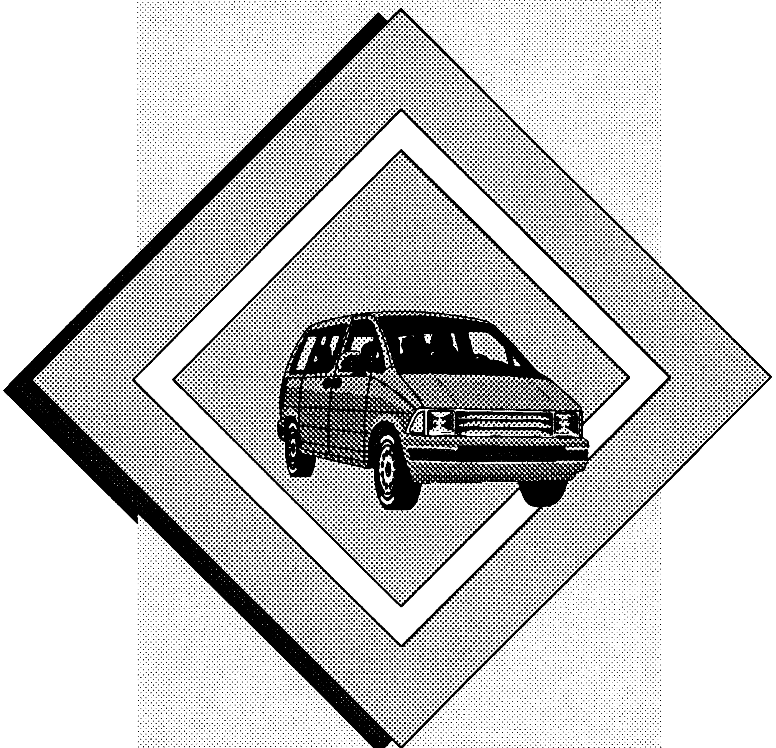
FINAL REPORT

# HOV SYSTEMS ANALYSIS



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16. Abstract

This study focuses on defining HOV systems and their components, criteria, and related issues in a systems planning context (as compared with the conventional project level planning). Definitions are provided to establish the physical and socioeconomic elements of HOV systems. Appropriate system performance criteria are developed for the purpose of evaluating HOV facility designs, operational strategies, and policy options. A set of timely issues associated with a systems level for HOV planning and analysis are established. Methods to evaluate alternative policies specifically for HOV systems are then investigated. Representative analytical models that have been used in HOV studies (for demand estimation and system simulation) that appear appropriate in the analysis of HOV systems are reviewed. A test case scenario in Northern Virginia is used to demonstrate this utility of a mode choice model (MWCOG Mode Choice Model) and a freeway simulation model (FREFLO) to address the choice between HOV3+ and HOV2+. The mode choice model demonstrates the changing levels of patronage for the HOV facility, and the simulation model evaluates the performance of the facility for changing conditions. The execution of the case study demonstrates the basis for a methodology for a complete HOV systems analysis.

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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## ABSTRACT

This study focuses on defining HOV systems and their components, criteria, and related issues in a systems planning context (as compared with the conventional project level planning). Definitions are provided to establish the physical and socio-economic elements of HOV systems. Appropriate system performance criteria are developed for the purpose of evaluating HOV facility designs, operational strategies, and policy options. A set of timely issues associated with a systems level for HOV planning and analysis are established. Methods to evaluate alternative policies specifically for HOV systems are then investigated. Representative analytical models that have been used in HOV studies (for demand estimation and system simulation) that appear appropriate in the analysis of HOV systems are reviewed. A test case scenario in Northern Virginia is used to demonstrate this use of a mode choice model (MWCOG Mode Choice Model) and a freeway simulation model (FREFLO) to address the choice between HOV3+ and HOV2+. The mode choice model demonstrates the changing levels of patronage for the HOV facility, and the simulation model evaluates the performance of the facility for changing conditions. The execution of the case study demonstrates the basis for a methodology for a complete HOV systems analysis.

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## INTRODUCTION

High-occupancy-vehicle (HOV) facilities have been accepted throughout North America in recent years as a way to move more people on existing roadways. A survey completed by the Texas Transportation Institute reported more than 40 HOV projects in 20 metropolitan areas.[1] In many cases, HOV projects have encountered emotional public opposition because of the perceived increase in congestion the facility appears to create at its inception by reducing the capacity available to low-occupancy vehicles. Typically, in such cases, the public does not give the HOV project a chance to work and transportation planners must then justify the decision for the HOV facility to elected officials. In these cases, it is often the planning process that comes under scrutiny and must be defended.

Sometimes, the best case cannot be made for establishing an HOV facility because HOV projects have not typically been developed in the context of area-wide transportation plans for congestion management; that is, a formal planning approach was not used. However, since HOV facilities have been successful in urban corridors throughout the country, the inclusion of a system of HOV routes in regional transportation plans as formulated by metropolitan planning organizations is a natural progression.[2] In order to accomplish the integration of HOV facilities and the arterial street system, the paths of trips from origin to destination must be considered.

Although no actual physical HOV system has been fully defined and built, several states, including Washington and Virginia, have HOV systems in the planning stages that have some component routes already in use. For example, Virginia has established what state planners feel will become a relatively large HOV system for the Northern Virginia area. At present, the Northern Virginia system has two fully dedicated facilities comprising approximately 19.0 miles on I-66 and I-395. Future plans indicate a commitment of 18.0 additional miles by

1995, an adopted plan for the year 2010 that totals about 50.0 miles, and a recommended plan for the year 2010 that brings the total HOV system to approximately 115.0 miles.[3] The planned layout of the existing and recommended HOV system is shown in Figure 1.

## PURPOSE AND SCOPE

The purpose of this study was to develop a framework for identifying and evaluating alternative HOV-related policies with a systems perspective. The study had four objectives:

1. Establish and define the physical components, policies, and influencing variables of HOV systems that can be employed to fashion alternative service options and the performance criteria that can be used to evaluate these options.

2. Identify and examine models that simulate HOV facility performance and estimate related demand in order to determine their usefulness in analyzing proposed HOV projects.

3. Design an analytical modeling system of HOV facilities using existing techniques.

4. Demonstrate the application of this model in a case study to show how the model can be used to evaluate HOV policy decisions.

## METHODS

The objectives of the study were accomplished using a three-phase approach: (1) HOV systems analysis, (2) HOV systems modeling, and (3) case study development.

In Phase 1, a complete specification of an HOV system was developed in terms of a definition of an HOV system, the elements of a system, influencing variables, performance criteria, and issues identified as typical problems that HOV systems should resolve.

In Phase 2, available demand forecasting and network simulation models that can be used to address relevant HOV issues were identified. From this collection of models, a practical integrated analysis package was developed.

