AN EXAMINATION OF OPERATIONAL ALTERNATIVES FOR EXISTING AND PROPOSED HOV FACILITIES

by

Carl Brian Shamburger

Professional Mentor
Leslie N. Jacobson, P.E.
Washington State Department of Transportation

Prepared for
CVEN 677
Advanced Surface Transportation Systems

Course Instructor
Conrad L. Dudek, Ph.D., P.E.

Department of Civil Engineering
Texas A&M University
College Station, TX

August 1995
SUMMARY

Traffic congestion continues to be a significant problem for most metropolitan areas in North America and throughout the rest of the world. HOV facilities are an effective tool to help address the issue of traffic congestion. While most HOV lanes have experienced continuous growth since becoming operational, several facilities are faced with the problem of either congestion or underutilization.

The source of this problem revolves around what vehicles are allowed to use the HOV lane during the peak hour. Traditionally, if an HOV lane begins to approach capacity, the occupancy requirements are tightened to lower the demand on the system. Unfortunately, increasing the occupancy requirement can result in unused capacity. In response to this problem, this report examined alternative approaches for managing vehicular demand on existing and proposed HOV lanes. A requirement of each approach developed was that it must help to maintain the original goals and objectives of the HOV concept (i.e., promote higher occupancy vehicles and improve travel time savings and reliability).
# TABLE OF CONTENTS

## INTRODUCTION
- Background .......................................................... K-1
- Objectives ........................................................... K-1
- Scope ................................................................. K-2
- Organization of Report ............................................ K-2

## CASE HISTORY OF MODIFIED OCCUPANCY REQUIREMENTS
- Katy Freeway (I-10 W) HOV Lane - Houston, Texas .............. K-3
- I-5 North HOV Lane - Seattle, Washington .......................... K-7
  - HOV Lane Use Levels .................................. K-7
  - Travel Times and Travel Time Savings ...................... K-7
  - Travel Time Reliability ................................ K-10

## SUGGESTED OPERATIONAL ALTERNATIVES FOR HOV LANES
- Procedures for Implementing HOV Restrictions .................. K-11
  - Defining the Eligible User Group .......................... K-11
  - Staged Occupancy Implementation Strategy ............... K-11
  - A Change of Attitude ........................................ K-13
- Metering HOV Lanes .............................................. K-14
  - Critical Issues ............................................... K-14
  - General Metering Concept ................................ K-14
  - Eligibility .................................................... K-14
  - Geometric Design and Access ................................ K-15
  - Determining Occupancy ..................................... K-15
  - Metering Rates ............................................... K-17
  - Motorist Information ....................................... K-17
  - Enforcement .................................................. K-17
  - Public Acceptance .......................................... K-18
  - Equity ........................................................... K-18
  - Measures of Effectiveness .................................. K-18
  - Institutional Concerns ....................................... K-19
- Evaluation of Metering HOV Lanes ................................ K-19
  - Advantages ................................................... K-19
  - Disadvantages ................................................ K-20
- Congestion Pricing on HOV Lanes ................................ K-20
  - Case Study Design .......................................... K-20
  - Case Study Objectives ..................................... K-21
  - Critical Issues ............................................... K-21
- Evaluation of Congestion Pricing on HOV Lanes .................. K-24
  - Advantages ................................................... K-24
  - Disadvantages ................................................ K-25
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional Operational Alternatives</td>
<td>K-25</td>
</tr>
<tr>
<td>Non-HOV Users</td>
<td>K-25</td>
</tr>
<tr>
<td>Extended Travel SOVs</td>
<td>K-26</td>
</tr>
<tr>
<td>KEY ISSUES FOR IMPLEMENTATION</td>
<td>K-29</td>
</tr>
<tr>
<td>Proposed HOV Facility</td>
<td>K-29</td>
</tr>
<tr>
<td>Existing HOV Facility</td>
<td>K-30</td>
</tr>
<tr>
<td>Admit Non-HOV Users</td>
<td>K-30</td>
</tr>
<tr>
<td>Ramp Metering</td>
<td>K-31</td>
</tr>
<tr>
<td>Congestion Pricing</td>
<td>K-32</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>K-33</td>
</tr>
<tr>
<td>RECOMMENDATIONS</td>
<td>K-34</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>K-35</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>K-36</td>
</tr>
</tbody>
</table>
INTRODUCTION

Background

Traffic congestion continues to be a significant problem for most metropolitan areas in North America and throughout the rest of the world. HOV facilities provide one approach that may be appropriate to help address the issue of traffic congestion.

Operational definitions such as vehicle occupancy requirements and hours of operation affect the operating characteristics of HOV facilities. Managers and operators of HOV facilities are currently faced with the problem of HOV lanes that are either congested or underutilized during peak period operation. Occupancy restrictions that are too strict will more than likely result in wasted capacity; whereas, hours of operation having congestion flow might improve if restrictions are tightened (e.g., increase occupancy restrictions from 2+ to 3+).

The task of selecting the appropriate occupancy requirement for use on an HOV facility has traditionally been a simple one. Continuous monitoring and extensive research have provided the transportation planners and engineers responsible for the design and operation of HOV lanes with the necessary tools to say confidently which occupancy will ensure free-flow conditions. Unfortunately, the public does not always perceive a selected occupancy requirement as the most appropriate one, therefore, transportation professionals are faced with the problem of how best to present sound engineering judgement to the public. The possible solutions may require some creative thinking and are examined in this report.

The applications of advanced technologies such as ramp metering and automatic vehicle identification (AVI) have been suggested for use with traditional HOV facility operations. Metering HOV lanes is very similar to the metering of freeway mainlanes. As a facility approaches congested flow, vehicles entering the system are metered at a predetermined rate to achieve an optimal level of service and yet still maintain the original goals and objectives of the HOV facility. Metering can also be applied to an underutilized HOV lane, where additional user groups are allowed access onto the facility while the current user’s service does not deteriorate.

Congestion pricing can be considered a form of metering when applied to vacant HOV lanes. The theory behind congestion pricing is that motorists should pay a premium price if they want a better level of service than is available to all motorists. Here, additional user groups pay to use the HOV lane when the adjacent general purpose lanes are overloaded.

Objectives

The overall objective of this research study was to examine various HOV lane operation alternatives (i.e., evaluate how HOV facilities operate under various physical designs, occupancy requirements, hours of operation, and advanced technologies such as ramp metering and congestion pricing) with the intent of developing recommendations for use by operators faced with the problem of either congested or underutilized HOV facilities. To accomplish this objective, the following tasks were performed:
Examine the structure of existing HOV facilities to document their operation and use;

Assemble HOV lane operation before/after data from various case studies that have changed occupancy requirements;

Document concerns and difficulties the transportation profession is experiencing with the operation and use of HOV lanes;

Consolidate HOV lane operations with different occupancy requirements, operating hours; and

Evaluate and develop appraisals of existing and proposed operational alternatives.

Scope

The purpose of this paper was to provide an insight into the current HOV operational issues and alternatives those transportation agencies must manage. Although an agency must consider many operational issues, this paper briefly examined the selection, use, and public perception of the required occupancy requirement(s) for an HOV facility. This paper examined the feasibility of metering, congestion pricing, and the use of other operational alternatives on HOV facilities. Included in the discussion was an assessment of the technology available for use, the practicality of such a system, and the public perception of the alternatives discussed. The content of this paper was based on a review of literature, case studies, and discussions and correspondence with various transportation professionals.

Organization of Report

This report is organized into five sections. The next section provides an overview of the key elements associated with the utilization trends of HOV facilities that have either changed their occupancy requirements or variable occupancy requirements by time of day. Section III examines possible operational alternatives for HOV lanes. Included in this discussion is a summary of the suggested procedures for implementing occupancy requirements for an HOV facility where the potential of public disagreement or disapproval is high. The feasibility of metering HOV facilities, the use of congestion pricing, and other operational alternatives are also examined. Section IV provides suggestions for setting up the alternatives discussed on proposed and existing HOV facilities. Finally, this report concludes with a summary of the issues examined and recommendations concerning their logic.
CASE HISTORY OF MODIFIED OCCUPANCY REQUIREMENTS

This section provides an overview of the key elements associated with the utilization trends related to HOV facilities that have either changed their occupancy requirements or variable occupancy requirements by time of day. This section presents the operational history of two HOV facilities that have modified their occupancy requirements. The two facilities examined are the Katy Freeway (I-10 W) in Houston, Texas, and the I-5 North HOV lane in Seattle, Washington. The information is presented to provide as a platform for future discussions and issues in this report.

Katy Freeway (I-10 W) HOV Lane - Houston, Texas

Based on the successful operation of the I-45 North Freeway Contraflow Lane in north Houston, only authorized buses and 8+ vanpools were initially envisioned to be eligible users of the HOV system in Houston (note: the term “authorized” meant that each carpool received a permit to use the facility and the drivers were trained, eligibility did not solely depend on complying with the occupancy requirements).

