Predicting High Occupancy Vehicle Lane Demand

Final Report

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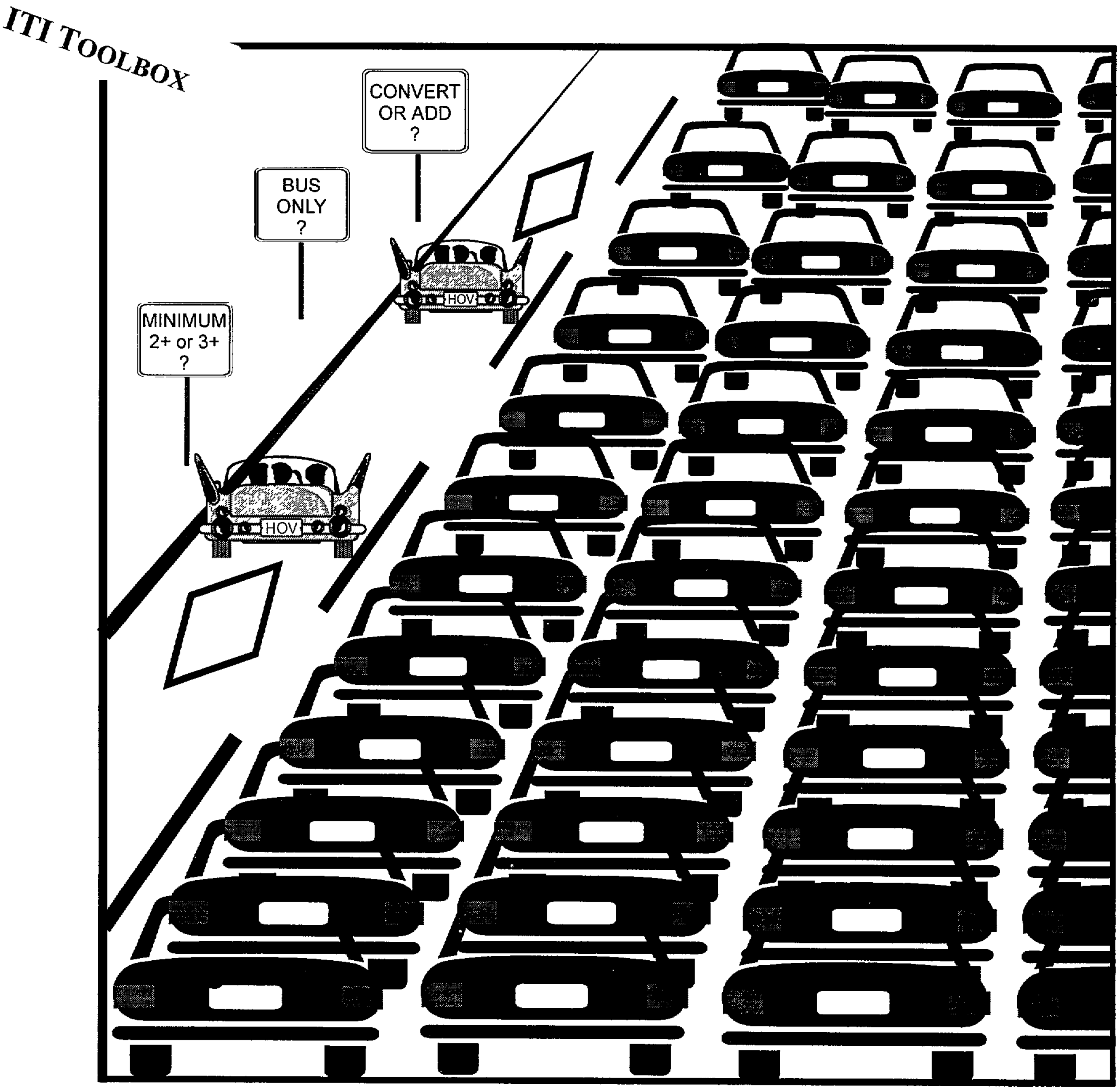
U.S. Department
of Transportation

Federal Highway Administration

Predicting High Occupancy Vehicle Lane Demand

Final Report



August 1996

Report No. FHWA -SA-96-073

Foreword

The Federal Highway Administration Project #42-10-4172, "Predicting the Demand for High Occupancy Vehicle (HOV) Lanes" is a two year effort to develop a methodology and micro-computer software model for quickly analyzing HOV lane demand and operations.

This document, the Final Report, presents the results of this project.

Notice

Predicting the Demand for High Occupancy Vehicle Lanes

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd ❑ 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2 = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (Lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp ❑ 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] ^{o}F ❑ y ^{o}C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) ❑ 0.03 fluid ounce (fl oz)
1 liter (1) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] ^{o}C ❑ x ^{o}F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. Cl3 10286.

Predicting the Demand for High Occupancy Vehicle Lanes

Final Report

Preface

This report presents the results of the literature review and data collection effort for the Federal Highway Administration Project #42-10-4172, "Predicting the Demand for High Occupancy Vehicle (HOV) Lanes". This research project is a two year effort to develop a methodology and micro-computer software model for quickly analyzing HOV lane demand and operations. The methodology is designed to be applied by planners and engineers with limited or no access to or experience with regional travel demand modelling.

The methodology provides a set of "quick response" procedures for predicting and evaluating the impacts of HOV lanes on person demand, vehicle demand, auto occupancy, congestion, delay, and air quality. This methodology is applicable to corridor, network, and system level HOV demand analysis.

The objectives of this project have been to:

1. Identify and document state-of-the-art practices in predicting, analyzing, and evaluating travel demand for HOV lanes.
2. Collect, analyze, and report data relevent to the prediction, analysis, and evaluation of HOV lanes.
3. Formulate a methodology for assessing HOV travel demand on freeway and arterial facilities for use by personnel not experienced in regional travel demand modelling.
4. Develop a computer model with a user's guide to predict and analyze planned and actual HOV travel demand that is consistent with the methodology.

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This report presents the results of the Federal Highway Administration Project #42-10-4172, "Predicting the Demand for High Occupancy Vehicle Lanes". The report provides: A review of the available literature and the experiences of public agencies with current methods for predicting the demand for HOV lanes; the recommended new methodology for predicting the demand for HOV lanes; and The data on existing HOV lane projects in the United States that was used to calibrate and validate the new HOV lane demand estimation methodology.</td></tr>
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Predicting the Demand for High Occupancy Vehicle Lanes
Literature Review and Data Collection Report

Table of Contents

List of Tables

List of Figures

List of Figures (continued)

Predicting the Demand for High Occupancy Vehicle Lanes

Final Report

EXECUTIVE SUMMARY

Federal Highway Administration Project #42-10-4172, "Predicting the Demand for High Occupancy Vehicle Lanes", is a two year effort to develop a methodology and micro-computer software model for quickly analyzing HOV lane demand and operations. The methodology is designed to be applied by planners and engineers with limited or no access to or experience with regional travel demand modeling.

This report presents the interim results of this project, specifically:

1. A review of the available literature and the experiences of public agencies with current methods for predicting the demand for HOV lanes,
2. The proposed new methodology for predicting the demand for HOV lanes, and
3. The data on existing HOV lane projects in the United States that will be used to calibrate and validate the new HOV lane demand estimation methodology.

E.1 Literature Review

The literature review included technical reports, periodicals, computer models, and software documentation. The review began with a search of the National Technical Information Service (NTIS) and Transportation Research Information System (TRIS) data bases, as well as computerized files of newsletters, journals, business news sources and newspaper articles maintained by Dialog Information Service.

Abstracts of reports and articles identified through the initial search process were reviewed and copies of promising references were obtained. The reference list assembled in this fashion was submitted for the review of the consulting team and members of a Steering Committee of state DOT representatives, MPO members, university researchers, practitioners and federal transportation officials assembled under the supervision of FHWA. This process led to the identification and review of over seventy references listed in the bibliography of this report.

E.l.l Regionwide Logit Models

The most prevalent approach to the regionwide estimation of HOV lane mode shares entails the use of disaggregate logit models embedded in the traditional regional four-step transportation planning process of (1) trip generation; (2) trip distribution; (3) mode split; and (4) traffic assignment. Typically these disaggregate models have been respecified to handle carpool modes as well as transit and solo driving, either simultaneously or sequentially in "nested" formats which separate auto and transit ridership before addressing Carpool mode shares.

Regionwide logit models are mathematically tractable and widely used in regional planning, so that their use is well understood in the planning community. Since the models incorporate a regionwide network, they are particularly useful in representing the network impacts of HOV lanes, such as the diversion of carpool and solo driver trips from parallel routes.

Regionwide network models require extensive data input and model calibration. This can be a cumbersome process when the issue at hand deals with the impact of HOV lanes on a limited number of corridors.

These models also require extensive recalibration from location to location. Recalibration is not only a geographic issue. Model parameters are not stable over time. Thus recalibration is necessary to ensure temporal transferability as well.

Many regionwide logit mode split models have been developed and calibrated to estimate HOV mode split only for home based work trips. Non-work trips are not modelled at all, or are dealt with using an expansion factor.

Traditional regionwide network models have limited ability to estimate the operational impacts of HOV facilities on speed, average delays, and traffic queues. As highway networks become more and more congested, regionwide models are less and less successful in estimating travel times and delays. In particular, they fail to replicate the manner in which congestion queues transmit delays throughout the system. As a result, they are ill-equipped to represent the travel-time advantages provided by HOV lanes that are crucial in influencing shifts to ridesharing modes.

As a practical matter, regionwide logit models have historically not performed well in replicating the impact of HOV facilities on actual mode choices. One investigator observes that "..in the application of travel demand models, there are frequently considerable discrepancies between HOV model estimates and observed roadway counts of multi-occupant vehicles." Another further cautions that "regional mode-choice models in general, and regional mode-choice models with components in particular, have not performed well in terms of their ability to predict mode shares." In view of the fact that most regional models of HOV use were not originally designed to handle trip-dependent changes in travel time and have been carved out of traditional logit models developed with only two modes (transit and auto) in mind and calibrated to match overall corridor flows, it is hardly surprising that they have not performed well in representing the impact of HOV lanes on mode share.

Although regional logit models are used widely to analyze the network-wide impacts of alternative systems, they do not seem to be flexible enough to focus on the corridor-specific impacts of HOV facilities. Existing regionwide models tend to be data-intensive and require extensive recalibration to accommodate transfers both from location to location and from one time frame to another. They are ill-equipped to represent the operational impacts of HOV lanes on travel times and have historically not performed well in predicting the impact of these lanes on modal shifts.

E.1.2 Corridor Models

Many attempts to model HOV demand have focused on a single corridor, usually ignoring impacts of HOV facilities in the broader regionwide network and sometimes glossing over the interdependencies between mode choice and travel times on HOV facilities and adjacent mixed-flow lanes. While some of these models use the multinomial logit formulation described in connection with regionwide network models, others use quick-response regression relationships in which HOV lane usage is computed as a function of travel time savings or some other measure of congestion.

Corridor models can also differ markedly with respect to their field of vision within the corridor. For example, such models can include parallel routes, limit their field of vision to a single freeway (or arterial), or focus on a single point along a freeway segment.

Corridor models fall generally into two classes of models:

- Demand models, which emphasize the estimation of demand and employ only simplistic approaches to estimating changes in facility operations, and
- Supply models that emphasize the modeling of facility operations and employ only simplistic techniques for estimating changes in demand.

Supply Models: In recent years, a number of macroscopic simulations of freeway conditions have been developed as an aid for studying the detailed impacts of design alternatives on speed, delays, and traffic queues in a specific corridor. Examples of these simulation models include FREQ and FREFLO. These models typically take the demand for access to HOV lanes and mixed flow lanes within a specific time frame as an input variable in simulating the propagation of traffic queues and congestion delays from one section of the freeway to another. Although these models focus on the elaborate delineation of freeway operations data, they can be used iteratively with corridor demand models or with regionwide network models in computing the impact of HOV lanes on mode choices.

Demand Models: The corridor demand models reviewed in this report represent simple, transparent approaches that are easy to understand and apply. Data requirements are minimal, and at least one model, that of Parody, appears to perform well in replicating overall demand measurements on existing HOV lanes.

Even the best of existing corridor models have been calibrated on limited data sets, either because relatively few HOV lanes were in operation at the time they were calibrated, or because the modelers had a narrow focus. The geographic transferability of these models is not well understood, and none are equipped to deal with spatial and temporal shifts in trip making. Those models that are based on regression relationships tie their predictions to a single explanatory variable.

Supply/Demand Interaction: Some corridor models of HOV demand ignore the interaction between mode choice and travel time, accepting the travel time differential between HOV lanes and mixed-flow traffic as a given input variable and using it to compute the demand for carpools in the corridor. Other models treat the interaction between demand and travel time explicitly by iterating between demand model results and travel time models until convergence is obtained.

Simple corridor-based regression models, updated to reflect current HOV lane experience, represent a promising means of predicting the overall number of carpools attracted to a new HOV lane. Some mechanism needs to be found for coupling these models with level-of-service estimates and addressing issues of spatial and temporal diversion in a manner consistent with a quick-response modeling effort.

E.1.3 Agency Survey

A survey of HOV Lane planners and engineers was conducted to assist in the identification of gaps and problems with current methodologies for predicting the demand for and impacts of HOV lanes. Another objective of this survey was to obtain technical staff opinions and input regarding possible approaches for modeling HOV facility demand. In addition, information was collected on the availability of input data for estimating HOV demand. The information obtained through this agency survey was used in the methodology development task of the project.

Personnel at nine agencies were selected for the telephone survey.

HOV Lane Analysis Needs: The analysis needs which tended to be most critical were the ability to analyze the impacts of HOV lanes on: vehicle demand, congestion, person demand, and air quality. Other HOV facility analysis needs which were mentioned were cost, noise, transit usage, mode split and trip distribution.

Methods Currently Employed: The agencies use a variety of methodologies and models for predicting HOV lane demand and evaluating its impacts. Three of the agencies stated that they use sketch planning methodologies (pivot-point). Four agencies use macroscopic simulation models, such as FREQ and TRANSYT-7F. Two agencies use microscopic simulation models, such as FRESIM.

All of the agencies use regional travel demand models for some part of their evaluation of HOV facilities. The regional travel demand models being used by the agencies include TRANPLAN, MINUTP, EMME/2, and UTPS or UTPS-based models. Approximately half of the agencies represented in the survey use some sort of post-processors to refine the estimates produced by the regional models. The post-processors tend to be used to enhance speed and emissions estimates, for operational analysis, or for re-estimating mode choice and distribution.

Experience With Current Methods: The agencies were also asked about their experience using the various existing HOV lane methodologies and models, specifically the level of effort involved and any key advantages or weaknesses. On average, the individuals surveyed have been using the existing methodologies and models for over seven years.

With respect to regional travel demand models, most of the agencies stated that once the model was operational, the level of effort was minimal. However, the network coding and calibration efforts required to get the model running is extremely time consuming, demanding of personnel, and data intensive. According to the agencies surveyed, the macroscopic and microscopic simulation models tended to be fairly data intensive, but necessary to obtain the desired output.

Satisfaction/Dissatisfaction With Current Methods: The agencies identified the following key advantages of the current methodologies and models:

- Corridor Supply Models can be calibrated. They are capable of evaluating operations on the first day and for longer time periods. These models are readily available.
- Regionwide Travel Demand Models (when combined with EPA approved emission models) provide better emissions estimates. Regional models represent the entire length of the trip so that route diversions and mode shifts due to HOV lanes can be more reliably estimated. Regional models are well understood and the agencies have confidence in the results.

The agencies however also pointed out the following major weaknesses of the existing methodologies and models:

- Corridor Supply models, for all the detail with which they model road operations, still lack the flexibility to model certain facility geometrics (start and end of HOV lane, right-side HOV facilities, exclusive on- and off-ramps, grade, expanding or constricting number of lanes, HOV merging, extending or shortening HOV facilities, and general condition changes);
- Corridor models, since they model only a portion of the entire trip, are not reliable for predicting spatial diversion of traffic to other corridors.
- There are no generally available models for predicting temporal shifts in trip making;
- Regional models require extensive network coding, calibration, and data collection They are slow and time consuming to run. Many mode split models contained in regional models evaluate only work trips;
- Only produces HOV trips for those with a time savings of greater than five minutes;
- All models assume 100% of the eligible HOV's will use the HOV lane.

Desired Features of New Method: The agencies identified the following desired features of any new or improved method for evaluating the demand for and impacts of HOV lanes:

1. The model and software should be simple and user friendly. The model outputs should be understandable to a lay person. The software should be able to output schematics, maps, and/or graphs of facility geometrics and model outputs (e.g., queuing, air quality, congestion, and speed/flow).
2. The methodology should be consistent with existing models and methodologies. The methodology however should provide improves route shift, time shift, and mode shift estimation capabilities.
3. The methodology should provide for the analysis of
   - Addition of HOV Lane or the conversion of a mixed flow lane to HOV lane,
   - Changes in eligibility rules (2+ versus 3+),
   - HOV lane access design (limited access versus continuous access),
   - Ramp metering with HOV bypass lanes, and

- Arterial HOV lanes.

Relationship to Regional Models. The agencies were also surveyed on what the relationship should be of a new model to an existing regional travel demand model if a regional travel demand model is available for the project study area. Most of the agencies stated that there should be a link or interface between the two models and that the results should be consistent. Most of the agencies also believed that if a regional model is available for the HOV project study area, the regional model should be used (but not necessarily required) for HOV analysis, especially for significant decisions such as major investment studies.

Data Availability. The agencies were asked to identify the types of input data they might have available for an HOV study. Turning movement counts for arterials, estimates of HOV growth , vehicle occupancy, average speeds, and information on parallel facilities were data types that tended to be more difficult for the agencies to obtain for an HOV lane study.

E.2 Recommended Methodology

The Agency survey indicated that agencies have a full spectrum of analytical needs when evaluating the impacts of HOV lanes. The need to be able to perform sketch planning studies to quickly identify and screen for promising locations for HOV lanes. They need more sophisticated corridor level models to evaluate the designs and operation of the HOV lane facility. They need comprehensive regionwide models to forecast the air quality impacts of the HOV lane project and ensure its conformity with the State Implementation Plan (SIP) for complying with the Federal Clean Air Act and Amendments.

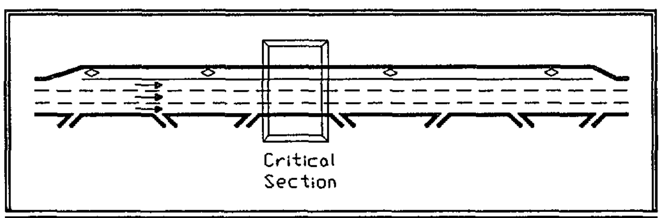
The project team concluded that no single method could hope to accommodate the full spectrum of agency analytical needs. The best way to provide for the full spectrum of analytical needs would be with a multi-level analytical approach. A sketch planning level method would be developed that requires relatively little data and yet can provide approximate answers for delay, congestion, and air quality. However, projects requiring greater detail would have to employ successively more detailed and data intensive methods.

E.2.1 A Multi-Level Analytical Approach

Three distinct levels of HOV analysis are proposed by the team:

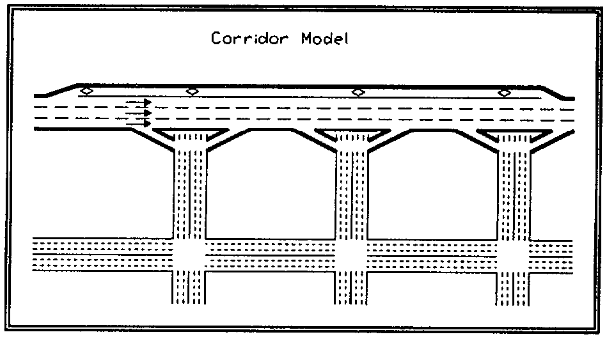
- Level One: The Critical Sub-Section Method;
- Level Two: The Corridor Model Method; and,
- Level Three: The Linked Corridor/Network Travel Demand Model.

The Level One Critical Sub-Section Method would consider only the controlling or critical sub-section of a proposed directional peak period HOV study section. The HOV study section would preferably have a fairly uniform demand and capacity profile over its length. The critical sub-section would be identified by having the highest demand-to-capacity ratio.



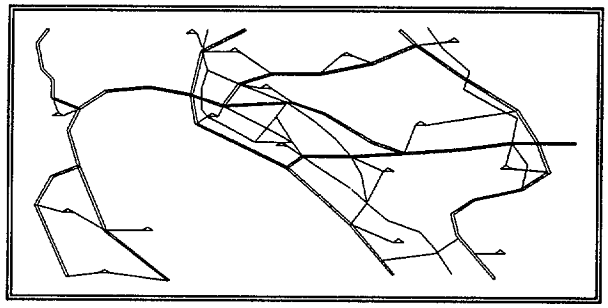
The intent of this approach would be to provide for a quick-response tool for predicting order-of-magnitude HOV and mixed-flow demand and traffic performance, with limited impact estimation capabilities. In this sense, the Critical Sub-Section Model can be considered as a screening tool from which peak-period directional freeway sections could be further investigated at the next level of analysis. This approach can be used to estimate traffic performance and mode shift in the HOV facility opening day, the short-term (e.g. 6 months after opening day), and long-term (e.g. after 7 years of operation).

<u>The Level Two Corridor Model Method</u> would consider the entire directional peak period HOV study section and an appropriate representation of the parallel facilities. Compared to the Critical Sub-Section Model, this model would require additional model input, incorporate a computerized simulation model, and would provide more precise estimates of HOV and mixed-flow demands as well as more accurate and more comprehensive measures of performance. The payoffs for the increased model requirements would include improved travel demand estimation, representation of traffic congestion, more accurate travel speed estimation, and the capability for corridor emissions estimation.



Computer simulation models, such as FREQ and CORFLO, are already available for this corridor modeling approach.

<u>The Level Three Linked Corridor/Network Travel Demand Model Method</u> considers an HOV facility in the context of a transportation network including trip origins and destinations, as well as many alternative routes. This model system also takes into account other transportation modes that might be competing with the HOV facility.



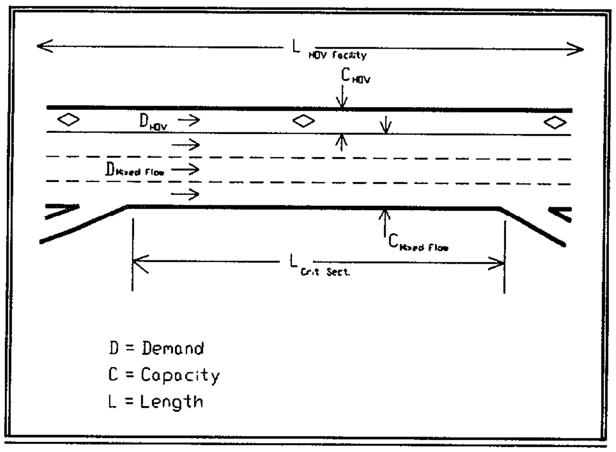
FHWA and Caltrans have recently developed prototypes of such linked regional and corridor models (see "IVHS Benefits Assessment Framework" project by VNTSC/U.S. DOT and "Travel Demand and Simulation Modeling" project by Caltrans headquarters).

E.2.2 Proposed Critical Subsection Methodology

Since software already exists to implement the more data intensive level two and level three methods, this research project focused exclusively on the development of the Level One Critical Subsection Method. This section describes in more detail the critical subsection model methodology which developed as part of this project.

<u>Input Data Requirements</u>:

1. Existing HOV and SOV demand at the critical sub-section (highest demand-to-capacity ratio). Demands would be required for each direction/peak period of the facility and analyzed separately.
2. HOV and SOV lane capacity for the critical sub-section (Example: HOV lane capacity = 1600 vphpl, SOV lane capacity = 2000 vphpl).
3. Existing occupancy distribution (Example: 80% SOV, 15% HOV2, 3% HOV3, 2% HOV3+/buses). Also, average vehicle occupancy for HOV3+/buses.



4. Existing and future number of HOV and SOV lanes at critical sub-section.

5. Length of critical sub-section and overall HOV study section in kilometers.
6. Existing average travel time (or speed in kilometers-per-hour).
7. Existing and estimated future free-flow speed in the HOV lane and mixed-flow lanes.
8. Availability and quality of parallel routes (none, poor, good, excellent).
9. Demand growth estimate for the appropriate year of analysis (Example: 3% annual growth).
10. Design and occupancy requirements for proposed HOV facility (2+, 3+, bus-only, added HOV lane, lane-conversion from mixed-flow to HOV, conversion from 3+ to 2+, conversion from 2+ to 3+).
11. Vehicle type distribution (i.e. percent passenger vehicles, buses, light trucks, heavy trucks, motorcycles, etc.). This information will be used to generate emissions and fuel consumption estimates.

Model Output:

1. HOV lane and mixed-flow lane demand-to-capacity (d/c) ratio.
2. HOV lane and mixed-flow lane volumes by occupancy type.
3. Persons/lane for HOV and mixed-flow lanes.
4. Average speed, trip time, and total travel time for the HOV lane and mixed-flow lanes over the critical sub-section and over the whole length of the HOV lane.
5. Differences in demand-to-capacity ratios, persons-per-lane, Level-of-Service (LOS), average speed, trip time, and total travel time between the HOV lane and mixed-flow lanes.
6. Vehicle-miles of travel (VMT), vehicle-hours of travel (VHT), and delay for HOVs and SOVs.
7. Breakdown of total response between mode shift and induced shift due to spatial diversion.
8. Estimates of emissions and fuel consumption.

Recommended Methodology. The recommended iterative HOV demand/supply estimation process consists of the following steps. The forecasted demand and travel times are equilibrated for both short term and long term demand forecasts.

Step 1: Identify the HOV Study Section and the Critical Sub-Section, and Input Demand and Supply Data

Step 2: Evaluate "Before" Scenario: Supply Model

Step 3: Evaluate "Opening Day" Performance (Before Traveler Response)

Step 4: Estimate Short-Term Traveler Response to the HOV Facility: Demand Model

Step 5: Evaluate Performance After Short-Term Traveler Response, and

Step 6: Continue the Iterative Process Between Demand and Modified Performance until Equilibrium is Obtained

Step 7: After Equilibrium is Achieved Between Steps 4 and 6, Allocate a Portion of the Total Response Estimated in Step 4 to Route Diversion

Step 8: Forecast Long-Term Growth

Step 9: Evaluate Long-Term Performance (Before Traveler Response)

Step 10: Estimate Long-Term Traveler Response

Step 11: Re-evaluate Performance after Long-Term Traveler Response, and

Step 12: Continue the Iterative Process Between Demand and Modified Performance until Equilibrium is Obtained

Step 13: After Equilibrium is Achieved Between Steps 10 and 12, Allocate a Portion of the Total Response Estimated in Step 10 to Route Diversion

Step 14: Compute, Summarize, and Report Measures of Performance.

E.3 Data Collection

This section describes the data collection effort. First the data needs were determined, then nine agencies were identified for data collections. The data sets were then assembled from each agency. The final step was to compile and reduce the various data sets into a single consistent set of HOV lane data for the development and calibration of an HOV lane demand model.

E.3.1. Data Needs

It was determined that the new HOV demand estimation methodology should be sensitive to the impacts of HOV lanes on travel time and should be able to predict HOV and non-HOV vehicle and passenger volumes. The methodology should also be able to predict the effects of different minimum vehicle occupancy rules.

It would have been desirable for the new methodology to be sensitive to tolls, however; it was determined that there was inadequate field experience to date for validating HOV cost sensitivities. (The San Francisco Bay Area has several toll bypass lanes, however; the benefits of a free toll are combined with significant time savings so that the effect of the cost difference cannot be easily isolated from the effect of the time savings.)

The travel time differences (HOV versus non-HOV, and “before” versus “after”) are the “stimulus” to be used in the demand estimation methodology. The differences in the vehicle volumes (“before” versus “after” for HOV and non-HOV vehicles) are the “response” to be predicted by the new methodology.

Thus the following data is required to test and validate the new HOV demand estimation methodology:

1. “Before and after” peak period vehicle volume data by:
   a. Occupancy type (e.g. 1 person, 2 persons, 3 persons, 4+ persons),
   b. Vehicle type (auto, bus, van, truck, motorcycle), and by
   c. Lane type (HOV lane, Other lanes).
2. “Before and after” travel time data by lane type

E.3.2. Selection of Nine Agencies

Nine agencies were selected for data collection based on:

1. The number and variety of HOV projects operated by the agency,
2. The frequency and quality of their past and on-going data collection efforts,
3. Their representativeness of a cross-section of agencies operating HOV facilities throughout the United States, and
4. Their ability to cooperate in this study (some agencies had insufficient human resources to assist in the assembly of the data for this project).

The selected agencies are:

1. Caltrans, District 4, San Francisco, California;
2. Caltrans, Districts 7 and 11, Los Angeles and San Diego, California;
3. Minnesota DOT, Minneapolis, Minnesota;
4. New Jersey DOT, Trenton, New Jersey;
5. Metropolitan Transit Authority of Harris County, Houston, Texas;
6. Virginia DOT, Richmond, Virginia;
7. Washington DOT, Seattle, Washington;
8. Santa Clara County, San Jose, California;
9. Snohomish County, Seattle, Washington.

The nine agencies operate a combined total of 56 freeway and arterial HOV projects with a total of 640 lane-miles (1024 lane-km)(see Table Ex-1). The selected agencies together operate 54% of the 1188 freeway HOV lane-miles (1,912 lane-km) in the United States and Canada. Many of the selected agencies collect and publish data on HOV lane usage annually, semi-annually, or quarterly. Most have conducted "before and after" studies for some of their HOV facilities.

E.3.3. Collection of Before/After Data Sets

Each agency was requested to forward a copy of every available published "before and after" study for HOV facilities under their control. Some agencies no longer had available copies of "before/after" studies for projects which were opened over 20 years ago. In those cases, the University of California, Institute of Transportation Studies library was searched for information on the older projects.

Minnesota DOT, the Texas Transportation Institute, and the California State University, San Diego (Caltrans District 11) had the most extensive series of "before and after" studies available for their HOV facility projects.

New Jersey DOT's "before and after" study of their I-80 facility is still in progress and could not yet be released at the date of publication of this report.

Agencies also provided copies of their monitoring program reports. The Texas Transportation Institute, Caltrans District 4, Washington Metro COG, and Washington State DOT provided extensive monitoring data.

The history of each HOV facility was then reviewed to determine which "changes" in facility operation or characteristics would be useful "actions" for inclusion in the methodology development database. An "action" usually consists of construction of a new HOV facility, a change in the length of an existing HOV facility, or changes in eligibility rules (e.g. 2+ versus 3+ carpools allowed).

It was particularly valuable when several "actions" could be identified on a single facility, because then the effects of different actions on the identical facility could be tested without interference caused by differences in driver types in different geographic areas. The Katy Transitway in Houston, and the I-5 freeway in Seattle were two particularly rich sources of multiple "actions" occurring on the same facility.

A few, otherwise excellent, "before/after" studies were not included in the database because the HOV facility was not the only major change occurring in the corridor at that time. For example, a portion of the I-394 Minneapolis data set was not included in the database because the later portions of the HOV project occurred at the same time as freeway construction was proceeding. Some of the earlier studies of the Shirley Highway in Washington D.C. have not been included because of potential confusion of the effects of gasoline shortages in 1973 and 1979 with the impacts of the HOV facility.

