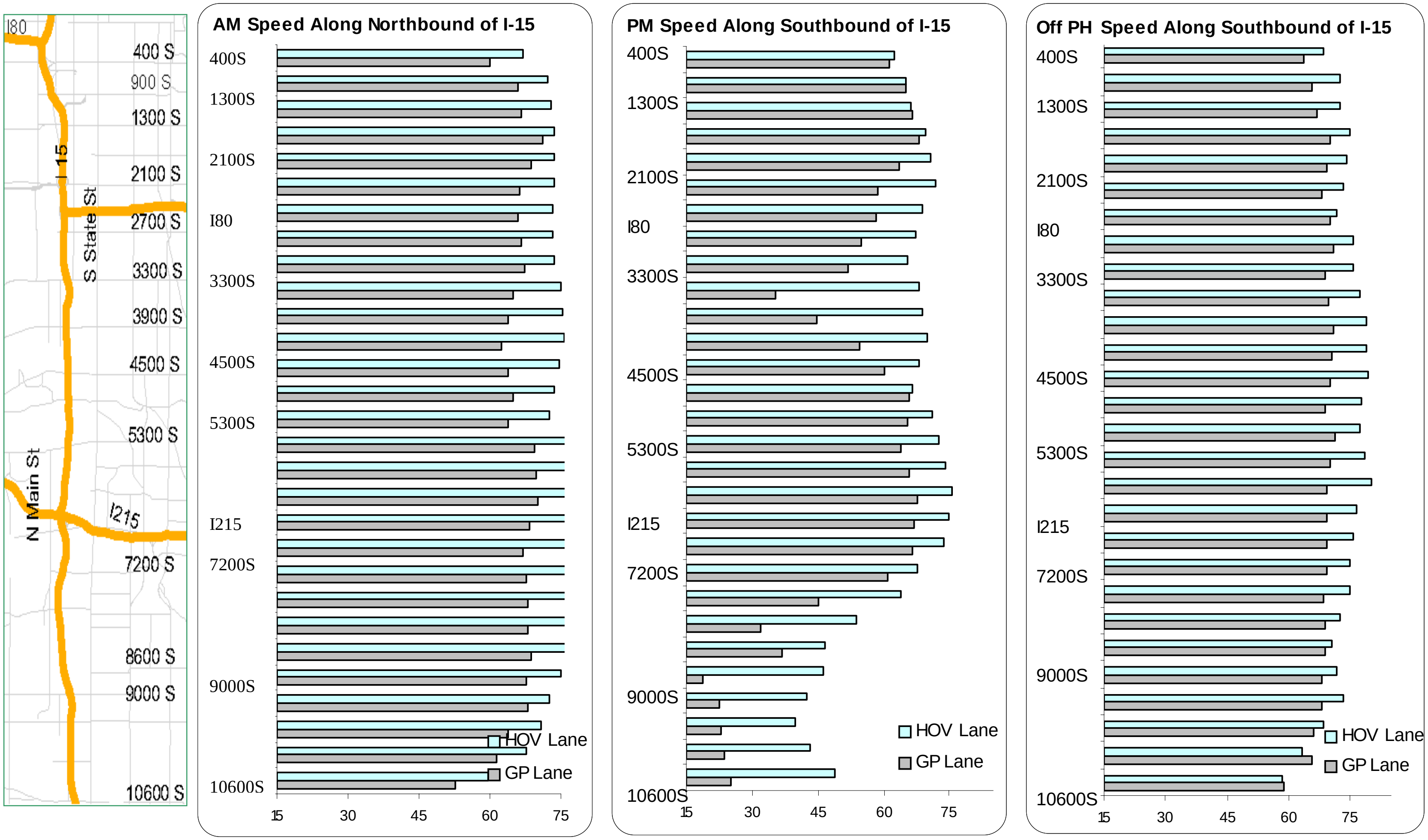
5.1.2 Trip Reliability

Trip reliability measures the expected range in travel time and provides a quantitative measure of its predictability. Reliable travel time allows travelers to accurately predict travel times and to budget less time for their trips. Travel time saving is another measure of corridor-wide HOV performance. It can track changes in facility performance over time and between GP and HOV lane performance. Travel times are estimated for a range of start times for trips that traverse the length of the particular GP and HOV lanes from 400 South to 10600 South. Table 5.1-2 quantifies changes in travel time on average weekdays. For all runs during the congested p.m. peak period, travel-time difference on the HOV lane was 3.9 minutes less than on the GP lane. During the off-peak period and a.m. peak period with low congestion level, the difference of travel time on both the HOV and GP lane was small. It should be noted that travel time runs occurred on days where there were no incidents on I-15. Qualitative observations show that the HOV benefit increases dramatically when an incident causes above-normal congestion on the GP lanes.