The Katy Freeway HOV lane is on I-10 West in Houston, Texas. The HOV lane was opened in October 1984 under a joint venture between the Metropolitan Transit Authority of Harris County (METRO) and the Texas Department of Transportation (TxDOT). It is a 13-mile, barrier-separated, single-lane, reversible HOV lane, serving as a major travel corridor on the west side of the city (see Figure 1). Three park-and-ride lots and three park-and-pool lots are along the corridor. Access and egress to the facility is provided by slip ramps and direct access ramps (1).

As mentioned above, the Katy HOV lane is a barrier-separated, reversible-flow facility. The HOV lane is open in the inbound in the morning from 4:00 a.m. to 1:00 p.m. It is then closed from 1:00-2:00 p.m. to reverse the flow of the HOV traffic. The lane reopens at 2:00 p.m. and operates in the outbound direction until 10:00 p.m.

The Katy HOV lane has changed its vehicle occupancy requirements often since its opening in 1984. During its initial inception, use of the Katy Lane was limited to authorized buses and 8+ vanpools. Unfortunately, under this operating strategy, fewer than 150 vehicles occupied the facility in the peak period during the first few months of operation. Obviously, the original use of the transitway was well below METRO’s and TxDOT’s initial expectations. In an attempt to increase the use of the lane, the decision was made to allow authorized 4+ carpools on the HOV lane in April 1985. Lowering the occupancy requirement to 4+ did not result in any appreciable difference in use. Therefore, in December 1985 the occupancy requirement was lowered to authorized 3+ carpools, and in August 1986 it was changed to 2+ and the authorization requirement was dropped.

The traffic volumes during the morning peak hour (7:00-8:15 a.m.) continued to increase steadily, almost reaching 1500 vph, the assumed lane capacity of the HOV lane. The result of this increase was a decline in the travel speeds and travel time reliability. Bottlenecks typically occur at the exit nodes where HOV traffic attempted to merge with the freeway mainlane traffic. To relieve this peak hour congestion, a 3+ vehicle occupancy requirement from 6:45-8:15 a.m. was reinstated in October 1988; 2+ carpools were still allowed to use the facility in the mornings before
and after the 3+ restricted use period and during the entire p.m. period. The morning peak hour was revised slightly in May 1990 to 6:45-8:00 a.m. The vehicle and person volumes dropped off initially after the start of the 3+ requirement. Due to an increase in traffic volumes in the afternoon peak period in the fall of 1991, the 3+ occupancy requirement was applied to the afternoon peak hour from 5:00-6:00 p.m. The historical trends in vehicle and passenger volumes since the inception of the Katy HOV lane in October 1984 are shown in Figures 2 and 3, respectively. Currently, during the 3+ operating periods, only about 500 vehicles per hour use the facility (1, 2).

Figure 1. Katy Freeway HOV Lane, Houston, Texas (1).
Figure 2. Katy Freeway (I-10 W) HOV Lane - A.M. Peak Hour HOV Lane Vehicle Movement (3).
Figure 3. Katy Freeway (I-10 W) HOV Lane - A.M. Peak Hour HOV Lane Person Movement (3).
In July 1991, the Washington State Department of Transportation (WSDOT) lowered the minimum occupancy requirement on the I-5 North HOV lanes from 3+ to 2+ as part of a six-month demonstration project. The segment of the HOV lane included in the demonstration is shown in Figure 4. It is a concurrent flow section that operates with a 3+ HOV requirement on a 24-hour basis. The only thing separating the HOV lane from the general purpose lanes is a painted line, special pavement markings, and additional signing. Continuous access and egress are provided along the entire length of the lanes. One objective of the demonstration project was to examine the impact the reduction in an occupancy requirement had on the utilization levels, travel times, and travel time reliability. These impacts are presented in the following sections.

**HOV Lane Use Levels**

For the demonstration, HOV lane volumes in 1990 and 1991, at the 3+ occupancy requirement, were compared with the data obtained when the 2+ occupancy requirement was in effect. Overall, the peak hour and peak-period volumes in the HOV lanes under 2+ operations more than doubled when compared with previous years’ data. Before the start of the demonstration, recorded volumes on the HOV lanes were between 400 and 700 vehicles per hour in the peak hour. Almost immediately after the demonstration began, volumes were recorded as high as 1400 to 1600 vehicles per hour in the peak hour period. Similar trends were observed for both the morning and afternoon operations. Figure 5 shows the general utilization trend observed at all data stations along the I-5 North corridor.

**Travel Times and Travel Time Savings**

Travel times for vehicles using the HOV lane were measured and are presented in Table 1. Overall, there was no significant change in travel times with the 2+ requirement. Although there was no statistical difference in travel times, usually the travel times increased because of the change. More important than the travel times is the travel time savings, or lack of it, produced by the 2+ change. Table 2 provides a comparison of the average travel time savings for HOVs in the HOV lanes with the travel time savings of vehicles in the general purpose lanes. The results are inconsistent (i.e., savings decreased in the morning and increased in the afternoon). Much can be attributed to operations on the general purpose lanes, since as seen in Table 1, no significant changes in travel times occurred because of the occupancy change.
Figure 4. I-5 North HOV Lanes, Seattle, Washington (4).
Figure 5. I-5 North HOV Lane - Comparison of Peak Hour HOV Volumes (4).

Table 1. I-5 North HOV Lane - Travel Time Changes (4).

<table>
<thead>
<tr>
<th>Peak Hour Period</th>
<th>Direction</th>
<th>Day of Week</th>
<th>Time Period</th>
<th>Travel Time (minutes)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.M.</td>
<td>SB</td>
<td>M-Th</td>
<td>Pre</td>
<td>5.82</td>
<td>-0.34%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post</td>
<td>5.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Friday</td>
<td>Pre</td>
<td>5.53</td>
<td>+1.27%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post</td>
<td>5.60</td>
<td></td>
</tr>
<tr>
<td>P.M.</td>
<td>NB</td>
<td>M-Th</td>
<td>Pre</td>
<td>7.50</td>
<td>+6.40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post</td>
<td>7.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Friday</td>
<td>Pre</td>
<td>9.45</td>
<td>+3.39%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post</td>
<td>9.77</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. I-5 North HOV Lanes - Travel Time Savings over General Purpose Lanes (4).

<table>
<thead>
<tr>
<th>Peak Hour Period</th>
<th>Direction</th>
<th>Day of Week</th>
<th>Time Period</th>
<th>Travel Time Savings (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.M.</td>
<td>SB</td>
<td>M-Th</td>
<td>Pre</td>
<td>2.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Friday</td>
<td>Pre</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post</td>
<td>0.13</td>
</tr>
<tr>
<td>P.M.</td>
<td>NB</td>
<td>M-Th</td>
<td>Pre</td>
<td>1.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post</td>
<td>3.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Friday</td>
<td>Pre</td>
<td>6.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post</td>
<td>9.66</td>
</tr>
</tbody>
</table>

Travels Time Reliability

Another factor used to describe the effective use of an HOV facility is the travel time reliability. For this demonstration, the effect of the change in occupancy requirement was measured by calculating the standard deviation of vehicle speeds along the HOV corridor before and after the change. Figure 6 showed that travel time reliability decreased significantly during the demonstration period, showed by the extreme difference in speed variation for the before (3+) and after (2+) data.

![Figure 6. I-5 North Demonstration - Overall Speed Variation for HOVs (4).](image-url)
The previous sections provided a brief history of two HOV facilities that have either had difficulty maintaining a desired usage or modified their existing occupancy requirements to examine the effect on HOV lane use and overall efficiency. The following sections suggest potential operational alternatives that could be used to increase the use of HOV facilities experiencing similar problems. Although several HOV facilities are mentioned throughout this report, the Katy Freeway (I-10 W) HOV lane in Houston, Texas is the primary case study.

**Procedures for Implementing HOV Restrictions**

*Defining the Eligible User Group*

Examining the events that took place over a four-year period on the Katy HOV lane can be a learning experience. The Katy HOV lane opened for use in 1984 with authorized buses and 8+ carpools as eligible users. The idea of having only authorized users on the facility was based on the successful operation of the I-45 North Freeway Contraflow lane (1). Note, the North Freeway was a contraflow lane with geometric deficiencies and the Katy Freeway is a barrier-separated HOV facility having very restricted access and egress.

Comparison of the two user groups on the North and Katy Freeway HOV facilities produces obvious differences. Recommendations to use experienced drivers on the North Freeway Contraflow lane made good sense. The contraflow lane was separated from the off-peak direction general purpose travel lanes using only plastic posts or pylons. The author believes that the potential for conflict increased with an increase in driver workload; therefore, the need to use only experienced drivers was reasonable. Applying that same idea to a barrier-separated facility, such as the Katy HOV lane, may not have been the most appropriate decision.