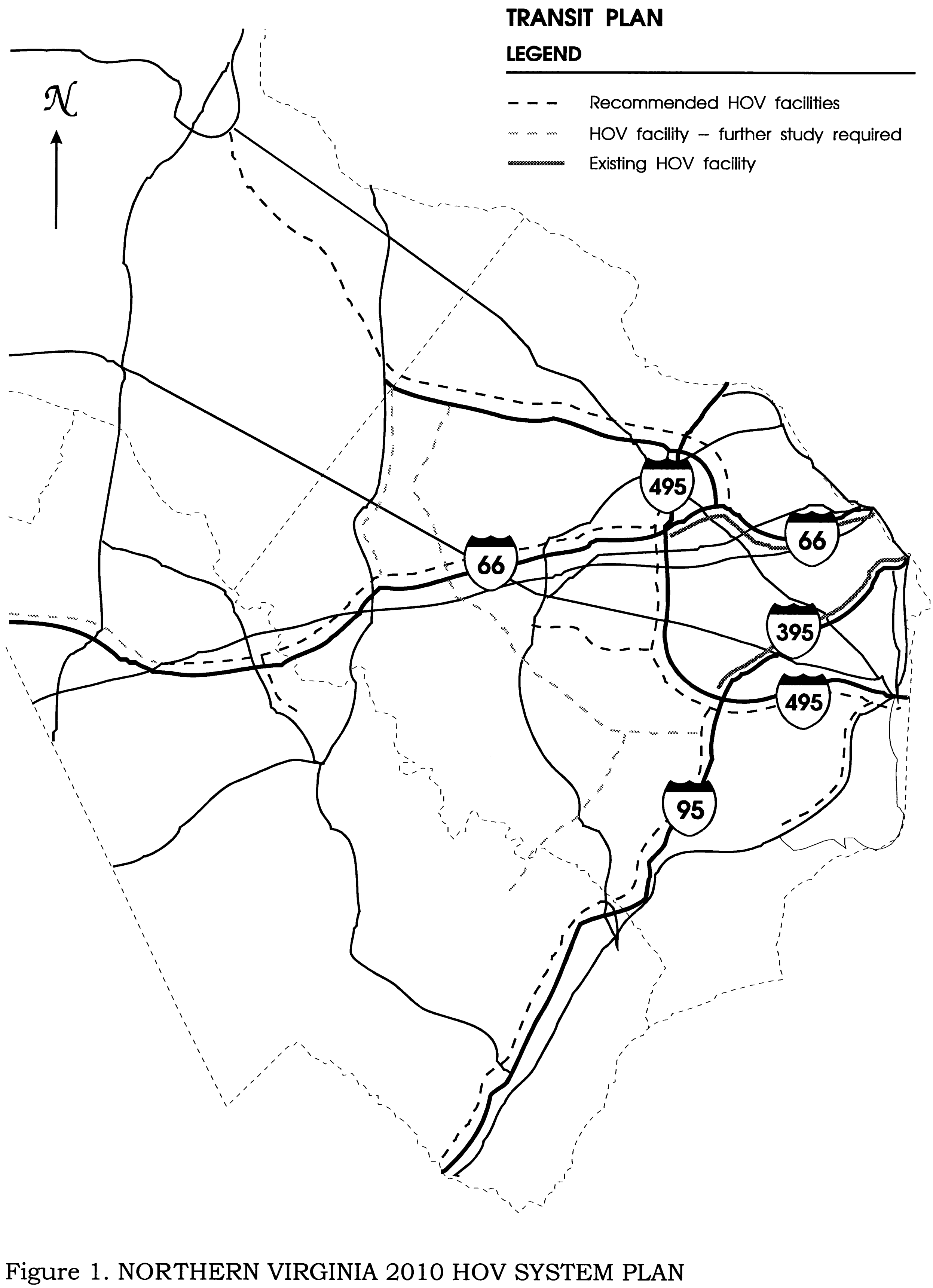


Figure 1. NORTHERN VIRGINIA 2010 HOV SYSTEM PLAN

In Phase 3, the analysis package was used in a case study to demonstrate the analysis of alternative HOV policies at a systems planning level.

Figure 2 lists the steps in this systems analytic method. The inventory process begins with a definition of the system of interest. Guidelines are provided to aid the planner in isolating an appropriate system for analysis. Once the system is defined, the physical components, policy, and local environmental characteristics that affect the supply and demand for the system are established. Specific evaluation criteria are then selected as performance measures to be used in evaluating the various issues that differentiate service options.

After the scenario has been identified and relevant parameters have been defined, the evaluation process begins. Here, specific design and policy options are characterized, specific evaluation criteria are selected, an appropriate modeling strategy is chosen and applied, the performances of the alternatives are evaluated, and a choice for implementation is made.

This study develops information bases for steps 1 through 8 and modeling concepts for steps 9 and 10. The remainder of the steps shown are typical of any systems analysis process. Not all feedback loops are shown in Figure 2, but they will occur in an interactive process that includes serious negotiations between the public and elected officials.

## FINDINGS

### Systems Analysis

#### Definition of an HOV System

The Institute of Traffic Engineers defines HOV systems as "the collective application of physical facilities, programs, and policies that are effectively integrated to provide a comprehensive application of HOV incentives in a corridor or region."[4] This definition indicates that such a system could be composed of a single HOV facility or a collection of them. This interpretation considers the facility as being central to the system but interacting with other influences, such as policies that have a significant effect on the performance of the HOV operations.

HOV systems can also be defined in terms of supply and demand. *Supply* is defined by the physical elements of the HOV system and their availability, e.g., facilities, parking, and types of HOVs. The system supply is associated with capacity, volumes, and other measures that will distinguish "how much" is available for HOV use. *Demand* for an HOV system is defined by a number of

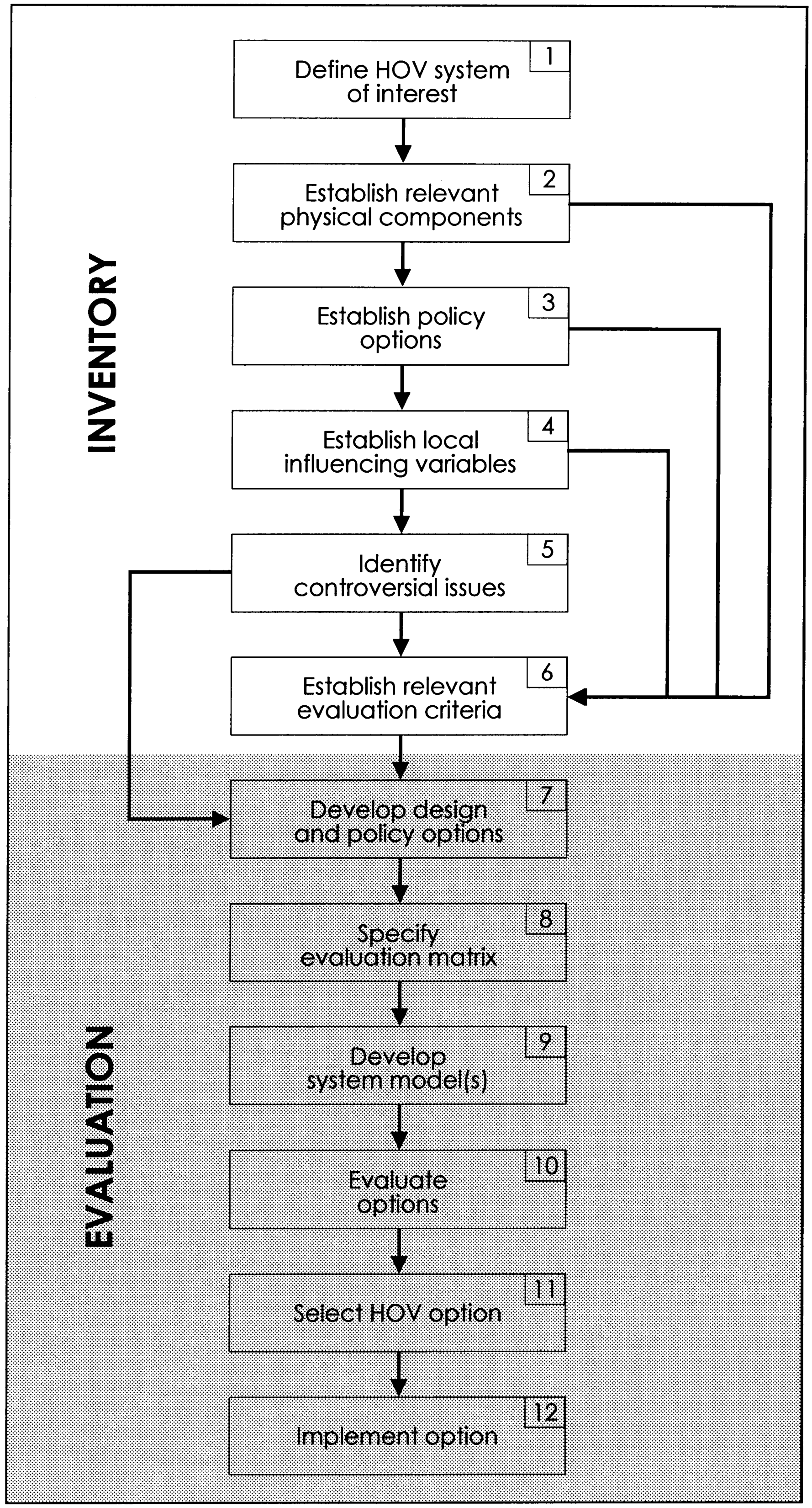


Figure 2. FRAMEWORK FOR HOV SYSTEMS ANALYSIS

parameters. One is defined in terms of trip generation and modal split. The state of Washington has established a definition for HOV systems that categorizes systems components by "hardware" and "software" elements. The hardware consists of the physical components of the system, and the software relates to the programs and policies that shape the operating environment of the system.[2]

For the purpose of this study, an HOV system is defined as "the physical regional network that includes one or more HOV facilities supported by other components of the transportation infrastructure and operational and regulatory policies." This definition incorporates hardware-software and supply-demand aspects and was used to provide a scope of the needs for a methodology for HOV system analysis.

## Elements of an HOV System

The elements of an HOV system consist of its physical components and the policies that govern it. Examples of physical components are lane/facility type and parking. Examples of policies are enforcement programs, occupancy and time-of-day restrictions, and marketing plans.