Table 5.1-2 Average Weekday HOV and GP Lane Travel Time Comparison

	Average Travel Time (min)		Time Savings (min)	Percentage HOV Time Savings
	HOV	GP		
AM Peak	11.3	13.1	1.8	13.4%
Off Peak	11.5	12.1	0.6	4.7%
PM Peak	14.7	21.2	6.5	30.7%

Figure 5.1-1 illustrates the variation of travel speeds along I-15 on the HOV and GP lane during the a.m., p.m., and off-peak periods. The figure shows that little advantage is available from HOV usage in the a.m. and off-peak times, but that HOV lane users travel at more stable and predictable speeds during the p.m. peak hours than GP lane travelers.



Note: Speed Unit is MPH

Figure 5.1-1 Variation of Speed Along the HOV And GP Lane in Different Periods

On average, HOV lane users experience a travel time advantage of nearly seven minutes during the PM peak period over the adjacent GP lane travelers. During the morning peak period with low levels of congestion, the HOV lane does show a users benefit of 13.4 percent in travel-time savings. In contrast, during the off peak period, the travel times along the HOV and GP lanes are almost the same.

HOV lane travel-time savings result from low levels of traffic congestion on the HOV lane during AM and off-peak commute. From the speed analysis, the vehicles traveling on the HOV lane always maintain a high and stable speed. In contrast, the GP lane vehicle speeds vary according to congestion, whether due to recurring traffic demand or non-recurring incidents.

Often HOV lanes do not operate at expected speeds relative to volume. For example, the speeds of a HOV lane adjacent to a congested GP lane are often less than the speed limit even though the flow is well below capacity. This is often a sympathy speed. To a HOV driver, the disparity in speed between their vehicle and the adjacent GP congested lane speed is uncomfortable and therefore the HOV lane traveler slows down. This can be thought of as a continuous incident. Typically a disabled vehicle on the shoulder causes the speed of the adjacent lane to slow at the point of the disabled vehicle. The congested GP lane acts as a continuous line of “disabled” vehicles that slows the HOV lane travel speeds. The greater the separation between the HOV lanes and GP lanes, the lower the impact of sympathy speeds. In Southern California, a 4-foot striped median is incorporated to provide more positive separation between the HOV and GP lane. On some freeways, a physical separator, such as jersey barriers or pylons, limits entry and exit points to the HOV lanes but further reduces the impact of sympathy speeds.

5.2 Site–Specific Operational Performance

Examining the operation of HOV lanes at specific locations shows more details about HOV lane performance. Figure 5.2-1 illustrates the average travel speed in 15-minute intervals on each lane throughout one 24-hour weekday at a sample location.

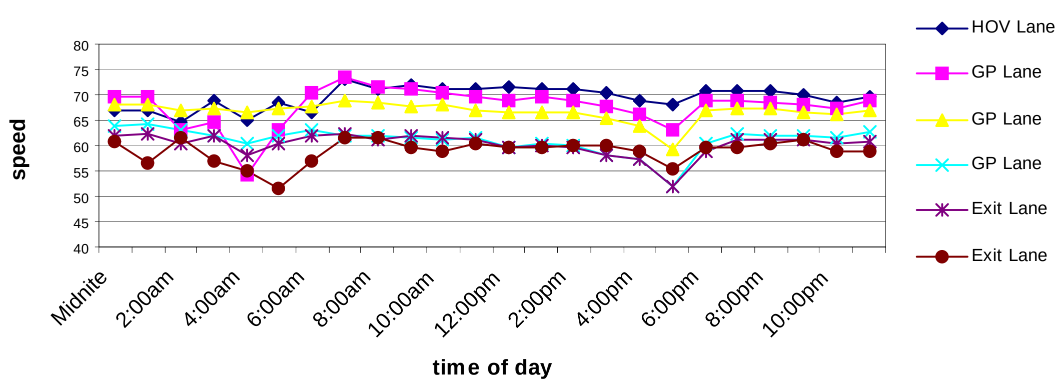


Figure 5.2-1 24-hour Traffic Speed Profile at 5800 South Southbound.