A total of 27 "before/after" data sets out of a total 56 projects operated by the nine agencies have been identified and included in the methodology development database. Table Ex-2 lists the projects and the rationale for including or excluding each one in the database. Table Ex-3 lists the selected project datasets and their salient characteristics.

E.3.4. Data Reduction

The various "before/after" data sets identified in the previous step were reduced and consolidated into a single consistent database. This step involved converting percentages into volumes, translating travel time data into travel time differences, and tilling in gaps in the reported data based upon information available from related sources.

For example, vehicle occupancies were sometimes reported for the overall (HOV plus mixed flow) facility but not specifically for the HOV or mixed flow lanes. This information plus information on violation rates, average vehicle occupancy by lane, and total lane volumes were then used to assign vehicles by occupancy type to each lane type.

In other cases, travel times were reported for a section of the freeway that was longer than the section in which the HOV lane was located. These times were converted to travel times for the shorter section of freeway with the HOV lane by assuming that all of the observed travel time difference between the HOV lane floating car run and the mixed flow lane floating car run was due to the HOV lane.

In some cases, only mean or only maximum travel time savings were reported and these had to be converted to the other missing measurement (mean or maximum) using an estimated ratio of mean to maximum travel times based on data collected on the Houston and San Francisco HOV facilities.

Table Ex-1. Agency Profiles

Agency:	Caltrans 04	Houston Metro	Washington State DOT	Virginia DOT	Minnesota DOT	Caltrans 07 Caltrans 11	New Jersey DOT	Santa Clara County	King/ Snohomish Counties
Metro. Area	San Francisco, California	Houston, Texas	Seattle, Washington	Washington D.C.	Minneapolis, Minnesota	Los Angeles, San Diego, California	Morris County, New Jersey	San Jose, California	Seattle, Washington
Length of HOV Lanes (lane-miles and lane-km)	158 mi. 254 km	64 mi. 103 km	121 mi. 195 km	65 mi. 105 km	34 mi. 55 km	157 mi. 253 km	21 mi. 34 km	22 mi. 35 km	4 mi. 6 km
Barrier Separated Projects	None	5	2	2	21	3	None	None	None
Concurrent Flow Projects	11	None	7	1	2	6	1	2	4
Queue Bypass Projects	10	None	part of HOV lane projects	part of HOV lane projects	part of HOV lane projects	None	None	1	None
Before & After Studies	7	continuous monitoring	2	tri-annual monitoring	3	7	in progress	1	1
HOV Facility Monitoring Program	semi-annual reports since 1988	Quarterly reports since 1979	Quarterly reports since 1992. No travel time data after 1993	Tri-annual cordon counts, No speed data	Continuous and Biennial counts, No Speeds	None	None	Annual Report	None
HOV Traveler Surveys	8 sites in 1990 1 site in 1995	Annual Surveys 1985 to 1989	Surveys 1990, 1994	1986, 1987 Surveys	1986, 1993 Surveys	1989 on I-15	None	None	None

1 One of these projects was replaced by a new freeway HOV facility.

Table Ex-2. Selection of Projects for Methodology Development Database						
Agency	HOV Project	HOV Type	Lane-Miles	Before-After Report?	Selected for Database?	Rationale
1. MnDOT Minneapolis Minnesota	1. I-394	freeway-reversible	6	Yes	No	HOV lane during freeway construction
	2. I-394	freeway -concurrent	16	Yes	No	HOV lane during freeway construction
	3. I-394[2]	expressway -reversible	4	Yes	Yes	shows expressway HOV
	4. I-35 w	freeway -concurrent	12	No	No	No Data
2. Houston Metro Houston Texas	5. Katy	freeway-reversible	13	Yes	Yes	very rich data set for rule changes
	6. North	freeway-reversible	14	Yes	Yes	shows rule change
	7. Northwest	freeway-reversible	14	Yes	Yes	shows HOV lane addition
	8. Gulf	freeway-reversible	12	No	No	No After Data
	9. Southwest	freeway-reversible	12	No	No	No Data
3. caltrans Los Angeles & San Diego California	10. I-10 LA	freeway-barrier	22	Yes	Yes	shows conversion of busway to HOV
	11. I-405 LA	freeway-concurrent	12	No	No	No before data
	12. SR-91 LA	freeway-concurrent	16	Yes	Yes	shows construction of HOV lanes
	13. I-105 LA	freeway-barrier	16	No	No	HOV and freeway opened same date
	14.1210 LA	freeway-concurrent	34	Yes	Yes	shows construction of HOV lanes
	56. SR-55 OR	freeway-concurrent	22	Yes	Yes	shows buffer separated HOV lanes
	15. I-15 SD	freeway-reversible	20	Yes	Yes	Extensive data
	16. SR-163 SD	freeway-concurrent	0	No	No	No data
	17. SR 75 SD	freeway-concurrent	0	No	No	No data
	18. I-5 SD	freeway-concurrent	0	No	No	Customs station bypass
4. WSDOT Seattle Washington	19. I-5 (north)	freeway-concurrent	12	No	No	No data
	20. I-5 (central)	freeway-concurrent	4	Yes	Yes	shows ramp meters, rule change, etc.
	21. I-5 (south)	freeway-concurrent	14	No	No	No data
	22. I-90 (west)	freeway-barrier	3	No	No	No data
	23. I-90 (centr)	freeway-barrier	12	No	No	No data
	24. I-90 (east)	freeway-concurrent	14	Yes	Yes	shows lane conversion
	25. I-405	freeway-concurrent	17	No	No	No data
	26. SR-167	freeway-concurrent	4	No	No	No data
	27. SR-520	freeway-concurrent	2	No	No	No data

2 Tbis project was replaced by freeway HOV facility.

Table Ex-2. Selection of Projects for Methodology Development Database

Agency	HOV Project	HOV Type	Lane-Miles	Before-After Report?	Selected for Database?	Rationale
5. Caltrans 4	28. us-101 Marin (S)	freeway-concurrent	7	No	Yes	shows conversions bus to HOV
San Francisco	29. us-101 Marin (N)	freeway-concurrent	12	No	Yes	shows conversion bus to HOV
California	30. us-101 Santa Clara (N)	freeway-concurrent	37	Yes	Yes	shows HOV add
	31. us-101 Santa Clara (S)	freeway-concurrent	26	Yes	Yes	shows HOV add
	32. I-880	freeway-concurrent	15	No	No	No data
	33. I-280	freeway-concurrent	22	Yes	Yes	shows HOV add
	34. I-680	freeway-concurrent	21	No	No	Too recent for after study
	35. I-580	freeway-concurrent	10	No	No	No data
	36. SR-237	expressway-concurrent	12	Yes	Yes	shows expressway
	37. SR-85	freeway-concurrent	44	No	No	HOV and freeway open same date
	3 8-44. Toll Bypass	freeway-concurrent	N/A.	No	No	No data
6. Santa Clara	45. San Tomas	expressway-concurrent	13	Yes	Yes	shows expressway
San Jose	46. Montague	expressway-concurrent	9	Yes	No	Incomplete before data
California	47. Central	expressway-concurrent	N/A.	No	No	No data
7. Snohomish	48. 2nd/5th	arterial-concurrent	2	?	No	No data
Seattle	49. SR-99	arterial-concurrent	2	?	No	No data
Washington	50. SR-522	arterial-concurrent	1	?	No	No data
	51. Airport/l28	arterial-concurrent	4	Yes	Yes	shows arterial HOV
8. VDOT	52. I-395	freeway-barrier	22	Yes	No	No travel time data
North Virginia	53. I-66 (east)	freeway-barrier	19	Yes	No	study in progress
Virginia	54. I-66 (west)	freeway-concurrent	14	Yes	No	study in progress
9. NJDOT	55. I-80	freeway-concurrent	21	Yes	No	After study not yet available
Total:		lane-miles:	640	398	311	

Table Ex-3. Characteristics of Selected Validation Data Sets

No	Facility	Location	State	Road Type	HOV Facility Type	Eligibility Rule	Action	Length (miles)	Peak Hour Data	Peak Period Data
1	US 12	Minneapolis	Minnesota	Expresswy	Reversible	2+	Add Lane	3.0+1.0	√	
2	I-10	Houston	Texas	Freeway	Reversible	2+	Convert 3+ to 2+	6.4	√	√
3	I-10	Houston	Texas	Freeway	Reversible	2+	Extend 5 miles	11.4	√	√
4	I-10	Houston	Texas	Freeway	Reversible	2+/3+	Convert 2+ to 3+	11.4	√	√
5	I-10	Houston	Texas	Freeway	Reversible	2+	Extend 1.5 miles	12.6	√	√
6	I-45N	Houston	Texas	Freeway	Reversible	2+	Convert 3+ to 2+	13.5	√	
7	US-290	Houston	Texas	Freeway	Reversible	2+	Add Lane	9.5	√	√
8	I-15	San Diego	California	Freeway	Reversible	2+	Add Lane	8.0	√	√
9	I-90	Seattle	Washington	Freeway	Concurrent	2+	Convert SOV to HOV	6.2		√
10	I-5	Seattle	Washington	Freeway	Concurrent	2+	Convert 3+ to 2+	7.7	√	
11	I-5	Seattle	Washington	Freeway	Ramp Meters	?	HOV Bypass Lns	N/A.		√
12	I-5	Seattle	Washington	Freeway	Concurrent	3+	Add Lane	5.6	√	
13	US 101	San Jose	California	Freeway	Concurrent	2+	Add SOV + HOV Lane	6.0	√	√
14	US 101	San Jose	California	Freeway	Concurrent	2+	Add Lane	2.8	√	√
15	I-280	San Jose	California	Freeway	Concurrent	2+	Add Lane	10.7	√	√
16	Airport Rd	Seattle	Washington	Arterial	Concurrent	2+	Add Lane	3.3	√	
17	SR 237	San Jose	California	Expresswy	Concurrent	2+	Add Lane	5.9		√
18	San Tomas	San Jose	California	Expresswy	Concurrent	2+	Add Lane	4.9		√
19	I-10	Santa Monica	California	Freeway	Concurrent	3+	Convert SOV to HOV	12.0		√
20	I-10	San Bernardino	California	Freeway	Barrier Separated	3+	Convert Bus to HOV	11.0		√
21	US 101	Marin	California	Freeway	Concurrent	3+	Convert Bus to HOV	3.7	√	
22	SR 91 EB	Los Angeles	California	Freeway	Concurrent	2+	Add Lane	8.0	√	
23	I-210	Pasadena	California	Freeway	Concurrent	2+	Add Lane	17.0	√	
24	SR 91 WB	Los Angeles	California	Freeway	Concurrent	2+	Add Lane	8.0	√	
25	SR 55	Orange	California	Freeway	Barrier Separated	2+	Add Lane	11.0	√	
26	US 101	Marin (S)	California	Freeway	Concurrent	2+	Convert 3+ to 2+	3.7		√
27	US 101	Marin (N)	California	Freeway	Concurrent	2+	Convert 3+ to 2+	3.0		√

1. INTRODUCTION

This report presents the results of the literature review and data collection effort for the Federal Highway Administration Project #42-10-4172, "Predicting the Demand for High Occupancy Vehicle (HOV) Lanes".

1.1 RESEARCH PROJECT OBJECTIVE AND SCOPE

This research project is a two year effort to develop a methodology and micro-computer software model for quickly analyzing HOV lane demand and operations. The methodology is designed to be applied by planners and engineers with limited or no access to or experience with regional travel demand modeling. The methodology will provide a set of "quick response" procedures for predicting and evaluating the impacts of HOV lanes on person demand, vehicle demand, auto occupancy, congestion, delay, and air quality. This methodology will be applicable to corridor, network, and system level HOV demand analysis.

The objectives of this project are to:

1. Identity and document state-of-the-art practices in predicting, analyzing, and evaluating travel demand for HOV lanes.
2. Collect, analyze, and report data relevant to the prediction, analysis, and evaluation of HOV lanes.
3. Formulate a methodology for assessing HOV travel demand on freeway and arterial facilities for use by personnel not experienced in regional travel demand modeling.
4. Develop a computer model with a user's guide to predict and analyze planned and actual HOV travel demand that is consistent with the methodology.

1.2 OUTLINE OF REPORT

The executive summary provides an overview of the content of this report.

This first chapter of this report serves as an introduction to the project and the report.

The second chapter is an inventory of HOV facilities in the United States and Canada. This information is useful in gaining a perspective of the distribution and type of HOV projects and for determining the validity of the sample used to create the methodology development database.

The third chapter describes the characteristics of HOV lane users that are useful for understanding the basis for developing a methodology for predicting HOV demand.

The fourth chapter describes the available methods for predicting HOV lane demand and their impacts.

The fifth chapter uses the results of a survey of HOV agencies and the results of the literature review to identify the need for a new methodology for predicting HOV lane demand and impacts.

The sixth chapter defines the recommended new methodology for predicting the demand for HOV lanes.

The seventh chapter presents the data that was assembled from various HOV lane operators for the purpose of calibrating and validating the proposed new HOV lane demand estimation methodology.

The Appendices present tabulations of the database, definitions of terminology used in this report, and a bibliography.

2. INVENTORY OF HOV PROJECTS

There are 94 HOV projects consisting of 1,188 lane-miles of facilities currently operating on freeways in 17 states of the United States and in Canada. These 17 states plus North Carolina have plans to add 92 more HOV projects consisting of 2,296 additional lane-miles.

Six states; California, Florida, Virginia, Washington, Texas, and Hawaii, together account for over 75% of the existing lane-miles of freeway HOV facilities in the United States. About one-third of the existing HOV projects and one-half of the proposed HOV projects are located in California.

Over half of the existing HOV projects on freeways and 80% of proposed HOV projects on freeways are for concurrent flow HOV lanes.

This chapter presents an overview of existing and proposed HOV facilities in the United States and Canada, and current HOV planning practices. HOV facilities are categorized by facility type, eligibility requirements, hours of operation, and their location.

The inventory is divided into two broad categories of HOV facilities - freeways and arterials.

2.1 EXISTING HOV PROJECTS

As a starting point, the list compiled by Charles Fuhs published in January 1995 provided a comprehensive inventory of existing and proposed HOV facilities located on freeways and separate rights-of ways in North America.[1] This list is updated every six months. For current freeway HOV lane projects, the inventory includes HOV facility information by type of facility, state route, number of lanes, project length in miles, operation period, eligibility requirements, and changes in rules since opening. The information on proposed HOV lane projects is summarized by state route, project length in miles, and anticipated opening year.

Figure 2-1 shows the geographic distribution of HOV projects in the U.S. and Canada. Currently, HOV facilities are in operation in a total of 17 U.S. states and Canada. The existing freeway HOV facilities include 94 projects which have a total directional mileage of 1,188 miles. Proposed freeway HOV facilities total 92 projects (both new and extension plans) that cover a total directional mileage of 2,296 miles.

2.1.1 Existing Freeway HOV Projects

The inventory of existing HOV facilities are grouped into the following four categories:

- type of HOV design/operations
- location/state
- occupancy requirement
- hours of operation

Current HOV lane projects in the United States and Canada are tabulated by both the total number of projects and the total number of directional lane miles.

1 Charles Fuhs. "Inventory of Current and Proposed HOV Projects in the U.S. and Canada," January 1995.

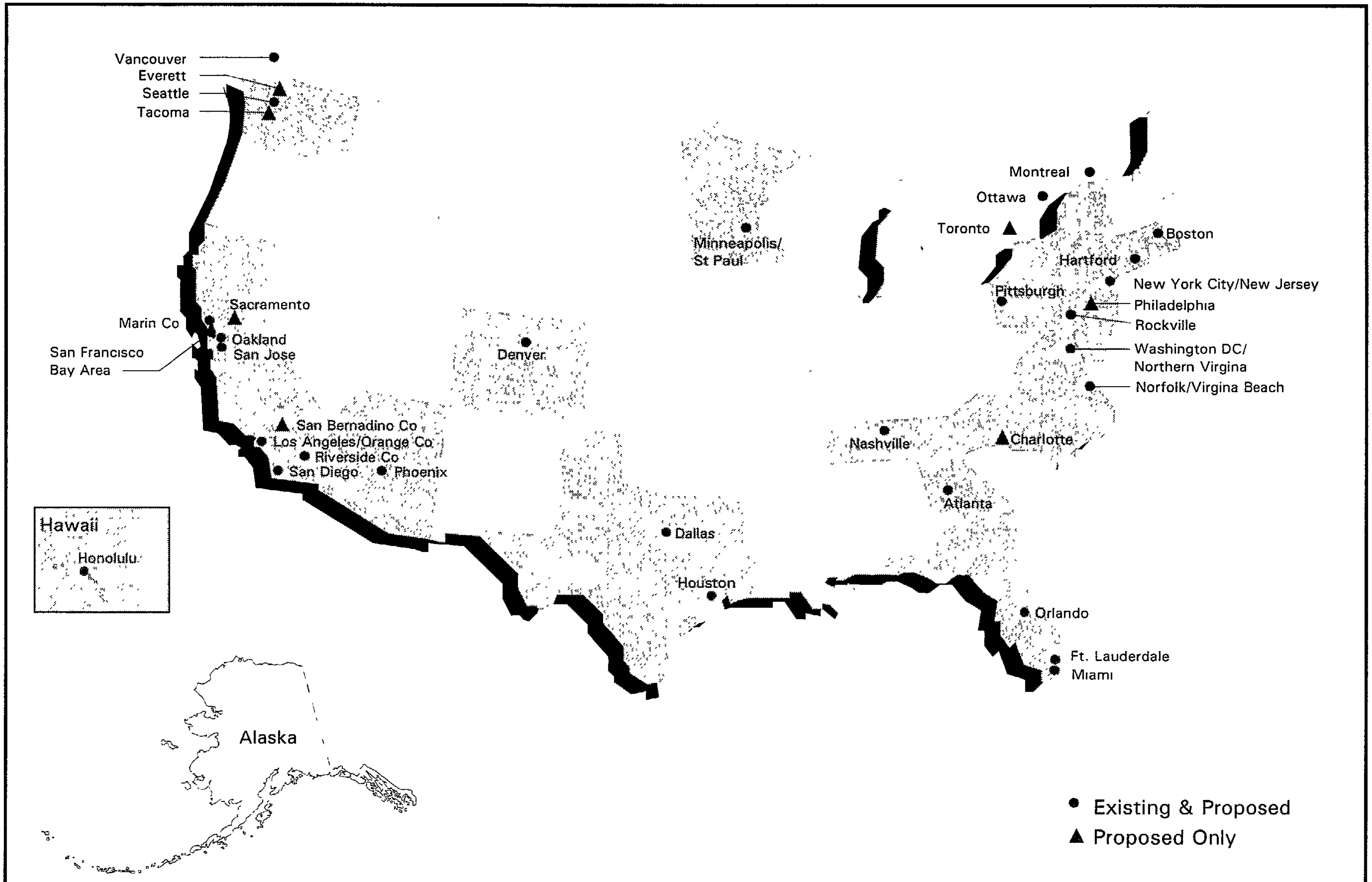


Figure 2-1
Locations of HOV Facilities in US and Canada
(as of January 1995)

94044 FIG2-1.cdr

Geographic Distribution

As shown in Figure 1, existing HOV facilities are located in several cities throughout the U.S. and Canada. California (28) has the largest number of HOV projects followed by Washington (13) and Virginia (8). California also has the most HOV directional lane mileage (454 miles or 38%). Florida and Virginia are the next highest with 138 miles or 12% and 106 miles or l0%, respectively. Figure 2 shows the number of existing HOV projects and the corresponding directional lane mileage by state and Canada.

Facility Types

Concurrent HOV facilities have by far the greatest number of projects (49 out of 94) and directional lane mileage (875 miles or 74%). Figure 3 exhibits the number of existing HOV projects and the directional lane mileage by type of HOV facility into the following categories: busway, barrier-separated (two-way), barrier-separated (reversible), concurrent, contra-flow, and queue bypasses. For the barrier-separated reversible flow HOV facilities, the total lane mileage does not reflect the reversible use of the facility. HOV queue bypass projects are counted on a geographic area basis and not by individual project.

Occupancy Requirements

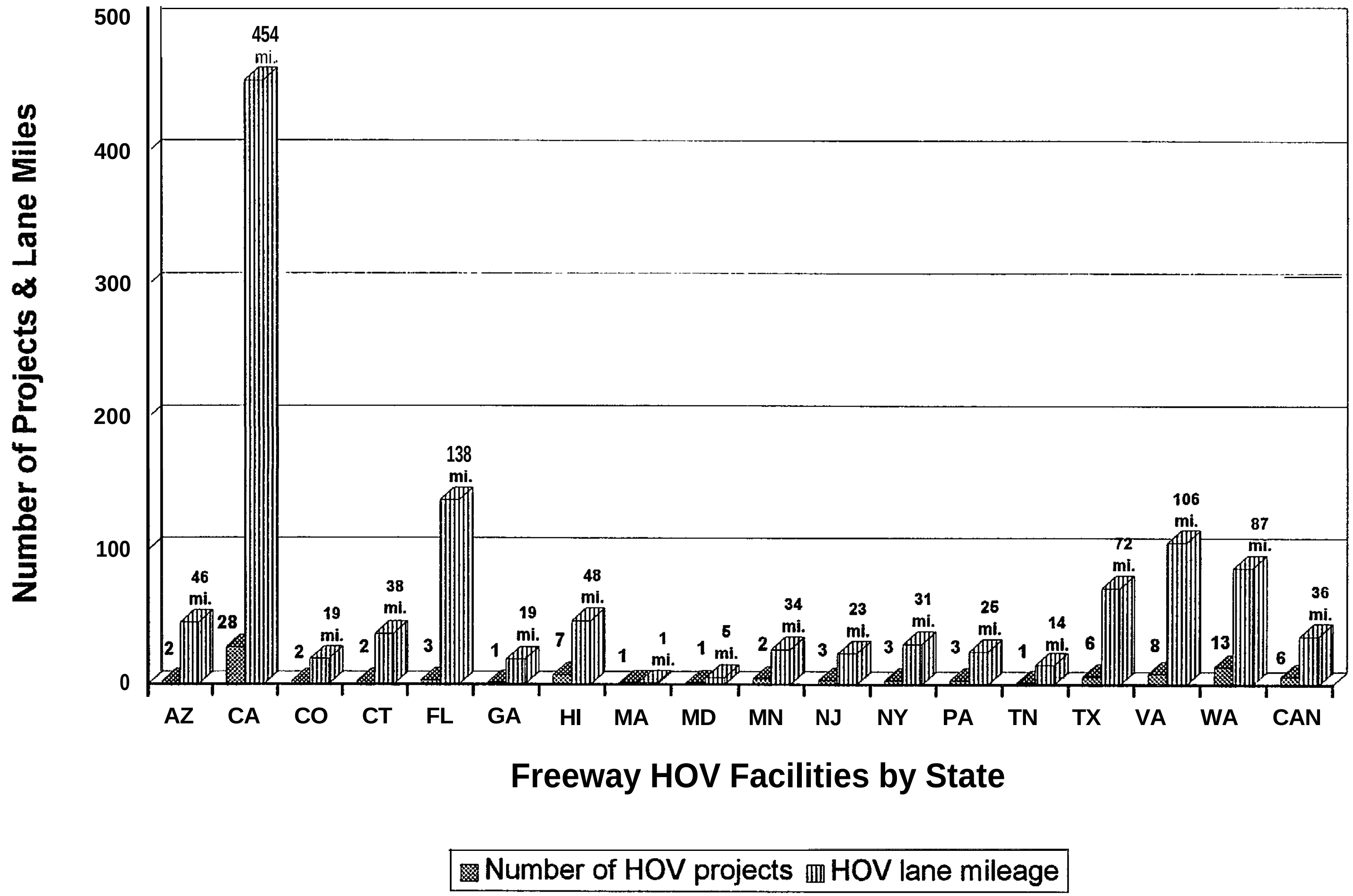
Occupancy requirements for existing HOV facilities range from 2 or more persons per vehicle to bus only facilities. Most existing HOV facilities (68 out of 94) have an occupancy requirement of 2 or more, which amounts to 998 directional lane miles or 84% of the total lane mileage. Those HOV facilities that require 3 or more persons per vehicle total 10 projects (11%) and 104 directional lane miles (9%). The occupancy requirement of buses-only includes 14 projects (15%) and 82 directional lane-mile (7%). Figure 4 displays the number of current HOV projects and the directional lane mileage by HOV eligibility requirement. The eligibility requirements are classified into the following groups: 2+, 3+, buses only, and others. The “others” category includes HOV facilities that are only used by either registered Vanpools or taxis.

Hours of Operation

The hours of operation for a HOV facility vary from a few hours during the morning peak period to 24 hours a day for 7 days a week. HOV lanes operating 24 hours for seven days a week have the largest number of HOV projects (29) and directional lane mileage (462 miles or 39%). Several of these facilities are located in the Los Angeles and Seattle metropolitan areas. Figure 2-5 illustrates the number of current HOV projects and the directional lane mileage by total hours of operation. The existing HOV projects are grouped by total number of hour in operation. Although not evident from the figure, most of the HOV facilities operate during the weekday AM and PM peak periods.

FIGURE 2-2: Freeway HOV Projects by State

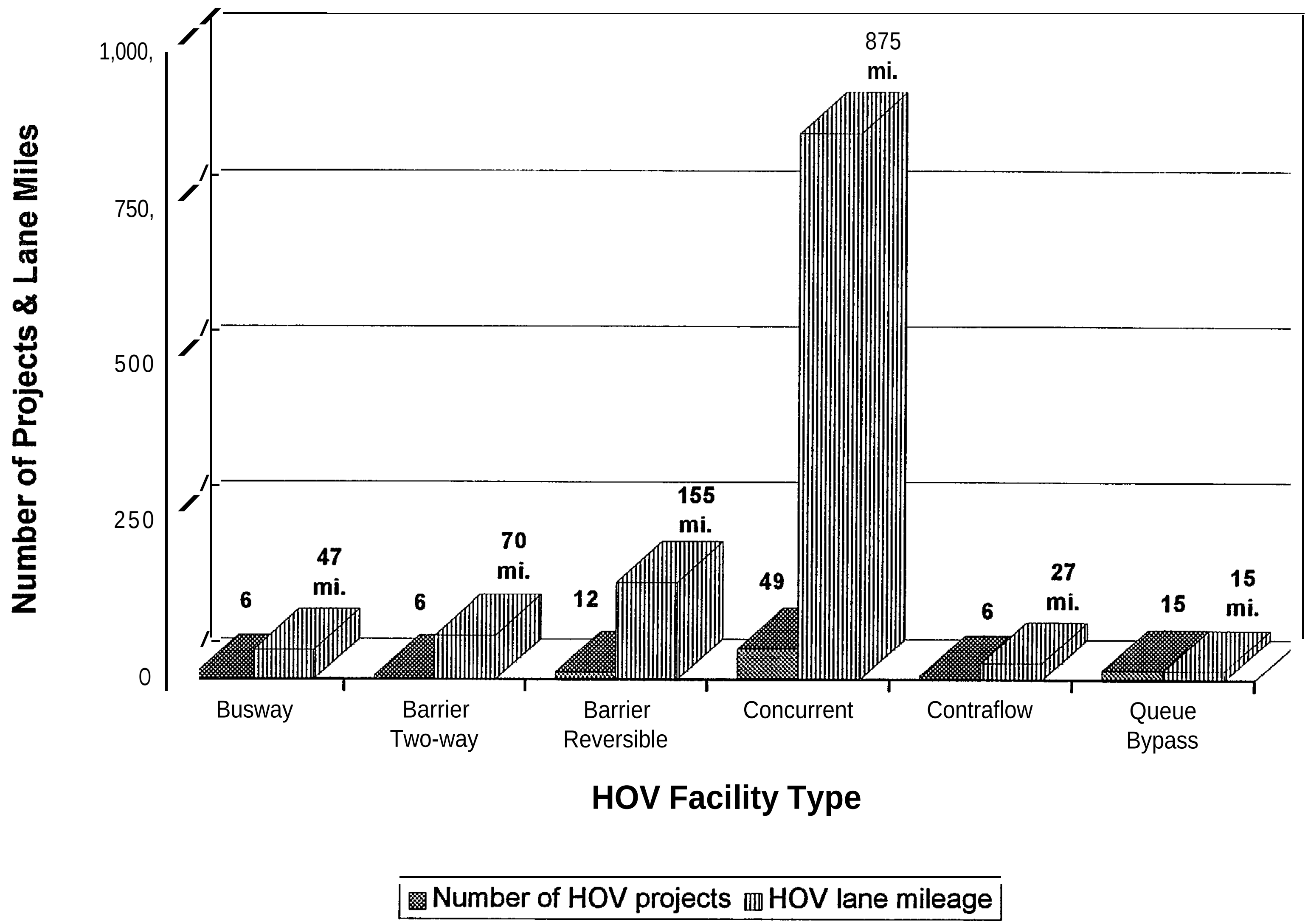
(January 1995 inventory - Total of 94 Projects and 1,188 Miles)



Source: 1. Charles Fuhs. Inventory of Current and Proposed HOV Projects in the U.S. and Canada, January 1995.
2. Dr. Adolf May. TRB Presentation to the HOV Systems Committee

FIGURE 2-3: Freeway HOV Projects in the U.S. and Canada by HOV Facility Type

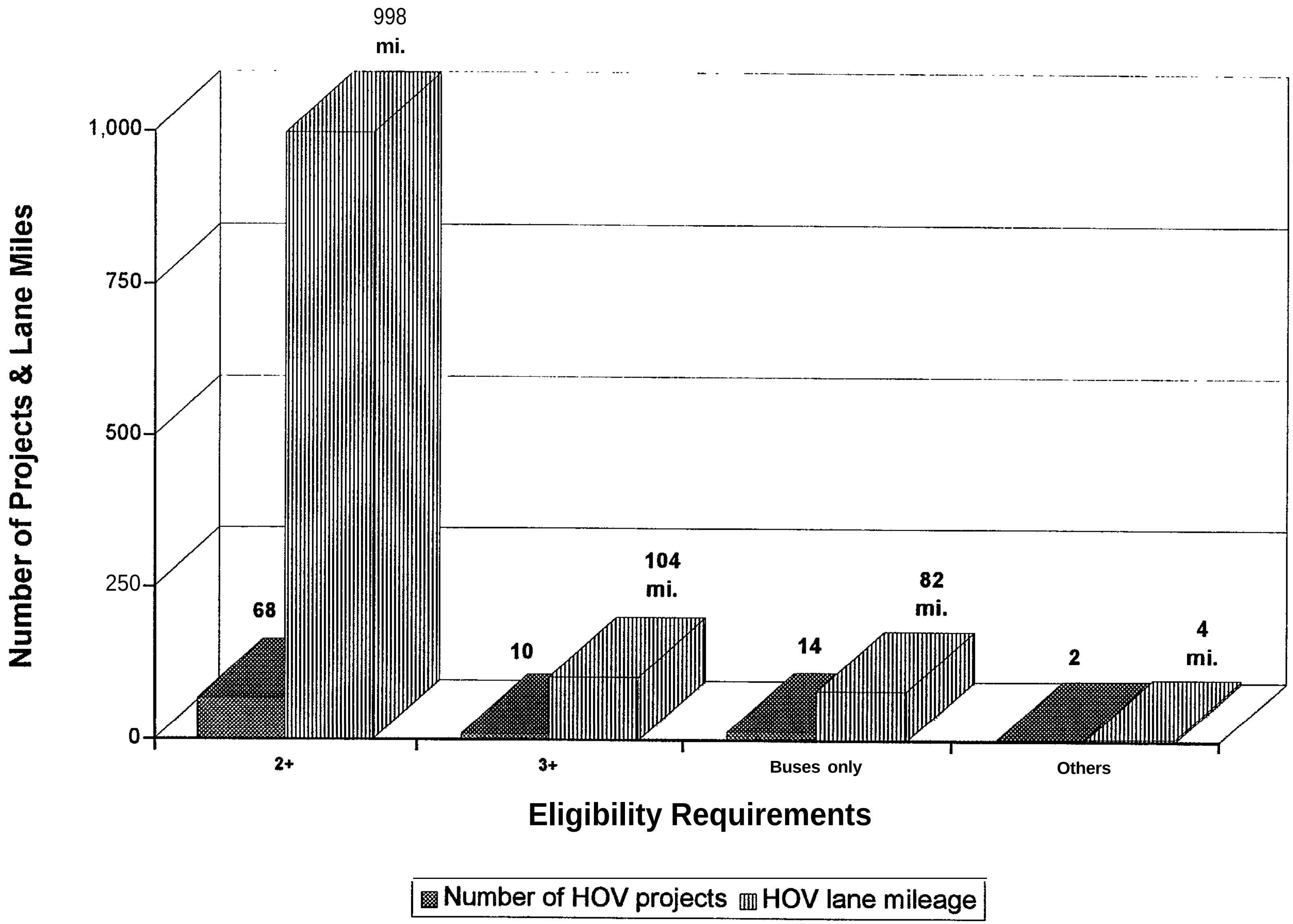
(January 1995 Inventory - Total of 94 Projects and 1,188 Miles)



Source: 1. Charles Fuhs. Inventory of Current and Proposed HOV Projects in the U.S. and **Canada.** **January 1995.**
2. Dr. Adolf May. TRB Presentation to HOV Systems Committee.