Understanding the original goals and objectives of the HOV system in Houston is important for Houston. Houston obviously wanted to provide better mobility for HOVs, especially those motorists using mass transit. The original engineers and planners on the Katy project may have been naive to think that the users of the facility were going to change their driving behavior for the benefit of transit ridership. The geometric design of the facility warranted concern for driver safety. A vertical curve at the Old Katy Road access road was substandard. Both the Federal Highway Administration (FHWA) and the engineers responsible for operating the facility felt that trained drivers were required to negotiate the substandard curve (5).

Considerable care must be taken to decide the most appropriate user group for a facility. Unreasonable restrictions imposed on SOVs and HOVs without the necessary market research can lead to misunderstandings, criticisms, and loss of public support, and organized opposition.

*Staged Occupancy Implementation Strategy*

The Houston experience in going from 2+ to 3+ in the peak hour can be instructive. Congestion existed and then the solution came. No solution was thought up and carried out by engineers and planners before the motorists had a chance to experience the problems (i.e., congestion). Traditionally, this is some problem engineers and planners have faced in the past. They
have done the analysis, determined the best solution for this HOV facility (i.e., selected an occupancy requirement), and implemented the solution before the public had the chance to see the problem they were trying to solve.

The following hypothetical situation helps to explain the previous statements (Note: this scenario only applies for when the public is unfamiliar with HOV lane operations. It the author’s opinion that an experienced public would not respond in the same manner).

Good engineering and planning practice say to look at the volumes and decide whether a 2+ or 3+ occupancy is required. Upon examining the data it is determined that a 3+ occupancy is required, because at the current 2+ volumes and with a minimum amount of growth, the lane capacity and operations will quickly deteriorate. This is excellent technical analysis. Reality though is people do not have the chance to see the data used for analysis and see the condition the engineer and planner says will result. Therefore, the public never understands what the real problem is. They simply see that the facility was opened at 3+ on day one and only 500 vehicles were using it. The public response to this lack of use is that the lane should have been opened at 2+ and not 3+. Engineers and planners may argue the fact that at 2+ the lane would have been congested. The public typically responds in disbelief. There is no way to prove that congestion would have occurred unless the operators allow it to happen. The reality of this problem is that those responsible almost have to err on the side of allowing the congestion to occur.

The following steps have been provided as one possible solution to gaining the public acceptance needed.

1. Phase in the required occupancy over time, explaining to the public that this facility will eventually operate at a 2+ occupancy requirement (e.g., begin operations at buses only and stair-step down to a 2+ occupancy in a short period).

2. Explain to the public that this short period will be used as a training period to educate maintenance and enforcement officials responsible for the day-to-day operations of the facility.

3. Send the public a schedule explaining the transition: week 1 - buses only; week 2 - buses and 4+; week 3 - buses and 3+; week 4 - buses and 2+ (i.e., virtually any HOV).

4. Monitor the facility at 2+ with the understanding and philosophy that if congestion does appear, actions will be considered and carried out to ensure that this facility operates at free flow conditions (i.e., changing carpool occupancy levels, hours of operation, metering, etc.).

5. If changes are to be made, survey the users to find out what solutions they feel should be made. Keep in mind though that priority must be given to the facilities best customers (i.e., buses, vanpools, 4-person carpools), since they move more people using the fewest vehicles. Once those vehicles have been accommodated, allow others on as they can be handled.

The bottom line is that engineers and planners are asking motorists to change their driving behavior. We need to be flexible in how we present our logic to them, and motorists need to understand the problem as we do. Allowing the public to understand the problem may mean implementing a strategy that may or may not be the correct technical answer. Engineers can either
let the public experience bad congestion (under the heading of we are going to experiment with the occupancy levels to decide the desired level of operation), or carry out the correct technical, engineering solution without any thought to marketing the solution, and have the public respond by having the project canceled (5).

A Change of Attitude

HOV projects cannot be sold today using a “we know best” attitude, where any suggestions or criticism can only be negative suggestions or criticism. This attitude is not acceptable. Ample evidence is available to suggest this attitude does not work and will not work in most places. The following example has been provided in support.

Dulles Toll Road HOV Lane (6)

The Dulles Toll Road is a twelve-mile roadway connecting the Dulles International Airport to Tysons Corner, Virginia. In 1988, the State of Virginia passed a bill, which allowed for the construction of one new lane in each direction on the toll road. A requirement of this bill was that the additional lanes would be constructed as HOV lanes. The lanes were reserved for buses and carpool with 3+ occupancy. Well before the anticipated date of completion, the entire twelve-mile section of the new roadway was completed. In response to existing congestion, the Virginia Department of Transportation (VDOT) decided to open the new lane as a mixed, general purpose lane. Opening the new lane removed the existing traffic congestion and VDOT was faced with the problem of having to convert a successful general purpose lane to an HOV lane.

Both public and political opposition severely opposed the opening of the Dulles Toll Road HOV lanes. Nevertheless, VDOT stood by its intention to introduce 3+ occupancy restrictions and the HOV lanes were opened as scheduled. As a result, congestion on the toll road was worse than before construction, the HOV lanes appeared empty in comparison to the general purpose lanes, and public opposition quickly intensified.

In one months time, toll road accidents increased, travel times doubled, and commuters left the toll road in search of other modes of travel, which caused toll road revenues to drop some ten to 15 percent. Although, VDOT continued to report that use of the HOV lane was increasing, a bill was passed banning the use HOV lanes on toll roads on federal lands. The HOV lanes were changed back to mixed-use lanes a month after their initial inception.

Conclusions

Several conclusions can be made about the events leading up to the closing of the Dulles Toll Road HOV lanes. When the lanes were opened to mixed traffic, VDOTs marketing attempts focused only on the coming of the HOV lanes. Unfortunately by allowing mixed lane use, VDOT gave the public a solution to their existing congestion problem. The public could not understand why VDOT wanted to revert the lanes over to restricted HOV use, and VDOT did little to support their case.

Experience has shown that change cannot be forced onto the public. Public acceptance and approval are important in the success of any HOV project. Good marketing will not convert a bad project into a good HOV project, nor will it fix a bad project. Good marketing can help in selling an already good HOV project and overcome some negative perceptions about a good project (5, 7).
Metering HOV Lanes

The primary goal of a metering project is to improve the efficiency of the facility. As applied to freeway sections, ramp volumes can continue to increase since vehicle speeds, travel times, and accident experience along the metered sections do not deteriorate. The same idea can be applied to HOV facilities. If the volumes on a 2+ HOV facility are too high, why not meter HOV traffic? Also, HOV lanes operating at a 3+ occupancy level have traditionally had difficulty in obtaining the 3+ demand necessary to fill the lane. Something must be done to fill the gaps. Metering is an option to allow additional HOVs onto an existing underutilized facility and still provide a premium service to existing 3+ HOVs. The following sections discuss the feasibility of metering HOV lanes. The Katy Freeway HOV lane has been selected as a case study.

Critical Issues

Several critical issues concerning metering HOV facilities have been identified. These issues include:

- General Metering Concept;
- Eligibility;
- Geometric Design and Access;
- Motorist Information;
- Level of Operation;
- Determining Occupancy;
- Enforcement;
- Public Acceptance;
- Equity;
- Measures of Effectiveness; and
- Institutional Concerns.

Each issue must be addressed so that the system operates efficiently and the public accepts it.

General Metering Concept

Two levels of operation can occur before metering is started. For example, an excess demand of 2+ carpools wanting to enter the HOV lane exists. The volumes are high enough such that the system begins to breakdown. At limited access points the excess demand (i.e., excess 2+ carpools) is then metered at a rate to allow for optimum efficiency. For the case where the HOV lane is underutilized at 3+ (as with Katy Freeway), 2+ carpools are allowed entrance into the lane until a desired level of service is obtained. Once obtained, the 2+ carpools are metered at a rate so that free flow speeds are obtained (or speeds above a certain threshold are reached).

Eligibility

It is important that access into an HOV facility be limited to only HOVs (i.e., any vehicle with two or more occupants). If the lane is underutilized at a 3+ occupancy requirement, 2+ HOVs should be the only additional eligible users. Other suggestions call for consideration of allowing SOVs onto HOV lanes when excess capacity is available. The author does not recommend this since
the demand for SOV use would typically be too high for metering to be effective. Allowing SOVs the opportunity to travel in an HOV lane also goes against many original goals and objectives of the HOV concept. One objective is to create an incentive to influence SOVs to change their driving behavior and form a higher occupancy vehicle. Under the heading of admitting SOVs, the incentive no longer exists (7).

Geometric Design and Access

Metering can realistically be applied to only certain types of facilities. The geometrics and physical design of the system play an important part in its success. The geometrics issue consists of several factors. First, adequate storage must be available for the queued vehicles entering the HOV lane. This severely limits the use of metering on many facilities (8).