6. VIOLATIONS

HOV lane violations reflect public acceptance of the system. High violation rates reduce HOV lane effectiveness. HOV violation rates are not constant and vary from location to location along a facility. Figure 6-1-1 represents the average violation rate at representative locations along I-15. This graph is based upon the field data collected within the peak periods.

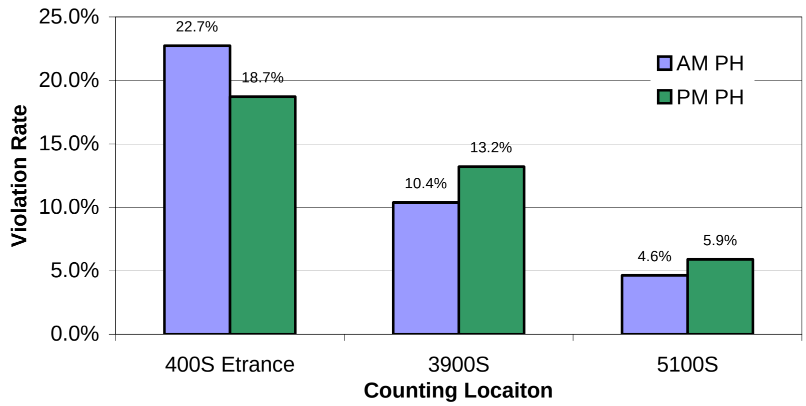


Figure 6.1-1 Violation Comparison by Location

In general, the higher the congestion level, the higher the violation rate as SOVs are more likely to take advantage of the HOV. They perceive the benefit of violation as higher than the risk. In addition, violation rates tend to increase near points where HOV lanes merge with general purpose lanes and HOV ramps. Some motorists seem to believe that getting into the HOV lane "just a little early" is not really a violation and the short time spent in the HOV lane limits the chance that they will be observed by a highway patrol officer. For example, the violation rates at HOV lane's 400 South entrance is above 20 percent. Violation rates vary depending on the level and method of enforcement, but are typically around 10 percent according to national experience and enforcement. Concurrent flow HOV lanes typically have higher violation rates, especially at HOV ramps. The results of a more detailed investigation at the 400 South HOV ramp include monthly violation counts throughout the year as well as one-week of continuous peak hour monitoring. The results from the continuous week of observations are shown in Table 6.1-1 by direction.

Table 6.1-1 Violation Rates at HOV Lane's Ramp During Weekdays

Day of Week	On ramp				Off ramp			
	From East to SB I-15		From West to SB I-15		From NB I-15 to East		From NB I-15 to West	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
Monday	17.6%	16.4%	15.0%	21.3%	1.1%	7.3%	20.5%	16.8%
Tuesday	22.8%	21.3%	18.6%	21.0%	2.9%	7.4%	23.6%	15.3%
Wednesday	21.7%	18.5%	17.0%	20.0%	1.6%	4.9%	27.2%	19.0%
Thursday	29.7%	17.6%	30.1%	16.9%	2.8%	5.6%	27.0%	15.1%
Friday	26.9%	18.9%	24.3%	17.6%	3.4%	3.9%	27.7%	14.9%
Average	23.7%	18.5%	21.0%	19.4%	2.3%	5.8%	25.2%	16.2%

The higher HOV ramp violations resulted in the ramp being monitored closely throughout the initial year of operation to determine how enforcement and education influenced the violations. Figure 6.1-2 shows how the violation rate changes during the initial year of HOV operations. The most dramatic change in violation rates occurred during the early stages of operation. This was indicative of early enforcement and education. The violation rate was approximately 50 percent the first month of HOV operation. Generally, the number of violations has decreased steadily from 24 percent on July 2001 to 18.7 percent the following year. However, the 18.7 percent violation is still high for a facility of this nature.