FIGURE 2-4: Freeway HOV Projects in U.S. and Canada by HOV Eligibility

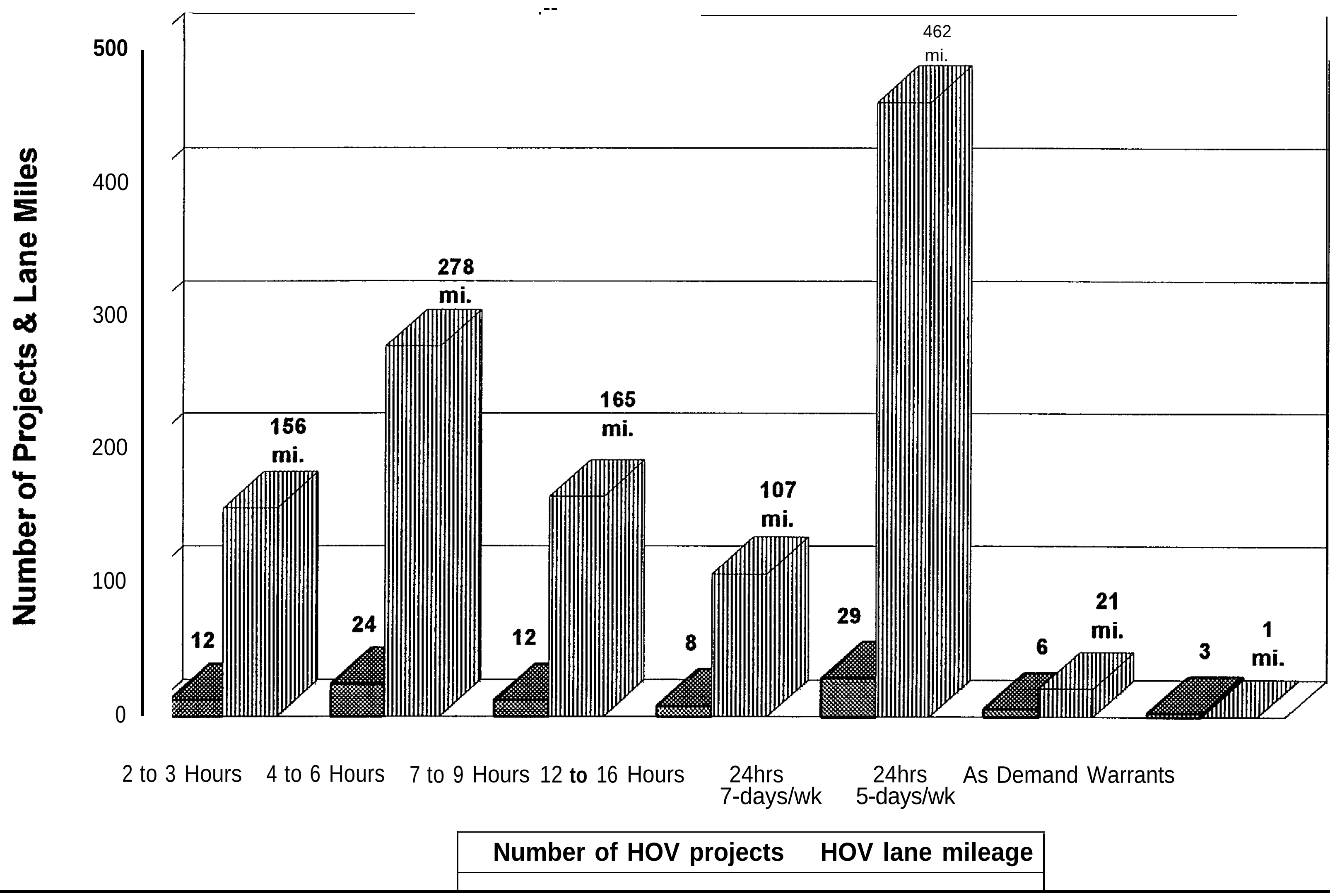
(January 1995 Inventory - Total of 94 Projects and 1,188 Miles)



Source: 1. Charles Fuhs. Inventory of Current and Proposed HOV Projects in the U.S. and Canada, January 1995.
2. Dr. Adolf May. TRB Presentation to HOV Systems Committee.

FIGURE 2-5: Freeway HOV Projects in U.S. and Canada by Hours of Operation

(January 1995 Inventory - Total of 94 Projects and 1,188 Miles)



Source: 1, Charles Fuhs. Inventory of Current and Proposed HOV Projects in the U.S. and Canada, January 1995.

2. Dr. Adolf May. TRB Presentation to the HOV Systems Commitee.

2.1.2 Existing Arterial and Expressway HOV Projects

A national database of current arterial HOV facilities does not exist. Arterial HOV facilities range from reserved bus only lanes in the urban core area to suburban HOV lanes that resemble freeway HOV lanes in characteristics and operations, Some arterial HOV lanes are queue bypasses at bottlenecks on major arterials, such as approaches to bridges or tunnels. Arterial HOV lanes are difficult to generalize since the number of facilities nationwide is limited and the differences among operating facilities are great.

A study done in the 1980's found 95 concurrent flow HOV lanes nationally.' Of these, 22 arterial HOV facilities were suspended due to low use, enforcement problems, pedestrian fatalities, or operational problems.

Many of the arterial HOV facilities are bus lanes that are for exclusive use by buses. Carpools are not permitted on these facilities. The location of bus lanes vary from curb lanes to median lanes to contra-flow lanes. Some streets are designated as "bus streets". Examples of bus lanes can be found in most major cities in the U.S. including: Minneapolis, Washington, D.C., Baltimore, New York City, New Orleans, Chicago, and San Francisco.[3]

The following arterial or expressway HOV facilities are not restricted solely to buses:

1. Montague Expressway, Santa Clara County, California
2. San Tomas Expressway, Santa Clara County, California
3. SR 237, Santa Clara County, California[4]
4. SR 99, Seattle, Washington
5. NE Pacific Street, Seattle, Washington
6. Airport Road, Snohomish County, Washington

The arterial HOV facilities in Santa Clara County are part of the Santa Clara County Commuter Lane network. The County's Transportation 2000 Plan includes a 140-mile network of commuter lanes on freeways and expressways. About 17 lane miles of concurrent flow arterial HOV lanes are operational during the peak period only.

The arterial HOV facilities in the Seattle area operate as independent facilities and represent an array of arterial HOV types. The downtown Seattle HOV lanes converts the right parking lane for use by buses only during the AM and PM peak periods. SR 99 reserves the outside right lane for buses, 3+ car-pools, and right turning vehicles. The HOV lane on NE Pacific Street provides a queue bypass for buses and carpools at the Montlake Bridge.

SR 522 in Seattle is an arterial HOV facility that is partially restricted to buses. The northbound parking lane on SR 522 is reserved for buses and 3+ car-pools on the approach to the bottleneck at NE 145th Street during the AM peak period. The southbound direction of SR 522 between Kenmore and 145th (approximately 3 miles) is reserved for buses only 24 hours a day.

The outside lane of Airport Road in the Seattle area is converted to a 2+ HOV lane during the peak periods.

2.2 PROPOSED HOV PROJECTS

The inventory of proposed HOV facilities are grouped into the following two categories: type of HOV design/operations, and location/state. For each category, the data is summarized by both the total number of

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[2]Batz, T.M., "High Occupancy Vehicle Turnouts, Impacts, and Parameters," FHWA, NTIS #PB87203212/HDM, August 1986, Two Volumes.

[3]Herbert S. Levinson, Crosby L. Adams, and William F. Hoey. Bus Use of Highways: Planning and Design Guidelines. NCHRP Report 155, Transportation Research Board, National Research Council, Washington, D.C., 1975, Table 1.

[4]Has since been upgraded to freeway.

projects and the total number of directional lane miles. Proposed freeway HOV lane projects in the U.S. and Canada are included.

The total lane mileage for the proposed HOV facilities almost doubles the number of existing lane miles. The vast majority of proposed HOV lane projects are located in California. Most of the proposed HOV lane projects are concurrent flow facilities. These HOV lane projects are at various stages of development. Some are slated to open in 1995, while others are still in the planning stages.

Similar to existing HOV projects, concurrent HOV lanes have the largest number of projects (73 out of 92) and directional lane miles (2,025 miles or 88%). Figure 2-6 shows the number of proposed HOV projects and the corresponding directional lane mileage by type of HOV facility.

Some of the proposed HOV projects are extensions of existing projects and others are new facilities. As noted in Figure 6, 12% of the proposed HOV projects are HOV extension projects, and 88% of proposed HOV lane projects are new HOV lane projects.

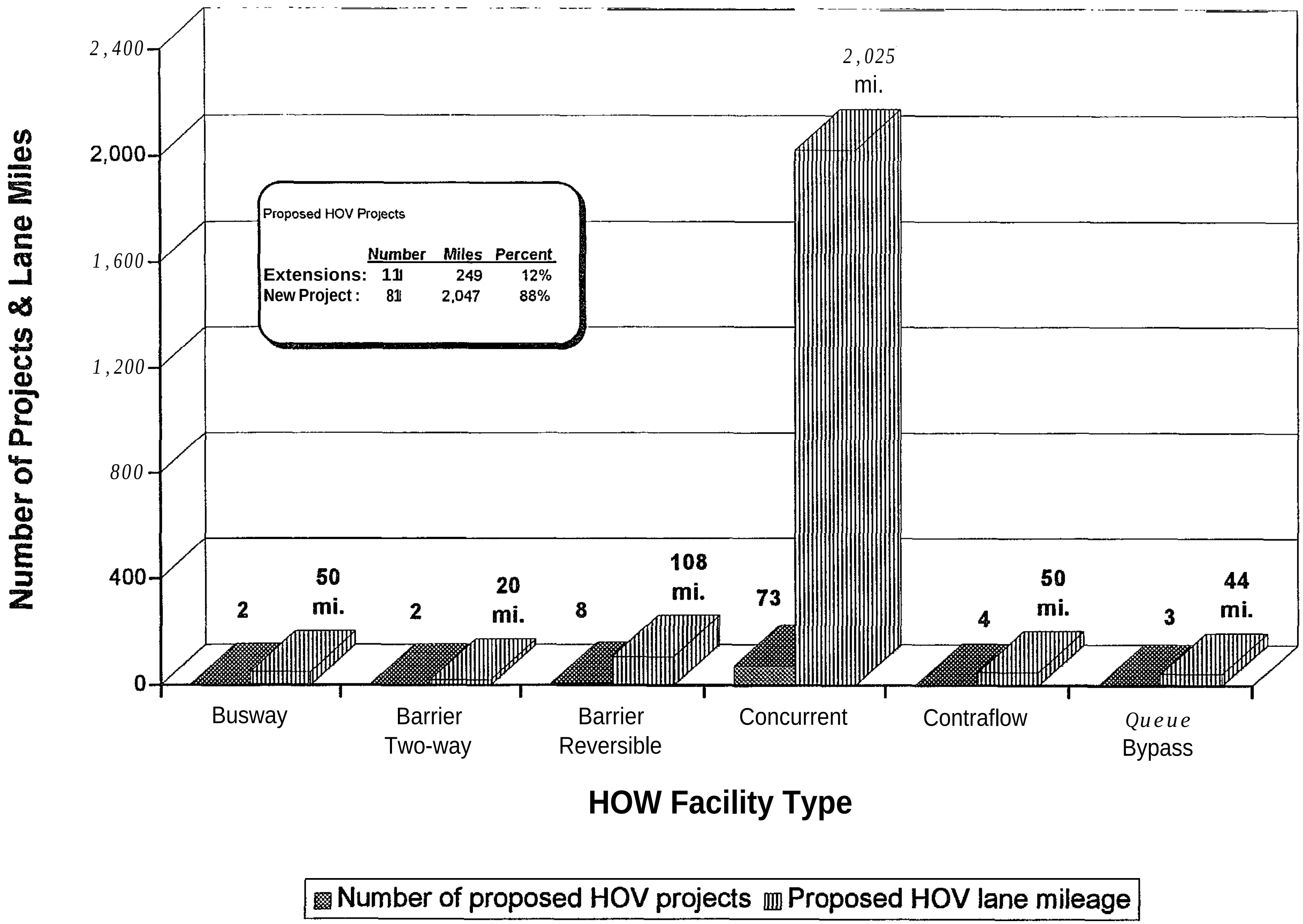
California has the largest number of proposed projects (38) and directional lane miles (1,247 miles or 54%). Washington and Texas continue to extend and expand their HOV systems in Seattle and Houston, respectively. Massachusetts has several HOV projects planned for the Boston area. Figure 2-7 exhibits the number of proposed HOV projects and directional lane mileage by state.

2.3 KEY FINDINGS

The inventory of existing and proposed HOV facilities in the United States and Canada can be summarized as follows:

- Six states; California, Florida, Virginia, Washington, Texas, and Hawaii, together account for over 75% of the existing lane-miles of freeway HOV facilities in the United States. About one-third of the existing HOV projects and one-half of the proposed HOV projects are located in California.
- Over half of the existing HOV projects on freeways and 80% of proposed HOV projects on freeways are for concurrent flow HOV lanes.
- About 72% of the existing HOV facilities many of the new facilities define HOV's as 2 or more persons per vehicle.
- Most HOV facilities operate only during the weekday am and PM peak hours. However, about 30% of the existing HOV facilities operate on a 24-hour basis for 7 days a week.

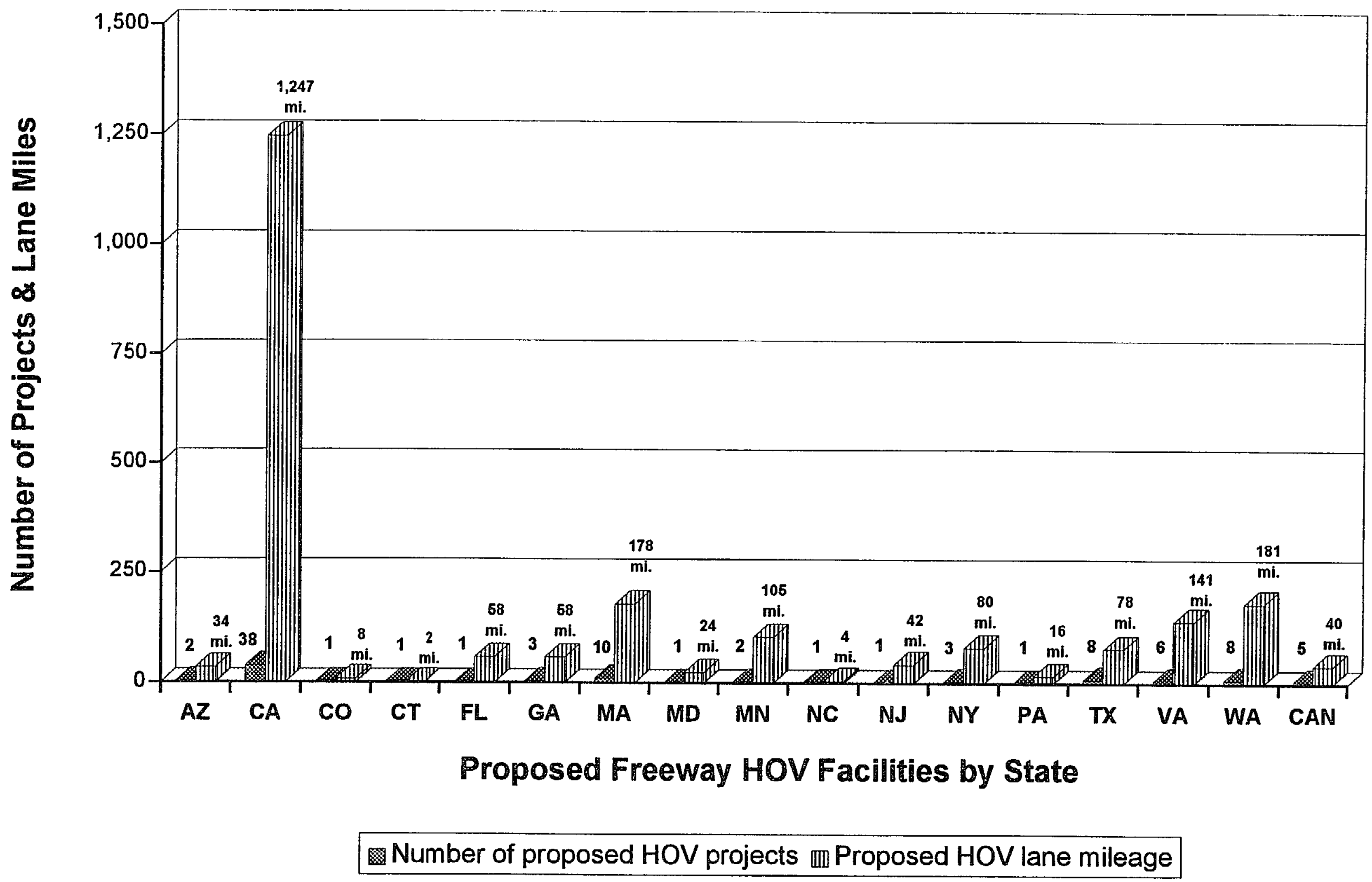
FIGURE 2-6: Proposed Freeway HOV Projects by Facility Type
(January 1995 inventory - Total of 92 Projects and 2,296 Miles)



Source: Charles Fuhs. Inventory of Current and Proposed HOV Projects in the U.S. and Canada. January 1995.

FIGURE 2-7: Proposed Freeway HOV Projects by State

(January 1995 Inventory - Total of 92 Projects and 2,296 Miles)



Source: Charles Fuhs. Inventory of Current and Proposed HOV Projects in the U.S. and Canada, January 1995.

3. CHARACTERISTICS OF HOV DEMAND

3.1 OVERVIEW

Several investigators have interviewed commuters or analyzed the results of driver surveys in an attempt to isolate those demographic, geographic, attitudinal, or trip-specific characteristics which separate carpoolers from drive-alone commuters and transit users. Some of these investigations supported the development of explicit mode-choice models, while others have been undertaken in the course of evaluating specific HOV projects. The findings of these analyses can shed light on the relative importance of different parameters in predicting the use of a new HOV facility.

Driver surveys have been conducted in conjunction with a wide range of existing HOV projects. Sites where drivers have been interviewed extensively include Seattle (Ulberg, 1994), the San Francisco Bay Area (Billheimer, June 1990), Orange County (Giuliano, et al., 1990), Houston (Christiansen and Morris, 1991), and Minneapolis (Strgar-Roscoe-Fausch, 1987). In addition, at least two researchers (Teal, 1987 and Ferguson, 1995) have analyzed driver responses to the Nationwide Personal Transportation Study (NPTS) in an attempt to develop a comprehensive nationwide overview of the demographics and logistics of carpooling. This chapter examines the key findings of these studies with the aim of identifying those parameters which can be expected to affect the use of HOV lanes.

3.2 KEY FINDINGS

3.2.1 Travel Time and Distance

<u>Trip Length</u> Nearly every study of carpooling tendencies has found that carpooling rates increase with travel time and trip length. A recent survey of carpoolers on the Route 91 Freeway linking Riverside and Orange Counties DKS, 1990) found that “only 8% of commuters who travel less than ten miles to work Carpool, as compared to 25% of those who commute 60 miles or more to work.” In terms of travel time, “only 5% of those on the road for 20 to 30 minutes carpool, whereas 21% of those on the road 90 to 110 minutes carpool.” These Southern California statistics show lower carpooling tendencies than have been reported elsewhere. In an analysis of nationwide carpooling trends based on the 1977-78 National Personal Transportation Study (NPTS), Teal (1987) found that carpooling tendencies increased from 15.5% for trips under ten miles to 33% for trips of more than 25 miles. In a more recent study based on the 1990 NPTS, Ferguson (1995) found that carpooling percentages decreased with distance for trips under 10 miles, hovered around 14% for trips between 10 and 20 miles in length and then increased with distance, rising to 20.7% for trips longer than 30 miles. A comparison of year-to-year carpooling trends in the U.S. as revealed in successive NPTS studies showed that overall carpooling declined 34% between 1980 and 1990 (Ferguson, 1995).

<u>Perceived HOV Time Savings</u> Several studies (Dobson and Tischer, 1977, Billheimer 1981, and Billheimer, January 1990) have distinguished between perceived and actual travel times and have found that carpoolers and solo drivers alike tend to overestimate the time savings available from the use of HOV lanes. A recent study of carpool lanes in the San Francisco Bay Area (Billheimer, January, 1990), for example showed that “drivers perceived HOV time savings that were more than double the average savings recorded during the heaviest traffic period and nearly four times the savings realized by all drivers throughout the morning commute period.” (See Figure 3-).

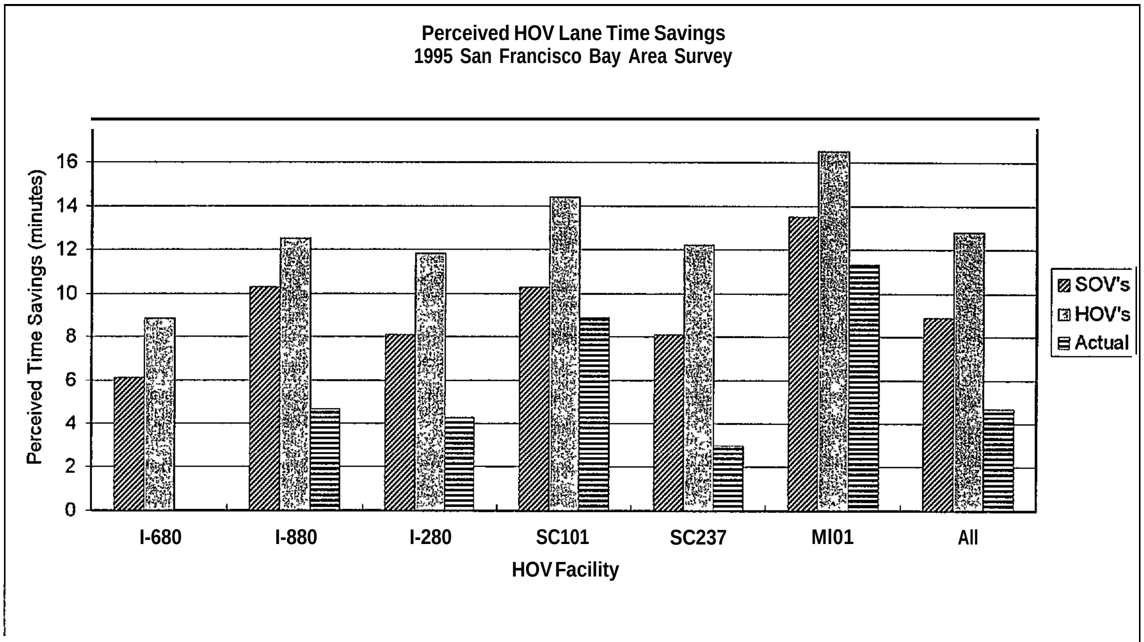


Figure 3-1. Perceived And Actual HOV Lane Travel Time Savings

This tendency to perceive greater time savings in the Carpool alternative lane makes Carpool lanes more attractive to drivers than a direct comparison of alternative travel times might indicate, and suggests that there may be a psychological advantage in providing a Carpool lane even when the available time savings appear minimal.

Carpool Set-Up Time. In view of the importance of travel time in mode choice, one significant barrier to carpooling is the amount of time carpoolers spend driving out of their way to pick-up passengers and waiting for other riders. In a recent MTC-sponsored survey (Billheimer, May 1990) Bay Area carpoolers were asked to estimate these times. The answers varied with car-pool size and location. However, for an average trip of 47 minutes, carpoolers spent 2.4 minutes (5.7% of their time) waiting for other carpoolers to get ready, 4.8 minutes (10.2% of their time) traveling to pick up passengers, and 39.9 minutes (84.7%) traveling to their destination. Three-person carpoolers required twice as much formation time (roughly 11 minutes) as two-person carpoolers.

It should be emphasized that these estimates of Carpool formation time came from carpoolers. It is possible that these times may be perceived to be much greater by non-carpoolers, who stress the need for convenience and minimal door-to-door travel times in justifying their decision to drive alone.

3.2.2 Travel Cost

Researchers have generally found that travel costs are less important than travel time in determining mode choice (McGillivray, 1970; DKS, 1990). Except in areas where drivers incur significant parking costs, travel costs tend to be directly related to travel time and distance.

Perceived Costs. Several researchers (Dobson and Tischer, 1977 and Henley, et al., 1981) have found that drivers tend to underestimate the true cost of their commute by including only gas and oil in their estimates and ignoring the costs of vehicle ownership and maintenance. Reflecting this finding, Dobson and Tischer (1977) demonstrated that perceived costs were more accurate than actual costs as a predictor of mode choice.

Parking Costs. Where they exist, parking costs can be an important element of mode choice. Shoup (1982) estimated that at least 20% of those drive-alone commuters who park for free would switch to ridesharing if they had to pay for parking. Ulberg (1994) reports on a Seattle study that found that only 10% of the bus riders commuting from Northern King County had access to free parking if they drove, while 84% of the commuters driving alone paid nothing to park. The relative proportion of commuters who personally pay for parking varies from area to area, and from destination to destination within an area. A survey of carpoolers on Minnesota's I-394 showed that 50% of those destined for downtown Minneapolis paid parking charges (an average of $85 per month per space), while overall only 20% of all carpoolers in the general Twin-Cities area had to pay for parking (Strgar-Roscoe-Fausch, 1989). A recent survey of carpoolers in the San Francisco Bay Area (Billheimer, June 1990) found that 22% personally paid for parking at their destination. The average charge paid by these carpoolers was $118 per month. Shoup (reported in Ulberg, 1994) estimates that, nationwide, 93% of all commuters park free at work.

Perceived Carpool Savings. Not all carpoolers perceive that carpooling saves them money. In the San Francisco Bay Area survey cited above (Billheimer, June, 1990), 77% of the carpoolers surveyed thought that they saved money by carpooling. Those who didn't recognize any savings tended to be either drivers who bore the entire cost of the trip themselves or members of single-household Carpools who didn't perceive that would be more expensive for household members to travel separately. The average perceived savings reported by all carpoolers was $14.00 per week.

3.2.3 Household Characteristics

Household Size. Carpool research has uuiformly shown that a substantial portion of carpoolers come from the same household. Teal's study of 1977-78 National Personal Transportation Study (NPTS) Data showed that 42% of all carpoolers came from the same household (Teal, 1983). By 1990, the proportion of household-based carpools in the NPTS survey had increased to 59% of all home-based work trips (Ferguson, 1995). A 1988 telephone survey of working Orange County residents found that 54% of the carpoolers surveyed carpooled with members of their own household (OCTD, 1988). A recent survey of Bay Area carpoolers reported that 54% of the car-pools using HOV lanes had been formed with other household members (Billheimer, June 1990). As would be expected, the prevalence of household-based Carpools on HOV lanes depends on the occupancy levels required for the use of the lanes. Household-based carpools are much more likely to be found in lanes admitting two or more occupants than in lanes with higher occupancy requirements. In a survey of eight Bay Area HOV lanes (Billheimer, June 1990) on the Bay Bridge, where the HOV lane requires 3-persons, only 33% of the carpoolers surveyed came from the same household. On HOV projects requiring only two persons, however, in-household carpools always exceeded 50% of the total,

The prevalence of carpools composed of persons from the same household suggests that the number of workers per household might be a useful predictor of Carpool formation. Ferguson (1995) reported that the 1990 NPTS showed that ". . commuters living in households with 5 or more persons are two and one half times more likely to Carpool than those living in single-person households." He also noted that the dramatic increases in carpooling tendencies with household size were related almost entirely to household-based carpools. Carpools formed outside the home were relatively unaffected by household size.

Recognizing the importance of single-household carpools, some researchers have isolated those Carpools and treated them separately. Teal (1987), for example recognized three types of carpoolers:

1. Household Carpoolers, who commute together with at least one other worker from the same household (42% of 1977-78 NPTS total);
2. External Carpoolers, who share transportation with unrelated individuals and who either share driving responsibilities or who always drive (36% of 1977-78 NPTS total); and
3. Carpool Riders, who commute with other unrelated workers but who only ride and never provide a vehicle (27% of 1977-78 NPTS total).

External Carpools tend to carry more people than household Carpools. Teal (1987) found that only 5% of all household Carpools had more than two members, while 39% of cat-pools formed outside the household had three or more members.

Household Income. Research findings differ with respect to the impact of household income on carpooling tendencies. A recent Orange County Marketing Study (McKever, et al., 1991) found no significant correlation between household income and carpooling tendencies. Ulberg (1994) noted that Seattle surveys showed a greater propensity to carpool among higher income households, but suggested that this finding reflected the presence of more wage earners in larger households. In his earlier nationwide study of NPTS data, Teal (1987) found that carpoolers tended to have lower incomes than drive-alone commuters. This was particularly true of carpoolers who rode with members of other households and never provided a vehicle. Teal also concocted a variable composed of the ratio of drive-alone commuting costs to income, which he called the Commuting Cost to Income (CCTI) burden, and which proved to be positively correlated with the decision to carpool. The CCTI ratio for all carpoolers was 4.4%, as compared with 2.5% for commuters who drive alone.