Concurrent flow lanes would not support metering since access is provided at all points along the lane. The only thing separating the HOV lane from the general purpose lane is a painted stripe, pavement markings, and possibly pylons or plastic delineators. Using pylons can help in restricting access, but storage for the metered vehicles would not be provided.

Buffer separated HOV lanes could store 2+ vehicles inside the median/buffer area if the proper channelization was provided. Usually this would not be practical considering the space required and limited highway right-of-way. A storage lane, acceleration lane, and an HOV bypass lane are required to ease merging. Operations on the general purpose lanes could deteriorate if the 2+ demand was high enough such that the queues extended back into the general purpose lanes. From a safety standpoint, storing vehicles along the inside lane of a freeway section is undesirable (5).

The design that best supports metering is a barrier-separated facility with limited access, such as the Katy Freeway HOV lane. Access into and out of the facility is restricted to either slip ramps or park-and-ride lots. Metering at slip ramps is not possible and should not be considered since no storage can be provided along the center median. Due to lack of storage, the use of metering should be restricted to two locations: the park-and-ride lot at Addicks during the morning operation, and the entrance ramp at Post Oak during the afternoon operation (see Figure 1). At the park-and-ride lot, 2+ HOVs can be stored and metered from inside the facility (9).

Limiting 2+ access to a single location may create a problem for those users not near the Addicks park-and-ride lot. Those 2+ carpools downstream of the park-and-ride lot may feel that they are being treated unfairly by having to travel out of their way to reach the HOV lane. The time spent traveling upstream to the park-and-ride lot may increase their normal overall travel time. On the other hand, if their travel time decreases by using the park-and-ride access ramp, equity is no longer an issue. Equity will be discussed later in this section.

Determining Occupancy

One of the biggest questions concerning the operations of a metered HOV facility is how the occupancy of each vehicle entering the HOV lane is determined. The potential for a 2+ carpool to enter the HOV lane exists while the 3+ occupancy restriction is in effect. The system therefore needs to be able to distinguish between 2+ and 3+ carpools. Use of AVI has been suggested. Two scenarios have been identified (both including the AVI technology) and are described below.
**HOV User Account** Any carpool wanting to use the facility would be required to purchase an AVI tag and set up an HOV account with the local operating agency in charge of maintaining the facility (e.g., METRO in Houston). The account tag would identify the carpool as either a 2+ or a 3+ carpool using the number the driver or registrant said was normally in the carpool. Other information such as vehicle owner, license plate, and the registered members of the carpool would be available for enforcement purposes once the tag is read. If a carpool violates the current occupancy restriction, the information could be processed through a central computer system and a citation would then be issued through the mail. Unfortunately, many flaws exist in an account-based occupancy system. Two potential problems are addressed below.

Setting up an account is one possible solution is the future occupancy in the vehicle never changes from its original occupancy. Experience has shown that maintaining a 3+ carpool daily is very difficult. If a member of the carpool is sick or on vacation, the remaining members must either search for an additional rider or travel as a 2+ carpool. If they do continue as a 2+ carpool and desire to use the HOV lane, they should follow the same restrictions that an authorized 2+ carpool follows. Unfortunately, they possess an AVI tag that identifies their carpool as a 3+ carpool and now have the opportunity to cheat the system (10).

Similarly, a carpool may initially consist of only two people. If the carpool wants to use the facility during the peak hour (i.e., during 3+ occupancy restriction), the carpool would set up an account at a 2+ occupancy. Over time, the carpool may pick up an additional rider. Unless the carpool has some means of changing the current occupancy on their tag, they must continue to use the HOV lane as a 2+ carpool or chance being cited by an automated enforcement system (10).

An account-based system must be flexible. The system would have to provide carpools the means to change their current tag occupancy definition to match their actual carpool occupancy. If a carpool loses or gains an additional member, the carpool could contact the local authority and make the adjustment immediately. If the problem occurs only once or twice a month, a carpool could be allowed some predetermined number of “free days” (or free violations) that could be available if a carpool member is ill or has the day off. The only realistic method of determining when a carpool is using one of its “free days” would be through manual enforcement. Although, this is only one solution to the problems mentioned, using an account-based occupancy system creates additional headaches for the local operating agency.

**Multiple-Portable Tags** One limitation in using an HOV account-based system is the lack of flexibility in setting up or modifying a user account. An alternative to the account system is the use of multiple tags for a single vehicle. The Hughes Company has developed an AVI system that can read more than one (up to 270) tag simultaneously (11). Once the reader identifies a single tag, it searches for additional tags within a given radius around the first tag (the radius can be for example the dimension of a passenger car). Unfortunately, the Hughes system is not being used as part of the Houston AVI system (there are approximately 30-35,000 Amtech AVI tags in the Houston metropolitan area, which do not have the capabilities mentioned above, 12).

AVI tags have also become extremely portable. Tags today are approximately the size of a credit card. This ability increases the flexibility of a metered AVI system. Each member of the carpool can now have their own portable tag that identifies them by name and address. When a rider gets into a carpool each morning, the rider could hand the driver his or her portable AVI tag and the driver places the tag onto the front windshield. As the vehicle enters the HOV lane, the multiple tags
would then be read by a single overhead AVI reader. The occupancy of the vehicle would be determined by simply counting the number of identifiable tags within the given radius mentioned above. Having a portable system such as the one described above does not restrict the users to a single carpool. As carpools increase, decrease, merge, or disband, riders can take their personal tag with them for future use.

A problem with the multiple-portable tag system is that SOVs could “pool” their tags to beat the system. For example, three people could each drive alone, but share their tags so that once every three days each would get a free ride in the HOV lane. The only practical means of deterring this type of behavior is through manual enforcement. Unfortunately, for any type of tag-based HOV system, manual enforcement is required. Unless significant advancements are made, manual enforcement may continue to be the most effective way to detect vehicle occupancy (13).

**Infrequent Carpools** It is logical to assume that some carpools will continue using the HOV lane and not purchase an AVI tag or setup an account. Many people pool flexibly (i.e., they carpool infrequently or for non work trips). Here, an account-based or a multiple-portable tag system would not be practical. Unless the lane is converted over to an authorized HOV lane, manual enforcement is required to detect the occupancy of these carpools (14).

**Metering Rates**

The author recommends use of a staged metering implementation strategy, starting with fixed-time or actuated control and progressing to local traffic-responsive or system-wide control. This strategy will allow for early success without incurring excessive costs. Extensive literature has been produced on different metering rate schemes and should be consulted.

**Motorist Information**

Changeable message signs (CMSs) upstream of the selected access points can be used to tell the motorist which occupancy requirement is in effect. They should be placed far enough upstream so that motorists have ample time to make the decision either to use the HOV lane or continue using the general purpose lanes. CMSs can also be used to inform motorists that 2+ HOV metering is in effect, since this could alter their decision. Finally, combined use of CMSs and directional arrow boards can help in the channelization of 2+ and 3+ carpools during metered operation.

**Enforcement**

Enforcement is complicated by any mix of users on an HOV lane, especially if no physical separation exists between the HOV lane and the adjacent general purpose lanes. Enforcement on most HOV facilities today is handled through manual enforcement, a costly procedure. Using a tag-reader identification system to operate an HOV lane may still warrant the presence of manual enforcement. Whatever system an agency selects as its occupancy/identification system, there still exists the potential for abusers or cheaters of the system. Through time, manual enforcement may be reduced once the public understands that the penalty for violating the occupancy requirement is substantial. Unfortunately, fines for violating HOV lane restrictions in Texas are only about $50-$60, compared with California fines of $217. California has had great success in maintaining a low violation rate since the change to a higher fine (10, 8, 15).
Access restrictions (i.e., limited to the park-and-ride lots) placed on 2+ carpools create an enforcement problem. Although 2+ carpools are instructed to use the park-and-ride lots to reach the HOV lane, many vehicles may attempt to enter using the 3+ ONLY slip ramps. The solution to this problem is simple. AVI readers can be placed at each entrance to the HOV lane. Violators are identified immediately based on their user identification, coded occupancy, and point of entry. This information would then be relayed downstream to an observing officer equipped with a heads-up display monitor inside the patrol vehicle. All carpools would be identified a final time at the exit of the HOV lane. When a match is made, the officer verifies the occupancy visually and either directs the vehicle to pull over or processes the tag data for a mail-out citation.

The enforcement practices described would be difficult if practical without widespread administration of an HOV tagging system which could be read by enforcement officers externally. If tags are not provided free or at a cost to each potential user of the facility, the enforcing officer would have to rely on observation alone.

Public Acceptance

Public acceptance of metered facilities is often low when the meters are first installed. The public views the metering system as an unnecessary restraint on a roadway with a normally high degree of freedom. Their perception of being stationary is far worse than normal stop-and-go traffic. Unfortunately, the public does not consider the increased travel time savings they will receive by waiting in queue. Experience has shown (at least for freeway ramp metering) that the negative perception of metering diminishes greatly as time continues and the metering system is allowed to work (16).