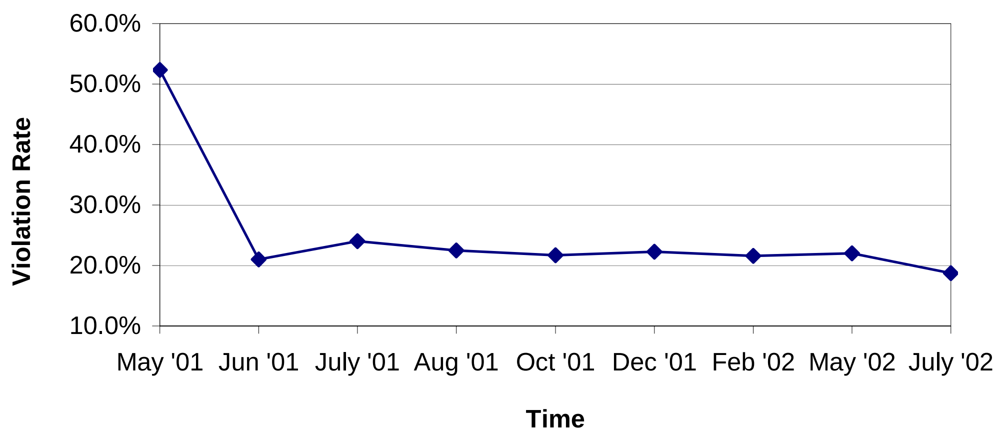


Figure 6.1-2 Violation Rates at 400 South HOV Ramp

7. AVERAGE VEHICLE OCCUPANCY

Successful HOV lanes must not simply divert existing HOVs from GP lanes to the HOV lane, but must also generate new HOVs, resulting in increased AVO. According to nationwide statistics, as automobile ownership has increased, AVO from home to work trips has declined from 1.3 in 1977 to about 1.14 in 1995 (3). With the reconstruction of I-15, the increase in capacity may actually promote a decrease in occupancy by increasing available travel opportunities. Figure 7.1-1 illustrates AVO changes during peak periods before and after HOV lane operation. In order to provide a comprehensive evaluation of freeway operations throughout the Salt Lake Valley, other freeways without HOV lanes were surveyed during the same survey periods. Some of these non-HOV selected locations include I-15 and 600 North, I–215 West and 3100 South, I-215 East and 4500 South.

At the locations without HOV facilities, the AVO remained constant. In contrast, on the I-15 corridors with HOV lanes, AVO had a significant increase of twenty percent, increasing from 1.1 to 1.3. The meaningful increase in AVO, contrasted with a national decline of AVO, suggest that the HOV lane implementation has increased transit and ridesharing.