### *Physical Components*

**Facility Type**. The HOV facility, whether it be one lane or an entire roadway, is the main physical component of any HOV system. Three types of facilities have been implemented to date: exclusive HOV facilities, concurrent flow lanes, and contraflow lanes.[3,5,6] An exclusive facility is one in which the facility is separated from mixed-flow traffic by concrete barriers or physically separate lane(s). Concurrent flow lanes are those that are placed in the peak direction of travel but are not physically separated. These are often located in the inside lane. Contraflow lanes provide an exclusive lane for HOVs running in the peak direction through removal of a lane from service in the off-peak direction. Contraflow lanes usually operate only during peak periods. Selection of the type of HOV facility is dependent on a number of variables, such as congestion levels, space, costs, and funding, as well as the influence of the other elements of the HOV system.

Exclusive facilities are much more desirable to the transportation agency than the other types because they keep mixed-flow traffic off HOV facilities and thus make enforcement easier. Their disadvantage is that more space is usually needed to construct exclusive facilities. For the most part, the capacity of these facilities is 1,500 to 2,000 vehicles per hour (vph) per lane. It has been found that when volumes begin to exceed 1,200 to 1,500 vph, the vehicle speeds on these facilities drop below 55 mph.[6]

**Parking**. A number of parking alternatives are available for implementation in an HOV system, and the alternative that is selected can have a direct bearing on the system's demand. Park-and-ride lots are one of the more popular alternatives for accessing HOV facilities. Users who carpool park in park-and-ride lots and are then picked up by bus, van, or car. These lots allow for the easy formation of carpools and represent an integral part of the overall HOV system by providing this service as well as allowing for easy access to the facility itself.

A second parking alternative is preferential parking, where parking is allocated to HOV users at the trip destination. Usually, this destination is a work place, but it could also be a nonwork destination such as a shopping center. This type of parking is easily provided by businesses that have ample parking supplies and can be offered to the carpooler as an incentive to be an HOV user. Parking incentives might be based simply on parking availability or cost savings.

**Vehicles**. Carpools, vanpools, and buses are classed as HOVs. When planning an HOV system, it is important to identify which of these will use the system. It is common to allow all three to use the system with an occupancy requirement placed on carpools and vanpools. One progressive way to provide parking is to integrate transit and HOV facilities. This can be accomplished through the use of transfer centers where, for example, a group of carpoolers can park, transfer onto a rail system, and then travel to downtown areas of employment.

**Facility Access**. Ingress/egress ramps are used when the HOV facility is physically separated from mixed-flow traffic. Spacing of these access ramps is important since too few access points could inhibit use and too many could interrupt the flow of HOV traffic on the facility. When HOV traffic is involved with mixed-flow traffic, ramp metering and preferential toll treatments can be used to allow HOV users to bypass these congestion points in the system.

*Policies*

HOV policies define the restrictions and requirements of the HOV system. The policies for an HOV system typically include enforcement techniques, occupancy requirements, time restrictions, and marketing.

**Enforcement Techniques**. Enforcement for HOV systems can take many forms and can be greatly aided by facility design. For example, adequate shoulder space and enforcement areas that allow police to monitor and pull over violators will greatly facilitate enforcement. Signing is also an element of enforcement and can be used to publicize fines and facility restrictions. Enforcement can also be done by mail whereby violators are identified by monitoring police, the license plate number is recorded, and the violator is mailed a series of warnings. Another tactic that has proven to be effective is the use of excessive fines to persuade violators to respect restrictions.

An enforcement procedure that has been used successfully in the state of Washington is the HERO program in which HOV users carry out the enforcement. Users are encouraged to call a designated telephone number to report observed violators. The owner of the car in violation is then mailed instructional material describing the purpose of HOV projects. If violations continue, the vehicle's owner is sent a series of warnings.

As enforcement is a problem area, the list of enforcement strategies is growing and new techniques are continuously being researched, such as the use of photo-identification technology.[5-8]

**Occupancy Requirements**. Occupancy requirements for facilities have become a major issue. At present, most facilities have a requirement of 3 or more occupants per vehicle. Although current practice has shown that occupancy requirements should be set high and then lowered if the facility gets low usage, some planners believe that perhaps the opposite should be true. That is, the occupancy should be set at 2+ for new facilities and increased to 3+ or 4+ as the capacity of the lane(s) is approached.

The advantage of using 2+ in the early going is that it will encourage more carpools since it is easier to form 2-person carpools than 3-person pools. A disadvantage could be, however, that the system may reach its capacity much too quickly. On the other hand, the advantage of a 3+ system is that it best suits the long-term definition of carpooling—that is, moving more people per vehicle. The disadvantage of this system is that the facility must maintain a satisfactory level of usage to be successful.

**Time Restrictions**. Time restrictions for HOV facilities apply to those periods during which lanes are restricted to HOV traffic and usually take one of two forms: 4-hour restriction or peak-period restriction. A 24-hour restricted facility (referred to as a fully dedicated facility) is the more popular of the two. The 24-hour restriction makes signing and enforcement on the facility simpler and less confusing to HOV users.

Restricting operational hours of the facility to peak periods has been implemented for a number of facilities with some success. With this operational consideration come a number of options, the first of which is to restrict the entire facility to HOV traffic during peak periods and allow mixed-flow use during off-peak periods. A second option is to restrict the HOV facility to 3+ during peak periods and 2+ during off-peak periods. A third option is to implement 2+ or 3+ requirements during peak periods while using the HOV lane as a shoulder during off-peak periods.

**Marketing Plan**. The marketing of HOV systems establishes public perceptions of HOV concepts that contribute to the system's success. In the past, the public has deemed an HOV facility successful if it is at or near capacity. In other words, if the HOV facility at any time contains few to no vehicles while heavy congestion exists in mixed-flow lanes, the public tends to perceive the HOV operation as a failure. It is the responsibility of agencies to inform the users and nonusers of the system that the benefits of time savings, movement of more people per vehicle, and movement of more people per lane indicate the real success of HOV systems.

## Influencing Variables

Influencing variables in the context of HOV systems analysis consist of those socioeconomic characteristics that influence the public's response to the HOV alternative. Some of these characteristics are measurable, the two most important being cost considerations and auto availability. Data on socioeconomic characteristics of travelers and geographical areas are usually obtained with surveys, from which a system level demand is empirically determined. Cost considerations can be characterized by a number of variables, such as income and wealth. Income should be used cautiously because many people skip over or provide incorrect information on income on these surveys.[9] Auto ownership is sometimes used as a surrogate.

Auto availability pertains to the number of vehicles and competition for cars (number of cars versus number of licensed drivers) in a household. Other socioeconomic variables suggested for use in HOV systems planning include employment type, life cycle stage/age, and neighborhood setting or location.[9] Employment type can be effective in identifying what carpool incentives and programs may be available.[10] Employment areas can be useful for locating places that may experience high levels of congestion. By determining these areas early, service areas for the HOV system can be established during the planning stage. Life cycle stage or the maturation level of the family affects the amount of income available and the auto needs of the household. Also affected is the amount of travel being done and the times traveling is done. Neighborhood location affects auto needs and the accessibility area residents have to carpooling groups and facilities. It can also give some idea of the economic status of the area. This information can prove to be useful to planners when they try to determine if a suburban area will support HOV service.

## Performance Criteria

In order to plan and evaluate HOV operations, it is necessary to have measurable performance criteria that can be forecast or measured as the situation permits. These criteria should be based on parameters of the system and its operating service environment that have proven to be related to successes and failures of existing HOV operations. The following variables have been found to be indicative of HOV system performance: safety, costs, levels of service/lane volumes, occupancy rates, time savings, and costs.

### *Safety*

Safety is an important consideration in the design and operation of HOV systems, but little data and literature are available. Accident rates on HOV facilities have been found to be low compared to mixed-flow highways.[3] It has also been determined that accidents on these facilities are more likely to occur in the afternoon peak hours than in the morning peak hours. This tendency is attributed to the driver's attentiveness level being higher in the morning than in the afternoon.[11] Also, in some cases, accident rates tend to be higher on HOV facilities in the early phases of operation.[10]

Although safety is typically not a primary decision variable for establishing the need for an HOV facility, it might prove to be more important if high accident rates become associated with existing congestion levels. Consequently, one could maintain that safety should be included in the planning and design of HOV facilities at least when facility access/egress and enforcement areas are being designed and when mixed-flow traffic will be encountered.

*Level of Service/Lane Volumes*

A good measure of the system's performance is the lane utilization and its level of service. For all facilities (or the entire system), a satisfactory level of service is C[12] and occurs somewhere in the area of 1,200 vehicles per hour per lane for most facilities. Most agencies establish a range of values they consider as satisfactory for measuring lane utilization. Although the normal capacity of an HOV lane is 1,500 to 2,000 vph, acceptable traffic volumes can occur from 200 to 1,600 vph depending on the facility type. For example, lower values will be found on some concurrent and contraflow facilities and upper values in the range of 1,200 to 1,600 vph will be found on exclusive and concurrent flow facilities that are using regular traffic lanes.[3] Monitoring volumes on these facilities is important because as the facility reaches capacity, adjustments will be needed to avoid any slowdowns that occur in the lane or system.