Equity

Before and after start-up, commuters near the system usually consider metering inequitable. For the case of the Katy Freeway, access and metering 2+ vehicles should be limited to the park-and-ride facilities and the outbound entrance at Post Oak. The 2+ carpools downstream of the park-and-ride lot may be inconvenienced if they choose to use the park-and-ride lot. A way to weaken the argument of inequity is to promote the PM peak hour access at Post Oak for the 2+ carpools. Motorists then have access to the HOV lane in the peak hour for at least the afternoon trip home.

Measures of Effectiveness

Metering HOV lanes will need to provide some improvement over the existing HOV facility to which it is applied. Obviously, the goals and objectives of providing improved travel time savings and travel time reliability must be maintained. Metering can provide a consistent, controlled flow of traffic along an HOV lane and still provide a desired level of service.

One measure of effectiveness as it relates to metering and travel time savings could be the percent travel time savings spent in queue. Obviously, if a carpool is forced to wait at a metering station for an extended period and gain nothing in terms of reduction in travel time, the time spent in queue was a waste of time. Likewise, if a carpool waits at a meter for only one minute and saves ten minutes in overall travel time, the time spent in queue was well worth it. Therefore, the evaluation of the queuing operation must be thought of as percent travel time savings. The following equation has been developed to help in explaining the proposed measure of effectiveness:
where: \( M_{MOE} \) = HOV Metering MOE (percent travel time savings spent in queue)
\( Q_{Stopped} \) = Time spent in queue (min)
\( TT_{Before} \) = Travel time before metering operation (min)
\( TT_{After} \) = Travel time after metering operation (min)

Consistent negative values for \( M_{MOE} \) would suggest an increase in travel time after metering was in place and therefore warrant the removal of metering. Desirably, one would like \( M_{MOE} \) to be as small as possible, suggesting that the carpool spent a minimum time in queue and received the maximum travel time savings. Keep in mind that this measure of effectiveness is only applicable to vehicles required to wait at a metering station.

**Institutional Concerns**

Perhaps the most significant reason HOV metering has not taken form are institutional barriers, some going beyond the premise that metering has been an unpopular approach to managing traffic flow. One concern identified is who is responsible for administrating the AVI tags. If a system such as this is going to work, widespread administration of HOV tags is required. Use of the tag can be on a volunteer basis or the tag can be purchased. In any case, the labor and cost associated to administering the tags will be significant to whoever is responsible.

**Evaluation of Metering HOV Lanes**

Despite the anticipated public opposition, metering should be considered as a viable tool in alleviating HOV congestion or underutilization. The following advantages and disadvantages outline where potential benefits can be found from metering HOV lanes.

**Advantages**

- Metering HOV lanes promotes maximum lane efficiency, while providing a consistent, controlled traffic situation.
- Metering HOV lanes provides consistent travel time savings and travel time reliability for its customers.
- Metering HOV lanes improves flow through the ending merge areas, with attendant increases in HOV volumes.
- Metering HOV lanes can increase vehicle occupancy levels by creating an incentive for SOVs to create carpools during the peak hour period.
- Metering HOV lanes can reduce the safety problems associated with manual enforcement, by using AVI technology.
Disadvantages

- Excess demand of 2+ occupancy carpools will result in queues that will cause a reduction in travel time savings and travel time reliability.

- Existing HOV facility designs are not conducive to doing metering and may require upgrading or geometric changes to provide the necessary storage requirements for 2+ queues.

- Metering HOV lanes can decrease vehicle occupancy levels by eliminating the pressure for 3+ carpools to maintain their existing carpool.

- The effective use of AVI enforcement on HOV lanes has not been fully determined. Manual enforcement is still required to verify the actual occupancy implied by the coded AVI tag.

- Probably one of the largest problems associated with any HOV or metering projects is in convincing the commuting public that the systems do provide a measurable benefit.

Congestion Pricing on HOV Lanes

Traffic congestion continues to worsen despite all our time and effort. With limited highway right-of-way and shrinking funds to support the construction of additional roadway miles, we must look to other means to solve the problem of congestion. In recent years we have attempted to modify our existing facilities in an attempt to mold the excess demand to fit the existing supply better.

In the previous sections, the issue of metering HOV lanes was discussed. Metering is just one of the many successful transportation demand management (TDM) strategies used today. An additional demand management strategy that is attracting considerable attention is congestion pricing. Congestion pricing means that motorists should pay a premium if they want a better level of service than is available to all travelers.

This novel idea can be applied to HOV lanes. Everyday motorists are forced to experience congested mainlane traffic while an underutilized HOV lane sits adjacent to them. This problem occurs daily on the Katy HOV lane in Houston. As mentioned before, the hourly vehicle volumes during the peak hour period are quite low when using a 3+ occupancy requirement, whereas, queues extend for miles in the adjacent freeway mainlanes. The history of this facility has shown that the demand for 2+ carpools exceeds the capacity during the peak hour period. The Katy HOV lane is an excellent candidate for congestion pricing and will be referred to frequently during the discussions below. The following sections examine how congestion pricing can be applied to an HOV facility such as the Katy HOV lane.

Case Study Design

The Katy HOV lane was selected as a special use lane pricing case study for its surplus of excess capacity. Before the switch from 2+ to 3+ occupancy the Katy HOV lane was operating consistently at or near 1500 vph in the peak hour. After the change to 3+, the hourly volumes dropped off significantly during the peak hour where only about 500 vph used the lane. Thus, considerable unused capacity is available during the peak hour period.
The unused capacity could be “sold” to specified users. During the 3+ occupancy period, the excess capacity could be purchased by 2+ carpools for a fee (either static or dynamic). Fees should be selected such that the demand of 2+ carpool will not exceed the available excess capacity. Desirably, the pricing structure should create an incentive to form additional 3+ carpools. As the number of 3+ carpools increase, the fees will be increased in an attempt to lower the demand. Although it has been suggested that SOVs should be eligible to “buy into” the system, the author does not recommend it. The demand for SOVs wanting to use the HOV lane would cause operations to quickly deteriorate. The notion of SOV “buy in” and the inclusion of SOVs in general will be discussed in greater detail in later sections.

Case Study Objectives

Congestion pricing can be used to use this unused capacity better if the following objectives are accomplished:

- Increase the lane use using congestion pricing, while maintaining the service currently available to existing HOV users (i.e., “best customers” or 3+ HOVs), and

- Create an incentive to form higher occupancy vehicles.

Critical Issues

Several critical issues have been identified concerning the use of congestion pricing on HOV lanes. Those issues identified include:

- “Buying In” and Eligibility
- Geometric Design and Access
- Level of service
- Lane Pricing Structure
- Determining Occupancy
- Collection of Tolls
- Enforcement
- Equity
- Generated Revenues

To accomplish the objectives mentioned above, all of the issues identified must be addressed.

“Buying In” and Eligibility

The idea behind congestion pricing is that motorists pay a fee for use of a premium service that is available to all other motorists. Congestion pricing could be used on the Katy HOV lane due to the surplus of unused vehicular capacity. The excess capacity would then be sold to certain eligible users for a price. Observers have classified this form of demand management as “buying in.” The term “buying in” almost gives the reader a negative connotation. Paying to use a premium service should not be a new idea for the motorists of today. Forms of congestion pricing have also been adopted by the private sector: telephone services, television commercial time, and air fares.
The term “buying in” leaves room for loose interpretation and infers that all motorists should be eligible. Not all motorists should be eligible for inclusion, especially SOVs. One objective of the HOV concept is to increase vehicle occupancy. If SOVs were eligible, occupancy would decrease on both the HOV lane and the general purpose lane due to latent demand. SOV “buy in” does nothing to encourage what needed most - increase the person-carrying capacity of roadways through the formation of higher occupancy vehicles. In fact, SOV “buy in” creates the opposite incentive - drive alone. If people can afford to pay the toll and desire to have the flexibility of driving their own vehicle, most often they will choose to drive alone. This result is not desirable and for these reasons, congestion pricing should be limited to HOVs.

**Geometric Design and Access**

Congestion pricing, like metering, is difficult without some form of physical separation. Without physical separation, violators can enter and exit from the HOV lane at will. This creates problems for local enforcement and deteriorates the service provided to its users. Arguably, pylon separation on the California SR 91 project (concurrent HOV lane) will push this limit to test whether physical separation by means other than a concrete barrier is practicable (5). On the other hand, some facilities such as the Katy HOV lane allow for a captive audience and could easily facilitate congestion pricing. The Katy HOV lane is a 13-mile, barrier-separated HOV lane. Access and egress from the facility is restricted through slip ramps and park-and-ride lots.