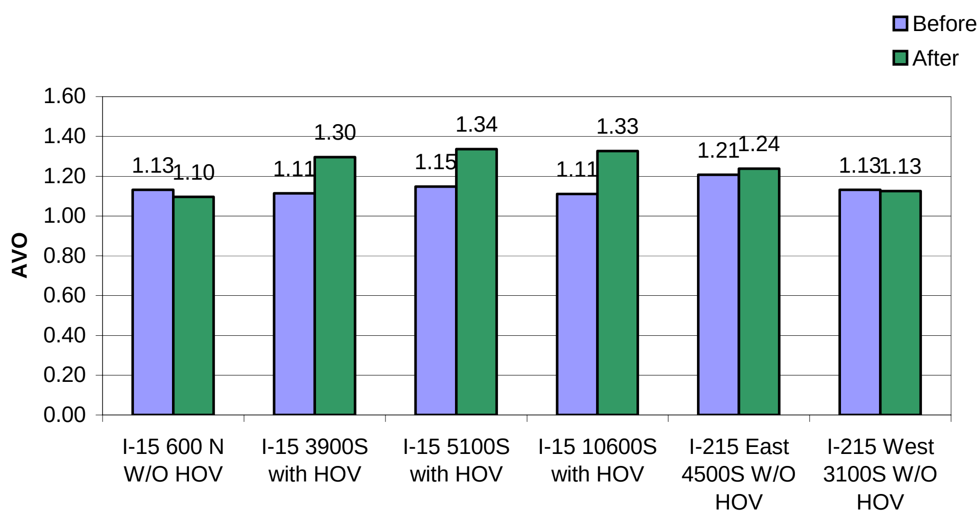


Figure 7.1-1 Change of AVO Before and After HOV Operations

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The analysis and results in this report are drawn from a comprehensive evaluation of the first year of HOV lane operation on I-15. Based on the per lane analysis, HOV lanes carried nearly the same volume of people as the GP lanes and 44 percent of vehicles carried by the GP lanes during the p.m. peak time. During the rest of the day HOV lanes moved less people per lane than their GP lane counterparts. However, this is to be expected as the freeway is much less congested during off-peak times. Judging from the person throughput of HOV lanes, the HOV facility approaches its minimum pre-construction goal, which is to be able to move at least as many people as a GP lane does during the peak periods.

The travel time savings and reliability available to HOV commuters include faster travel along their entire length during peak periods. Statistics show that vehicle speeds in HOV lanes were always higher than in GP lanes throughout the day. Based on the average weekday analysis, during the afternoon peak period in southbound traffic, the average speed in the HOV lane was 63.6 mph, a speed substantially greater than the 51.5 mph in GP lanes. During the morning peak period in northbound traffic, the average speed in the HOV lane was 74.0 mph, and was higher then 65.7 mph in GP lanes. Due to the difference of travel speed between HOV lanes and GP lanes, the travelers along the whole length of the HOV lane during the afternoon peak period had a 6.5 minute benefit compared to that of GP lanes. The HOV corridor p.m. peak time savings is 30.7 percent compared to the time spent in GP lanes while the morning peak period and off-peak period time savings are 13.4 percent and 4.7 percent respectively.

HOV violation rates vary in different times of operation, and also in different locations of the HOV lanes. During the peak periods, the average violation rates was 20 percent at the 400 South HOV on/off ramp, which is substantially higher than violations on other segments of I-15, which range from 5 percent to 13 percent. Generally, the violation rate in the afternoon peak period, with higher levels of congestion, is higher than the morning peak period.

Public acceptance of HOV lanes is judged on the number of people who shift from SOV use to transit or HOVs. After HOV lanes in the I-15 corridors had been in operation for one year, AVO had a 17 percent increase from 1.1 to 1.3. AVO on other Salt Lake Valley freeway segments without HOV lanes remained the same during the analysis period. Therefore, implementation of the HOV lanes has obtained the public support and increased the volume of carpools.

8.2 Considerations / Recommendations

The findings indicate a successful HOV system. Relative to other urban areas where HOV lanes have been installed, Salt Lake City has relatively low congestion and therefore lower need for HOV facilities. As congestion increases, the benefits of the HOV lanes should also increase. Continued monitoring is the best way to identify and track these increasing benefits.

As shown in Figure 4.1 and Figure 4.2-1, it is apparent that HOV lanes are currently underutilized. In contrast, traffic volumes in GP lanes remain consistently high between morning and afternoon peak travel times. Therefore, in the short term, opening HOV lanes to all traffic during off-peak times would more efficiently move traffic flow. However, in the long term, as congestion during off-peak times increases, the advantages to the HOV users would be eliminated. Consequently, monitoring of the system is key to adjusting policy as congestion demands.

According to violation rates analysis, violations are higher than national averages, particularly at the 400 South ramps. Although the lack of barrier separation makes it difficult to enforce HOV regulations, actions such as utilizing media to educate people about HOV lane restrictions, more rigorous violation enforcement, and a program for drivers to report HOV violators, such as Seattle's HERO program, could be implemented.

Compared with HOV lanes performance in other states, I-15 lanes do not meet their potential. Additional marketing of the program may increase usage, particularly if the potential travel time savings were more widely known. More public surveys of HOV users and non-users would help examine why HOV lane demand has not been higher. The most obvious reason is that the newly reconstructed I-15 simply does not have sufficient congestion to encourage large-scale use of HOV lanes. As congestion increases, usage should also. For this reason a continued monitoring effort should be made to track the HOV operations.