*Occupancy Rates*

Occupancy rates should be continuously monitored on HOV and surrounding facilities. One main use of these rates is to measure how effectively the implemented HOV facilities are working.[13] This is often done by taking occupancy counts on mixed-flow facilities before HOV implementation and again after implementation to determine what kind of increase in occupancy has occurred. One issue this report addresses later is the use of these counts to trigger changes in occupancy requirements.

*Time Savings*

The most important issue to HOV users is time savings. If no significant time savings can be realized, users may cease to use the HOV facility. Further, potential users currently traveling in low-occupancy vehicles will be reluctant to become HOV users. The expected time savings used by agencies that deploy HOV facilities is 1 minute per mile with a minimum savings of 5 minutes for the trip. For most agencies, a time savings of 8 to 10 minutes is preferred.[9,12] Another element of time savings to be considered is the wait time or the amount of time HOV users spend waiting for buses, vans, and other carpool vehicles at pickup sites. (A minimum wait time should be planned so that there is little or no reduction in travel time savings.)

*Costs*

Costs and funding play major roles in the construction and operation of an HOV system. Some of the associated costs include

- construction/capital costs
- operation and maintenance costs
- parking costs
- enforcement costs
- operating costs
- bus/transit fares.

Construction/capital costs can vary depending on the type of facility desired. Operation and maintenance costs also vary according to the size of the system and what is required to operate it. Contraflow lanes commonly have larger operating and maintenance costs than exclusive-flow lanes because parking costs depend on the amount of parking dedicated for HOV users at both park-and-ride lots and employment areas. Fees charged to HOV system users are minimized to influence usage, and non-HOV users are assessed higher parking fees. Enforcement costs can be included in the operating costs of the facility and will depend on the type and amount of enforcement provided.

## Issues for Investigation

This section identifies some issues cited by transportation planners as typical problems that use of the HOV systems framework should resolve that less comprehensive approaches do not address.[14] These issues identify the demand and supply analysis requirements for the analytical framework and are stated in terms of the HOV systems framework given here as estimates of the appropriate performance measures.

*Demand Issues*

The following demand-related considerations were found to be important to HOV systems development: the market for HOVs, influence of parking, shifts from buses to carpools, and occupancy requirements.

**Market for HOVs**. A number of models exist for predicting the number of carpools, vanpools, and buses that will be using an HOV facility. The transferability of these models is somewhat questionable since their applications have typically been localized to the facility for which they were developed. A need exists for a general demand model that can be applied to a number of facilities or an entire system.

**Influence of Parking on HOV Travel**. Parking supplies can influence the system at the origin of trips, the destination of trips, or both, depending on the system design. At the origin of trips, available parking for park-and-ride facilities can help influence an individual's decision to carpool. Parking variables are often reflected in a mode choice model. At the destination end of the system, preferential parking can be provided for HOVs. In Seattle, for example, parking costs for carpools and vanpools are lower than for other vehicles. For carpools and vanpools, the city is providing parking at a price of $17 per month whereas single-occupant vehicles are still being charged $4 to $6 per day.[13]

**Shifts from Buses to Carpools**. To estimate shifts from buses to carpools, a mode choice model appears to be appropriate because users of HOV systems may choose carpooling over taking a bus due to greater time savings and less wait time. The difficulty of organizing a carpool is also a factor. The modeling process becomes clouded when some options are considered as an alternative to a permanent carpool. For example, drivers sometimes pick up riders waiting at bus stops to form carpools, thus saving riders time and allowing drivers to meet occupancy requirements. Another form of mode shift is from feeder buses to carpools at park-and-ride locations. In many cases, these buses were destined to provide service to line-haul buses. Determining what shifts may occur will allow planners to decide how much supply the system should offer in the form of buses (and possibly vanpools as well). The results of these shifts, supplied by the mode choice model, can then be placed into an analysis model, such as a simulation model, to determine the performance of the system.

**Occupancy Requirements**. A number of agencies have established guidelines to be used in setting occupancy restrictions for HOV facilities. Two variables used to help establish such guidelines are average vehicle occupancy and traffic volumes on HOV lanes. Average vehicle occupancy is the average number of passengers per car using the facility. For establishing the initial restrictions on HOV facilities, one source[13] established the following guidelines:

| Average Occupancy | Occupancy Restriction |
|---|---|
| < 1.2 | 2+ |
| > 1.2 | 3+ |
| > 1.4 | 4+ |

These settings are assumed to ensure initial usage and accommodate increased patronage.

If the traffic volumes for the different occupancy restrictions can be predicted, they may be used for setting initial restrictions. If volumes on the facility are predicted to be 400 to 800 vph for carpools of two or more, then the restriction can be set at 2+. If the analysis is done for carpools of three or more, the volume on the facility must be 400 vph or greater and the restriction may be set at 3+. If the volume prediction falls below 400 vph, the facility will appear underutilized and the restriction should be set at 2+.

Recent leanings have been toward establishing the facility as 2+, then, when the facility reaches capacity, raising it to 3+. The same strategy holds true when going from 3+ to 4+. The biggest problem with this method is that changing restrictions forces HOV users to alter their carpools to meet requirements. Therefore, it is imperative that agencies coordinate a proper marketing campaign to inform the public of upcoming changes in the system.

*Network Performance (Supply) Issues*

HOV network performance measures indicate the effectiveness of the operation of an HOV facility as part of a regional transportation system. Measures investigated here relate to parallel routes and continuity of travel.

**Parallel Routes**. The performance of parallel routes is used to compare conditions on such routes to those on HOV facilities. Such conditions as speed and travel times show the relative level of service for the HOV facility.

**Continuity of Travel**. Areas of friction in the HOV system that need to be addressed include:

- *Mixed-flow traffic interruption.* Often, this is a design problem that allows mixed flow to enter the HOV system. Mixed-flow traffic must be kept off HOV facilities to avoid interruption of system continuity.

- *Toll facilities.* With the advances in automatic vehicle identification technology, this problem is quickly being lessened. To take care of any interruption caused by toll facilities, system users are given preferential treatment and allowed to pass through toll facilities along the system.

- *Intersections with signalization.* Along arterial areas of the system, HOVs are given the right of way through intersections, thus eliminating any delays that might be caused by these intersections.

- *Connecting ramps.* Locations where HOV facilities connect or where HOV facilities connect with mixed-flow traffic will be important areas to monitor to avoid a disruption in continuity. One successful method to avoid problems at these locations is the deployment of ramp metering techniques that give preferential treatment to HOVs.

## Summary

The elements of the HOV systems framework that have been introduced are listed in Figure 3, and the relation of each to supply and/or demand is noted. The physical components, HOV policies, and influencing variables can be employed to fashion alternative service options, and the performance criteria used to evaluate these options. The overall demand for the facility is an implicit criterion.

# Systems Modeling

This section describes analytical models that can be used to analyze HOV systems. Demand forecasting models, a network simulation model, and urban transportation planning packages are considered.

## Demand Forecasting

*Models Pivot Point Analysis*

This demand analysis method was developed in 1976 to aid in energy conservation plans.[15] The technique predicts revised travel behavior based on data describing both existing travel and changes in level of service. Travel demand coefficients are used to pivot around base data, and revised travel behavior forecasts are formulated. Data requirements are minimal.

*Orange County Package*

This approach was implemented by the Orange County (California) Transit District to forecast HOV and transit choices.[16] Journey-to-work travel data collected in 1980 from The Census Bureau Urban Transportation Planning Package were used. These data were then expanded to the year 2010 using population and employment growth factors. Mode split probabilities were determined using travel time savings of trips taken on the preferential facilities versus trips taken on mixed-flow facilities in addition to origin-destination (O-D) attributes. The change in the mode split probabilities was based on before-and-after data from other U.S. facilities. HOV trip totals were then assigned to transitway links using a microcomputer assignment application developed by the staff.