Access into the HOV lane could be provided at each possible entry point. The use of CMSs upstream of the access ramps could inform the driver which occupancy requirement was in effect and its associated toll. Since metering is not an option on the slip ramps leading into the HOV lane, placement of the CMS is important. Two person carpools will also enter using the park-and-ride lots. The park-and-ride lots provide the opportunity to store excess demand, giving flexibility to the system. If the demand for 2+ vehicles is too high, they can be stored and metered into the HOV lane.

**Level of Service**

Keeping in mind that a successful congestion pricing project requires that the same or an improved level of service be provided to all current users of the HOV lane is important. For example, the 500 3+ carpools currently using the Katy HOV lane during the peak hour should (at a minimum) receive the same travel time savings and reliability after the change to a lane pricing scheme. To accomplish this, the total volume on the lane should be kept sufficiently low (i.e., 1200 to 1400 vph) to ensure that travel time reliability is provided to all current users of the HOV lane.

**Lane Pricing Structure**

The pricing structure under a congestion pricing scheme can be either static or dynamic. If a static pricing system is used then 2+ users will pay the same price despite the characteristics of their trip. It makes more sense to use a dynamic pricing system. For example, during the peak hour 3+ vehicles are allowed to use the facility free (no change over the present). Similarly, 2+ vehicles are also allowed to use the facility during the peak hour at a base cost. As the congestion on the HOV lane increases, tolls on 2+ vehicles will increase to lower the demand. Communication of what price is in effect can be handled by CMSs. CMSs should be placed far enough upstream of each access point to provide the driver enough time to decide whether to enter the HOV lane or use the
general purpose lanes. Extensive market and economic research will need to be conducted to set the
pricing structure required to produce a desired 2+ demand volume.

For those HOV lanes having more than one access and exit point, length of the trip should
also be considered. The idea is that longer trips should pay more than shorter trips. This idea is not
new to toll facilities. A premium service is being provided to the 2+ vehicle, and therefore, the
longer the vehicle uses the service, the more the carpool should pay. A problem with this type of
system is communication. Multiple origin-destination combinations along with their associated cost
could be displayed to the driver upstream of each access point using CMSs. A problem with this
form of communication is that too much information is provided to the driver within a short period.
The driver can become confused besides various other problems. A simple solution is to show the
current charge to use the HOV lane in cost per mile. Commuters typically know how far they travel
each day (especially on an HOV lane), and this type of system allows them to quickly decide what
their user cost will be.

A cost per mile pricing system can also help maintain public acceptance or at least weaken
the public misconceptions related to congestion pricing. Hypothetically speaking, a realistic cost to
use the HOV lane could be 10 cents per mile (i.e., 10 miles = $1). The perception of only having
to pay 10 cents per mile, compared with the static price of $1, may create the illusion to the motorist
that they are paying less. This observation is hardly proved by fact. Additional research is
recommended to learn what the average motorist or carpool will pay to use a priced HOV lane.

Collection of Tolls

Tolls can be collected using the same technology described for use on a metered HOV lane.
Recent claims of improvements in the AVI industry allow for the implementation of congestion
pricing on HOV lanes. Using AVI enables the operator to overcome the technological barrier of
distinguishing 2+ tolled users from “free” 3+ HOV users. Individual users of the facility are required
to purchase their own AVI tag and set up a debit account with the local operating agency. This has
been done for years to fit frequent users of tolled facilities. For 2+ tolled users, tolls are paid by the
individual carpool member on a shared use basis. Shared use refers to dividing the cost equally by
each member of the carpool.

It has been suggested that toll booths can be used to collect tolls at HOV lane entrances.
Providing toll booths at each entrance will require additional highway right-of-way that is typically
not available. HOV lanes by nature are already limited in the space they can provide. Assuming that
access is provided at locations outside the existing right-of-way where space is available (e.g., grade
separated entrance ramps or park-and-ride lots), toll booths can be used to collect user fees. At toll
booths locations, 2+ carpools without AVI tags could pay daily. This does create a problem for
enforcement downstream. Without identification tags, local enforcement has no way of identifying
whether or not they have paid. The license plate of the valid 2+ carpool would therefore have to
entered manually upstream at the toll booth and be visually verified downstream. This again creates
additional headaches and problems for the local enforcement agency.

Enforcement

Enforcement on an HOV lane pricing system can be handled again using the same techniques
described for metering HOV lanes. As technology continues to improve and collection procedures
become more automated, the need for manual enforcement will decrease. Unfortunately, the use of AVI technology creates potentials for system abuse by cheaters, and therefore, manual enforcement must be present.

**Equity**

Equity, depending on how the system is setup, is not an issue concerning congestion pricing on HOV lanes. Equity would be a valid argument if the current available service to existing users were being changed. The same “free” service is being provided to all current users of the HOV lane. Three person carpools are still allowed to travel “free” during the peak hour period and two person carpools are allowed onto the HOV lane at no charge during all other hours of operation. The only change to the existing system is that 2+ vehicles have now been given the opportunity to buy additional time on the HOV lane. No one is forcing 2+ carpools to purchase the premium service. If they want to continue to use the general purpose lane during the peak hour period at 2+ occupancy, they can do so. On the other hand, if they want to increase their travel time savings and travel time reliability, they can pay for it.

Another argument for inequity is that the HOV lanes of today will become the “Lexus Lanes” of tomorrow (7). It is possible that some 2+ HOVs cannot afford to use the HOV lane during the peak hour. Their options are either to continue using the same service they use every day or form a higher occupancy vehicle (i.e., 3+ or higher) and use the HOV lane free. Understand, a major goal of priority lane pricing is to increase overall vehicle occupancy.

**Generated Revenues**

Revenues obtained from a congestion pricing system can be used in many ways. First, the revenues could be used to formulate additional measures or incentives to promote the use of higher occupancy vehicles. For example, parking subsidies can be provided for 3+ occupancy vehicles. Revenues could be used to expand limited bus services or allow for the reduction in bus fares by creating subsidies for bus operations. Manual enforcement is most of the local operating agency’s budget. The revenues generated could be used to cover the cost of manual enforcement and fund improvements to the HOV facility.

**Evaluation of Congestion Pricing on HOV Lanes**

While almost no documentation is available concerning the feasibility of congestion pricing, the following advantages and disadvantages outline where potential benefits can be found from pricing HOV lanes.

**Advantages**

- This congestion pricing strategy encourages increased ridesharing and use of public transportation, which indirectly increases vehicle occupancy and reduces traffic volumes.
- This congestion pricing strategy promotes maximum lane efficiency, while making improvements to travel time savings and travel time reliability.
This congestion pricing strategy uses excess lane capacity to move more people, therefore improving the public acceptance of HOV lanes.

Enforcing 3+ carpools at no fee, creates the incentive to form a higher occupancy vehicle.

Generated revenues can be used to subsidize alternative modes such as transit.

Generated revenues can be used to recover operating and enforcement costs associated with HOV lanes.

Generated revenues can be used to fund improvements to the HOV facility

Reduced volumes improve air quality and energy consumption.

**Disadvantages**

- Allowing mixed user group makes enforcement more difficult.

- This congestion pricing strategy can cause a decrease in HOV lane occupancy, caused by a shift from 3+ to 2+ occupancy. An existing 3+ carpool can probably save additional travel time savings by eliminating one rider from their carpool and pay the 2+ occupancy toll. The additional travel time savings is obtained by not having to pick up an additional third rider.

- Requiring carpools to purchase or obtain an AVI tag to use the HOV lane could lessen the attractiveness of carpooling. The answer to this problem may be that only 2+ carpools are required to purchase an AVI tag. Consistent 3+ carpools could continue to use the HOV lane at no fee and rely on manual enforcement to verify their occupancy.

**Additional Operational Alternatives**

Other operational alternatives may deserve consideration if an HOV lane is to operate at its maximum efficiency. Where effective use of the facility has been limited by its occupancy requirement, non-HOV user groups (i.e., trucks, taxis, extended travel SOVs) could use the HOV lane when excess capacity is available. Several special user groups have been identified and are discussed below.

**Non-HOV Users**

**Trucks**

The potential demand for truck use of HOV lanes during the peak hour period can be significant in certain freeway corridors. Within the normal mix of freeway traffic, heavy vehicles consistently pose the threat of an accident or simply increased vehicle interference. From a safety standpoint, it might be speculated that allowing truck use of HOV lanes would decrease peak hour truck accidents. A reduction in truck-related accidents could provide improved travel time savings and reliability for both the trucks and the general freeway traffic. However, some argue that if trucks are allowed to use HOV lanes besides the current user mix (i.e., buses, vanpools, carpools, etc.), the
resulting vehicle mix would be little different from on the freeway mainlanes. Several problems associated with truck use of HOV lanes have been identified and are summarized below:

- Extensive demand estimates for potential truck use of HOV lanes need to be determined for each freeway/HOV corridor. If the demand for truck use is low, then there is no real need to pursue the matter. Similarly, the demand for truck use cannot exceed the available excess capacity on the HOV lane. The HOV lane must also provide trucks an additional travel time savings for there to be a shift in lane use. Without additional savings, it is highly unlikely that trucks will use the facility.