In examining the most recent NPTS data, Ferguson (1995) found that "...carpooling declines with income at lower income levels, but is largely unrelated to income at higher income levels." For household incomes below $30,000 per year, the lower the income level the greater the likelihood of ridesharing. Workers living in households with family incomes of $30,000 or more showed virtually no change in their tendency to rideshare as income increased. This is consistent with the earlier findings of Teal (1987), who reported that the propensity to carpool increased by a factor of 2 to 3 when the ratio of drive-alone commuting costs exceeded 5% of the average family income per worker. Workers living in higher income households in which commuting costs constituted a lower proportion of the family budget tended to base their commuting choice on factors other than cost.

Vehicle Availability. As would be expected, vehicle availability correlates well with the decision to drive alone rather than carpool. In reviewing research on the influence of socioeconomic characteristics on mode choice, Ulberg (1994) notes that "...one theme runs through the literature. The most important characteristic is automobile accessibility in a household." Teal (1987) found that "among households with fewer vehicles than workers, 38% of all household commuters are carpoolers, compared with only 15% when the Vehicle per Worker (VPW) ratio is at least one.

In his survey of the 1990 NPTS data, Ferguson (1995) also found that carpooling is sensitive to the number of vehicles in the household. Table 3- tabulates the percentage of carpooling found in households with different numbers of vehicles. It shows that commuters in households with no vehicles are almost twice as likely to carpool as those in households with four or more vehicles. For households with two or more vehicles, however (which accounted for 80% of the sampled households), the mode of travel to work was far less sensitive to the number of vehicles in the household.

Table 3-1. Impact of Vehicle Ownership on Carpooling

INCIDENCE OF CARPOOLING AS A FUNCTION OF HOUSEHOLD VEHICLES

Number of Household Vehicles	0	1	2	3	4+	All Households
Percent Carpooling to Work	26.5%	23.4%	14.9%	13.8%	13.5%	16.3%

Source: Ferguson, 1995

3.2.4 Individual Demographics

Most past researchers (Dobson and Tischer, 1977; Teal, 1987; and Ulberg, 1994, for example) have found little evidence that individual demographics can be used to explain carpooling tendencies. They have argued that carpoolers are much the same as drive-alones in terms of such characteristics as age, gender, and education. In a thorough early review of ridesharing research, Kostyniuk (1982) wrote that "There is agreement in the literature that any existing relationships between demographic and work-trip ridesharing behavior are very weak." More recently, in examining 1990 NPTS data, Ferguson (1995) found slight but significant differences between the demographic characteristics of carpoolers and solo drivers. While his findings may be helpful in separating markets and targeting advertising campaigns, the relationships do not appear to be sufficiently strong to affect the current mode choice modeling effort.

Age Teal (1987) and Ulberg (1994) found no evidence that age affected Carpool choices. While Ferguson (1995) found that workers under 25 and over 65 were somewhat more likely to be carpoolers, he noted that the relationship between age and carpooling, although statistically significant, was not very powerful.

Gender. Several researchers (Dobson and Tischer, 1977, Teal , 1987, Strgar-Roscoe-Fausch, 1987) have found that female and/or clerical workers are more likely to carpool than male and/or professional and managerial workers. Teal (1987) also found that married females were more likely to Carpool than unmarried females or married or unmarried males. Ferguson (1995) found that the 1990 NPTS data showed that 14.0% of working males carpooled, as compared with 19.1% of working females. He found, however, that ". . .male workers are almost 50% more likely than female workers to Carpool with non-household members."

Education. Teal (1987) argued that there was no relationship between carpooling and education. Ulberg (1995) found carpoolers responding to Seattle surveys to have lower education levels than solo drivers. Ferguson (1995) found that ". . .Education is one of the few demographic variables to show any systematic relationship with the composition of carpools." In reviewing 1990 NPTS data, he found that commuters with no high school diploma were twice as likely to Carpool, bicycle, or walk to work. As education increased above the high school level, the propensity to Carpool with strangers declined steadily. Whereas 28% of commuters with no high school diploma carpooled and 17% of those who had only a high school diploma shared rides to work, the percentage of carpooling dropped to 14% for commuters with some college experience and to 11% for commuters who had attended graduate school.

3.2.5 Attitudes and Perceptions

Attitudinal Research. Several researchers (Horowitz and Sheth, 1977, Henley, et al., 1981, and Ulberg, 1995) have explored the attitudes of carpooler and non-carpoolers through survey questions designed to elicit psychological perceptions of travel modes and document cognitive preferences for different modal attributes. Horowitz and Sheth (1977) for example, in a psycho-social analysis of ridesharers, identified primary differences between ridesharers and solo drivers in their perceptions of the convenience, reliability, comfort, and time savings of the two modes. These studies sometimes belabor the obvious. Kostyniuk, for instance, reviews a semantic differential analysis that showed that "...poolers liked to drive with others, whereas solo drivers did not, and poolers perceived a real cost savings whereas nonpoolers felt that the amount of savings was not worthwhile." While attitudinal preferences are undoubtedly important in modal choice, isolating these preferences for predictive purposes requires a survey capability which is beyond the scope of the current modeling effort.

Anti-Carpooling Disposition. Nearly every series of focus group discussions or market-oriented interviews which has addressed the issue of carpooling has identified a hard core of solo drivers who will not carpool under any circumstances. Members of this group have a variety of reasons for their stance, including the need for a car before, during or after work, variable working hours, a short commute trip, or a lack of suitable Carpool matches. The size of this hard core may vary, but it seems safe to estimate that at least one-third of the current crop of solo drivers in Southern California could not be induced to Carpool under any circumstances. [1] This attitude, or more accurately, this set of circumstances, places an effective upper limit on the benefits which may be expected from any new HOV facility.

It is important to recognize that the upper limit on the number of drive-alones who might be induced to Carpool through the addition of an HOV lane to a corridor can represent a relatively small proportion of

1 In a recent survey of Riverside County commuters, who reported average commute times of over one hour, 35% said they would not Carpool under any circumstances (DKS, June 1990).

current corridor drivers. A survey conducted in advance of HOV lanes on the Long Island Expressway (Bloch, et al., 1994) found that only twenty percent of existing expressway users were willing to consider carpooling as an option. Market research conducted prior to the opening of I-394 in Minneapolis determined that only ten percent of existing corridor users would consider switching to carpooling or busing when the Express Lanes were complete (Strgar-Roscoe-Fausch, Inc., 1986). Females under the age of 35 represented the most likely target for this mode shift.

3.2.6 Trip End Characteristics

Employment Density. Teal (1987) found a higher percentage of carpooling among auto users in SMSAs which favor transit trips – those with dense populations and concentrated employment patterns. These lead to high employment densities and higher parking charges. As noted earlier (Section 3.2.2), drivers who have to pay for parking are more likely to carpool than those who park for free, and employment density is a useful surrogate for parking costs.

A Melbourne study (Richardson and Young, 1981) investigating the relative dispersion of individual origins and destinations at either end of the work trip found that most of those Carpools that are found among non-household members are work-based. Richardson defined the work-end radius of the commute trip as the maximum straight-line distance between the driver's place of work and any passenger's work place. The home-end radius was similarly defined in terms of the maximum straight-line distance from the driver's home to the home of any one of his passengers. Armed with these definitions, the investigating team found that 70% of those Carpools formed outside a single household had a zero work-end radius (i.e. carpoolers all work at the same place). By way of contrast, only 12% of those non-home-based external carpools have a zero home-end-radius. This indicates that external Carpools tend to be formed by commuters who work together (or near one another) rather than by those who live near one another. The average work-end radius in Melbourne was found to be 1.1 km for external Carpools, considerably lower than the corresponding home-end radius of 5.2 km.

Employer Incentives. At the work end of the trip, employers may offer such ridesharing incentives as subsidized parking, special parking privileges or a transportation allowance for carpoolers. Alternatively, employers may allow carpoolers to use company-owned vehicles or install a program of flexible working hours which makes it easier for employees to work out carpooling arrangements. Recent surveys show that relatively few carpoolers are exposed to these programs. In Houston, only 15% to 20% of employers offer any sort of carpooling incentive (TTI, 1989). A recent Bay Area survey (Billheimer, June 1990) also found few employers offering incentives. The most-used incentives in the Bay Area were special parking privileges, which were offered by 11.7% of employers, and parking subsidies, which were offered by 8.5% of employers.

3.3 SUMMARY

Commuter interviews undertaken before and after the installation of specific HOV lanes and as part of broader nationwide surveys such as the National Personal Transportation Study all showed that the variable with the most consistent impact on carpooling choices are travel time and trip length. Carpooling tendencies increase significantly with both these variables.

Since an estimated 59% of all work-related carpools are formed within a single household, household size and vehicle availability are also important predictors of carpooling tendencies. The need to pay for parking at the workplace also influences carpooling choices, although less than ten percent of all commuters are faced with this requirement.

Three-person carpools are much more likely to be formed outside the home than two-person carpools. As a result, size is not the only difference between carpools using 3+ HOV lanes and those using 2+ lanes. The Carpools will differ markedly in both composition and ease of formation, factors which must be considered in predicting HOV demand.

While households with very low incomes show a higher propensity to Carpool, this factor has little impact on carpool formation once household income exceeds $30,000 per year. Individual demographics also serve as relatively weak predictors of ridesharing tendencies, although females tend to be more likely to share rides than males, particularly in household-based car-pools, and, the tendency to car-pool seems to be inversely related to one's education level.

In summary, then, the tendency to car-pool:

- increases with travel time;
- increases with trip length;
- increases with household size;
- increases as income drops below $30,000 per year;
- increases as parking charges are levied at the workplace;
- is only weakly related to age; and
- decreases with one's education level.

It is important to recognize that a large proportion of drive-alones either cannot or will not rideshare, and that the maximum proportion of solo drivers who might be induced to shift to car-pooling through the addition of an HOV lane to a corridor could be as low as twenty percent of these drivers. While such a shift could effectively double the number of carpoolers in many corridors, surveys suggest that greater inroads into the population of solo drivers aren't likely.

4. EXISTING METHODS

4.1 APPROACH

The literature review included technical reports, periodicals, computer models, and software documentation. The review began with a search of the National Technical Information Service (NTIS) and Transportation Research Information System (TRIS) data bases, as well as computerized files of newsletters, journals, business news sources and newspaper articles maintained by Dialog Information Service. Key words used in the search process included high occupancy vehicle lanes, reserved lanes, ramp metering, evaluation, assessment, demand, forecasting, prediction, mode shift. as well as various permutations and combinations of these words. In addition, members of the consulting team scoured the library shelves of their own firms and conducted a bibliographic search of the subject categories at the Institute for Transportation Studies (ITS) Library at the University of California at Berkeley.

Abstracts of reports and articles identified through the initial search process were reviewed and copies of promising references were obtained. Typically, a review of these reports would yield citations leading to other relevant references. Two survey articles which were particularly useful in this regard were a state-of-the-art review of demand analysis for ridesharing from Transportation Research Record 876 (Kostyniuk, 1982)' and a literature review undertaken by Charles River Associates (CRA) in developing an early demand prediction model (CRA, 1982). The reference list assembled in this fashion was submitted for the review of the consulting team and members of a Steering Committee of state DOT representatives, MPO members, university researchers, practitioners and federal transportation officials assembled under the supervision of FHWA. This process led to the identification and review of over seventy references listed in the bibliography of this report.

4.2 REGIONWIDE LOGIT MODELS

4.2.1 OVERVIEW

The most prevalent approach to the regionwide estimation of HOV lane mode shares entails the use of disaggregate logit models embedded in the traditional four-step transportation planning process of (1) trip generation; (2) trip distribution; (3) mode split; and (4) traffic assignment. Typically these disaggregate models have been respecitied to handle carpool modes as well as transit and solo driving, either simultaneously or sequentially in "nested' formats which separate auto and transit ridership before addressing carpool mode shares.

'A reference list appears in Appendix C, organized alphabetically by author. In-text references to this list give the author's name and the year of publication (e.g., Kostyniuk, 1982). When the same author has more than one reference in the same year, the month of publication is included to identify the specific work.

4.2.1.1 Model Definition

Mathematical Formulation. The conventional multinomial logit formulation for mode share estimation can be represented as:

$$P_i = \frac{\exp(U_i)}{\sum_j \exp(U_j)} \qquad \text{(Equation 4.1)}$$

where:

P_i = probability of choosing mode i;

j = modes 1 to "n"; and

U_i = $U_i(S, X_i)$ = the utility to an individual of mode i as a function of transportation level of service variables and an individual's socioeconomic characteristics.

Additional details on the logit model may be found in Horowitz, et al. (1986), and the model's use in predicting HOV demand is well-treated in the Charles River Associates Report "Predicting Travel Volumes for HOV Priority Techniques" (Charles River Associates, 1982).

Model Input. The logit model formulation can accommodate a wide variety of input parameters in estimating the utility U_i of individual modes. Parameters used as explanatory variables in mode-share models have included the trip characteristics, tripmaker attributes, and trip-end descriptors listed below.

Table 4-1. HOV Mode Split Explanatory Variables

TRIP CHARACTERISTICS	TRIPMAKER ATTRIBUTES	TRIP-END DESCRIPTORS
TRAVEL TIME	HOUSEHOLD INCOME	EMPLOYMENT DENSITY
Waiting time	WORKERS/HOUSEHOLD	EMPLOYER INCENTIVES
Carpool pick-up time	AUTO AVAILABILITY	Subsidized Parking
Line-haul time	NEED FOR CAR BEFORE	Special Parking
Distribution time	DURING OR AFTER WORK	Privilege
TRIP DISTANCE	HOUSEHOLD SIZE	Flexible Hours
TRAVEL COST	LENGTH OF RESIDENCE	Transportation
Parking charges		Allowance
Gasoline costs		
Tolls		
HOV TIME SAVINGS		

4.2.1.2 Model Features

Nested Models. While Equation 4.1 implies a simultaneous selection process in which all modes compete for travelers at the same time, some regional logit models (Barton Aschman, 1986; Southern California Association of Governments, 1986) use a sequential or nested approach. These models first make the split between auto and transit, and then use submodels to divide auto users into drive-alone and two- or three-person carpools. This "nested" approach appears to replicate real choice procedures better than models in which carpools of various sizes and solo autos compete directly with transit for a fixed number of travelers.

Pivot Point Models. The pivot point, or incremental logit, model is a simple adaptation of the multinomial logit model that generally improves accuracy by predicting changes in existing travel behavior. The data input requirements consist of information on existing mode shares and changes in transportation service characteristics. Parody (Charles River Associates, 1982) notes that the incremental approach, in which model coefficients are used to pivot about existing mode shares, "...reduces data requirements and eliminates the need for detailed socioeconomic and level of service data for each household or traffic analysis zone." He further observes that "in general, the model coefficients from nearly any multimodal mode choice logit model can be reformulated into a pivot point model."

The basic form of the pivot point logit model is:

$$P_i' = \frac{P_i \exp(\Delta U_i)}{\sum_j P_j \exp(\Delta U_j)} \qquad \text{(Equation 4.2)}$$

where:

P_i' = new share of mode i;

P_i = original share of mode i;

j = all available modes; and

ΔU_i = change in utility for mode i

4.2.2 EXAMPLES

Table 4-2 lists the key features of a number of regionwide logit models designed for use in various urban areas. The table identifies the area, lists a reference describing the model in detail, documents the modes accepted by the model (in sequential stages for nested models), and lists the input variables used as a basis for modeling mode selection.

4.2.2.1 Input Data Needs

All of the models in Table 4-2 are multinomial logit formulations designed for use in a traditional regional urban transportation planning system (UTPS) network. As such, they require node-link representations of each of the networks represented in the mode choice model. At a minimum, this includes:

- Highway network time and distance files;
- HOV network time and distance files;
- Transit network time and distance files; and
- Zonal data reflecting model parameters (i.e. parking costs; household income; auto occupy tables; auto ownership; workers/household; HOV lane access; transit availability; transit fares).

Table 4-2. Summary of Selected Regionwide Logit Models

Model/Area	Reference	Mode Split Process		Model type	Variables	
		First Stage	Second Stage		Trip Descriptors	Socio-Economic
Metropolitan Washington COG	Barton Aschman, 1986 Ecosometrics	Drive Alone Transit Pool	Pool (2) Pool (3) Pool (4+)	Nested Multinomial Logit	Time, Cost, HOV Savings	Household Auto Ownership
Southern California Association of Governments	SCAG, 1986 Barton Aschman, 1987	Transit Auto	Walk Access Drive Access Pool Access Drive Alone Pool (2) Pool (3+)	Nested Multinomial Logit	Time, Cost, Income	Auto/House Drivers/HH Workers/HH Income
Network Performance Evaluation Model	Carnegie Mellon, Oak Ridge, Janson, et. al. 1987	Auto (1 or 2) Transit Pool (2) Pool (3+)		Multinomial Logit Iterative Assignment	Time, Cost	Income Zonal Land Area
San Francisco Metropolitan Transportation Commission	Kollo, 1987 Pulvis, 1988	Drive Alone Transit Pool (2) Pool (3+)		Multinomial Logit	Time, Cost	Autos/HH Workers/HH Employment Density Income
North Central Texas COG	NCTCOG, 1990	Drive Alone Pool (2) Pool (3+) Transit (walk) Transit (Drive)		Multinomial Logit	Time, Cost	CBD Attraction Autos/Person Choice/No Choice quadrants

The model also requires home-based work (HBW) trip tables linking all origin destination zones, as well as base-period traffic counts and transit ridership data for calibration and validation purposes.

The development of these regionwide models can require substantial commitments of time and resources. TTI (1988) estimates that the development of a workable regionwide model can require ". . .18-24 months of intensive effort." Most MPOs large enough to consider HOV lanes have already invested the effort in developing regionwide network models, although not all of them have incorporated existing or potential HOV networks into the models.

4.2.2.2 Typical Procedures

Mode Split. The regional UTPS approach to HOV demand estimation can be represented by any of the models listed in Table 4-2. In the nested model developed for the Southern California Association of Governments (SCAG, 1986), these models are used to separate modal shares. After a binary mode choice model estimates transit and auto shares, a disaggregate mode choice model developed by Cambridge Systematics (CSI, 1993) splits the auto share into shared-ride and drive-alone trips. Finally, a third mode choice model, developed by Barton Aschman Associates (Barton Aschman, 1987) splits the shared-ride trips into carpools of two persons and carpools involving three or more persons.

Supply/Demand Interaction. Travel time is an important component of the mode-share models embedded in the UTPS procedure. Accurate predictions of travel time, however, must reflect anticipated conditions of congestion on freeways, HOV lanes and arterials, which in turn are affec ted by modal choices. Traditional regionwide planting models may require several successive iterations of the traffic assignment and mode split procedures before the predicted mode shares accurately reflect congestion conditions on HOV facilities and adjacent mixed-flow lanes. For example, the SCAG model described above typically requires fifteen iterations before equilibrium is achieved.

4.2.3 CRITICAL ASSESSMENT

4.2.3.1 Advantages

Regionwide logit models are mathematically tractable and widely used in regional planning, so that their use is well understood in the planning community. Since the models incorporate a regionwide network, they are particularly useful in representing the network impacts of HOV lanes, such as the diversion of carpool and solo driver trips from parallel routes.

4.2.3.2 Disadvantages

Data Requirements. The use of regionwide network models require extensive data input and model calibration. This can be a cumbersome process when the issue at hand deals with the impact of HOV lanes on a limited number of corridors.

Recalibration. Regionwide models require extensive recalibration from location to location. TTI (1988) cautions that ". . .these models generally are not directly transferable from one urban area to another," and Galbraith and Hensher (1984) found it ". . .very difficult to define criteria that would enable a model to be transferred to another area," Recalibration is not only a geographic issue. Bedoe and Miller (1995) found that a model calibrated for use in Toronto using 1964 data performed very poorly in replicating 1986 travel patterns and concluded that ".. .model parameters had not remained stable over time." Thus recalibration was necessary to ensure temporal transferability as well.

Speed and Delay Estimation. Traditional regionwide network models have limited ability to estimate the operational impacts of HOV facilities on speed, average delays, and traffic queues. As highway networks become more and more congested, regionwide models are less and less successful in estimating travel times and delays. In particular, they fail to replicate the manner in which congestion queues transmit delays throughout the system. As a result, they are ill-equipped to represent the travel-time advantages provided by HOV lanes that are crucial in influencing shifts to ridesharing modes.

Validation. As a practical matter, regionwide logit models have historically not performed well in replicating the impact of HOV facilities on actual mode choices. A JHK report (JHK, 1994) observes that ". . .in the application of travel demand models, there are frequently considerable discrepancies between HOV model estimates and observed roadway counts of multi-occupant vehicles." TTI (1988) further cautions that "regional mode-choice models in general, and regional mode-choice models with components in particular, have not performed well in terms of their ability to predict mode shares." In view of the fact that most regional models of HOV use were not originally designed to handle trip-dependent changes in travel time and have been carved out of traditional logit models developed with only two modes (transit and auto) in mind and calibrated to match overall corridor flows, it is hardly surprising that they have not performed well in representing the impact of HOV lanes on mode share.

4.2.3.3 Summary

Although regional logit models are used widely to analyze the network-wide impacts of alternative systems, they do not seem to be flexible enough to focus on the corridor-specific impacts of HOV facilities. Existing regionwide models tend to be data-intensive and require extensive recalibration to accommodate transfers both from location to location and from one time frame to another. They are ill-equipped to represent the operational impacts of HOV lanes on travel times and have historically not performed well in predicting the impact of these lanes on modal shifts.

4.3 CORRIDOR MODELS

4.3.1 OVERVIEW

4.3.1.1 Model Formulation

Many attempts to model HOV demand have focused on a single corridor, usually ignoring impacts of HOV facilities in the broader regionwide network and sometimes glossing over the interdependencies between mode choice and travel times on HOV facilities and adjacent mixed-flow lanes. While some of these models use the multinomial logit formulation described in connection with regionwide network models, others use quick-response regression relationships in which HOV lane usage is computed as a function of travel time savings (for example, Mann, 1983, Parody, 1984, or Wesemann, 1987) or some other measure of congestion.

Corridor models can also differ markedly with respect to their field of vision within the corridor. For example, such models can include parallel routes, limit their field of vision to a single freeway (or arterial), or focus on a single point along a freeway segment.

Parallel Route Models include two or more parallel routes and typically model the interactions between these routes in an attempt to replicate the spatial responses, or diversion, which occurs when drivers switch routes.

Single Route Models ignore parallel routes to focus on a single route within the corridor. This narrower focus usually precludes the consideration of spatial response to proposed changes (i.e. diversion from parallel routes), simplifying the modeling approach at the expense of more robust results.

Critical Point Models focus on a single point along a route (usually the most congested point) and compute the traffic performance along the entire route as a function of the congestion at that point. These approaches greatly reduce data input requirements and simplify modeling efforts at the expense of overall performance data.

4.3.1.2 Demand Models vs. Supply Models

Corridor Demand Models. Some corridor models of HOV demand (i.e. Mann, 1983 and Wesemann, 1987) ignore the interaction between mode choice and travel time, accepting the travel time differential between HOV lanes and mixed-flow traffic as a given input variable and using it to compute the demand for carpools in the corridor. Other models (i.e. Small, 1977 and Talvitie, 1978) treat the interaction between demand and travel time explicitly by iterating between demand model results and travel time models until convergence is obtained.

Traffic Flow Simulations. In recent years, a number of macroscopic simulations of freeway conditions have been developed as an aid for studying the detailed impacts of design alternatives on speed, delays, and traffic queues in a specific corridor. Examples of these simulation models include FREQ (May, 1991) and FREFLO (FHWA, 1992). These models typically take the demand for access to HOV lanes and mixed flow lanes within a specific time frame as an input variable in simulating the propagation of traffic queues and congestion delays from one section of the freeway to another. Although these models focus on the elaborate delineation of freeway operations data, they can be used iteratively with corridor demand models (Scapinakis, et al., 1991) or with regionwide network models (JHK, 1994) in computing the impact of HOV lanes on mode choices.

4.3.1.3 Section Contents

This section reviews both corridor demand models designed to predict mode share as a function of freeway operations and supply models designed to predict freeway speeds and delays as a function of external demand, as well as attempts to combine both sets of models in a unified approach.

4.3.2 DEMAND MODELS

Table 4-3 lists the key features of a number of demand models designed to estimate the mode split among solo drivers, carpoolers, and transit users in a transportation corridor. The table identifies the corridor location, lists references describing the model in detail, documents the modes accepted by the model, and documents the input variables used as a basis for modeling mode split. The models are listed in approximate chronological order.

4.3.2.1 Logit Models

A number of investigators have applied the logit model formulation described earlier (See Equations 4.1 and 4.2) in estimating the impact of HOV lanes on mode choice within a single corridor. Cambridge Systematics (1977) used a pivot point logit model in estimating the effects of Carpool incentives for the Department of Energy. Coworkers from the Institute of Transportation Studies at the University of California in Berkeley (Kruger, et al., 1977) developed a disaggregate mode choice model designed to explore the implications of priority treatments by splitting corridor trips among four competing modes. The four modes were (1) noncarpooling auto; (2) Carpool (either 2+ or 3+ occupants); (3) bus with walk access; and (4) bus with auto access (park-and-ride). At the same time, Small (1977) combined a similar disaggregate model with a simple traffic flow model and Cilliers, May and Cooper (1978) incorporated the methodology into the FREQ traffic flow simulation. The results of these disaggregate modeling procedures suggested that increases in carpooling were almost directly proportional to the travel time differences between carpooling and solo driving afforded by priority treatments.

Talvitie (1978) developed a similar dissagregate model for the I-580 corridor in San Francisco that uses a logit model as the first stage in a three-stage process of (1) predicting demand; (2) calculating level-of-service parameters; and (3) equilibrating between demand and level-of-service estimates. While this model explicitly considers the interaction between demand and supply on both freeways and parallel arterials in the travel corridor, the author acknowledges that the supply model used is too insensitive to changes in highway capacity.

Table 4-3. Summary of Selected Corridor Demand Models

Model	Reference	Mode Split Method	Model Type	Variables: Trip Descriptors	Variables: Socio-Economic
Cambridge Systematics	CSI, 1977	Drive Alone Transit Carpool	Multinomial Logit, Pivot Point	Change in Travel Time and Cost by Mode	Location, Income, Auto Availability
UC. Berkeley	Kruger, et. al., 1977 Small, 1977 Cilliers, 1978	Non-Carpool Carpool (2+ or 3+) Bus (walk) Bus (Drive)	Multinomial Logit	Time and Cost Walk and Wait Time Bus Transfers	Income, Age, Length of Residence, No. of Children
I-580, San Francisco	Talvitite, 1978	Drive Alone Shared Ride Bus Bart	Multinomial Logit	Access Time Line Haul Time	Household Characteristics
Metropolitan Washington COG	Mann, 1983	Car Occupancy Distributions	Regression Nomograph	HOV Time Savings	None
Charles Rivers Associates	Parody CRA, 1984	Drive Alone Pool (2) Pool (3+) Transit	Pivot Point Regression	Change in Travel Time by Mode	None
Orange County	Wesemann, 1987	HOV Formation (% of Base)	Pivot Point Table Look-up	HOV Time Savings Trip Length	None
Texas Transitway	TTI, 1988	Drive Alone Transit Pool	Trip Table	Modal Time	Destination Attractions
Riverside County	DKS, 1990	Drive Alone Pool	Nonlinear Function	HOV Time Savings	Hard Core Drive Alone
Dallas	Poe, et. al. TTI, 1994	HOV Lane Use as a % of ADT	Regression	Congestion Level (ADT/Lane)	None

4.3.2.2 Regression Models and Trip Tables

A number of investigators (Mann, 1983, Parody, 1984, Poe, et al., 1994) have used linear regression relationships to model the effects of HOV lanes on mode share. In most cases, these models have used the travel time savings in the HOV lane as an independent variable to predict carpooling tendencies. These models mimic the relationships of the more complex logit formulations, which also showed mode share to be a nearly linear function of travel time differences.

Mann (1983). Mann reports on a technique developed to predict the use of carpools on HOV lanes in the Washington, D.C. region. The technique was developed by the Metropolitan Washington Council of Governments/Transportation Planning Board (COG/TPB) and uses a regression analysis in conjunction with nomographs designed to translate data on average vehicle occupancies into estimates of individual occupancy rates to predict the impact of HOV lanes on zone-to-zone auto occupancy rates. The regression relationships are plotted below in Figure 4-l.

As shown, the model uses data from ten existing HOV facilities to develop optimistic and pessimistic estimates of the impact of HOV time savings on car occupancy statistics. The author himself indicates that one drawback of the model is the limited number of data sets then available to support HOV demand estimates.

Another drawback lies in the fact that the model mixes data from HOV lanes requiring two or more persons (Los Angeles ramps, Honolulu freeways, Miami I-95) with lanes requiring three or more occupants (Shirley Highway, Santa Monica Diamond Lanes, El Monte Busway, and the San Francisco/Oakland Bay Bridge). Subsequent research (see, for example, Ulberg, 1994) suggests that the mechanism for Carpool formation differs greatly when occupancy requirements are raised from two to three persons.

Parody (1984). After undertaking a thorough review of existing techniques for predicting travel volumes on HOV facilities (Charles River Associates, 1982), Parody (1984) developed a set of demand and supply models based, respectively, on regression relationships and speed-volume relationships. The demand models were estimated using a consistent set of before-and-after empirical data from seven HOV facilities (Shirley Highway, El Monte Busway, U.S. 101, Banfield Freeway, Miami I-95, Boston's Southwest Expressway, and the Lincoln Tunnel). Five of these facilities were observed before and after the introduction of different priority requirements, providing additional pairs of observations.

The demand model formulation that produced the most favorable results for all modes is listed below:

$$\frac{V_1^m - V_0^m}{V_0^m} = a_0 + \sum_i a_i \frac{(T_1^i - T_0^i)}{T_0^i} \qquad \text{(Equation 4.3)}$$

where:

V^m_0	=	peak hour before volume for mode m;
V^m_1	=	peak hour after volume for mode m;
T^i_0	=	before travel times for modes i to m;
T^i_1	=	after travel times for modes i to m;
$a_{o,i}$	=	calibration coefficients.

Supply models were developed using traditional speed-volume relationships from the Bureau of Public Roads and combined with the demand models through a set of worksheets that predicted equilibrium flows of non-carpooling vehicles on general purpose freeway lanes and carpools and buses on HOV lanes.