*MWCOG Mode Choice Model*

The mode choice methodology developed by the Metropolitan Washington, D.C., Council of Governments (MWCOG) implements both a mode choice model and a car occupancy model. The mode choice model is a logit model that allocates trips to three modes: transit, one auto occupant (representing trips made by the driver alone), and auto group (trips made with more than one person in

| ELEMENTS/VARIABLES/CRITERIA | SUPPLY | DEMAND |
| --- | --- | --- |
| **PHYSICAL COMPONENTS** | | |
| -FACILITY TYPE | ☑ | |
| -PARKING | ☑ | ☑ |
| -VEHICLES REQUIREMENTS | ☑ | ☑ |
| -FACILITY ACCESS/EGRESS | ☑ | |
| **HOV POLICIES** | | |
| -OCCUPANCY REQUIREMENT | ☑ | ☑ |
| -RESTRICTION TIMES | ☑ | ☑ |
| -MARKETING/PERCEPTIONS | ☑ | ☑ |
| -ENFORCEMENT | ☑ | |
| **INFLUENCING VARIABLES** | | |
| -INCOME | | ☑ |
| -AUTO AVAILABILITY | | ☑ |
| -EMPLOYMENT TYPE | | ☑ |
| -LIFE/CYCLE STAGE/AGE | | ☑ |
| -NEIGHBORHOOD LOCATION | | ☑ |
| **PERFORMANCE CRITERIA** | | |
| -SAFETY | ☑ | ☑ |
| -LOS | ☑ | ☑ |
| -OCCUPANCY RATES | ☑ | ☑ |
| -PUBLIC ACCEPTANCE | | ☑ |
| -TIME SAVINGS | | ☑ |
| -COSTS | ☑ | ☑ |

Figure 3. HOV ELEMENTS/VARIABLES/CRITERIA VERSUS SUPPLY/DEMAND

the vehicle). This mode choice model is designed for home-based work trips. The car occupancy model is also a logit model that further defines the group mode of the mode choice model by breaking it down into two, three, and four (or more) persons per vehicle.

The MWCOG model appears to be acceptable for HOV applications. The car occupancy model allows for analysis of HOV facilities and the modeling of changes in occupancy restrictions.[17]

### Network Simulation

CORFLO is a macroscopic simulation model developed by the Federal Highway Administration.[18] It consists of four component models: FREFLO, a macroscopic freeway simulation model; NETFLO Level 1, an event-based surface street simulation model; NETFLO Level 2, a macroscopic surface street simulation model; and TRAFFIC, a traffic assignment model. CORFLO allows planners to simulate a variety of traffic conditions, traffic controls, and traffic mixes on freeways and surface streets, including HOV facilities.

FREFLO is a macroscopic simulation model that represents traffic with aggregate measures on each section of freeway. The measures used are flow rate, density, and space-mean speed in the section. Also, these variables represent different vehicle types (buses, carpools, autos, and trucks).[18]

NETFLO Level I is a simplified treatment of individual vehicles in the traffic stream that describes the traffic environment at a low level of detail.

NETFLO Level II describes the traffic stream in terms of a set of link-specific statistical flow histograms. Both models output similar measures of effectiveness.[18]

TRAFFIC is an equilibrium model interfaced with FREFLO and NETFLO. The planner develops an O-D table that represents the traffic demand for the analysis area for a specified period of time. TRAFFIC will transform this O-D table into turning percentages and entry volumes for the simulation models.[18]

### Urban Transportation Planning Packages

Standard computer planning packages include UTPS, MINUTP, and TRANPLAN. These packages are formed around the conventional planning methods that use the four-step planning process: trip generation, trip distribution, mode split model, and traffic assignment. Documented applications to HOV systems are not typically available. Current upgrades of MINUTP have made the analysis of HOV lanes available by permitting the user to assign HOV and non-HOV trips simultaneously.[19]

# CASE STUDY

Here, the policy option of HOV3+ to HOV2+ is evaluated using a set of methods from those previously identified. This demonstration of the application of the analytical framework follows the process illustrated in Figure 4.

## Identify Analysis Area

For this case study, the I-66 corridor in Northern Virginia was selected. Since the definition of an HOV system does include the possibility of having only one HOV facility with supporting elements, the section of I-66 designated for HOV traffic is suitable for this case study. Although the I-395 facility is also contained in the HOV system for the Northern Virginia area, the I-66 subsystem was considered to be independent and hence could be analyzed separately. This is shown in Figure 1.

## Input Data

The data for the case study consisted of O-D data and ground counts. O-D data for district-to-district travel were available in two forms: person trip tables and modal trip tables (trips were specified by LOV driver/LOV person trips, walk transit/auto transit passenger, and HOV driver/HOV person trips). The data were provided in 200 x 200 and 228 x 228 matrices for 1985 and 2010 data, respectively. Ground counts at 15-minute intervals for the peak period were supplied for the I-66 HOV facility for the years 1987 through 1990. In addition, average daily traffic counts for 1989 were available for I-66.

## Calibrate FREFLO

This step simulates current conditions along the network and allows for the evaluation of changes in traffic due to HOV policy changes. The FREFLO component of the CORFLO package was selected for this task. The statistics to be given for each link in the network period include vehicle miles, vehicle trips, delay time (in vehicle minutes, minutes/mile, seconds/vehicle, and person minutes), average volumes, average speed, person miles, person trips, and total move time (in same units as delay).

The FREFLO model was calibrated using current HOV O-D trip tables based on the current occupancy restriction of three or more persons per automobile. The first step in the application of FREFLO was to select the districts in the analysis area where trips to I-66 originate. To accomplish this, the MWCOG district map was examined and an area was designated as shown in Figure 5. It was assumed that districts which fell in the shaded area produced HOV trips for