- Access and egress points along an HOV lane are located and designed based on bus routings and HOV origins and destinations. Required truck origins and destinations may not match up with exiting ramp terminals.

- Certain facility designs (i.e., one or two-way barrier-separated) have narrow lane widths, making it difficult for large truck to pass a stalled vehicle.

- A stalled truck or accident involving a large truck could require closure of the entire facility. The closing of an HOV facility then directly effects the operations on the freeway mainlanes.

- The design vehicle for most HOV lanes is a bus; therefore, select vertical clearances (i.e., 15' 0") and ramp designs (minimum turning radii, limited sight distance curves, and merge lane lengths) would not accommodate extended height trucks.

- It is anticipated that infrequent, unfamiliar truck drivers would desire use of the HOV lane. Signing about when the HOV lane can be used by trucks, times of operation, and the various destinations available along the route would be difficult.

Trucks should be considered for use of HOV lanes during the peak hour. Their use would probably only be considered on a site by site basis, since there are so many problematic design and operational issues to discuss. Where applicable, truck use can provide increased use of HOV lanes and improved travel time savings and reliability.

**Taxis**

Taxi use of HOV lanes during the peak hour period deserves least consideration. Traffic market estimates in Houston show that taxis account for less than 1% of the peak hour and off-peak vehicle mix. The potential user benefits provided from taxi use would be insignificant and would only add to enforcement and operations costs.

**Extended Travel SOVs**

Recent developments in the state of Florida may change the way people think about HOV lanes. The Florida DOT enacted an interstate policy approximately five years ago placing a limit on the number of lanes that can be added to any corridor in the state at ten. Of those ten lanes, if there are no more than six lanes currently (i.e., three lanes in each direction), the remaining four lanes will be dedicated to HOV and interregional trips. The reason interregional trips are so important in Florida is that they want to bring back the original concept or policy of interstate travel. Special user
groups have been identified within their definition of interstate travel. The new interstate travel policy would like to give additional preference to commercial goods movement, interregional trips, and trucks (besides the HOVs currently using the system).

Included under the heading of interregional trips are SOVs. Although they are still SOVs, they have now been given priority based on the purpose and length of their trip. SOVs will be allowed entrance onto an HOV lane if they never intend to exit the facility. If the SOV leaves the HOV lane within the urban area, their inner-city travel will be considered a violation of the interstate travel policy and the vehicle is subject to a fine.

This form of restricted SOV use is unique in that the demand has been limited based on trip purpose. Traditional thoughts related to SOV “buy in” (i.e., congestion pricing) have been negative because of the potential for such a high demand and disincentive to create a higher occupancy vehicle. Here, SOV access is restricted to the beginning and ending nodes of the HOV lane. SOVs cannot enter at any point along the way. This type of demand management can be applied to underutilized HOV facilities, but keep in mind there are many issues to consider.

Enforcement is the most difficult obstacle to overcome. If the new interstate travel policy is going to be effective, enforcement must be visible. Enforcement can be carried out in a variety of ways. Patrol vehicles can be placed at each entrance and exit ramp along the corridor. Depending the number of access points, manual enforcement can be quite costly and is not recommended.

The use of AVI technology is another alternative. AVI tag readers can be placed at each entrance and exit ramp along the facility. Once a vehicle equipped with an AVI tag enters and exits the lane, their origin and destination are determined. If the vehicle is detected leaving the lane within the city limits, the driver is violating the occupancy restrictions and a citation is issued through the mail.

Several conclusions concerning the interstate HOV policy have been made and are presented below:

- The demand for interregional SOVs may exceed the available excess capacity of the HOV lane. Additional information is needed to decide if a market for this strategy exists, and if so, what is the anticipated demand. The demand may be so small that the benefits are insignificant. If so, a more cost effective approach may be warranted.

- Creates the incentive for drivers to cheat the system. Unless a visible means of enforcement is present (i.e., manual or AVI), violation rates for this system could be high.

- If AVI enforcement is used, each potential user of the system would have to be equipped with an AVI tag.

- If a SOV must leave the HOV lane for some reason beyond their control (e.g., to refuel or seek medical attention), they will violate the occupancy restriction. The restrictions could be perceived as unfair.
The local public’s perception of providing priority to interregional trip SOVs would most likely be poor. Some of this negative perception may stem from the local public’s inability to discern between an authorized SOV and an unauthorized SOV.
KEY ISSUES FOR IMPLEMENTATION

The following select issues take into consideration the information provided through conversations with the transportation profession, the literature review, and the author’s own judgement. The issues have been divided into two distinct groups based the type of HOV facility under consideration - proposed and existing. They are intended for use as a checklist of issues that should be considered during implementation and evaluation.

Proposed HOV Facility

Special consideration must be given to the implementation of a new HOV facility. The previous sections have outlined some problems associated with maintaining a desired level of occupancy on proposed and existing HOV facilities. Where it is anticipated that vehicular capacity will not be used to its full potential (i.e., underutilized at 3+ occupancy and congested at 2+ occupancy), the steps preceding actual activation are crucial to increase the likelihood of a successful system. The following issues have been provided for consideration.

- Develop cooperative relationship with all agencies involved. Any agency having a personal stake in the successful operation of the HOV facility should be consulted during the early stages of project development. Those agencies that should be consulted include the state operating agency, local transit authority, local enforcement agencies, and local city/county agencies.

- Establish both good public and media relations by sending them accurate information regarding the success and failure of similar HOV facilities. Make sure the public and media know that a considerable amount of time and effort has gone into the development of the best HOV facility design possible. Build constituency groups early, particularly among politicians, community leaders, and media representatives such as traffic reporters and columnists.

- Define the required user group. Knowing who should be the HOV lane’s primary user is important. This information should be obtained well before the activation of the lane. Extensive literature has been produced on determining the required occupancy of a proposed HOV facility based on existing freeway conditions and motorist characteristics.

- Is there a utilization problem? The anticipated vehicle and person-moving volumes of the facility may be acceptable. Study other metropolitan areas having similar operating and user characteristics to gain insight on how the system will work once started. This can also help to find out if any miscalculations were made. Reexamine the definition of utilization. Utilization can either be defined in terms of vehicle or person-moving capacity.

- Time the opening carefully. Open the lane(s) when freeway traffic is excessively high. Do not open the facility during a seasonal low period. The resulting HOV lane use may be low.

- Use a staged occupancy requirement implementation strategy, starting with authorized buses and 8+ carpools and progressing to the desired occupancy requirement over a short period. It is important that the public has the opportunity to experience congestion on the HOV lane before the final occupancy requirement is reached. If a utilization problem exists, this strategy should allow for early success without incurring excessive public disapproval.
• Are the motorists experienced HOV lane users? Use of a staged occupancy requirement implementation strategy will probably not be acceptable nor necessary for experienced HOV lane users. Understand that if HOV lanes are common within a given urban area, the likelihood of long-term public acceptance will be high and extensive “hand holding” by the local operating agencies is not required. A staged implementation strategy should only be considered in areas where HOV facilities are not common. In these cases, more proactive public information and an education campaign should be undertaken to explain HOV lane use to the motorists, provide logistics of activation, and point out the benefits derived by using HOV lanes.

• Monitor the volumes on the facility during each stage with the understanding and philosophy that if congestion does appear, actions will be considered and carried out to ensure that the lane operates at free flow conditions (i.e., changing carpool occupancy levels, hours of operation, metering, etc.).

The issues provided are not to be considered the only issues considered to ensure successful implementation of a proposed HOV facility. However, in almost every application, it is recommended that each issue addressed receive consideration.

Existing HOV Facility

The following section provides an overview of the operational alternatives discussed in this report. Keep in mind that the existing HOV facility under discussion in this report is experiencing congestion at 2+ and is underutilized at 3+ occupancy. At this stage in the development of the facility, the operator should have already attempted to increase lane use through traditional means (i.e., changing occupancy requirements, hours of operation, etc.). The intent of this section is to provide a summary of questions a local operating agency should ask before applying any additional operational alternatives to an existing HOV facility. The summary of alternatives and related questions have been ordered based on the author’s judgement of relative importance of each.

Admit Non-HOV Users

• Who are the non-HOV user groups (i.e., trucks, taxis, emergency vehicles, enforcement vehicles, maintenance vehicles, SOVs, etc.)?

• What is the demand forecasts for each of the potential non-HOV user groups?

• How much unused capacity is available?

• Is the anticipated additional demand going to be significant or excessive?

• If large trucks become authorized users, how accessible are they if they stall or get into an accident?

• Do the current travel patterns (i.e., origins and destinations) of trucks match up with the existing access and egress points along the HOV facility?