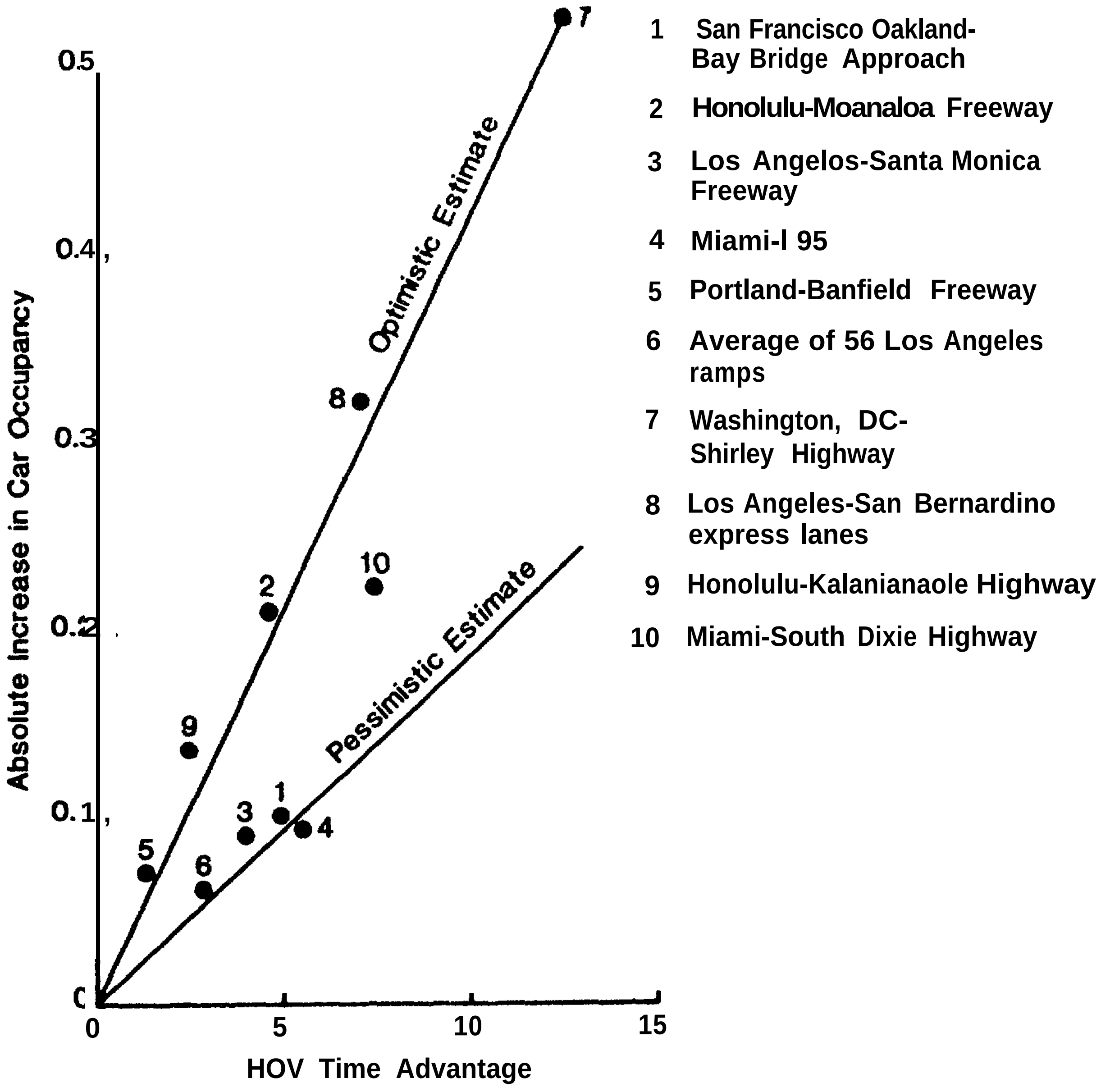
Parody characterizes this approach as a "quick-response" sketch planning techniques that could be subjected to additional and possibly more refined analyses. As in the case of Mann (1983), the data set used to calibrate the model is somewhat sparse, consisting of only twelve-before-after pairs. However, test applications of these procedures on the original data set yielded favorable results, producing average errors of less than four percent for the non-priority auto and bus modes, and less than fourteen percent for the carpool mode. Subsequent applications of the model to more recently developed HOV lanes (Billheimer, May 1990) also showed that the model performed credibly in predicting HOV lane usage.

Orange County. A simpler procedure for estimating demand on HOV lanes was developed by Wesemann (1987) for use in Orange County, California. The procedure reflects rates observed on facilities similar to those planned for Orange County and is summarized below in Table 4-4.

Table 4-4. Orange County HOV Lane Patronage Factors
Factors Used In Estimating Transitway Person Trip Usage For Transitways And Commuter Lanes In Orange County, California

Category of Travel TimeSavings	% of Existing Trips Shifting to Transitways: Trips 7 Miles Or Less in Length	% of Existing Trips Shifting to Transitways: Trips Greater Than 7 Miles In Length	% Increase in HOV Formation For Trips Using Transitways
Less than 5 minutes	No Shift	No Shift	No Increase
5-9 Minutes	No Shift	65-75%	20-30%
10-14 Minutes	No Shift	75-85%	30-40%
15 Minutes or Greater	No Shift	85-95%	40-50%

Source: Wesemann (1988)



Source: Mann 1983

Figure 4-1
Impact of HOV Facility based on Washington COG/TPB Model.

This demand model segments responses by trip length and is based entirely on the amount of time saved by the HOV facility. The model predicts no increase in HOV formation until travel time savings exceed five minutes. This flies in the face of experience on many HOV lanes in Northern and Southern California, which have experienced significant increases in carpool usage in response to travel time savings of two to four minutes. (Billheimer, May 1990). Carpooling on Los Angeles Route 91, for example, increased over 70 percent in response to an average savings of three minutes, while carpooling on Santa Clara Route 101 increased by 30% in response to a similar change. One possible reason why relatively minor savings in commute time have produced seemingly disproportionate mode shifts is that drivers tend to overestimate the time to be saved through the use of HOV lanes.

Texas Transitways. An alternative approach to HOV demand estimation developed by Texas Transportation Institute (TTI, 1988) uses trip tables which focus on employment centers served by specific HOV lanes. This technique was based on experience from Houston's Katy (I-10W) Transitway and entail the following steps:

Step 1: Define Transitway Marketing: Area by identifying the major activity centers served by a transitway;

Step 2: Compile Trip Tables. Census tracts where trips to the identified activity centers are likely to originate are identified, and Census Journey-to-Work files are used to estimate the number of person trips between each origin and the defined destinations.

Step 3: Estimate Carpool Mode Splits: Carpool mode splits for the identified activity centers are estimated using historical data. As a guide for this process, TTI offers the Katy Transitway information shown below is Table 4-5:

Table 4-5. Katy Transitway Characteristics

Activity Center	Trip Length (miles)	Total Employment	Square Feet Office Space (millions)	Employees/ Million sq. ft.	2+ Carpool Mode-Split
Downtown	13	178.300	51.8	3440	20%
City Post Oak	9	78.100	25.3	3090	25%
Greenway Plaza	13	34.200	12.1	2800	24%
Texas Medical Center	19	49.700	9.8	5100	15%

Source: TTI (1988).

This procedure suggests that for large activity centers with employment densities in the range of 3,000 to 3,500 employees per million square feet of office space and trip lengths in excess of ten miles, mode splits of 20-25% could be used in sketch planning applications. The exception to the rule is the Texas Medical Center, whose 24-hour a day, seven-day-a-week operation were not judged by the TTI authors to be " . . .particularly conducive to ridesharing arrangements."

Step 4: Assign Carpool Vehicle Trips to Transitway. Once the mode split is accomplished, trips are assigned to the transitway manually. This procedure provides results for peak-period demands for 2+ carpools. If analyses using other occupancy requirements and/or time periods are needed, TTI offers the following conversion factors based on Houston experience:

- To convert vehicle movement to person movement, multiply by 2.2.
- To convert from peak-period to peak-hour, multiply by 0.50.
- To convert from 2+ Carpool demand to 3+ carpool demand, multiply by 0.20.
- To convert unauthorized Carpool demand to authorized Carpool demand (i.e. if carpooling requires special identification or training), multiply by 0.60.

As presented, this approach relies exclusively on information from a single source, and demands some independent judgment on the part of the user, who must decide, at a minimum, which activity centers are "particularly conducive to ridesharing." It is possible that the method's application range could be broadened by analyzing and incorporating data from other locations, but this step remains to be taken.

Dallas Poe, et al. (1994) developed a simple regression model for use in developing preliminary planning estimates of future demand for HOV facilities in Dallas. HOV traffic was established through the use of a regression equation relating HOV ridership, expressed as a percentage of average daily traffic (ADT) levels, to overall corridor congestion, estimated as a function of ADT levels per lane. A graph of this regression relationship appears in Figure 4-2.

The regression relationship shown in Figure 4-2, suitably adjusted to reflect local conditions, and iterated until HOV ridership and congestion conditions are in balance, enables planners to develop preliminary projections of HOV ridership for various combinations of future traffic levels and alternative freeway designs. While this approach is simple, coherent, and logical, it uses fairly crude estimates of HOV ridership and congestion that are based on ADT measurements and are heavily tied to Houston data. The authors note that the Houston data are adequate for cities with similar land use patterns and densities. In most cases, however, planners will need to adjust the regression equations to reflect local conditions, traffic directionality, and the percentage of ADT occurring during the peak period.

4.3.3 SUPPLY MODELS

As drivers shift to Carpools and begin to use HOV lanes, the level of service on adjacent mixed flow lanes is affected. Significant shifts can improve flow in adjacent lanes, reducing the travel time savings available in the HOV lanes, and therefore lowering the incentive to use these lanes. While some models of HOV demand ignore the interaction, others have gone to great lengths to replicate levels of service in both HOV and mixed-flow lanes. Because the estimation of HOV travel time savings is crucial to the prediction of HOV mode shares, this section reviews the model and methodologies used to predict the impact of traffic flows on average traffic speeds.

4.3.3.1 Travel Time Estimation

Recent research shows that freeway speeds are comparatively insensitive to traffic flows until the flows reach capacity. When the volumes exceed capacity, then the average travel speed is determined by the extent of queuing at various bottlenecks along the freeway.

<u>The BPR Curve</u>. Regional planning models (e.g. UTPS, TRANPLAN, MINUTP, etc.) all incorporate a relatively simple speed-flow relationship originally developed by the Bureau of Public Roads (BPR) This curve uses the volume/capacity ratio to reduce the initial free-flow speed to a congested speed. The same curve is often applied to both arterials and freeways and is employed in queuing (v/c > 1) and non-queuing (v/c < 1) situations. This simplification tends to over-estimate speeds for arterials and for queuing situations.

The standard equation for the BPR curve is:

$$\text{Congested Speed} = [\text{Free Flow Speed}] / [1+0.15 * (v/c)^4]$$

where v/c = Volume/Capacity Ratio

<u>Highway Capacity Manual Curve.</u> The 1985 and 1994 Highway Capacity Manuals (HCM) also use the volume/capacity ratio to estimate freeway speeds. Figure 4-11 compares freeway speeds as a function of the volume/capacity ratio for both the 1985 and 1994 Highway Capacity Manuals and the BPR curve. As can be seen, the BPR curve falls between the 1985 and 1994 HCM curves. The greatest discrepancy between the BPR and HCM curves occur at the point at which volume equals capacity. Since most HOV lanes are installed on freeways operating under conditions of congestion, the estimation of speed-flow relationships in this range is of key importance in modeling HOV impacts.

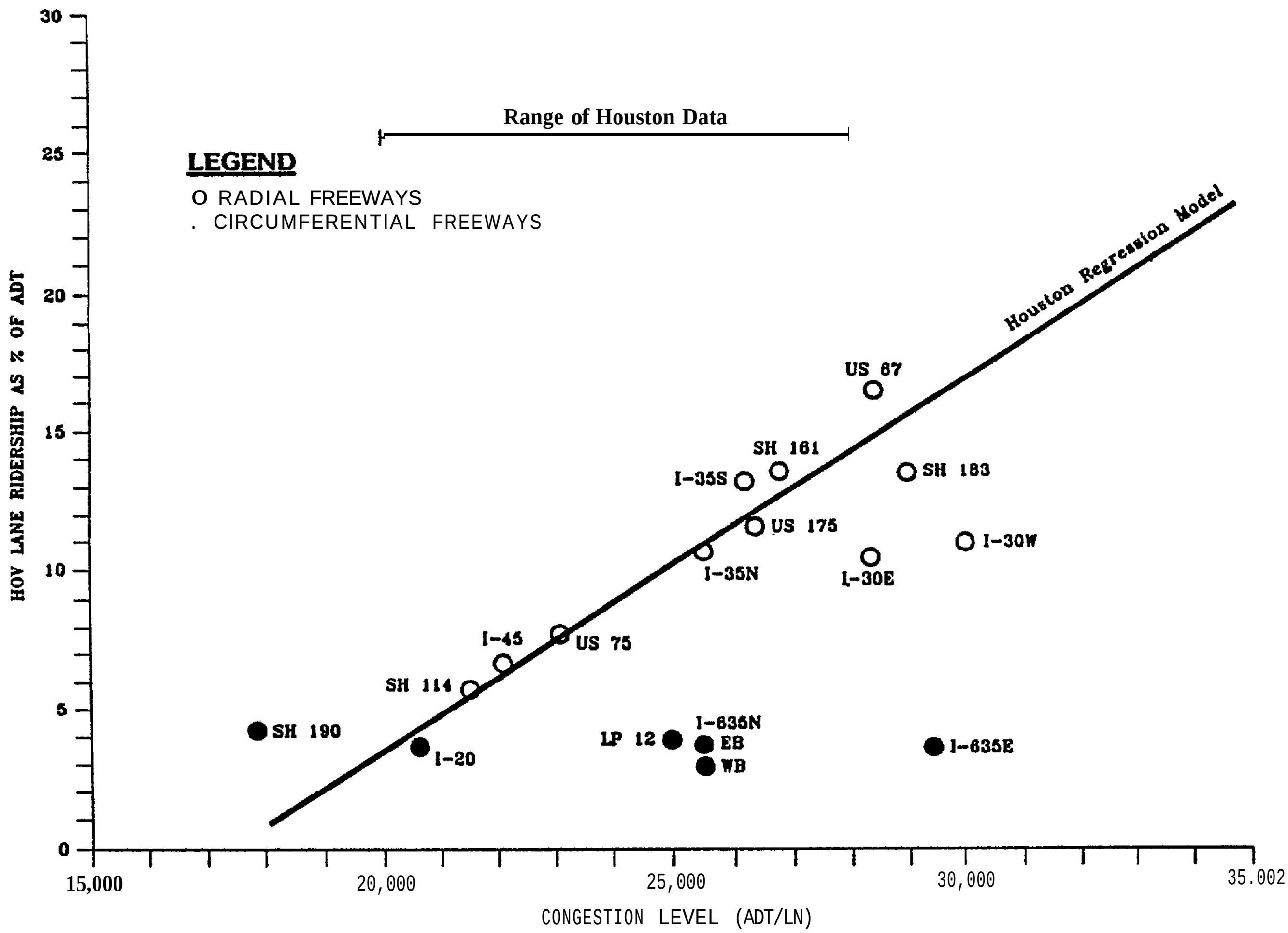


Figure 4-2
Houston Regression Model Relationship
Between HOV Ridership and Congestion Levels.

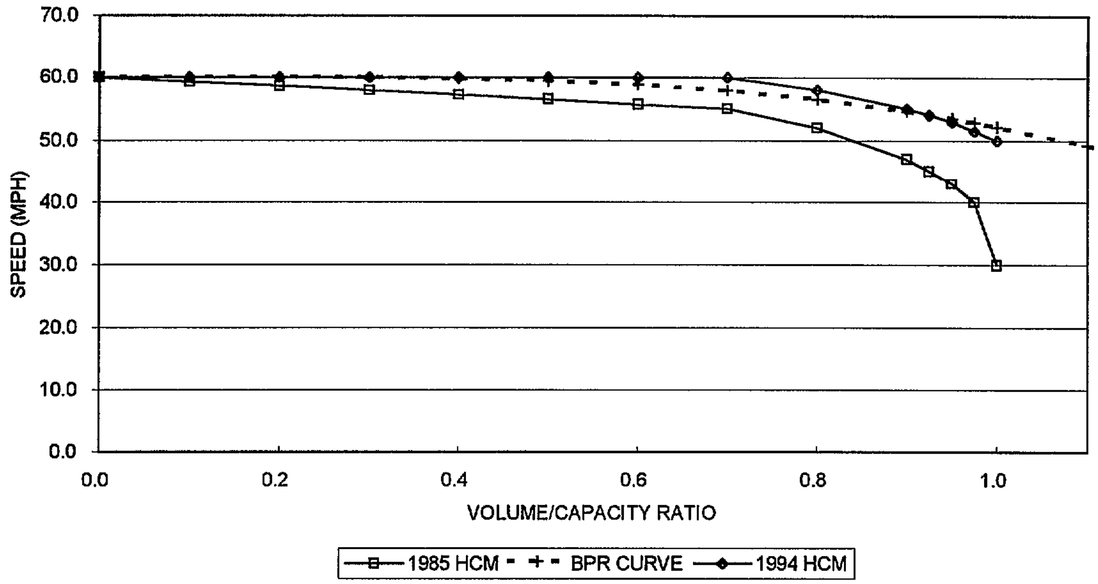


Figure 4-3. The BPR and HCM Speed Flow Curves

Because of the importance of understanding speed-flow relationships under conditions of congestion, many researchers have attempted to model those conditions in some detail. The following subsection describes several simulation models developed to replicate freeway flows as traffic volumes approach and exceed capacity.

4.3.3.2 Freeway Simulation Models

FREQ. FREQ is a macroscopic simulation model capable of modeling HOV lanes, adjacent freeway lanes and HOV ramp bypass facilities. The first version of FREQ was developed in 1970 by Adolf D. May and others at the University of California at Berkeley. The model has evolved through a number of modifications to produce the current parallel versions FREQ 11 PL (where PL signifies priority lanes) and FREQ 11 PE (where PE signifies priority entry). These models are discussed in some detail in Scapinakis (1991) and May, et al. (1991).

FREQ simulates traffic flow on a mainline freeway by dividing the freeway into subsections and the study time period into discrete time slices. The on ramp and mainline demands or service during each time slice are loaded into each subsection. If demand exceeds capacity, a queue is generated and the queue propagated upstream into later time slices. Downstream mainline demands are reduced according to the discharge capacity of each bottleneck subsection.

The use of the FREQ model in simulating HOV lanes has been well documented (Bacon, et al., 1994). FREQ 11 PL simulates an HOV facility by treating the facility as if it had been split into two separate roadways (HOV lanes and mixed-flow lanes) and analyzing each facility separately. Speed-flow curves and capacity restraints for HOV lanes differ from those used for mixed-flow facilities. The model has been modified through the addition of modules capable of analyzing both modal splits and spatial shifts, and is capable of simulating the following four situations:

- (Day – 1) Before implementation of the HOV lane.
- (Day + 1) Immediately after implementation of the HOV lane.
- (Middle term) After implementation of the HOV lane with spatial response.
- (Middle term) After implementation of the HOV lane with modal response.

FREQ simulates spatial responses to HOV lanes by modeling a representative arterial running parallel to the freeway. As carpoolers shift from the mixed-flow lane to the newly created HOV lane, travel times improve on the mixed-flow lane, inducing some vehicles to shift from the parallel arterial (which can represent the capacity of a number of roadways) to the freeway.

The model can also simulate modal shifts, which are assumed to occur after spatial shifts. Modal shifts are predicted using a multinomial logit model (Cilliers, 1978) calibrated with data from San Francisco. (If desired, the user can recalibrate the model using elasticities from another locale). The modal shift is accomplished through an iterative process in which a small number of vehicles are shifted from the mixed-flow lanes to the HOV lane. Travel times are recalculated, and the process continues until the travel time savings no longer induce mode shift.

The FREQ model has been in use for a number of years and is widely accepted as a useful tool for simulating mainline freeway sections. The model's unique features is its ability to simulate, at a macroscopic level, congested traffic flow conditions under alternative operating scenarios. Because of the heavy data input requirements and the complex set of calculations needed to replicate traffic queues and the promulgation of shock waves, however, the model itself is not likely to be part of a quick-response demand estimating procedure. It could, however, be part of a multi-level screening process in which more complex procedures are used to compute impacts too complex to be estimated through the use of quick-response techniques.

<u>FREFLO.</u> FREFLO is a macroscopic simulation model that represents traffic on a freeway in terms of aggregate measures of traffic flow, density, and speed. FREFLO is part of FHWA's TRAF system of models (FHWA, 1991) and is capable of modeling both HOV and mixed-flow lanes. This simulation models freeways as a series of sections which traffic attempts to enter. The capacity of each section determines the traffic flow that can be passed on to the next section within a specific time frame.

4.3.3.3 Arterial Simulation Models

The simulation of speed on arterial roadways is sensitive not only to volume/capacity ratios but also to signal timing and the spacing of intersections.

<u>Macroscopic Simulations</u>. Macroscopic simulations of arterial traffic flow apply deterministic relationships to individual roadway sections. Representative models include:

- TRANSYT-7F, a model developed by the FHWA, that simulates given non-dynamic traffic flows in a signalized surface street network and optimizes signal timing parameters.
- SATURN, a surface street simulation model that combines an operational evaluation of traffic signalization parameters with a traffic assignment technique. SATURN was developed at the Institute for Transportation Studies, University of Leeds.
- CONTRAM, a surface street network simulation model that evaluates and optimizes traffic signalization. CONTRAM was developed by the British Transport and Road Research Laboratory.

<u>Microscopic Simulations</u>. Microscopic models simulate the movement of individual vehicles, based on theories of car-following and lane-changing. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network on a second-by-second basis. Representative models in this category are:

- FRESIM, a model developed by the FHWA for simulation of freeway traffic operations.
- NETSIM, a model developed by the FHWA for optimization of traffic signal timing in a surface street network.
- INTEGRATION, a model that was developed to evaluate and optimize the operation of integrated freeway/signalized arterial networks during recurring and non-recurring congestion.

The INTEGRATION model can be used to represent an entire freeway corridor, along with numerous parallel arterials. Bacon, et al. (1994) describe the processes needed to model HOV lanes using the

INTEGRATION simulation. While the model successfully simulated an existing real-world condition, the authors noted that the coding process needed to represent an entire freeway corridor was "...quite data and labor intensive." Because INTEGRATION is a hybrid macroscopic and microscopic model moreover, the simulation time needed to model a test corridor was much longer than that consumed by the macroscopic model FREQ.

4.3.4 COMBINED APPROACHES

Modelers have found various ways of integrating supply and demand estimates to develop predictions of the impact of HOV lanes on mode choice. The most common approach iterates the application of mode shift equations and level-of-service estimates until the two estimates converge. This is the approach taken in most regionwide network models and by several analysts modeling corridor impacts (i.e., Small, 1977 and Talvitie, 1978). Some modelers have combined different approaches in an attempt to improve the accuracy and/or simplicity of HOV lane demand estimates. JHK and Associates, for example, combined traditional regionwide planning models with a freeway simulation to improve the level-of-service estimates available in the regional network. (JHK, 1994). In another combined approach, investigators at U.C. Berkeley developed a three-tiered HOV lane evaluation in which the analytic complexity increases in each of the three tiers (Scapinakis, 1991).

4.3.4.1 CALINK

Because traditional regional planning models typical use the BPR curve in estimating traffic flow levels, they have a limited capability for estimating the impacts of mode shifts on such important measures of traffic operations as speed, average, delays, and traffic queues. For this reason, these traditional models are ill-equipped to represent the travel time differences between carpools and single-occupant vehicles that are introduced by HOV facilities. In an attempt to remedy this defect, JHK & Associates undertook a project for CALTRANS (JHK, 1994) in which a freeway simulation model, FREQ (May, et al., 1991) was linked with a traditional planning model. The resulting analytical tool, called CALINK, executes the planning and simulation activities iteratively. Estimates of mode split and assigned traffic volumes produced by the planning model are introduced to the simulation model to produce revised estimates of freeway speeds and ramp delays. The revised travel time information is then introduced to the planning model for use in a new mode split and assignment. The process is repeated until the travel speeds and volumes converge from iteration to iteration.

4.3.4.2 Three- Tiered Screening Procedure

Investigators at U.C. Berkeley (Scapinakis, 1991) have suggested a three-tiered analytic methodology to help screen promising sites for HOV facilities. The three tiers proceed from a simple qualitative evaluation of many candidate sites (Level 1) to a relatively simple analytical model (Level 2) that can be used to identify the most promising candidates. These candidates are subjected to a detailed analysis using the FREQ freeway simulation.

<u>Tier One</u>. The first tier of the process entails a qualitative evaluation performed by professionals familiar with the candidate sites. These professionals exercise their judgment in answering a series of thirteen questions on a scoring sheet devised as an initial screening device. The scoring sheet with its thirteen questions appears in Figure 4-4.

<u>Tier Two</u>. In this tier, simple analytical models are used to address short- and medium-term operational issues. In the first phase of this analysis, a series of nomographs are used to evaluate the number of vehicles in priority and non-priority lanes immediately after implementation (before any demand response occurs). A sample nomograph used to assess lane conversion options in Seattle appears in Figure 4-5. In the second phase of this tier, the mode split model developed by Parody is used to predict the demand shifts likely to occur in the medium term.

Tier Three. The third tier entails a comprehensive evaluation of those surviving candidates using the FREQ computer simulation. Because the evaluation requires considerable resources, the authors recommend that it be limited to small numbers of candidate sites.

4.3.5 CRITICAL ASSESSMENT

4.3.5.1 Demand Models

Advantages The corridor demand models reviewed in this paper represent simple, transparent approaches that are easy to understand and apply. Data requirements are minimal, and at least one model, that of Parody (1984), appears to perform well in replicating overall demand measurements on existing HOV lanes (Billheimer, May, 1990).

Disadvantages. Even the best of existing corridor models have been calibrated on limited data sets, either because relatively few HOV lanes were in operation at the time they were developed (as in the case of the Mann and Parody models) or because the modelers had a narrow regional focus (as in the case of the TTI models). The geographic transferability of these models is not well understood, and none are equipped to deal with spatial and temporal shifts in trip making. Those models that are based on regression relationships tie their predictions to a single explanatory variable.

Individual models have specific drawbacks which have been covered in the discussion of those models. For example, Mann (1983) mixes two-person and three-person carpool lanes indiscriminately in developing his model, while Poe, et al. (1994) base their projections on a crude measure of congestion (ADT/lane) that is not easily transferred outside its Houston base of reference.

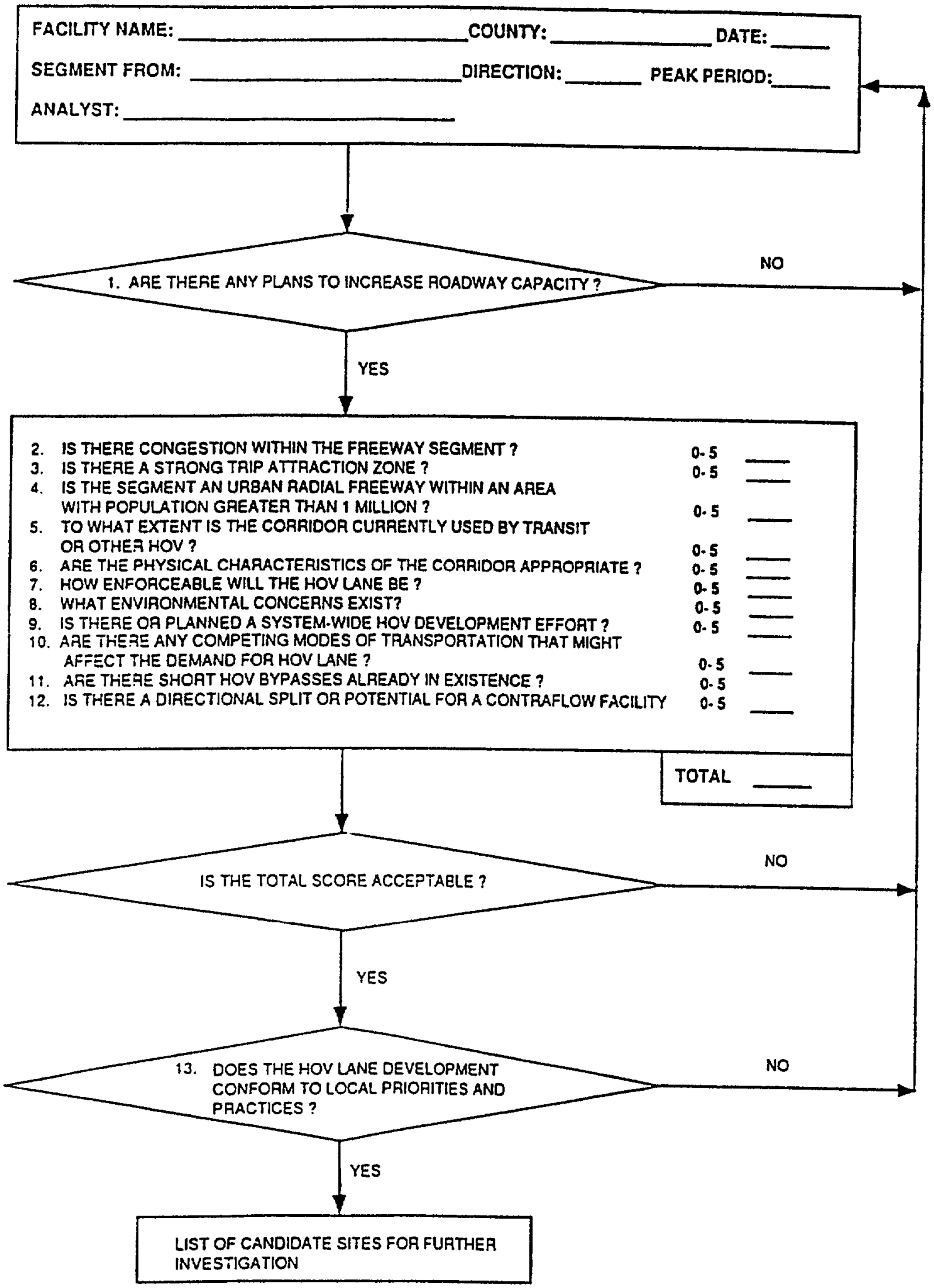
4.3.5.2 Supply Models

Advantages. Even the simplest speed/volume curves provide a useful mechanism for incorporating the feedback relationship between Carpool formation and traffic conditions in demand prediction.

Disadvantages. The iterative procedures needed to model the feedback between Carpool formation and travel times in adjacent mixed-flow lanes can be cumbersome. Simple speed-volume curves can forecast vastly different speeds under congested conditions, the only conditions in which HOV lanes are likely to be effective. While more complex simulations can address the impact of carpool formation and spatial and temporal shifts on travel times under congested conditions, these simulations require more data and resources than are appropriate for the current modeling effort. In short, simplified supply models do not replicate congestion conditions well, and those models which do replicate congestion adequately are not simple.

4.3.5.3 Summary

Simple corridor-based regression models, updated to reflect current HOV lane experience, represent a promising means of predicting the overall number of carpools attracted to a new HOV lane. Some mechanism needs to be found for coupling these models with level-of-service estimates and addressing issues of spatial and temporal diversion in a manner consistent with a quick-response modeling effort.



Source: Scapinakis, 1991.

Figure 4-4 The Scoring Sheet Used in the Tier One Evaluation.