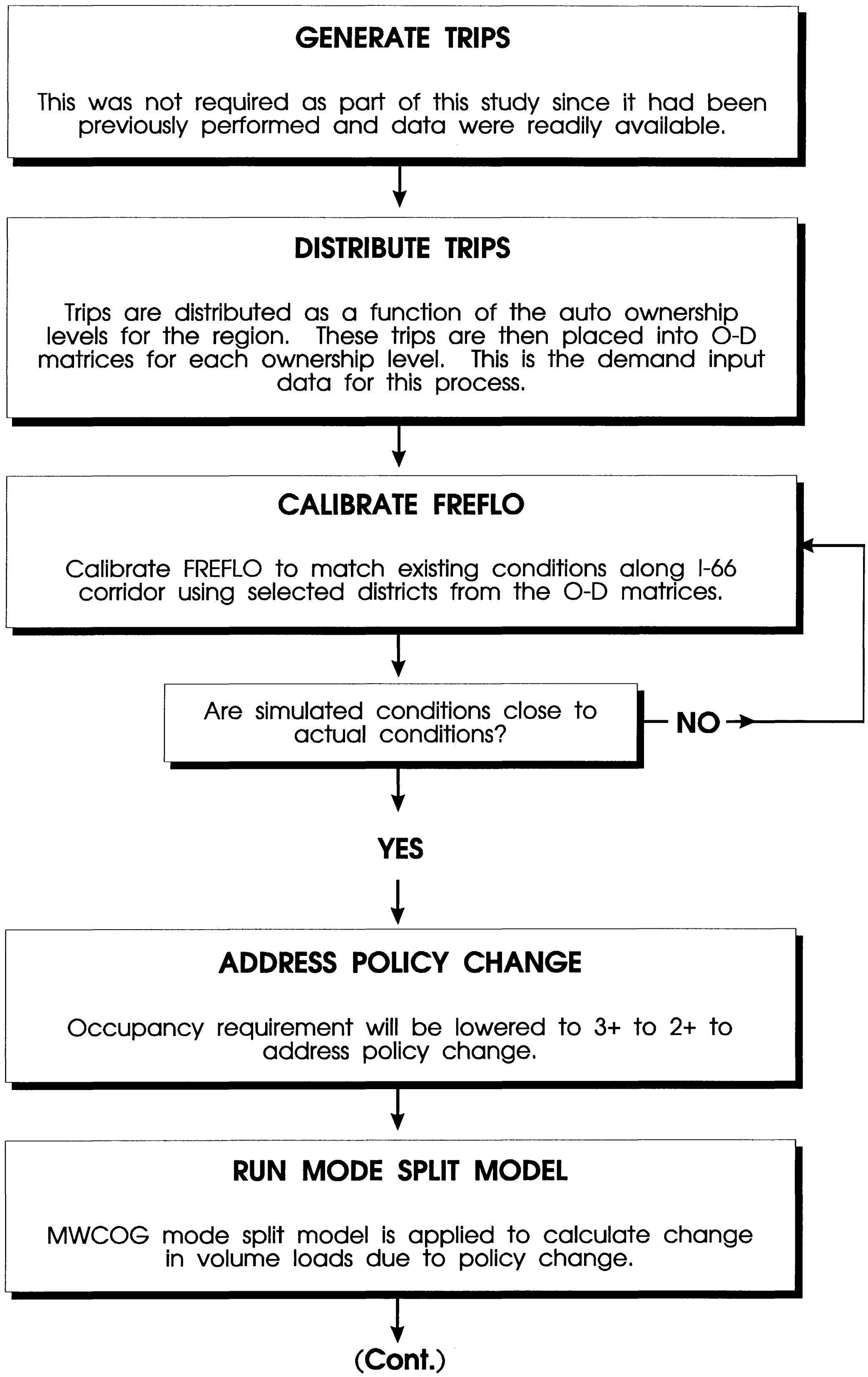


Figure 4. FLOW CHART FOR MODELING METHODOLOGY

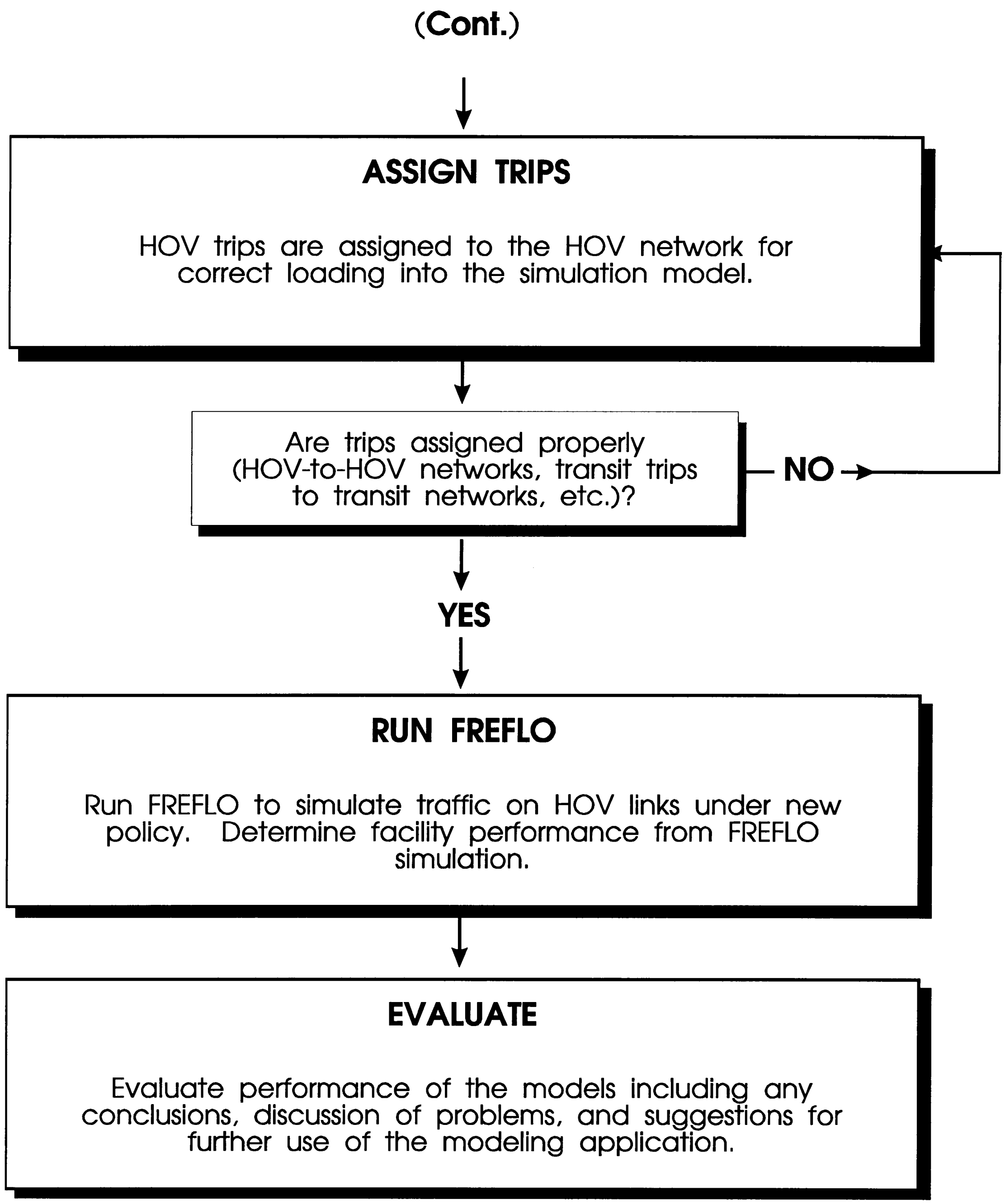


Figure 4. (continued)

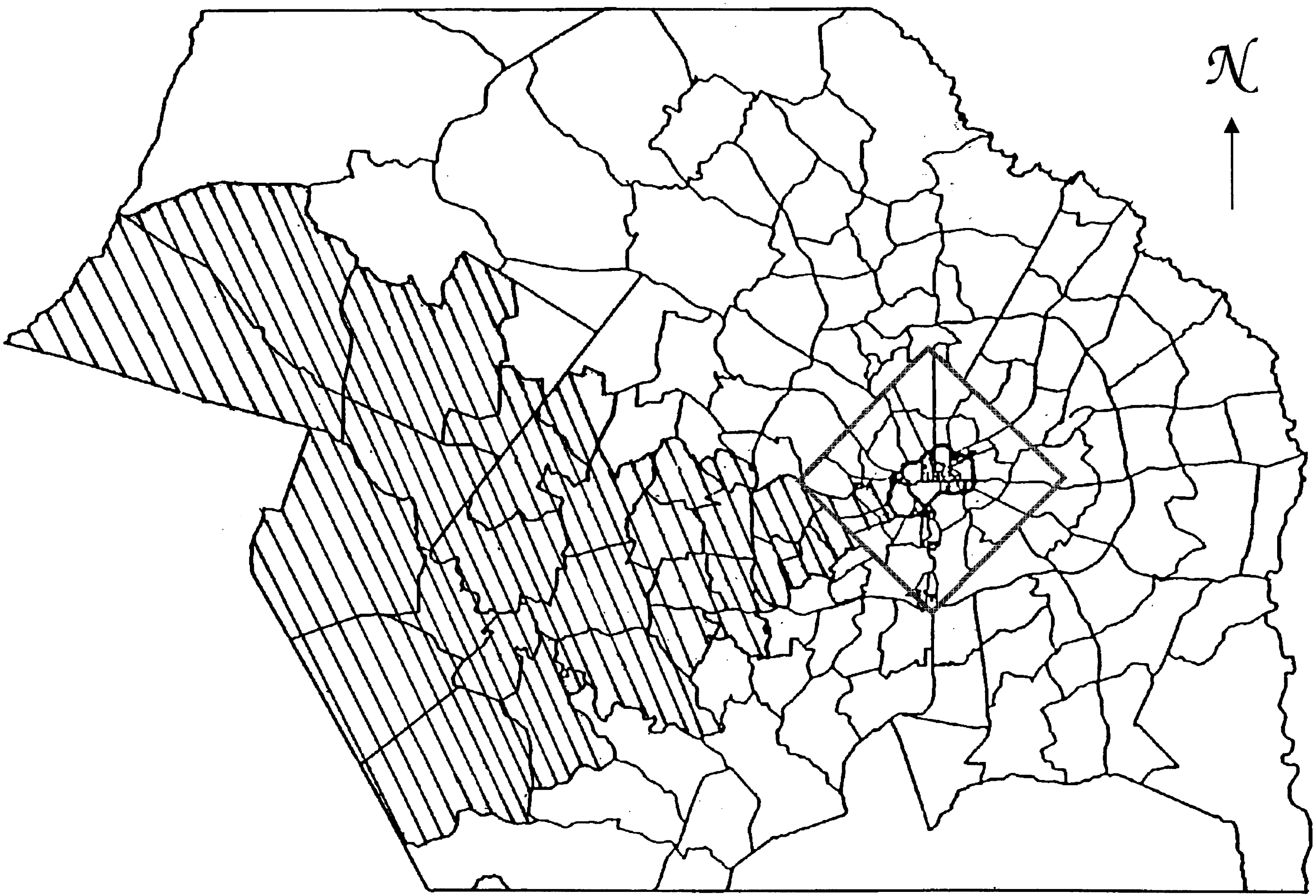


Figure 5. ANALYSIS AREA FOR I-66

I-66. Districts that fell outside this area were assumed to be production districts for other facilities (such as I-95). For the destination end of the HOV trips, only the Washington, D.C., core area was used. With the selection of O-D districts, it was then necessary to extract those trips from the HOV O-D trip tables that fell into the specified O-D pairs. The HOV person trips specified for these O-D pairs were then converted to vehicle per hour volumes. To perform this conversion, the person trips were divided by 3.5 (average person per vehicle occupancy for I-66) and again by 2.5 hours (number of hours in the morning HOV period). These volumes (vph) were then loaded into the FREFLO model using the layout shown in Figure 6, and the simulation was performed. The recorded ground counts compared favorably with the vehicle trips from the FREFLO simulation results; therefore, the network was assumed to be calibrated so that policy changes could be analyzed.