Some states, such as Minnesota and California, have conducted continuous HOV lane evaluations since the beginning of operation. New policies are recommended to improve the efficiency of HOV lanes each year. We suggest UDOT improve its HOV data collection efforts, conduct periodic statewide surveys to determine the impact of HOV lanes on carpooling, and report on and develop a statewide plan to promote lane usage. The report should include the automated information available from the TMSs as well as vehicle occupancy and violation rate measures. The measures set forth in this study should be the data collected. These include:

1. Average vehicle occupancy on HOV and GP lanes for I-15 and other freeways. (Manual collection process)
2. Volume for HOV and GP lanes
3. Travel time and reliability for the corridor by HOV and GP lanes. This can be acquired manually or implied from the TMS speed information.
4. Violation rates. While research in California is working on automated methods for determining vehicle occupancy, this is still primarily a manual process.

This data will support HOV lane performance assessments as reported in this study. With no national guidelines on the evaluation of a HOV facility, it is important that the DOTs take it upon themselves to monitor the facilities so if public discontent occurs, as experienced in New Jersey, data is available to document the advantages of the HOV lane and discourage the "empty syndrome" argument.

Statewide TMS is an important source of traffic data collection.During the process of data collection we found that only 70 percent of TMS can provide valid data in UDOT's more than 500 stations. Only 50 percent of TMSs covering the HOV lanes from 600 North to 10600 South along the I-15 corridor provided complete data, even fewer provide both reliable traffic speed data and volume data. For the continuous monitoring of HOV lanes, frequent maintenance of TMS is strongly recommended.

From Figure 5.1-1, the travel speed in both HOV lanes and GP lanes drop from 7200 South to 10600 South for I-15 Southbound during the p.m. peak period. This is not surprising because three separate directions of freeway converge at the I-215 / I-15 interchange. The high volume results in recurring congestion in both HOV lanes and GP lanes. Along that segment, with only 25 percent of entire road length, more than 35 percent of travel time was spent.

Much of the p.m. peak period congestions is caused by spillback from congestion at 10600 South where the HOV lane not only merges into GP lanes, but one GP lane is subtracted. A significant queuing in this segment occurs because of this road bottleneck. The primary value of the HOV lane lies in queue jumping. Making geometrical improvements, such as providing on/off ramp for HOV at the 10600 South exit or extension of HOV lanes after this point would greatly improve the travel-time-saving benefit of HOV lanes. Overall improvements to the widening of I-15 southbound from 10600 South is likely to result in reduced HOV benefits during the p.m. peak as the congestion diminishes.

Consideration should be given to inside ramps for the HOV lanes as HOV users in the p.m. peak must cross four congested GP lanes to exit the freeway and therefore many potential users do not use the HOV facility for short freeway trips. As the I-15 South widening occurs in the future, inside HOV ramps at 11400 South, 12600 South, Bangerter Highway and 14400 South should be considered. Atlanta, Seattle, and Los Angeles have all incorporated direct HOV ramps for freeway-to-freeway connections and arterial connections resulting in increased utilization.

REFERENCES

1. Mark J. Poppe, David J.P. Hook, and Ken M. Howell. Evaluation of High-Occupancy-Vehicle Lanes in Phoenix, Arizona. *Transportation Research Record 1446*, TRB, Transportation Research Board, National Research Council, Washington, D.C., 1994, pp. 1-7.

2. *Twin Cities HOV Study*. Minnesota Department of Transportation, February 2002.

3. HOV Lanes in California: Are They Achieving Their Goals? Legislative Analyst's Office, July 2000.

4. Joseph L. Schofer and Edward J. Czepiel, High Occupancy Vehicle Facilities for the Chicago Metropolitan Area: A Review of National Experience, Success Factors and Decision Issues. Northwestern University, May, 1999

5. HOV Lane/Current Evaluation Results. Oregon Department of Transportation, http://www.hov.odot.state.or.us/current_evaluation.htm, 2001.

6. *2000 HOV Annual Report*. California Department of Transportation, June 2001.

7. *HOV Lane Performance Monitoring: 2000 Report*. Washington State Transportation Center (TRAC), 2001.

8. *Washington State Freeway HOV program: Status, Performance, Questions and Answers.* Washington State Department of Transportation, January 2001.

9. Arnold Bloch, Margret Campbell. Marketing a High-Occupancy-Vehicle Lane in a Suburban Setting: Long Island Expressway Experience. *Transportation Research Record 1446*, TRB, Transportation Research Board, National Research Council, Washington, D.C., 1994, pp. 38-43.