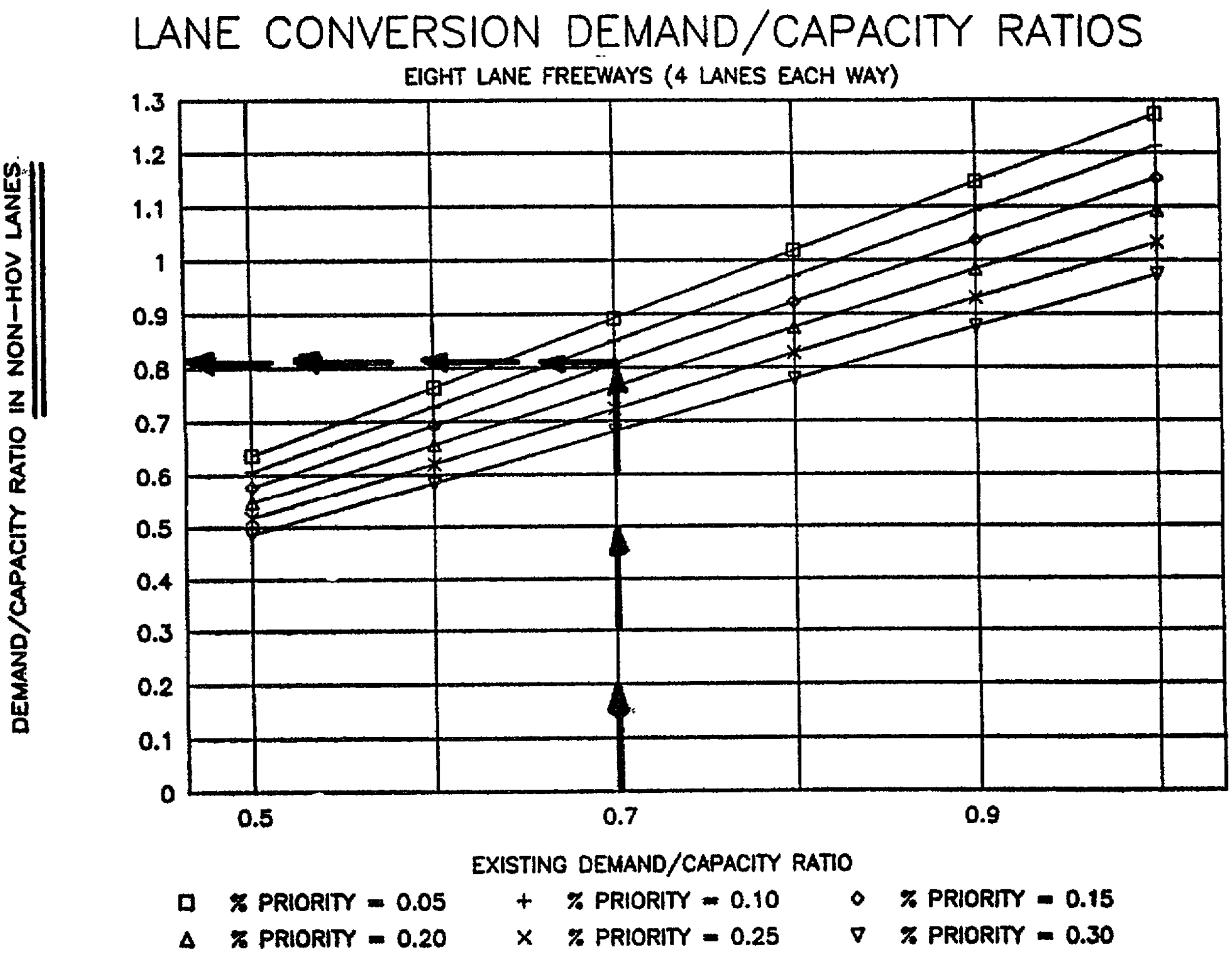


Figure 4-5 Seattle Nomograph for HOV Lane Conversions.

5. NEEDS ANALYSIS

This chapter presents a needs assessment by defining alternative approaches, methodologies, and computer analysis tools that are being used to predict HOV lane demand and by evaluating each of these methodologies in terms of its ability to satisfy analytical goals and objectives. The results of the user survey conducted for the methodology development task is also summarized. The purpose of the needs analysis effort is to assist in defining as clearly as possible the most desirable characteristics of the HOV methodology, and to prioritize the significance of various analysis objectives.

A summary of the needs assessment is presented in Table 5.1. Each of the analysis goals and objectives was assigned a row in Table 5.1 and is defined in Section 5.1. Each of the existing HOV methodology categories was assigned a column in Table 5.1 and is presented in Section 5.2. A (-) sign in Table 5.1 means that, based on the project team’s evaluation, the particular methodology does not address the corresponding analysis goal at all, or it addresses it in a poor fashion. A (+) sign in Table 5.1 means that the specific analysis goal is addressed by the corresponding methodology in a satisfactory way. A (0) sign in Table 5.1 means that the methodology is neutral in addressing the analytical goal.

5.1 Analysis Goals

There are several analysis goals and objectives for methodologies and the software models to predict HOV facility demand. Each of these goals was assigned a row in Table 5.1 and is described below.

5.1.1 HOV Facility Analysis Environment

HOV methodologies and software tools have varying degrees of analytical capabilities with respect to the HOV facility analysis environment, including:

- Analyze freeway congestion including mixed-flow and HOV lanes;
- Analyze arterial congestion including mixed-flow and HOV lanes;
- Model on-ramp entry control bypass (HOV bypass);
- Perform analysis at the corridor level;
- Perform analysis at the network level; and
- Perform analysis at the transportation system level.

HOV methodologies and software models are capable of analyzing freeway and arterial congestion including mixed-flow and HOV lanes. A (-) sign in the “freeway” and “arterial” rows in Table 5.1 means that the particular existing methodology does not address this requirement at all, or it addresses it in a poor fashion. A (+) sign in Table 5.1 means that freeway or arterial congestion is addressed by the corresponding methodology in a satisfactory way and that it incorporates the effect of queuing and delays onto congestion,

ISTEA and federal/state clean air legislation have reinforced the importance of traffic management and control of the existing highway capacity as an alternative to physical capacity improvements through new construction. In response to this strategy, an increasing number of urban freeways are ramp-metered. Even though the interaction of HOV lanes and ramp metering is often perceived as antagonistic, the provision of ramp meter HOV bypass lanes clearly reinstates the capability for a beneficial synergy between ramp metering and HOV lanes. A (-) sign in this row of Table 5.1 means that the corresponding methodology does not have the capability to model ramp meter HOV bypass lanes.

Table 5.1 Existing HOV Methodologies vs. Project Objectives

	EXISTING HOV METHODOLOGIES				
Analytical Goals	**Sketch Planning Methodologies**	**Macroscopic Simulation Models**	**Microscopic Simulation Models**	**Regional Models**	**Simulation/ Regional Model Linkage**
Traffic Operational Characteristics					
1. Freeway	0	+	+	0	+
2. HOV Bypass		+	0	-/0	+
3. Arterial		+	+	0	+
4. Corridor	-	0	+	+	+
5. Network	-		+	+	+
6. System				+	+
Traveler Response					
7. Temporal Diversion			0		+
8. Mode Shift	0/+	+		+	+
9. Route Diversion	-	+/0	+	+	+
10. Total Diversion					
11. Short-term Demand	+	+	+	+	+
12. Long-term Demand				+	+
13. HOV Support Systems	-/0				
Measures of Performance					
14. Emissions Analysis		0	0	0	+
15. Accurate Speed Estimation		0/+	+	0	0/+
Software Operational Characteristics					
16. Quick Method	+	0			
17. Current Use By DOT	+	0	-	0	
18. Operational Status	+	+	-/0	+	0/-
19. Hardware Requirements	+	+	+	+	+
20. Data Reauirements	+	0/+		0/-	

Note: (+): The specific analysis objective is generally addressed by the corresponding methodology.
(-) The particular methodology does not generally address the specific analysis objective.
(0): Neutral

Existing HOV methodologies are generally applicable to corridor, network, and system level HOV demand analysis. Definitions for corridor, network, and system level analysis are as follows:

- **Corridor** level analysis would include the freeway (with HOV and mixed-flow lanes) and parallel arterials.
- **Network** level analysis would include the whole network of highways and streets impacted by the HOV lane. Typically, this includes a grid of freeways, arterials, and local streets in the general vicinity of the HOV lane.
- **System** level analysis would include the impacted network as well as address the interaction of the HOV lane with all transportation modes (including SOV, HOV2, HOV3, HOV4+, passenger rail, and other modes).

5.1.2 Traveler Response

In terms of traveler response to traffic congestion, HOV methodologies and software are capable of estimating and representing:

- Temporal diversion;
- Mode shift;
- Route diversion;
- Total diversion;
- Short-term person/vehicle HOV demand;
- Long-term person/vehicle HOV demand; and
- The impact of HOV support systems.

In response to a new HOV lane, travelers can change their time of travel (temporal diversion), can use a different mode of transportation (mode shift), can select a different route (route diversion), or completely cancel or create a new trip (induced/suppressed demand). A (+) or (-) in the corresponding rows of Table 5.1, respectively represent how well or badly the corresponding methodology can model temporal, mode, route, or total diversion.

Short-term demand is the vehicle- or person-demand for the HOV lane shortly after it has opened for operation. Typically, estimation of short-term demand is based on forecasts of volumes, speeds, and travel times, and on achieving an equilibrium between travel times in the priority and non-priority lanes. Short-term demand estimation does not take into account factors such as trip length, route diversion, mode shift, temporal diversion, and total diversion. In contrast, estimation of long-term demand for HOV lanes takes into account the effects of trip length, alternative routes, transportation modes, times of travel, and overall congestion onto the demand for the HOV lane. A (+) in a cell of Table 5.1 means that the corresponding methodology provides the capability of estimating short- or long-term HOV demand.

The last analysis objective in this category reflects the ability of a particular methodology to analyze the impact of HOV lane support systems (such as Park-&-Ride facilities, rideshare programs, etc.) onto the demand for the HOV lane. A (+) or (-) in this row of Table 5.1, respectively represent how well or badly the corresponding methodology can model the impact of HOV lane support systems.

5.1.3 Measures of Performance

In reviewing analytical capabilities of existing HOV analysis methodologies, two measures of performance have emerged as critical in the prediction of HOV facility demand:

- Impact of HOV facilities on vehicular emissions; and
- Accuracy in travel speed estimation.

The Clean Air Act Amendments (CAAA) of 1990 and (to a lesser extent) the Intermodal Surface Transportation Efficiency Act (ISTEA) of 199 1 place great emphasis on modeling to provide accurate accountability towards meeting air quality goals and deadlines that, if not met, could lead to highway funds being withheld. HOV lanes will only be feasible if it can be shown that their implementation will not further impair air quality in specific areas. The ability of existing HOV models to predict and evaluate the impact of HOV lanes on air quality relates to the following issues:

- Ability to interface with emission rate models (e.g. DTIM) and emissions dispersion models (e.g. EMFAC and MOBILE);
- Ability to accurately predict traffic volumes and speeds since travel speeds are the most important determinant of mobile source emission models; generally, the detailed representation of capacity and flow provided by simulation models results in more accurate speed estimates than those of travel demand models;
- Ability to accurately model the effects of traffic congestion since emissions at low, congested speeds are different from emissions at uncongested speeds; this also relates to the ability to estimate vehicle flow profiles (vehicle operating mode) since emissions during vehicle acceleration are different from emissions during vehicle cruise or idle mode; and
- Ability to model the regional and system-wide impacts of HOV lanes on air quality. California experience shows that when HOV lanes were evaluated only at the corridor level, emissions increased when compared to the no-build scenario; however, when network-wide analysis was performed and regional modal and spatial shift was taken into account, HOV lanes showed air quality benefits.

A (-) sign in Table 5.1 signifies that the corresponding methodology has limited abilities to predict and evaluate the impact of HOV lanes on vehicular emissions.

HOV methodological procedures generally predict and evaluate the impact of an HOV facility on person demand, vehicle demand, auto occupancy, congestion, delay, and air quality. Accuracy in travel speed estimation is critical to the prediction and evaluation of all the above performance measures. A (+) sign in Table 5.1 means that the corresponding methodology is producing relatively accurate speed estimates.

5.1.4 Operational Characteristics

This section discusses the level of effort and operational characteristics associated with the implementation of HOV methodologies and software. These attributes include:

- Quick response method/level of effort;
- Current use of methodology by State DOTs;
- Operational status;
- Hardware requirements; and
- Data requirements.

The project scope of work calls for a methodology to "obtain quick analysis of HOV lane demand and operations". A (+) sign in Table 5.1 signifies that the corresponding methodology is a relatively quick response method for HOV analysis, while a (-) sign means that the methodology has a more labor-intensive implementation.

The second analysis objective in this category evaluates if a particular methodology is currently used by State Departments of Transportation (DOT). A (-) sign indicates that the specific methodology is generally not used by State DOTs.

The third analysis objective evaluates the operational status of each methodology including development status, proprietary status, and analysts' experience with use. A (-) in Table 5.1 indicates that the particular methodology is not fully operational (e.g.: not 100% debugged, not user-friendly, etc.).

The project scope of work calls for development of a "microcomputer model". This project objective evaluates the operating environment and hardware requirements (microcomputer, mainframe, etc.) for each methodology. A (+) in Table 5.1 means that the corresponding methodology currently operates in a microcomputer.

The last analysis objective in this section evaluates the amount of data required by each particular methodology. A (+) sign in Table 5.1 indicates that relatively few data are required for HOV demand analysis.

5.2 Existing HOV Methodologies

Several methodologies exist for predicting HOV facility demand, for evaluating traffic operations at HOV lanes, and for assessing impacts of HOV lanes. For the purpose of this needs analysis, the HOV methodologies/models were grouped into the following categories:

- Sketch planning methodologies;
- Macroscopic simulation models;
- Microscopic simulation models;
- Regional transportation planning models; and
- Linked regional planning/simulation models.

Each of the HOV demand methodology types shown above were assigned a column in Table 5.1 and representative models are briefly described in the remainder of this section.

5.2.1 Sketch Planning Methodologies

Sketch planning methodologies produce general order-of-magnitude estimates of HOV facility demand. Representative models in this category include:

- The methodology developed by Charles River Associates (CRA) for the FHWA ("Predicting Travel Volumes for HOV Priority Techniques – Technical Report and Final Report," 1982), otherwise known as the "Parody" method;
- The Pivot Point method developed by Cambridge Systematics ("HOV Support Facilities and Programs" for MTC – San Francisco Bay Area, 1990);
- The TDM model developed by COMSIS Corporation for the FHWA/FTA is used to evaluate HOV lanes as one of the TDM policies ("Congestion Management System Alternatives" – Maricopa Association of Governments, 1994); and
- The "TCM Tools" methodology developed by JHK & Associates ("Evaluate TDM/TSM Effectiveness" – Pima Association of Governments, 1993).

5.2.2 Macroscopic Simulation Models

Macroscopic simulation models are based on deterministic relationships developed through research on highway capacity and traffic flow. The simulation for a macroscopic model takes place on a section-by-section basis rather than tracking individual vehicles. The main representative models in this category are:

- CORFLO, a family of surface street and freeway models developed by the FHWA, including FREFLO, NETFLO 1, NETFLO2, and TRAFFIC.
- FREQ, a model developed by the Institute of Transportation Studies at the University of California at Berkeley, that simulates corridor traffic operations including one freeway and one parallel arterial.
- TRANSYT-7F, a model developed by the FHWA, that simulates given non-dynamic traffic flows in a signalized surface street network and optimizes signal timing parameters.

- SATURN, a surface street simulation model that combines an operational evaluation of traffic signalization parameters with a traffic assignment technique. SATURN was developed at the Institute for Transportation Studies, University of Leeds.
- CONTRAM, a surface street network simulation model that evaluates and optimizes traffic signalization. CONTRAM was developed by the British Transport and Road Research Laboratory.

5.2.3 Microscopic Simulation Models

Microscopic simulation models simulate the movement of individual vehicles, based on theories of car-following and lane-changing. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network on a second-by-second basis. Representative models in this category are:

- FRESIM, a model developed by the FHWA for simulation of freeway traffic operations.
- NETSIM, a model developed by the FHWA for optimization of traffic signal timing in a surface street network.
- INTEGRATION, a model that was developed to evaluate and optimize the operation.of integrated freeway/signalized arterial networks during recurring and non-recurring congestion.

5.2.4 Regional Travel Demand Models

Regional travel demand models follow a four-step modeling process including trip generation, trip distribution, mode choice and trip assignment. The four-step process can be implemented with a variety of software packages that follow the same overall guidelines for modeling practices but differ in the specific options or parameters that may be invoked for a particular module. The main regional travel demand software packages are UTPS, TRANPLAN, MINUTP, and EMME/2.

The mode choice element of regional travel demand models typically provides estimates of transit trips, single-occupant vehicle (SOV), and high-occupancy vehicle (HOV) trips. The most common application of the mode choice model is a logit model with numerous variables, including but not limited to:

- Transit and highway level-of-service (travel time and cost);
- Socioeconomic characteristics of the traveler (such as income); and
- Characteristics of household trip origins and destinations (such as autos per household, workers per household, parking charges, and access travel time).

Predicting HOV facility demand and assessment of impacts of HOV lanes requires specific analytical capabilities, such as the consideration of mode choice and major route choice and the representation of traffic flow in the highway network. These attributes are presently found only in the structure and orientation of regional travel demand models. Regional models, however, have only limited capability to accurately estimate changes in operational characteristics (such as speed, delay, and queuing) resulting from implementation of HOV lanes.

A typical problem with HOV demand modeling is that HOV assignments usually reflect only home-based work trips (excluding other trip purposes). This results in underestimation of HOV lane flows and correspondingly overestimation of mixed-flow lane flows. Another typical problem with HOV supply modeling is that in most regional models, the HOV assignment algorithm produces an all-or-nothing allocation that assigns all eligible vehicles to HOV lanes whenever the speed differential favors the HOV lane. In reality, proportionally more eligible vehicles are likely to use the HOV lane as the HOV speed advantage increases.

5.2.5 Linked Regional/Simulation Models

Accurate estimation of mode shift between HOV, SOV, and transit modes requires accurate estimates of travel times and speeds experienced by each travel mode. Criticism against regional model forecasts concentrates on the inadequate treatment of specific traffic operational characteristics, and the inaccuracy of travel speed and traffic volume estimates. These inadequacies generally occur because of poor representation of the dynamic nature of traffic in regional modeling. Estimation of realistic travel speeds requires realistic representation of queuing, congestion levels, congestion dissipation, and traffic diversion in space and in time.

To address regional model deficiencies, there are several efforts under way to link regional models with simulation models. This linkage uses the best characteristics of the two model systems: Simulation models provide accurate travel time and speed estimation for mixed-flow and HOV lanes. The regional model uses these speed estimates to perform route assignment and mode choice. This linkage iterates until convergence is achieved. This approach enhances travel demand forecasting by introducing accurate traffic operations analysis to travel demand modeling. In parallel, this approach enhances traffic operations analysis by introducing assignment and mode choice to freeway simulation modeling.

The linked planning/simulation model approach is currently used in several projects sponsored by various state and federal agencies. Examples of these projects include:

- "Travel Demand and Simulation Modeling" by Caltrans Headquarters; this project developed a model framework that integrates a regional travel demand model (MINUTP, TRANPLAN, or SYSTEM II) with a freeway simulation model (FREQ) and with an emissions model;
- "IVHS Benefits Assessment Framework" by the Volpe National Transportation Systems Center and the FHWA; in this project an analytical tool was developed that links a regional travel demand model with freeway and arterial macroscopic simulation models (FREQ and TRANSYT-7F, respectively), and with emissions, fuel consumption, and safety impact assessment models; and
- "Feasibility and Demonstration of Network Simulation Techniques for Estimation of Emissions in a Large Urban Area" by the California Air Resources Board; this project examined the feasibility of linking a microscopic freeway simulation model (FRESIM) with a travel demand model.

5.3 User Survey

The purpose of this section is to summarize the results of the user survey conducted for the methodology development task of the Federal Highway Administration Project #42-10-4172, Predicting the Demand for High Occupancy Vehicle (HOV) Lanes. The user survey is part of the methodology development task that will provide a set of "quick response" procedures for predicting and evaluating the impacts of HOV lanes on person demand, vehicle demand, auto occupancy, congestion, delay, and air quality.

The results of the user survey are summarized according to the following sections.

- Section 5.3.1 – Purpose and Approach;
- Section 5.3.2 – Critical HOV Impacts;
- Section 5.3.3 – Current Methodologies/Models;
- Section 5.3.4 – HOV Modeling Approach;
- Section 5.3.5 – Data Availability; and
- Section 5.3.6 – HOV Support Facilities.

5.3.1 Purpose and Approach

5.3.1.1 Purpose

The user survey was conducted to identify the existing methodologies being used by the technical planning community for predicting, analyzing, and evaluating travel demand for HOV lanes and to assess the needs of the potential model users. Another objective of this survey was to obtain technical staff opinions and input regarding possible approaches for modeling HOV facility demand. In addition, data availability information was collected for both model inputs and HOV support facilities.

5.3.1.2 Approach

One of the objectives of the project is to formulate a methodology which can be applied by planners and engineers with limited or no access to or experience with regional travel demand modeling. Nine agencies were selected for this user survey:

- California State Department of Transportation – District 4 (San Francisco, California);
- California State Department of Transportation – District 7 (Los Angeles, California);
- Minnesota Department of Transportation (Minneapolis, Minnesota);
- New Jersey Department of Transportation (Trenton, New Jersey);
- Texas State Department of Highways and Public Transportation (SDHPT) and Metropolitan Transit Authority of Harris County (Houston, Texas);
- Virginia Department of Transportation (Richmond, Virginia);
- Washington State Department of Transportation (Seattle, Washington);
- Santa Clara County (San Jose, California); and
- Snohomish County (Seattle, Washington).

Fifteen telephone surveys were conducted during the months of April and May, 1995. In some cases, more than one user was surveyed during one telephone call. The following sections present the results of the user survey.

5.3.2 Critical HOV Impacts

The new HOV methodology will guide users through a procedure which will predict and evaluate the impact of an HOV facility on person and vehicle demand, auto occupancy, congestion, delay, and air quality. To help determine the extent to which some of these performance measures might be evaluated in the new methodology and model the users were asked which of the following HOV facility impacts are most critical for their agency:

- Person demand;
- Vehicle demand;
- Auto occupancy;
- Congestion;
- Delay; and
- Air quality.

Table 5.2 presents the agencies' responses to which of the HOV facility impacts were most critical. A (J) in a cell of Table 5.2 means that one of the representatives of that agency identified the HOV facility impact as critical. Most of those surveyed responded that all of the HOV facility impacts under question are important; the level of importance depends on the situation (or project) under consideration. The impacts which tended to be most critical were vehicle demand, congestion, person demand, and air quality. Other HOV facility impacts or outputs which were mentioned as desired for inclusion in the methodology and model were cost, noise, transit usage, mode split and trip distribution.

Table 5.2 Most Critical HOV Impacts

Agency	Person Demand	Vehicle Demand	Auto Occupancy	Congestion	Delay	Air Quality
Caltrans - District 4 (San Francisco)	✓	✓	✓	✓	✓	✓
Caltrans - District 7 (Los Angeles)	✓	✓	✓	✓	✓	✓
Minnesota Department of Transportation	✓	✓		✓	✓	
New Jersey Department of Transportation	✓	✓			✓	✓
Texas (SDHPT) and Metropolitan Transit Authority of Harris County (Metro)	✓	✓	✓	✓		✓
Virginia Department of Transportation		✓	✓			✓
Washington State DOT and Snohomish and King Counties	✓	✓	✓	✓		
Santa Clara County, California		✓		✓		✓

Table 5.3 Methodologies/Models Used

Agency	Methodologies/Models
Caltrans - District 4 (San Francisco)	MINUTP EMME/2 FREQ
Caltrans - District 7 (Los Angeles)	UTPS DTIM
Minnesota Department of Transportation	FREQ FRESIM TRAVEL TRANPLAN EMME/2
New Jersey Department of Transportation	FREQ MINUTP TRANPLAN
Texas State Department of Highways and Public Transportation (SDHPT) and Metropolitan Transit Authority of Harris County (Metro)	Charles River's Pivot-Point Method FREQ TRANPLAN Texas Transportation Institute (TTI) Method Dallas/Fort Worth Regional Model (UTPS) MOBILE
Virginia Department of Transportation	Cambridge Systematics Pivot Point Method MINUTP
Washington State Department of Transportation and Snohomish and King Counties	Charles River's Pivot-Point Method University of Washington Method FREQ FRESIM TRANSYT-7F EMME/2 UTPS
Santa Clara County, California	TRANPLAN DTIM2

5.3.3 Current Methodologies/Models

Table 5.3 identifies existing methodologies or models used by the agencies represented in the user survey to predict, analyze, and/or evaluate travel demand for HOV lanes. Three of the agencies stated that they use sketch planning methodologies (pivot-point), four agencies identified use of macroscopic simulation models (FREQ and TRANSYT-7F), microscopic simulation models (FRESIM) were mentioned for two agencies, and all of the agencies use regional travel demand models for some type of evaluation of HOV facilities. The regional travel demand models being used by the agencies include TRANPLAN, MINUTP, EMME/2 and UTPS or UTPS-based models. Approximately half of the agencies represented in the survey use some sort of post-processors for enhancing speeds and emissions estimates, operational analysis, or for re-estimating mode choice and distribution.

The users were also asked about their experience using the various existing methodologies and models, specifically the level of effort involved and any key advantages or weaknesses. On average, the individuals surveyed have been using the existing methodologies and models for over seven years.

5.3.3.1 Level of Effort for Existing Methodologies/Models

With respect to regional travel demand models, most of the users stated that once the model was operational, the level of effort was minimal. However, the network coding and calibration efforts required to get the model running is time consuming, demanding of personnel, and data intensive. According to the users surveyed, the macroscopic and microscopic simulation models tended to be fairly data intensive, but necessary for the outputs desired.

5.3.3.2 Advantages of Existing Methodologies/Models

Some of the advantages of existing methodologies and models identified by the users include:

Macroscopic Simulation Models – calibration capabilities, capable of day-l and longer time period evaluations, readily available, and operational analysis capabilities; and

- **Travel Demand Models –** better emissions estimates, mode choice by zones, select-link analysis, all trips fully accountable (origin/destination capabilities), LOS analysis, diversions for travel time savings, integrated with transit, method/model well understood, and confidence in results.

5.3.3.3 Weaknesses of Existing Methodologies/Models

The disadvantages or weaknesses of the existing methodologies and models, as specified by the model users, include:

- Lack of flexibility for geometrics (start and end of HOV lane, right-side HOV facilities, exclusive on- and off-ramps, grade, expanding or constricting number of lanes, HOV merging and weaving, extending or shortening HOV facilities, and general condition changes);
- Inability to evaluate temporal diversion;
- Only evaluates work trips;
- Only produces HOV trips for those with a time savings of greater than five minutes;
- All or nothing assignment assumption for HOV analysis leading to overestimation of HOV lane volumes;
- Time period analysis constraints;
- Too many assumptions required (leap-of-faith);
- Extensive network coding, calibration, and data collection required for travel demand models; and
- Slow/time-consuming to run model.

5.3.4 HOV Modeling Approach

The following list identifies some of the issues which the model users would like to have addressed in a new model for predicting and evaluating HOV facility demand.

- Simple, user friendly, flexible, consistent with existing models and methodologies, better confidence in results, and outputs understandable to a lay person;
- Right-side HOV analysis, weaving effects (in-and-out of HOV lanes), speed differential, violation rates, ramp-metering and HOV bypass lanes, signal preemption strategies, eligibility considerations (2+ versus 3+), various effects of lane conversions (mixed flow to HOV), extending or shortening HOV lanes, access considerations (limited access versus continuous access), exclusive on- and off-ramps, and effects of various HOV facility terminations (merging/bottlenecks);
- Location considerations such as urban versus suburban and/or radial versus circumferential highways;
- Transit usage and performance, and evaluation of the various modes using the HOV facility (transit, Carpool, Vanpool, and motorcycles);
- Benefit/cost analysis, project costs (construction, operation, and congestion), and HOV project prioritization (or at a minimum outputs which could be used for prioritization efforts);
- Capture non-work trips as well as work trips;
- Impacts of peak spreading, toll facilities, Carpool incentives, congestion pricing, HOV buy-in programs (selling HOV lane use to SOV vehicles), and technology (ITS);
- Allow for "what-if" scenarios;
- Better origin-destination analysis capabilities;
- Actual utilization of HOV lane by HOV vehicles (not all HOV vehicles use the HOV facility);
- Better temporal diversion and mode shift estimation;
- Capability to design their own speed versus demand-to-capacity (d/c) curves, but default curves should also be available; and
- Capability of outputting schematics, maps, and/or graphs of facility geometrics and model outputs (e.g., queuing, air quality, congestion, and speed/flow).

Users were also surveyed on what the relationship should be of a new HOV model to an existing regional travel demand model if a regional travel demand model is available for the project study area. Most of the users stated that there should be a link or interface between the two models and that the results should be consistent. Most of the users also believed that if a regional model is available for the HOV project study area, the regional model should be used (but not necessarily required) for HOV analysis, especially for significant decisions such as major investment studies.

5.3.5 Data Availability

General data availability was investigated for several potential model inputs. The potential inputs included:

- Existing HOV and mixed-flow lane(s) demand and counts for freeways;
- Existing HOV and mixed-flow lane(s) demand and counts for on- and off-ramps;
- Existing HOV and mixed-flow lane(s) demand and counts for HOV arterial facilities;
- HOV demand growth estimates for future analysis periods;
- Existing HOV and mixed flow lane(s) occupancy distribution and breakdown options;

- Existing average speeds;
- HOV and mixed-flow lane capacity;
- Number of HOV and mixed-flow lanes;
- Length of facilities;
- Availability of parallel capacity (corridor characteristics); and
- Average speeds on parallel facilities.

Table 5.4 presents the availability of input data for each of the agencies. A (+) means that the data is readily available, a (+/-) means the data is somewhat available, and a (-) means the data is not available.

Most of the input data was readily or somewhat available. The potential inputs which tended to have less data availability included arterial counts (where an HOV facility on an arterial roadway is to be evaluated), HOV demand growth estimates, occupancy, average speeds, and information on parallel facilities.

5.3.6 HOV Support Facilities

The users were also surveyed on the data availability of several HOV support facilities, including:

- Ramp-metering;
- Park-and-ride facilities;
- Carpool/vanpool parking;
- Rideshare programs;
- Public information/marketing programs;
- Automated traffic management systems;
- Transit and/or intermodal stations;
- HOV bypass lanes;
- Exclusive HOV facility on- and off-ramps (skyways); and
- Quantity and type of bus services.

Table 5.5 presents the data availability for various HOV support facilities by agency. A (+) means that the data is readily available, a (+/-) means the data is somewhat available, and a (-) means the data is not available. Overall, most of the agencies surveyed stated that all of the HOV support facilities data or information is available or somewhat available.