For the base case simulation, hourly O-D volumes were input for each of the 15-minute periods from 6:30 A.M. to 9:00 A.M. on eastbound I-66. The results indicated an excessive amount of vehicle trips on the west end (link 1-2) of I-66. The expected number was approximately 1,700 vehicle trips (from ground count data [Table 1]) for the HOV period, and the model simulated 2,957 trips, as indicated in Table 2. Although the simulated vehicle counts at the west end of the facility were quite high, the counts at the middle (4,500 assumed [Table 1], 3,935 simulated [see Table 2]) of the facility were closer to the actual conditions. This indicated that the traffic was entering the HOV facility at a point downstream, east of the I-495 entry point. This error was due to the lack of an assignment analysis, which would have indicated a minimum path of travel. If this minimum path had been designated, it might have shown that vehicles would enter the facility slightly further downstream due to the congestion around the I-66/I-495 junction.

Ground counts in 1990 at three locations along I-66 were provided by the VDOT Northern Virginia Planning Office and used in a second simulation of the base case. The ground counts for 15-minute increments were given as total vehicles, which were further broken down by occupancy. The total vehicle count for each 15-minute period was converted into vehicles per hour to make them acceptable input for the model. Table 1 shows the ground counts at the three locations that were converted to vph volumes for the FREFLO model and the cumulative ground counts at the west entry, middle, and east exit points of I-66. The results of this simulation were compared to the actual person trips extracted from the O-D trip tables. The expected number of person trips was approximately 16,000, and the model predicted 14,481 person trips (9.5% error).

The first simulation that used O-D trip tables was assumed to be adequate for the purpose of this study with the recommendation that future research consider using a traffic assignment model along with FREFLO.

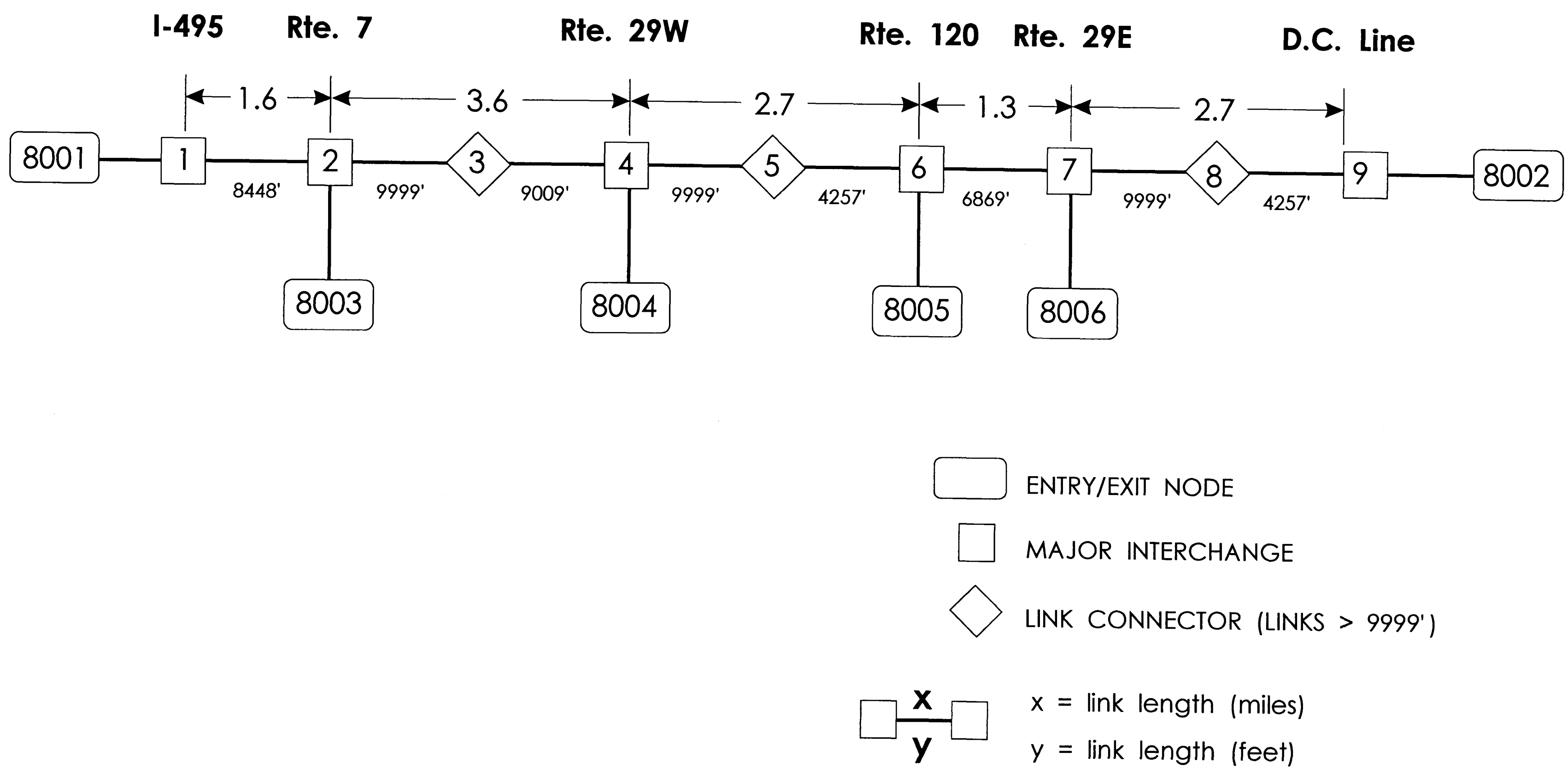


Figure 6. HOV LAYOUT FOR FREFLO MODEL

Table 1
GROUND COUNT ENTRY VOLUMES

| Time | At Rt. 495 Veh (v/hr) | At Rt. 7 Veh (v/hr) | At Rt. 29W Veh (v/hr) |
|---|---|---|---|
| 6:30–6:45 | 243 (972) | 19 (76) | 43 (172) |
| 6:45–7:00 | 159 (636) | 12 (48) | 28 (112) |
| 7:00–7:15 | 176 (704) | 14 (56) | 31 (124) |
| 7:15–7:30 | 197 (788) | 15 (60) | 34 (136) |
| 7:30–7:45 | 169 (676) | 13 (52) | 30 (120) |
| 7:45–8:00 | 137 (548) | 11 (44) | 24 (96) |
| 8:00–8:15 | 135 (540) | 10 (40) | 24 (96) |
| 8:15–8:30 | 112 (448) | 9 (36) | 20 (80) |
| 8:30–8:45 | 107 (428) | 8 (32) | 19 (76) |
| 8:45–9:00 | 243 (972) | 19 (76) | 43 (172) |

Note: # = number of vehicles in 15-minute period.
(#) = conversion to vehicles/hour.

Table 2
FREFLO HOV3 CUMULATIVE RESULTS AT 9:00 A.M.

| Link | Vehicle Trips | Average Speed | Person Trips |
|---|---|---|---|
| 80011 | 2,947 | | |
| 1-2 | 2,957 | 55.0 | 10,228 |
| 2-3 | 4,433 | 55.0 | 15,314 |
| 3-4 | 4,385 | 55.0 | 15,158 |
| 4-5 | 4,505 | 55.0 | 15,557 |
| 5-6 | 4,459 | 55.0 | 15,460 |
| 6-7 | 4,378 | 55.0 | 15,150 |
| 7-8 | 3,935 | 55.0 | 13,583 |
| 8-9 | 3,892 | 55.0 | 13,492 |

There were some drawbacks to the simulations. For example, using I-66 as the analysis area provided some problems mainly because the I-66 facility has so many HOV violations. At the 15-minute fringe periods (first and last 15 minutes of the restriction period), violation rates were exceptionally high, ranging from 70% to 90% at each location. This forced a number of assumptions concerning the loading of the facility. To input only those vehicles that qualified at the 3+ HOV restriction would not accurately depict the number of vehicles utilizing the facility. Similar problems would arise if the percentage of HOV traffic input (% HOV) was set at 1% violation, since the model would remove traffic from the overall load. For example, if the facility has an 80% violation rate, then the % HOV would be 100 – 80, or 20%. This means that only 20% of the total load would be allowed onto the facility by the model. In addition, the model would not accept a value of 100% HOV for the simulation; therefore, a setting of 99% was used.

To solve this, it was easiest to assume all traffic was HOV, since overall, there would be no great change in average occupancy and the model would depict the actual conditions of the facility better.