• Are all SOVs eligible for inclusion or is only a select group eligible (i.e., interregional trips)? How will enforcement of non-eligible SOVs be handled?
How restricted is access and egress (i.e., barrier-separated, concurrent flow, buffer-separated)? It is recommended that the additional non-HOV users be a captive audience. Therefore, the author recommends use of a barrier-separated facility.

How effective are current enforcement procedures/policies? If need be, can they adapt to handle non-HOV lane use? Is enforcement visible?

**Ramp Metering**

- Will the design of the existing HOV facility support metering (i.e., can the metered traffic be contained)? Can any changes be made to the existing facility to allow for containment?

- How is access and egress provided to the facility (i.e., grade-separated, slip ramps, continuous access/egress, direct connector via park-and-ride lots, and merge lanes)?

- Is there sufficient storage on the ramps leading into the HOV lane? Several of the design types such as center median slip ramps, continuous access/egress, and merge lanes do not provide the necessary storage required for metering.

- If certain ramps are to be closed or maintain restricted access only (i.e., continue to allow only 3+ carpools while other ramps allow 2+ carpools), will the available demand provide the increase in 2+ demand desired?

- What type of metering strategy should be used (i.e., fixed-time, actuated control, or system-wide)? The author recommends use of a staged metering implementation strategy, starting with fixed-time or actuated control and progressing to local traffic-responsive or system control. This strategy will allow for early success without incurring excessive costs. Extensive literature has been produced on different metering rate schemes and should be consulted.

- How will the public respond to the use of ramp metering? Will all potential users (i.e., all 2+ carpools) have equal access to the metering stations during hours of operation?

- Will the 2+ carpools be provided an outlet or choice once they approach a metering station? It is important that motorists be provided with the option to either enter the facility, wait in queue, or return to the freeway general purpose lanes.

- Is there an existing AVI system that can be applied for use with a proposed metering strategy (i.e., can the technology do what is being asked)? If so, who is responsible for administering the AVI tags?

- Are any additional operating agencies needed to set up a metered/AVI system successfully (i.e., collection services)?

- Is the public familiar with the idea of metering? Are the adjacent freeway travel lanes currently being metered? If so, initial public acceptance of a metered HOV lane could be high or low depending on the performance of the existing metered system. If motorists are unfamiliar with metering, a proactive public information and education campaign should be undertaken.
Congestion Pricing

- Have all of the key issues identified in the discussion section of this report been addressed? How do they apply to the existing HOV facility?

- What is the public’s viewpoint concerning the use of congestion pricing on HOV lanes? Have they been consulted through focus groups, interviews with community leaders, telephone surveys, mail-back surveys, etc.?

- Is the system setup such that the current “free” service is still provided to all HOVs? It is important to maintain the existing “free” service so that equity does not become an issue.

- What user group is eligible for “paid” access?

- Should SOVs be allowed to “buy in?”

- Will congestion pricing encourage ridesharing and transit use, by that increasing vehicle occupancy?

- How can the system be applied to the existing HOV facility?

- Depending on the type of facility, what types of enforcement problems can be expected and how will they be addressed?

- What type of marketing is required and what time frame is needed to start such a project?

- Should a static or dynamic tolling system be used?

- What will the generated revenues be used for?

Understand that these questions are only some of those that could be asked during the implementation of the alternatives discussed. However, in almost every application, it is recommended that each question identified be addressed.
CONCLUSIONS

Traffic congestion continues to worsen despite all our time and effort. With limited highway right-of-way and lack of additional funds to support the construction of additional roadway miles, we must look to other means to solve the problem of congestion. In recent years we have attempted to modify our existing facilities into HOV lanes in an attempt to mold the excess demand to fit the existing supply better. HOV lanes have been quite successful and will continue to be built. This does not mean that they are without some flaws.

HOV lanes experience the same type of congestion that freeway general purpose lanes experience. They are also faced with the problem of being underutilized. Somehow transportation engineers must come up with a solution to solve both problems. To do so will require the backing of both the public and the policy officials. Fortunately, the public and political officials are slowly realizing that traditional transportation ideas and solutions will not provide the answers we want.

Traditional methods used by engineers and planners to implement the HOV concept may become outdated. HOV projects cannot be sold today using a “we know best” attitude. This attitude is not acceptable. Ample evidence is available to suggest this attitude does not work and will not work in most places (e.g., Dulles Toll Road HOV Lane Closure). The truth is that engineers and planners are asking motorists to change their driving behavior. We need to be flexible in how we present our logic to them, and motorists need to understand the problem as we do.

Operational alternatives such as metering and congestion pricing may also offer potential solutions to the problems discussed. The supply of transportation is heavily constrained, whereas, demand solutions to transportation needs have been untapped. The public today seems to understand the severe need to remedy the problem of traffic congestion. It also appears that they will accept some more taxing solutions.

Special user groups could be used to consume some excess capacity available on some more underutilized HOV lanes during the peak hour. Trucks have been identified as a potential special user. Truck use of HOV lanes during the peak hour period does provide a means of segregating these problematic vehicles from the normal mix of freeway traffic. Keep in mind that access to and from HOV lanes may or may not match up with the truck origins and destinations.

Interregional trip SOVs are another special user group. The potential outcome of allowing SOVs onto HOV lanes has not been tested. The idea of promoting interstate travel and providing priority lane treatment to interstate travelers is sound. Enforcing such a system is no easy task and could create many headaches for the local operating agencies.
RECOMMENDATIONS

Several recommendations can be made for the operational alternatives presented in this report. These recommendations cover several topics from a need for research to marketing.

- **Increase Public and Political Awareness and Acceptance**
  Both metering and congestion pricing have traditionally experienced both public and political opposition. Additional research is required thoroughly to document the public and political perceptions using a variety of approaches. Possible alternatives include focus groups, interviews with local community leaders, and public opinion surveys.

- **Adoption of AVI Standards**
  Both the metering and congestion pricing alternatives mentioned rely heavily on the success of AVI technology. The adoption of a homogeneous set of standards is needed. Currently, many different standards are used for the manufacturing of AVI tags, transponders, and readers. Also, only certain AVI manufacturers have produced the technology necessary to do the tasks requested.

- **Benefit/Cost Analysis**
  The alternatives mentioned require a substantial capital investment by the local operating agencies. A complete cost analysis will be required to assess whether or not use of the systems mentioned is warranted.

- **Consider the Key Issues for Implementation**
  The key issues identified should be used as a checklist of considerations during the implementation process.
ACKNOWLEDGMENTS

The author would like to thank Mr. Leslie N. Jacobson who served as mentor for this paper. Without his guidance and support, this paper would not have been possible. The author would also like to thank Dr. Conrad Dudek and Dr. Donald Capelle for their guidance toward completion of this paper. Special thanks go to those transportation professionals who generously gave of their time to respond to my requests:

Glen Carlson - Minnesota Department of Transportation
Dennis Christiansen - Texas Transportation Institute
Charles Fuhs - Parsons Brinkerhoff, Inc.
Alice Gilmarten - Florida Department of Transportation
Russell Henk - Texas Transportation Institute
Kern Jacobson - Parsons Brinkerhoff, Inc.
Tim Lomax - Texas Transportation Institute
Heidi Stamm - Pacific Rim Resources
Bill Stockton - Texas Transportation Institute
Katie Turnbull - Texas Transportation Institute
REFERENCES


5. Interview with Dr. Tim Lomax of the Texas Transportation Institute concerning HOV operational alternatives.


7. Telephone interview with Ms. Heidi Stamm of Pacific Rim Resources concerning HOV operational alternatives.

8. Telephone interview with Mr. Charles Fuhs of Parsons Brinkerhoff, Inc. concerning HOV operational alternatives.

9. Telephone interview with Mr. Bill Stockton of the Texas Transportation Institute concerning HOV operational alternatives.

10. Telephone interview with Dr. Glenn Carlson of the Minnesota Department of Transportation concerning HOV operational alternatives.


12. Telephone interview with Mr. Mike Ogden of Texas Transportation Institute-Houston concerning HOV operational alternatives.

14. Telephone interview with Mr. Les Jacobson of the Washington Department of Transportation concerning HOV alternatives.

15. Interview with Dr. Donald Capelle of Parsons Brinkerhoff, Inc. concerning HOV operational alternatives.


Carl Brian Shamburger received his B.S. in Civil Engineering from Texas A&M University in May 1994. During the summer of 1993, he participated in the Undergraduate Transportation Engineering Fellows Program at Texas A&M University. Brian is currently pursuing his M.S. in Civil Engineering from Texas A&M University. He has been employed by the Texas Transportation Institute as a Graduate Research Assistant since May 1994. University activities he has been involved in included: Institute of Transportation Engineers, where he has served as Membership Secretary and Vice-President in charge of technical projects, American Society of Civil Engineers and Chi Epsilon. His areas of interests include: transportation operations and design.