10. Heidi F. Van Luven, The Program to Gain Public Acceptance of Tennessee's First HOV Lanes. 7th National Conference on High-Occupancy Vehicle System, June, 1994.

11. James J. Synder, Marketing I-80 in New Jersey. 7th National Conference on High-Occupancy Vehicle System, June, 1994.

12. Donna Carter, Frank Wilson, Marketing Features and Benefits of Carpool Lanes. 7th National Conference on High-Occupancy Vehicle System, June, 1994.

13. U.S. Department of Transportation. 1997. *Final Performance and Benefits Summary*. From CD-ROM titled "The National Architecture for ITS: A Framework for Integrated Transportation into the 21st Century." Washington, D.C., 1997.

14. *Intelligent Transportation Systems at the 2002 Salt Lake City Olympic Games*. Utah Department of Transportation of Transportation.

APPENDIX

I-15 Northbound 24-Hour Traffic Volume Profiles at 5800 South during a Weekday

Detector	Mid	*A.M.*											*P.M.*											
Location	**Night**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
HOV Lane	32	17	65	18	32	67	256	611	518	343	280	315	357	432	463	635	531	534	683	420	289	265	189	121
Exit Lane	46	36	16	14	30	90	338	653	799	594	546	540	596	630	588	705	722	735	522	394	323	316	239	142
GP Lane	185	122	100	100	170	456	1111	1728	1700	1382	1285	1386	1349	1380	1425	1521	1446	1371	1282	1067	889	873	667	511
GP Lane	214	139	106	134	198	578	1295	1912	1812	1459	1325	1339	1406	1376	1394	1537	1432	1413	1372	1115	966	907	696	563
GP Lane	169	88	66	81	150	497	1296	1850	1774	1311	1196	1253	1275	1255	1206	1453	1356	1357	1314	1081	856	808	625	465
Exit Lane	33	21	14	15	31	202	993	1930	1641	1017	806	808	865	887	948	1195	1056	1108	1048	725	481	456	313	170

I-15 Southbound 24-Hour Traffic Volume Profiles at 5800 South during a Weekday

Detector	Mid	*A.M.*											*P.M.*											
Location	**Night**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
HOV Lane	22	15	2	3	4	13	43	117	151	179	190	266	331	411	482	632	873	879	670	377	264	323	304	115
GP Lane	127	47	26	18	26	77	281	635	759	704	796	924	1119	1207	1343	1726	1964	1950	1362	873	571	639	567	281
GP Lane	289	185	111	61	106	290	650	999	1100	1060	1159	1254	1365	1405	1540	1676	1789	1751	1457	1116	847	917	769	533
GP Lane	385	280	189	148	195	349	760	1227	1287	1250	1340	1458	1697	1760	1830	2042	2125	2100	1763	1309	1089	1101	1013	704
Exit Lane	190	123	82	58	62	145	291	681	841	826	827	1043	1227	1231	1302	1461	1651	1758	1345	894	716	675	642	402
Exit Lane	62	27	31	22	17	40	61	221	255	249	300	337	439	426	416	513	539	680	427	270	211	227	182	136

Unit: Vehicles Per Hour

I-15 Northbound 24-Hour Traffic Volume Profiles at 5800 South during the Olympics

Detector Location	Mid Night	A.M.											P.M.											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
HOV Lane	115	29	14	4	31	163	335	443	403	326	364	448	408	469	601	636	784	837	761	468	359	291	281	139
Exit Lane	91	50	43	22	58	128	364	720	820	567	521	600	607	624	656	691	696	621	515	377	323	265	215	185
GP Lane	265	193	139	112	251	605	1092	1687	1667	1458	1347	1412	1488	1477	1438	1464	1459	1399	1235	987	858	791	651	487
GP Lane	367	221	178	164	319	836	1310	1806	1674	1387	1333	1367	1410	1471	1497	1508	1446	1500	1314	1132	926	904	786	605
GP Lane	316	162	125	112	263	786	1312	1742	1624	1334	1252	1271	1274	1334	1379	1398	1421	1415	1267	1002	877	838	751	518
Exit Lane	143	34	29	24	69	426	1065	1592	1323	1004	818	868	893	954	1031	1158	1228	1243	1070	710	530	489	428	239