## Address Policy Change

The policy change selected to demonstrate the methodology consisted of reducing the occupancy restriction on the I-66 facility from 3+ per vehicle to 2+ per vehicle. The purpose of this policy change analysis was two-fold. First, it demonstrated the application of a mode split model that was sensitive to the policy change and forecast additional traffic on I-66. Second, it showed how the FREFLO model can evaluate the addition of new traffic and determine the effectiveness of the policy change.

## Run Mode Split Model

A mode choice model was used to determine volume changes for different ridership policies. After discussions with the VDOT Northern Virginia Planning Division and evaluation of alternative methods, the calibrated form MWCOG mode choice model was selected for this study.[18] The mode split model calibration requires intensive data, which were beyond the scope and resources of this study. However, default average values for the Northern Virginia area were provided in the model documentation. From these average values, the model produced average mode split percentages for the Northern Virginia area. Average probabilities for the mode choice analysis are provided in Table 3. Results of the mode split analysis are presented in Table 4 that provide the total person trips for each mode at the three general access points (these are the totals of all the O-D trip pairs).

Table 3
AVERAGE PROBABILITIES FOR MODE CHOICE

| MODE CHOICE MODEL | | |
|---|---|---|
| TRANSIT | = | 0.266 |
| ONE | = | 0.416 |
| GROUP | = | 0.318 |
| **CAR OCCUPANCY MODEL** | | |
| TWO | = | 0.632 |
| THREE | = | 0.184 |
| FOUR+ | = | 0.184 |

Table 4
RESULTS OF MODE SPLIT MODEL

| LOCATION[a] | GROUP | TWO | THREE | FOUR+ |
|---|---|---|---|---|
| TOTALS RT 7 TO RT 29W | 11,753 | 7,428 | 2,163 | 2,163 |
| TOTALS JUST INSIDE I-495 | 13,162 | 8,318 | 2,422 | 2,422 |
| TOTALS OUTSIDE I-495 | 25,265 | 15,967 | 4,649 | 4,649 |
| TOTALS FOR I-66 | 50,180 | 31,714 | 9,233 | 9,233 |

[a]Sum of all O-D person trips at each location.

## Assign Trips

Hourly volumes for FREFLO were input from the results of the mode split model. These person trips were converted to vehicles per hour by first dividing by the number of hours in the analysis period (2.5). Then, this result was divided by the average persons per vehicle (assumed to be 2.5) to convert to vehicles per hour.

In addition to this change, the program had an additional card to change the default values for the average occupancy for any vehicle type.

For the simulation, with the required occupancy dropped to 2+, the average occupancy would also show a significant drop. Since 2.5 was used for the conversion of the data to vehicles per hour, this was input into the data cards for the simulation model.

## Run FREFLO

The simulation of the policy change showed interesting results. First, the delay on the facility for HOV 2+ was significantly higher than during HOV 3+ operation. Table 5 indicates the average speeds in the first 15 minutes (6:30–6:45) being half (26 mph) of those speeds during the 3+ operation (55 mph). By the conclusion of the analysis period, the speeds on the facility had dropped considerably at the front end of the facility (2.4 mph). Traffic speeds at the east end of I-66 (link 8-9) were slightly below previous conditions, with the average speed at approximately 53 mph. In addition, the number of vehicle trips on link 1-2 at the conclusion of the time period (8:45 A.M.–9:00 A.M.) dropped off from the number of trips entering at entry link 8001-1. The cumulative number of vehicle trips on the entry link was 5,800 but only 1,360 at the next link (1-2). After consulting with FHWA researchers on FREFLO, it was decided that the low number of vehicle trips at the front end of I-66 (link 1-2 at 9:00 A.M.) was a result of the heavy volumes being loaded at the front; thus bottlenecking was occurring at the front end. The corridor was becoming congested as soon as the vehicles were loaded onto the facility. To combat this problem, it was first suggested that the assumed capacity be raised to 2,000 vehicles/lane/hour, but the resulting simulation showed only a limited increase in vehicle trips on link 1-2.

To counter the loading problem, a lane was added to increase the capacity of the facility. Thus, simulation was performed again with an additional lane added at the first entry link (8001-1) and the subsequent link (1-2). As with the previous simulations, the delay was still quite high and average speeds did not increase enough to warrant the addition of a lane while dropping the occupancy restriction to 2+.

Table 5
RESULTS OF HOV3 VS. HOV2

FREFLO HOV3 SIMULATION CUMULATIVE RESULTS AT 6:45 A.M.

| Link | Vehicle Trips | Average Speed | Person Trips |
|---|---|---|---|
| 80011 | 209 | | |
| 12 | 307 | 55.0 | 1,009 |
| 23 | 444 | 55.0 | 1,440 |
| 34 | 396 | 55.0 | 1,284 |
| 45 | 359 | 55.0 | 1,139 |
| 56 | 314 | 55.0 | 1,043 |
| 67 | 275 | 55.0 | 883 |
| 78 | 204 | 55.0 | 617 |
| 89 | 166 | 55.0 | 537 |

FREFLO HOV2 SIMULATION CUMULATIVE RESULTS AT 6:45 A.M.

| Link | Vehicle Trips | Average Speed | Person Trips |
|---|---|---|---|
| 80011 | 914 | | |
| 12 | 720 | 26.2 | 1,448 |
| 23 | 992 | 26.0 | 1,896 |
| 34 | 701 | 38.2 | 1,493 |
| 45 | 945 | 30.8 | 1,843 |
| 56 | 724 | 42.9 | 1,695 |
| 67 | 646 | 53.4 | 1,489 |
| 78 | 503 | 55.0 | 1,119 |
| 89 | 434 | 55.0 | 1,018 |

FREFLO HOV3 SIMULATION CUMULATIVE RESULTS AT 9:00 A.M.

| Link | Vehicle Trips | Average Speed | Person Trips |
|---|---|---|---|
| 80011 | 2,947 | | |
| 12 | 2,957 | 55.0 | 10,228 |
| 23 | 4,433 | 55.0 | 15,314 |
| 34 | 4,385 | 55.0 | 15,158 |
| 45 | 4,505 | 55.0 | 15,557 |
| 56 | 4,459 | 55.0 | 15,460 |
| 67 | 4,378 | 55.0 | 15,150 |
| 78 | 3,935 | 55.0 | 13,583 |
| 89 | 3,892 | 55.0 | 13,492 |

FREFLO HOV2 SIMULATION CUMULATIVE RESULTS AT 9:00 A.M.

| Link | Vehicle Trips | Average Speed | Person Trips |
|---|---|---|---|
| 80011 | 5,808 | | |
| 12 | 1,360 | 2.4 | 2,798 |
| 23 | 4,401 | 7.6 | 10,274 |
| 34 | 4,006 | 7.9 | 9,350 |
| 45 | 7,880 | 14.0 | 18,923 |
| 56 | 7,626 | 30.3 | 18,748 |
| 67 | 7,466 | 41.8 | 18,335 |
| 78 | 6,696 | 49.6 | 16,416 |
| 89 | 6,619 | 52.8 | 16,303 |

### Evaluate

A traffic assignment model could have been applied to this study. Although all HOV trips were placed on the HOV network for this study, the exact locations that trips enter the facility were approximated to one of the three specified entries (for reasons of simplifying the data coding). In reality, a percentage of these trips may be entering further downstream from I-495, via parallel routes, due to drivers knowing the congestion levels at and around the Beltway junction with I-66.

In consideration of the traffic assignment problem, the FREFLO model was simulating traffic close enough to actual conditions to warrant considering the use of this model to study policy changes. The level of traffic delay was quite high as can be seen in Table 5, which presents the output from the FREFLO simulation for the 2+ policy change. Even with the numerous assumptions and approximations used, this analysis provides a better argument than now exists to keep the HOV policy at its current status of 3+. The analysis has shown that dropping occupancy restrictions to 2+ would cause significant delay (most probably not to the extremes of the simulation but high enough) and would cause user time savings to drop to almost nothing.

## RECOMMENDATIONS

This study produced a framework to enable planners, decision makers, and the public to plan and review HOV options in an objective manner. Analytical models for simulating the impacts on HOV policy options show potential in reducing the uncertainty inherent in many HOV policy decisions. The results of this study encourage localized development of HOV-sensitive analysis tools for specific locations and led to the following recommendations.

1. The issues and analytical framework developed in this study should be used by planners to guide future HOV planning and policy analysis studies. This approach would provide a basis for developing a data base on issue-related HOV experiences that would go beyond mere reports on HOV projects.

2. VDOT should pursue the refinement of the demand/network/simulation modeling methodology. This could be accomplished on a project-by-project basis wherein planning studies are documented.

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