Table 5.4 Input Data Availability

Agency	Freeway Demand	Ramp Demand	Arterial Demand	Demand Growth	Vehicle Occup.	Average Speeds	Lane Capacity	No. of Lanes	Facility Length	Parallel Capacity	Parallel Speeds
Caltrans - District 4 (San Francisco)	+	+/-	+/-	+	+	+/-	+/-	+	+/-	-	-
Caltrans - District 7 (Los Angeles)	+	+/-	+/-	+/-	+/-	+	+	+	+	+/-	+/-
Minnesota DOT	+/-	+/-	+/-	+/-	+/-	+	+/-	+	+	+/-	
New Jersey DOT	+/-	+/-	+/-	+/-		+/-	+	+	+	+/-	
Texas (SDHPT) and Metro	+	+/-	+		+/-	+	+	+	+	+	+/-
Virginia DOT	+	+/-	+/-		+/-		+	+	+	+	
Washington State DOT/Snohomish	+	+	+/-	+/-	+/-	+	+	+	+	+	-
Santa Clara County, California	+	+	+/-	+/-	+/-	+/-	+	+	+	+	+/-

Note: **(+):** Input data are available.
(+/-): Input data are somewhat available.
(-): Input data are not available.

Table 5.5 Availability of HOV Support Facilities

Agency	Ramp Metering	Park-&-Ride Facilities	Carpool/ Vanpool Parking	Rideshare Programs	Public Info/ Mkting	Automated Traffic Mgmt	Transit/ Intermodal Stations	Bypass Lanes	Skyways	Bus Services
Caltrans - District 4 (San Francisco)	+/-	+	+/-	+	+/-	+/-	+	+/-		+
Caltrans - District 7 (Los Angeles)	+	+	+/-	+	+/-	+/-	+	+	+/-	+
Minnesota DOT	+	+	+	+	+	+	+/-	+/-	+/-	+
New Jersey DOT	+/-	+	+/-	+/-	+/-	+/-	+	+/-	n/a	+
Texas (SDHPT) and Metro	+/-	+	+/-	+	+/-	+/-	+	n/a	+	+
Virginia DOT	+/-	+	+/-	+	+/-	+/-	+	n/a	+	+
Washington State DOT/Snohomish	+	+	+/-	+	+	+	+/-	+	+	+
Santa Clara County, California	+	+		+/-	+/-	+/-	+/-	+	n/a	+

Note: (+): Data are available.
(+/-): Data are somewhat available.
(-): Data are not available.
n/a: Not applicable (either the facility does not exist or the user is unsure if the data is available).

6. RECOMMENDED MODELING APPROACH

This chapter provides an overview of the HOV modeling approach for predicting HOV facility demand and resulting HOV and mixed-flow lane(s) performance. The approach design is based upon contract objectives (and constraints) as well as on input received from the Steering Committee augmented through research team deliberations,

6.1 Data for Model Development and Testing

The purpose of the new HOV model is to provide a "quick response" methodology for predicting and evaluating the impacts of HOV lanes on person and vehicle demand, auto occupancy, congestion, delay, emissions, and fuel consumption. The new HOV model methodology uses travel time differences (HOV versus non-HOV, and before versus after) as the "stimulus" in the demand estimation, and the differences in vehicle volumes (HOV versus non-HOV, and before versus after) as the "response" to be predicted by the methodology.

Table 6.1 contains a summary of the data collected for use in the model development and framework. The key elements used in the model development include HOV lane(s) eligibility, facility length (study section length), violation rate, action type (add lane, lane conversion, etc.), travel times, vehicle volumes, and person volumes. A description of the data collection effort including detailed summaries for each of the HOV facilities is presented in Appendix D.

6.2 HOV Modeling Approach

The analysis of project objectives and needs, the user requirements survey, and the availability of HOV facility data have helped to define the most desirable characteristics of the HOV model methodology. The intent of the new approach is to provide for a quick-response tool for predicting HOV and mixed-flow lane(s) demand and traffic performance, with limited impact estimation capabilities. In this sense, the HOV model can be considered as a screening tool used to evaluate peak period directional roadway sections. The new approach can be used to estimate traffic performance and impacts in the short-term (six months to one year after opening day) and long-term (after one or more years in operation).

The iterative HOV demand/supply estimation process consists of several steps and iterations as shown in Figure 6.1. The model involves seven individual modules including:

- **Input Module –** Accepts and edits the input data;
- **Allocation Module –** Distributes traffic to the HOV and mixed-flow lanes (occurs three times in the process);
- **Supply Module –** Predicts travel times for the HOV and mixed-flow lanes;
- **Total Response Module –** Predicts the total response by vehicle type;
- **Equilibration Module – Checks closing criterion**;
- **Spatial and Modal Response Module –** Allocates total response into spatial and modal components; and
- **Output Module –** Computes measures of performance including vehicle and person volumes, travel times, vehicle and person miles of travel, vehicle and person hours of travel, vehicle and person delay, air quality/emissions, and fuel consumption.

Table 6.1 Summary of Data

NO.	Location	Date	Eligible	Roadway Classification	No. of HOV Lanes	No. of MF Lanes	Facility Length (miles)	Time (Peak Hour Peak Period)	violation Rate (%)	Action Type
1	U.S. 12/I-394 - Minneapolis	11/85	2	**Arterial**	1	2	4.0	**PH**	5.0	Construct new HOV lane
2	I-10 Katy - Houston	8/86	2	Freeway	1	3	6.4	**PH**	5.0	Convert 3+ (pre-authorized) to 2+ (unauthorized)
2	I-10 Katy - Houston	8/86	2	Freeway	1	3	6.4	PP	5.0	Convert 3+ (pre-authorized) to 2+ (unauthorized)
3	I-10 Katy - Houston	6/87	2	Freeway	1	3	11.4	PH	5.0	Extend lane 5 miles
3	I-10 Katy - Houston	6/87	2	Freeway	1	3	11.4	PP	5.0	Extend lane 5 miles
4	I-10 Katy - Houston	10/88	3	Freeway	1	3	11.4	PH	5.0	Convert from 2+ to 3+
4	I-10 Katy - Houston	10/88	3	Freeway	1	3	11.4	PP	5.0	Convert from 2+ to 3+
5	I-10 Katy - Houston	l/90	3	Freeway	1	4	12.6	PH	5.0	Extend lane 1.5 miles
5	I-10 Katy - Houston	l/90	3	Freeway	1	4	12.6	PP	5.0	Extend lane 1.5 miles
6	I-45N North Fwy - Houston	6/90	2	Freeway	1	4	13.5	PH	1.7	Convert 3+ (pre-authorized) to 2+ (unauthorized)
7	U.S. 290 NW Fwy - Houston	8/88	2	Freeway	1	3	9.5	PH	3.6	Construct new HOV lane
7	U.S. 290 NW Fwy - Houston	8/88	2	Freeway	1	3	9.5	PP	3.6	Construct new HOV lane
8	I-15 - San Diego	10/88	2	Freeway	2	4	8.0	PH		Construct new HOV lane
8	I-15 - San Diego	10/88	2	Freeway	2	4	8.0	PP		Construct new HOV lane
9	I-90 - Seattle	11/93	2	Freeway	1	3	6.2	PP	4.6	Convert 3.7 mi to HOV and add 2.5 mi HOV lane
10	I-5 - Seattle	7/91	2	Freeway	1	3	7.7	PH	22.0	Convert from 3+ to 2+
11	I-5 - Seattle	9/81		Ramp		1	6.0	PP	3.0	Install ramp meters with HOV bypass
12	I-5 - Seattle	8/83	3	Freeway	1	3-4	5.6	PP	19.0	Construct new HOV lane
13	U.S. 101 - San Jose	4/93	2	Freeway	1	3	6.0	PH	5.2	Add SOV and HOV lane (HOV lane gap closure)
13	U.S. 101 - San Jose	4/93	2	Freeway	1	3	6.0	PP	5.2	Add SOV and HOV lane (HOV lane gap closure)
14	U.S. 101 - San Jose	11/86	2	Freeway	1	3	2.8	PI-I	24.3	Add new HOV lane
14	U.S. 101 - San Jose	11/86	2	Freeway	1	3	2.8	PP	13.0	Add new HOV lane
15	I-280 - San Jose	11/90	2	Freeway	1	3	10.7	PH	9.2	Add new HOV lane
15	I-280 - San Jose	11/90	2	Freeway	1	3	10.7	PP	9.2	Add new HOV lane
16	128th/Airport Rd - Seattle	l/93	2	Arterial	1	l-2	3.3	PH		Add new HOV lane
17	S.R. 237 - San Jose	10/84	2	Arterial	1	2	5.9	PP	9.0	Add new HOV lane
18	San Tomas Expwy - San Jose	11/82	2	Arterial	1	3	4.9	PP	5.0	Add new HOV lane
19	Santa Monica Diamond Lanes	3/76	3	Freeway	1	3	12.0	PP	12.6	Convert lane to HOV
20	San Bernardino Express Busway	11/76	3	Freeway	1	4	11.0	PP	8.8	Allow carpools to use exclusive busway
21	Route 101 - Marin County	6/76	3	Freeway	1	3	3.7	PH	21.5	Convert bus only lane to carpool lane
22	Route 91- Los Angeles	6/85	2	Freeway	1	4	8.0	PH	7.8	Convert median to carpool lane
23	l-210 - Los Angeles	10/93	2	Freeway	1	5	17.0	PH	2.8	Add new HOV lane
24	Route 91- Los Angeles	3/93	2	Freeway	1	4	10.5	PH	2.3	Convert median to carpool lane
25	Route 55 - Orange County	11/85	2	Freeway	1	3	11.0	PH	12.0	Convert median to carpool lane
26	Route 101 - Corte Madera	10/88	2	Freeway	1	3	3.7	PP	11.0	Convert 3+ to 2+
27	Route 101- San Rafael	10/88	2	Freeway	1	3	3.0	PP	10.0	Convert 3+ to 2+

Table 6.1 Summary of Data (continued)

		Average Travel Time (minutes)				Person-Volumes				Vehicle-Volumes			
NO.	Location	HOV Before	MF Before	HOV After	MF After	HOV Before	Non-HOV Before	HOV After	Non-HOV After	HOV Before	Non-HOV Before	HOV After	Non-HOV After
1	U.S. 12/I-394 - Minneapolis	14.0	14.0	7.8	11.0	1814	3719	2581	3594	281	3719	656	3594
2	I-10 Katy - Houston	12.6	15.0	8.1	15.0	2905	3811	4795	3474	720	3811	1625	3474
2	I-10 Katy - Houston	10.2	11.0	7.9	11.0	6920	11418	9430	11335	1785	11418	3330	11335
3	I-10 Katy - Houston	20.0	26.0	14.2	26.0	4795	3474	4920	4084	1625	3474	1671	4084
3	I-10 Katy - Houston	15.9	19.0	13.8	19.0	9430	11335	11260	12654	3330	11335	3940	12654
4	I-10 Katy - Houston	13.3	22.9	13.2	25.6	2300	6674	3310	6346	361	5374	531	5596
4	I-10 Katy - Houston	13.8	17.9	12.9	18.6	5060	18854	6941	19302	840	15754	1300	17102
5	I-10 Katy - Houston	16.4	28.8	15.3	28.3	3310	6346	3760	6921	531	5496	631	5891
5	I-10 Katy - Houston	15.0	22.0	14.8	22.0	6941	19302	7811	20399	1300	17102	1590	17599
6	I-45N North Fwy - Houston	17.9	19.0	15.4	19.0	4280	7220	6030	6350	700	7220	1380	6350
7	U S. 290 NW Fwy - Houston	20.0	20.0	14.4	18.0	1320	4880	3006	5064	490	4880	1226	5064
7	U.S. 290 NW Fwy - Houston	14.1	14.1	11.5	12.0	3520	13930	6460	14890	1365	13930	2510	14890
8	I-15 - San Diego	18.0	18.0	8.6	11.0	4910	8601	7845	11266	1749	8601	3047	11266
8	I-15 -San Diego	14.0	14.0	8.7	10.0	10194	23084	13240	27504	3707	23084	4788	27504
9	I-90 - Seattle	6.6	6.6	6.4	6.4	3615	9675	4067	8815	2195	9675	2633	8815
10	I-5 - Seattle	7.4	8.0	6.0	6.2	5440	4561	6580	4761	1439	4561	1939	4761
11	I-5 -Seattle												
12	I-5 - Seattle	8.0	8.0	6.0	7.0								
13	U.S. 101 - San Jose	19.0	19.0	7.0	14.0	1815	3895	3580	3745	511	3895	1582	3745
13	U.S. 101 - San Jose	15.0	15.0	7.0	14.0	3062	7233	6478	7269	1227	7233	3079	7269
14	U.S. 101 - San Jose	11.0	11.0	4.4	7.0	1288	5112	1936	5224	581	5112	836	5224
14	U.S. 101 -San Jose	9.0	9.0	3.9	5.0	3920	14880	5635	15165	1820	14880	2635	15165
15	I-280 - San Jose	26.0	26.0	13.1	20.0	1130	5780	1832	6588	340	5780	732	6588
15	I-280 - San Jose	22.0	22.0	14.1	16.0	3152	15518	7204	18926	1297	15518	3060	18926
16	128th/Airport Rd - Seattle	8.0	8.0	7.0	8.0								
17	S.R. 237 - San Jose	11.0	11.0	6.0	7.5	2534	6566	4625	8575	1034	6566	2025	8575
18	San Tomas Expwy - San Jose	9.0	9.0	7.5	9.0	1528	7301	2659	7773	741	7296	1297	7766
19	Santa Monica Diamond Lanes	15.7	15.7	15.5	20.5	2055	28151	4456	22659	492	25270	883	19985
20	San Bernardino Express Busway	17.4	19.0	13.2	20.0	7460	30600	10810	31748	840	26800	1886	27808
21	Route 101 - Marin County	3.9	3.9	3.6	3.9	5155	6229	5620	7590	450	5120	500	5400
22	Route 91- Los Angeles	26.0	26.0	10.1	13.5	2314	6926	3751	6833	1015	6926	1645	6833
23	I-210 - Los Angeles	40.5	40.5	23.9	28.6	4023	9922	4555	8755	1875	9922	2218	8755
24	Route 91- Los Angeles	25.2	25.2	11.7	14.5	2657	6437	4648	6934	1205	6437	2075	6934
25	Route 55 - Orange County	32.0	32.0	16.3	29.0	1999	5079	3196	5666	921	5079	1484	5666
26	Route 101 - Corte Madera	5.4	5.8	4.35	4.4	11650	11460	12125	11870	2460	11460	2885	11870
27	Route 101- San Rafael	9.1	10.9	6.6	11.1	8240	12490	8950	13040	2080	12490	2620	13040

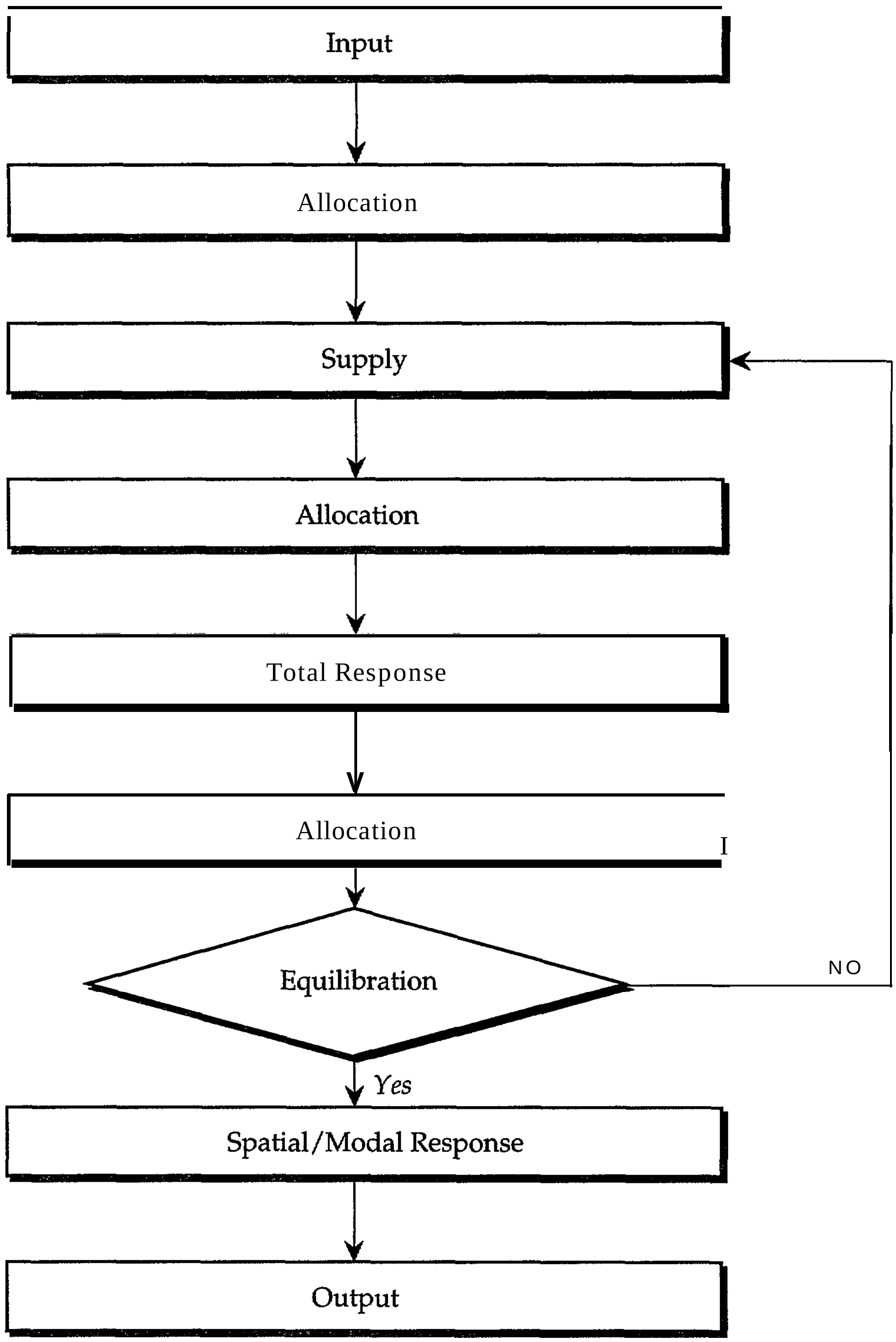


Figure 6.1 HOV Model Structure

6.3 Methodology

The following sections describe each of the modules which formulate the HOV methodology approach. The description of each module includes the purpose, key inputs, the methodology approach, and outputs

6.3.1 Input and Background Calculations Module

The purpose of the input module is to accept and edit the input data. This first step involves identifying the HOV study section and the critical sub-section, inputting demand and supply data, and performing background calculations to adapt the data to the model structure.

The HOV model methodology takes into consideration the controlling or critical sub-section of a directional peak period HOV study section. The critical sub-section is identified as having the highest demand-to-capacity ratio over the study section length. The remainder of the HOV study section should have a fairly uniform demand and capacity profile over its length. Since the HOV model evaluates the impacts of HOV lane(s) for a single direction of travel, each direction of the proposed facility must be analyzed separately.

A summary list of data inputs required by the user is presented in Table 6.2. Inputs marked with the symbol (1) represent the data required for the model. The remaining data inputs are optional since default values are provided by the methodology. The data inputs have been separated into three categories: project description inputs; current demand and travel characteristics; and arterial HOV facility inputs. Project description inputs include proposed design characteristics, facility geometrics, and model parameters. Data inputs such as travel speed, traffic volumes, and occupancy rates are included under current demand and travel characteristics. The inputs listed under arterial HOV facility inputs are only required for users who want to assess an HOV lane on an arterial facility. Table 6.2 also identifies the inputs which are only required for specific analysis options; for example, lane width is only required if the user selects the 1994 HCM based option for calculating running time. Table 6.3 contains the default values for the data inputs.

Table 6.4 presents the model calibration ranges for data inputs and computations for the HOV model methodology. The ranges typically contain a minimum and maximum value, and may further be divided into eligibility type. If any of the input or output values do not fall within these minimum and/or maximum ranges, a warning is issued to inform the user that the value is outside of the model's calibrated range.

Figure 6.2 contains a flow diagram for the input module framework. The user has four options for inputting data into the HOV model: a batch file; an input module for users with minimum data; an input module for users with complex data sets; or the data editor routine. The ASCII batch file method is completely non-interactive. The other three forms are interactive for novice or experience users. The minimum data set routine takes the user though a series of detailed questions to input the data. The complete data set routine involves inputting the data using a series of spreadsheet screens. The complex data set routine offers more flexibility and detail for inputting the data.

Depending on the availability of data, the existing volumes can be input in several different forms. Existing demand (volumes) is requested by vehicle and lane type. If a critical sub-section is specified by the user, data are required for both the critical sub-section and the remainder of the study section. For users with very limited data (minimum data set routine), the HOV model methodology contains a process for deriving traffic volumes by auto occupancy category based on the total directional volume and the average vehicle occupancy for the entire facility. The auto occupancy categories used throughout the HOV model framework include:

- Single occupant vehicles (SOV);
- Two-occupant vehicles (HOV2);

Table 6.2 Summary List of Inputs

Project Description Inputs

- User novice or experienced(1)
- FREQ based or 1994 HCM based running time calculation option(1)
- EMFAC or MOBILE 5 air quality calculation option(1)
- Roadway type
- Proposed HOV lane eligibility(1)
- Action type(1)
- Proposed HOV lane barrier availability(‘)
- Length of the study section and/or critical sub-section”)
- Existing and proposed number of lanes for the study section and/or critical sub-section”)
- Capacity per lane for the study section and/or at the critical sub-section
- Length of peak period
- Distance from traveled way to obstruction (1994 HCM based option only)
- Obstruction on one or both sides (1994 HCM based option only)
- Lane width (1994 HCM based option only)
- Type of terrain (1994 HCM based option only)
- Peaking characteristics
- Existing and estimated ramp meter delay
- Violation rate
- Stop criterion
- Average annual temperature (EMFAC option only)(1)
- Trip table allocation percentages (spatial and modal response)
- Analysis period

Current Demand and Travel Characteristics

- Travel direction(1)
- Existing peak period vehicle speed for the study section(1)
- Free-flow speed or posted speed limit
- Existing peak period average speed on parallel roadways(1)
- Traffic stream type (1994 HCM based option only)
- Percentage of trucks which are gas versus diesel
- Percentage of total vehicles which are recreational vehicles (1994 HCM based option only)
- Occupancy rate(s) and/or distributions by vehicle type(1)
- Existing peak period demand (volume) for study section and/or critical sub-section(1)
- Maximum percentage of peak period HOV eligible vehicles in the HOV lane(s)
- Peak hour factor (1994 HCM based option only)

Arterial HOV Facility Inputs (only necessary if proposed facility is an arterial)

- Number of traffic signals over the length of the study section(1)
- Percentage of turns which are from exclusive lanes
- Quality of signal progression
- Average cycle length
- Average effective green time

Note: (1) Required data inputs.

Table 6.3 Input Data Default Values

Data Inputs	Default Values
Project Description Inputs	
Roadway type	Freeway
Capacity per lane for the study section and/or at the critical sub-section	
HOV lane on a 6+ or 4-lane freeway or multi-lane highway	1600 vph
HOV lane on an arterial (saturation flow rate)	1300 vph
Mixed-flow lane on a 6+ lane freeway	2300 vph
Mixed-flow lane on a 4-lane freeway or multi-lane highway	2200 vph
Mixed-flow lane on an arterial (saturation flow rate)	1900 vph
Length of peak period	3 hours
Distance from traveled way to obstruction (1994 HCM based option only)	6 feet
Obstruction on one or both sides (1994 HCM based option only)	Both sides
Lane width (1994 HCM based option only)	12 feet
Type of terrain (1994 HCM based option only)	Level
Peaking characteristics	
Number of sub-periods	4
Length of sub-periods as a portion of the peak period	l/6, l/3, l/3, 1/6
Flow rates as a percentage of peak hour volume	I I%, 45%, 32%, 12%
HOV lane on a 6+ or 4-lane freeway or multi-lane highway	1600 vph
Existing and estimated average ramp meter delay	
No ramp metering	0
With ramp metering	1 minute
Violation rate	0%
Stop criterion	1%
Trip table allocation percentages (spatial and modal response)	
Facility	
-- Non-HOV to non-HOV	75%
-- Non-HOV to HOV	27%
-- Non-HOV to bus	10%
-- HOV to non-HOV	9%
-- HOV to HOV	37%
-- HOV to bus	35%
-- Bus to non-HOV	1%
-- Bus to HOV	12%
-- Bus to bus	50%
Parallel Facilities	
-- Non-HOV to non-HOV	**13%**
-- Non-HOV to HOV	12%
-- Non-HOV to bus	1%
-- HOV fo non-HOV	1%
-- HOV to HOV	8%
-- HOV to bus	1%
-- Bus to non-HOV	1%
-- Bus to HOV	4%
-- Bus to bus	3%

Table 6.3 Input Data Default Values (continued)

Data Inputs	Default Values
- **Analysis** period	Short-term
Current Demand and Travel Characteristics	
. Free-flow speed or posted speed limit	
– Freeway	60 mph
– Arterial	35 mph
• Average vehicle occupancy	1.25
• Average vehicle occupancy for vehicles with 3 or more persons	3.4
• Average vehicle occupancy for buses	34
• Traffic stream type **(1994** HCM based option only)	Commuter
• Percentage of total vehicle volume which are	
– Trucks	5%
– Buses	0.5%
– Motorcycles	0.8%
– Recreational vehicles (1994 HCM based option only)	0%
- Percentage of total trucks on the facility which are	
– Gas trucks	**70%**
– Diesel trucks	**30%**
. Maximum percent peak period HOV eligible vehicles in the HOV lane(s)	
– 2+ eligibility	**80%**
– 3+ eligibility	**90%**
• Peak hour factor (1994 HCM based option only)	**0.85**
Arterial HOV Facility Inputs (only necessary if proposed facility is an arterial)	
• Percentage of turns which are from exclusive lanes	12%
• Quality of signal progression	**4**
• Average cycle length	120 seconds
• Average effective green time	**54** seconds

Table 6.4 Model Calibration Ranges

Data Inputs and Computations	Minimum	Maximum
(TTAHOVL-TTAMF)/TTAMF	-0.67	0.02
Percent HOV eligible vehicles in the HOV lane(s)		
• 2+ eligibility	22.4%	77.2%
• 3+ eligibility	75.6%	89.9%
Length of study section (FREQ option only)	5 miles	20 miles
Free-flow speed for freeways	55 mph	65 mph
D/C	---	1.25
Number of sub-periods for peaking characteristics	---	4
Percent HOV change (growth)		
• 2+ eligibility	17%	151%
• 3+ eligibility	11%	125%
(TTAH-TTBH)/TTBH		
• 2+ eligibility	-0.533	-0.030
• 3+ eligibility	-0.241	-0.013
(TTAS-TTAH)/TTBS (3+ eligibility only)	0.077	0.038
Percent non-HOV change (growth)		
• 2+ eligibility	-12%	22%
• 3+ eligibility	-21%	9%
(TTAS-TTBS)/TTBS		
• 2+ eligibility	-0.286	0.018
• 3+ eligibility	0.000	0.303
Length of study section		
• 2+ eligibility	3.0 miles	13.5 miles
• 3+ eligibility	3.7 miles	12.6 miles
Stop criterion	---	10%
Average annual temperature (EMFAC option only)	55°F	95°F
Lane width (1994 HCM option only)	10 feet	---
Average effective green time per cycle (g/cycle)	0.20	0.70

Where: TTAHOVL = Estimated (future) peak period travel time for vehicles in the HOV lane(s)
TTAMF = Estimated (future) peak period travel time for vehicles in the mixed-flow lane(s)
TTAH = Estimated (future) peak period HOV eligible vehicle travel time
TTBH = Existing (before) peak period HOV eligible vehicle travel time
TTAS = Estimated (future) peak period non-HOV eligible vehicle travel time
TTBS = Existing (before) peak period non-HOV eligible vehicle travel time

Purpose: To ***Accept and*** Edit ***Input*** Data

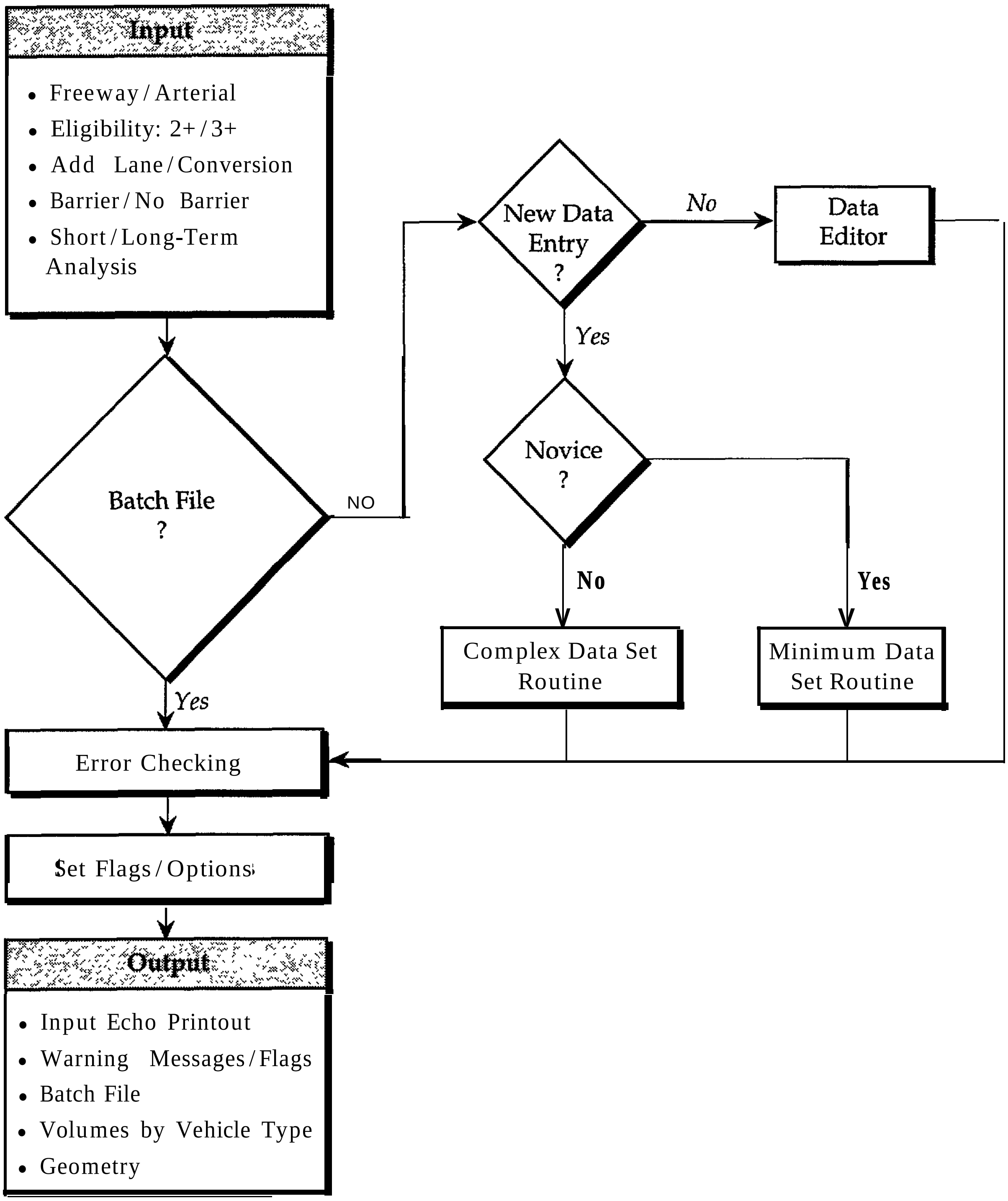


Figure 6.2 Input Module

- Three-or more occupant vehicles (HOV3+);
- Trucks;
- Buses; and
- Motorcycles.