I-15 Southbound 24-Hour Traffic Volume Profiles at 5800 South during the Olympics

Detector Location	Mid Night	A.M.											P.M.											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
HOV Lane	113	33	20	7	6	18	56	146	140	179	210	293	311	361	545	655	954	799	575	385	334	621	637	509
Exit Lane	304	138	68	38	46	133	338	695	704	665	728	939	1035	1078	1425	1726	1767	1673	1206	878	687	922	882	796
GP Lane	497	299	199	130	151	327	644	1098	1075	1077	1112	1195	1293	1336	1476	1734	1623	1628	1311	1100	910	1093	1080	939
GP Lane	595	427	301	182	230	437	746	1241	1380	1306	1326	1470	1524	1684	1923	2023	2051	2019	1594	1314	1100	1242	1201	1056
GP Lane	305	228	152	87	98	160	320	671	940	842	837	1096	1175	1263	1437	1504	1587	1670	1178	848	691	764	696	616
Exit Lane	66	76	41	20	21	40	85	193	262	260	259	318	386	438	472	536	552	571	350	292	230	221	212	169

Unit: Vehicles Per Hour

24-hour Traffic Speed Profile at 5800 South Southbound during a Weekday

Detector Location	Mid Night	A.M. 1	2	3	4	5	6	7	8	9	10	11	P.M. 12	1	2	3	4	5	6	7	8	9	10	11
HOV Lane	67	67	64.5	69	65	68.3	66.5	73	71.3	71.8	71.3	71.3	71.5	71	71.3	70.5	69	68	70.8	70.8	70.8	70	68.5	69.5
Exit Lane	69.5	69.5	63.3	64.8	54.3	63.3	70.3	73.5	71.5	71	70.3	69.8	69	69.5	68.8	67.8	66.3	63	68.8	69	68.5	68.3	67.5	68.75
GP Lane	68.25	68.3	67	67.3	66.5	67.3	67.8	68.8	68.5	67.8	68	66.8	66.5	66.5	66.5	65.5	63.8	59.3	66.8	67.3	67.3	66.5	66.3	67
GP Lane	63.75	64.3	63	62	60.3	61.8	63	62	61.8	61.5	61.3	61.5	59.8	60.5	60	58.3	57.3	51.8	60.5	62.3	62	61.8	61.5	62.75
GP Lane	62	62.3	60.5	61.8	58.3	60.3	61.8	62.3	61.3	62	61.5	61	59.5	60	59.5	58	57.3	52	58.8	61	61.3	61	60.5	60.75
Exit Lane	60.75	56.5	61.5	56.8	55	51.5	56.8	61.5	61.5	59.8	58.8	60.5	59.8	59.8	60	60	59	55.3	59.5	59.8	60.5	61	59	59

Unit: Miles Per Hour

Variation of Speed along the HOV and GP Lane in Different Periods

Intersection	P.M. Peak Southbound		A.M. Peak Northbound		Off-Peak Time	
Location	GP	HOV	GP	HOV	GP	HOV
10600S	25	49	53	60	59	58
	24	43	61	68	66	63
	23	40	64	71	66	68
	23	43	68	73	68	73
	19	46	68	75	68	72
9000S	37	47	69	78	69	71
	32	54	68	78	69	73
	45	64	68	78	69	75
8600S	61	68	68	78	69	75
	67	74	67	78	69	76
	67	75	69	78	70	77
7200S	68	76	70	79	69	80
	66	74	70	78	70	79
I215	64	73	70	76	71	77
	65	71	64	73	69	78
5300S	66	67	65	74	70	79
	60	68	64	75	71	79
4500S	55	70	63	76	71	79
	45	69	64	75	70	77
3900S	35	68	65	75	69	76
3300S	52	66	67	74	71	76
	55	67	67	73	70	72
I80	58	69	66	73	68	73
2100S	59	72	66	74	69	74
	64	71	69	74	70	75
1300S	68	70	71	74	67	73
	67	66	67	73	66	73
600S	65	65	66	72	65	68
400S	61	63	60	67	64	65

Unit: Miles Per Hour