Since trucks, buses, and motorcycles are typically only a small portion of the total traffic volume, average percentage values were calculated from the project data set to be used as defaults. Using the available data sets, percent flows (volumes) versus average vehicle occupancies (AVO) were plotted for each vehicle type. Figure 6.3 shows the lines fitted to the regression equations developed for the SOV and HOV2 vehicle types. Note that the percentage of HOV3+ vehicles is the remaining percentage out of the sum of SOV and HOV2. The equations developed to determine the percentage of SOVs and HOV2s in the total traffic stream based on AVO take the following form:

$$\%\ SOV = [(-0.80 * \text{Average Vehicle Occupancy}) + 1.80] * 100$$

$$\%\ HOV2 = [(0.667 * \text{Average Vehicle Occupancy}) - 0.667] * 100$$

The input and background calculations module distributes the existing (or before) vehicle volumes according to the proposed HOV lane(s) eligibility (HOV eligible or non-HOV eligible). It is assumed that for2+ eligibility, all vehicles carrying two or more persons, buses, and motorcycles are considered HOV eligible. For3+ facilities, all vehicles with three or more persons, buses, and motorcycles are HOV eligible.

The demand model's parameters were estimated based upon actual observations of short-term impacts (six-months to one year); there was minimal data available for long-term impacts. Therefore, if the user is interested in conducting a long-term analysis of the HOV facility (longer than one year), the following equation is applied to the existing volumes input or calculated in this module.

$$\text{Long - term volume} = \text{Existing volume} * \left(1 + \frac{\%\ Growth}{100}\right)^{\text{Number of analysis years}}$$

6.3.2 Allocation Module

The purpose of the allocation module is to allocate the HOV and non-HOV eligible vehicles into the HOV and mixed-flow lane(s). The allocation module framework is presented in Figure 6.4. The necessary inputs for the allocation module include:

- HOV lane(s) eligibility;
- HOV lane(s) barrier availability;
- Violation rate;
- Maximum percentage of peak period HOV eligible vehicles in the HOV lane(s) for the study section;
- Existing (before) peak period travel times for the HOV and mixed-flow lane(s); and
- Existing (before) peak period HOV eligible and non-HOV eligible vehicle volumes.

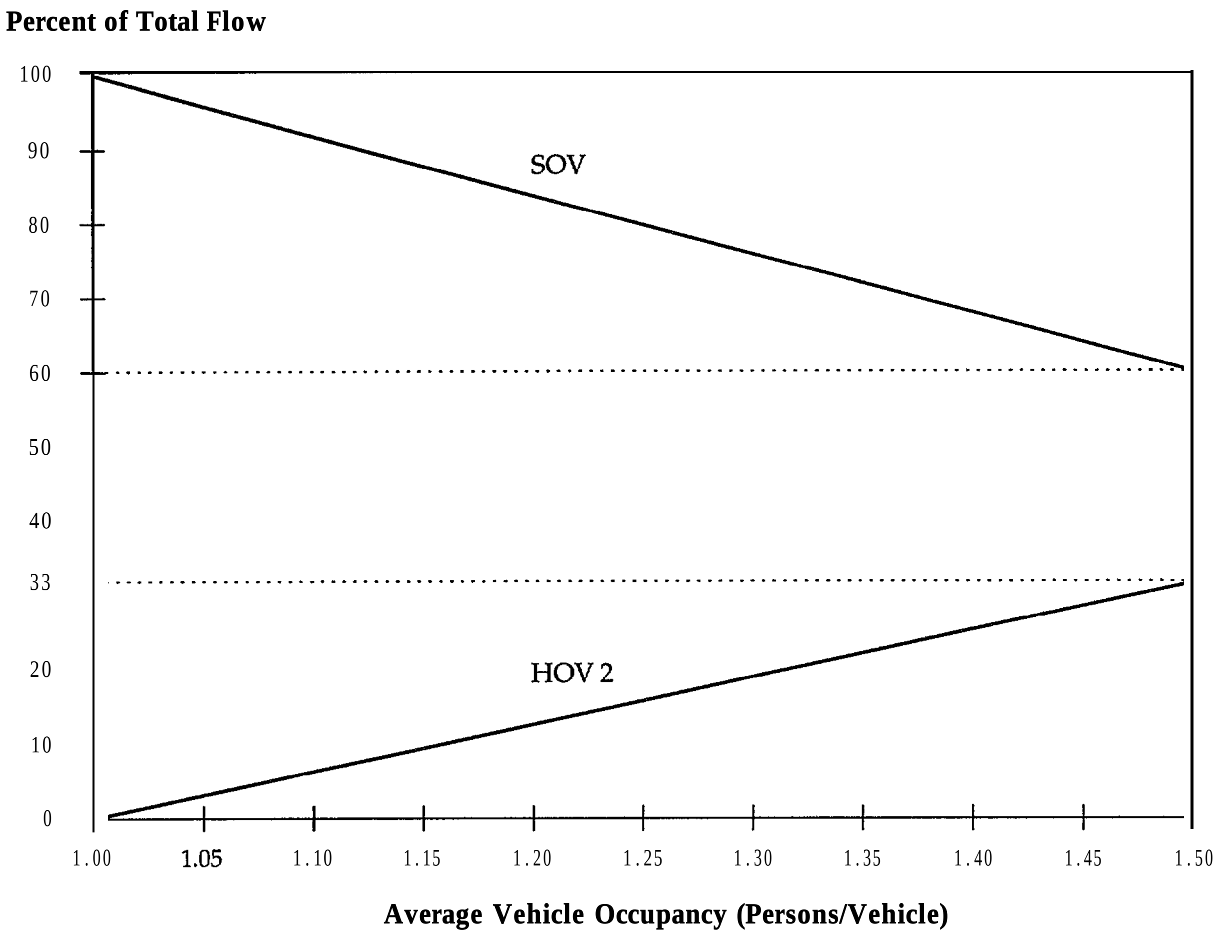


Figure 6.3 Percent Flow vs. Average Vehicle Occupancy (AVO)

Purpose: To Allocate ***Traffic to HOV and Mixed-Flow Lane(s)***

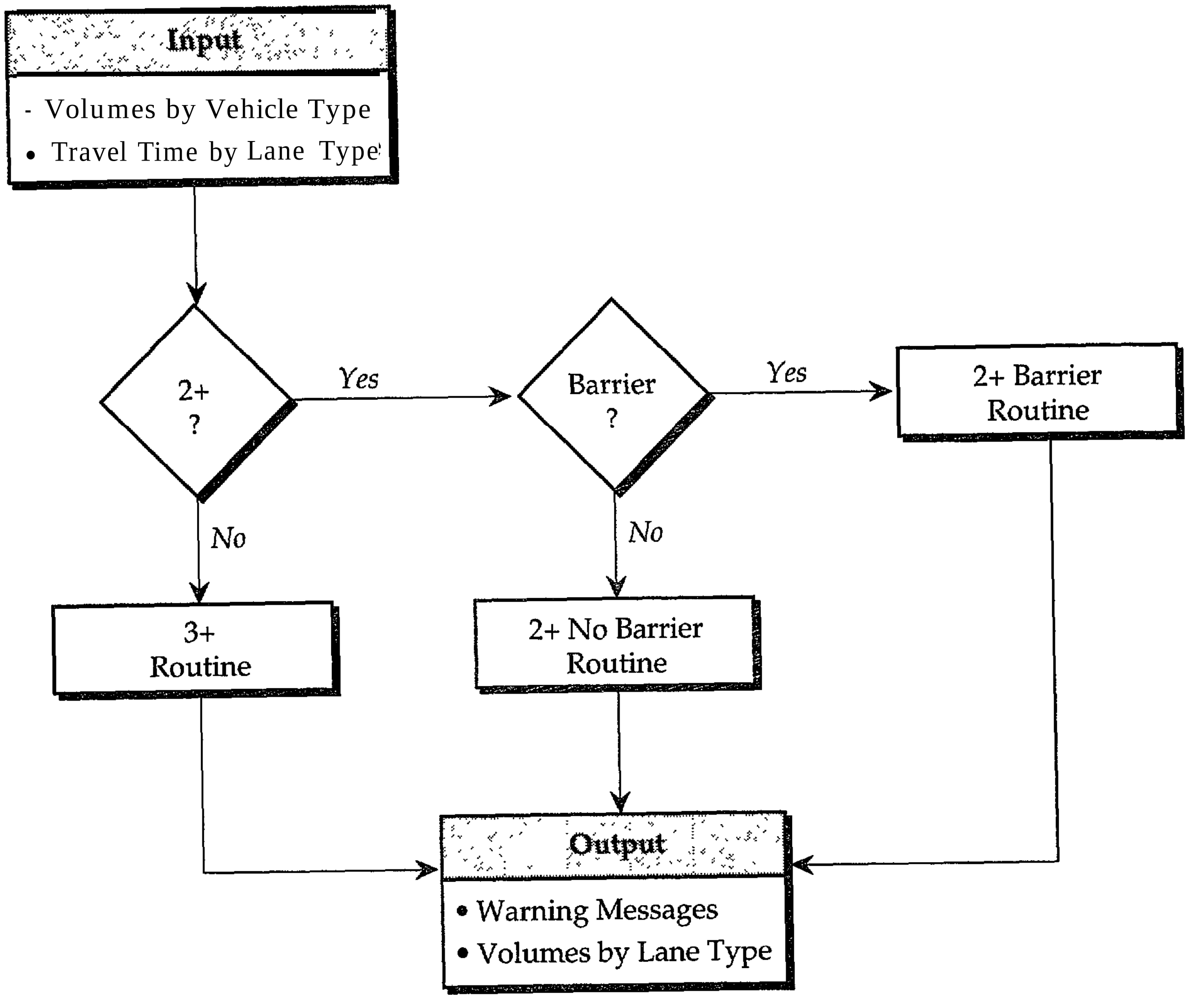


Figure 6.4 Allocation Module

As visible from Figure 6.4, the vehicle volumes are distributed into the HOV and mixed-flow lane(s) using one of three routines depending upon HOV lane(s) eligibility and barrier availability. The three routines include the 2+ barrier routine, the 2+ no-barrier routine, and the 3+ routine (based upon actual data, there is no differentiation between barrier and no-barrier for the 3+ eligibility routine). A barrier-separated HOV facility is defined as a facility separated from the mixed-flow lanes by a stripe or barrier that limits access. Using the available data sets, the percent HOV eligible vehicles in the HOV lane(s) were plotted against the percent differential in travel times between the HOV and mixed-flow lane(s) for each of the three cases. Regression equations were developed from these plots for estimating the percent of HOV eligible vehicles in the HOV lane(s). Figures 6.5 to 6.7 present the plots for each of the three routines. The equations for estimating the percentage of HOV eligible vehicles in the HOV lane are as follows:

- For 2+ eligibility and barrier-separated HOV facilities:

$$\%\,HOVs\ in\ the\ HOV\ lane = \left[0.352 - (1.053) * \left(\frac{TTAHOVL - TTAMF}{TTAMF}\right)\right] * 100$$

Where: TTAHOVL = Estimated (future) HOV lane(s) travel time
TTAMF = Estimated (future) mixed-flow lane(s) travel time
Maximum = 80% or user override
Minimum = 0%

- For 2+ eligibility and no-barrier facilities:

$$\%\,HOVs\ in\ the\ HOV\ lane = \left[0.439 - (0.389) * \frac{(TTAHOVL - TTAMF)}{TTAMF}\right] * 100$$

Where: TTAHOVL = Estimated (future) HOV lane(s) travel time
TTAMF = Estimated (future) mixed-flow lane(s) travel time
Maximum = 80% or user override
Minimum = 0%

- For all 3+ eligible facilities:

$$\%\,HOVs\ in\ the\ HOV\ lane = \left[0.503 - (0.882) * \frac{(TTAHOVL - TTAMF)}{TTAMF}\right] * 100$$

Where: TTAHOVL = Estimated (future) HOV lane(s) travel time
TTAMF = Estimated (future) mixed-flow lane(s) travel time
Maximum = 90% or user override
Minimum = 0%

As evident in the statements following the equations, the user has the capability of overriding the maximum percentage of HOV eligible vehicles using the HOV lane(s).

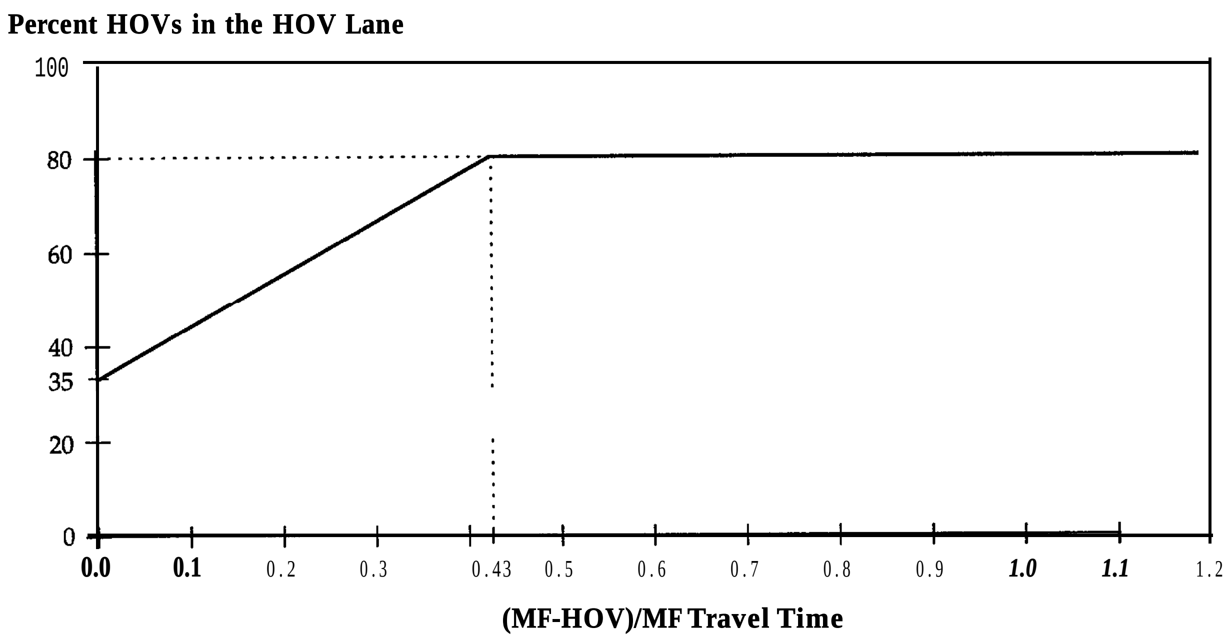


Figure 6.5 HOV 2+/Barrier Allocation Routine

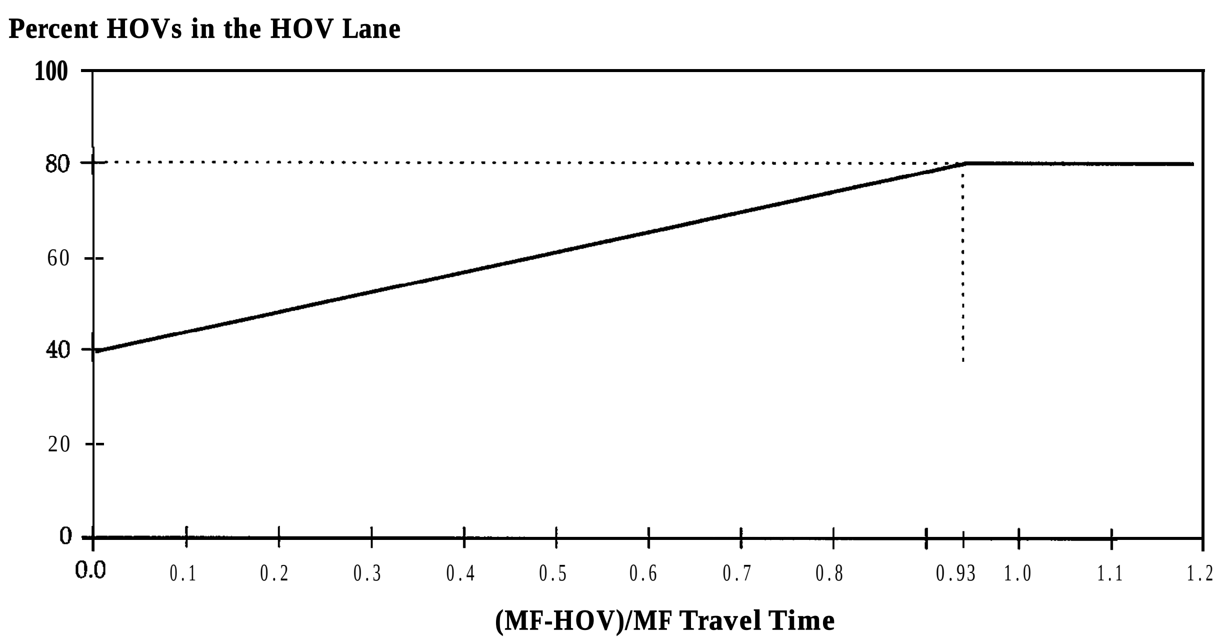


Figure 6.6 HOV 2+/No Barrier Allocation Routine

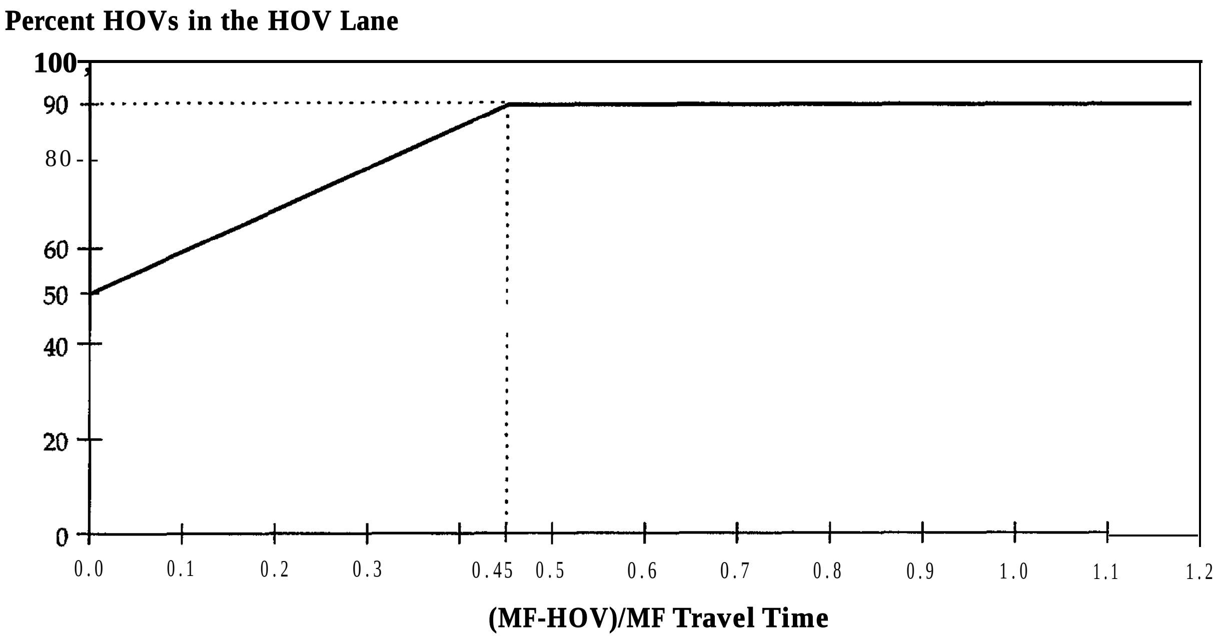


Figure 6.7 HOV 3+ Allocation Routine

The model then estimates the violators in the HOV lane(s) using the following equation and the violation rate input by the user.

$$\begin{bmatrix} Estimated\ violators \\ in\ the\ HOV\ lane(s) \end{bmatrix} = \begin{bmatrix} Estimated\ HOVs\ in\ the \\ HOV\ lane(s)\ volume \end{bmatrix} * \begin{bmatrix} \frac{Violation\ rate}{100} \end{bmatrix}$$

The sum of the HOV eligible vehicles in the HOV lane(s) and the violators is the estimated peak period HOV lane(s) volume. The estimated mixed-flow lane(s) volume is the non-HOV eligible vehicle volume minus the violators in the HOV lane(s) plus the HOV eligible vehicles in the mixed-flow lane(s).

The allocation module is used in three steps within the general model framework as shown in Figure 6.1. Initially it is used to allocate the existing vehicle volumes into each lane type for existing travel times. Using the travel times estimated within the supply module, the volumes are then reallocated for estimating HOV and non-HOV eligible vehicle travel times within the total response module. Finally, the module estimates the HOV and non-HOV eligible total response which must be allocated into the HOV and mixed-flow lane(s) for use in the equilibration, spatial and modal response, and output modules.

6.3.3 Supply Module

The supply module computes the travel times for the HOV and mixed-flow lane(s). Within this module, the travel time computation is different for proposed HOV facilities on a freeway versus an arterial. The inputs to the supply module include:

- Running time calculation option (FREQ or 1994 HCM based);
- Roadway type;
- Length of study section and critical sub-section;
- Length of peak period and peaking characteristics;
- Existing and proposed average ramp meter delay;
- Existing and proposed number of lanes for the study section and/or at critical sub-section;
- Capacity per lane for the study section and/or at the critical sub-section (saturation flow rate for arterials);
- Free-flow speed;
- Existing travel time;
- Peak hour factor (1994 HCM option only);
- Obstructions and distance from obstruction to traveled way (1994 HCM option only);
- Lane width (1994 HCM option only);
- Traffic stream type (1994 HCM option only);
- Percentage of total vehicles which are trucks (1994 HCM option only);
- Percentage of total vehicles which are recreational vehicles (1994 HCM option only);
- Type of terrain (1994 HCM option only);
- Existing and estimated peak period demand (volumes) by lane type for the study section and/or at the critical sub-section;

- Percentage of turns which are from exclusive lanes (for arterials □■●⊠◑▭
- Quality of signal progression (for arterials only);
- Average cycle length (for arterials only);
- Average effective green time (for arterials only);
- Average number of signals per mile (for arterials only); and
- Average signal spacing (for arterials only).

Figure 6.8 presents the structure for the supply module. The supply module computes travel times for the HOV and mixed-flow lane(s) using the basic computation:

[Travel Time] = [Running Time] + [Queue Delay] + [Ramp Meter Delay] + [Travel Time Calibration Value]

For proposed HOV facilities on freeways or arterials, demand to capacity ratios are computed for the critical sub-section and the remainder of the study section to determine if there will be a queue delay. If the demand to capacity ratio (D/C) is greater than one then the queuing delay must be added to the running time, ramp meter delay, and calibration value.

The running time is computed differently for freeways and arterials. Separate computations of running time are performed for the critical sub-section and the remainder of the study section. The total running time for the study section is obtained by summing the two values. There are two alternative procedures used to compute running time for freeways. The options include a FREQ based computation and a 1994 Highway Capacity Manual (HCM) based approach.

The FREQ based running time computation routine is identified in Figure 6.9. This procedure was developed based on supply curves estimated using a series of parametric simulations using the macroscopic simulation model FREQ. The FREQ model was used to estimate the directional freeway study section speed as a function of the freeway critical sub-section demand to capacity ratio. Based upon the D/C and the free-flow speed, the running time in minutes per mile can be estimated and multiplied by the length of the study section to obtain the running time.

The 1994 HCM based option computes the running time according to the equations shown in Figure 6.10 The estimated volume is converted to an ideal volume which is then used to look-up the speed in Figure 3-2 of the HCM. The BPR curve-type equation contained in Figure 6.10 was fitted to the curve in Figure 3-2 of the HCM. The speed obtained from this equation is then multiplied by the section length to obtain the running time.

The methodology for estimating running time for arterial HOV facilities is based upon the techniques described in the arterials chapter of the 1994 HCM. The arterial travel time estimation procedure uses the HCM arterial speed computation routine as presented in Figure 6.11. The running time per mile is estimated based upon the free-flow speed and the average distance between signals computed in the input module. Next the intersection approach delay is computed according to equation 2 in Figure 6.11 The arterial running time is a function of the section length, the average number of signals per mile, the running time between signals, and the average intersection approach delay, and is computed as follows:

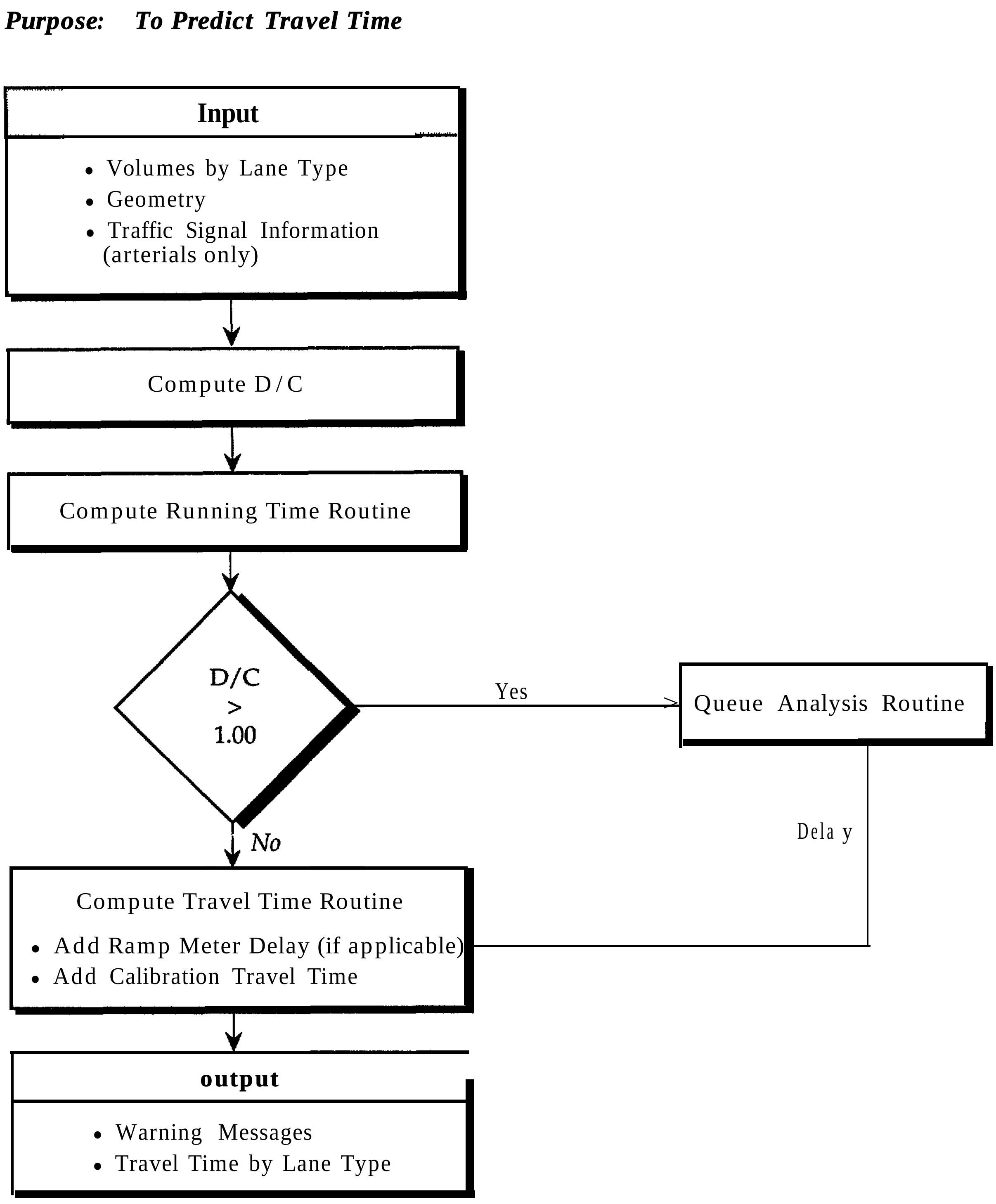
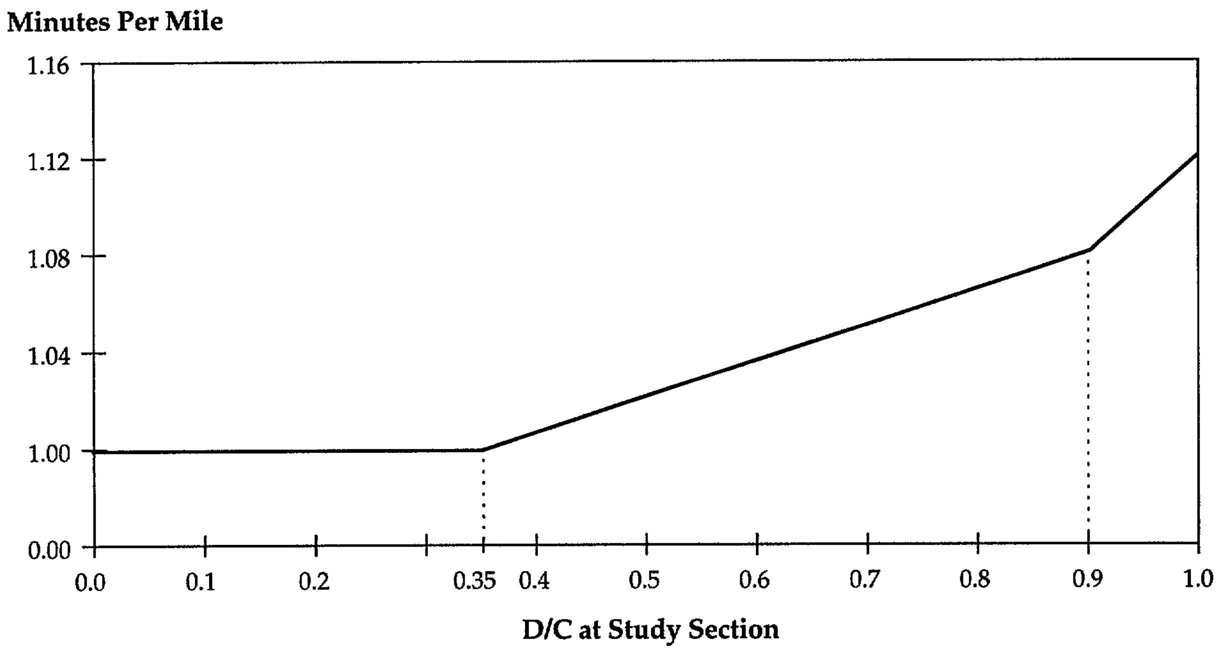


Figure 6.8 Supply Module



If: Dss/C ≤ 0.35

$$\text{Running Time} = \frac{\text{Section length} \cdot 60}{\text{Free - flow speed}}$$

If: 0.35 < Dss/C ≤ 0.90

$$\text{Running Time} = \left[(0.1497 \cdot \text{Dss/C}) + 0.9467 + \left(\frac{60}{\text{Free - flow speed}} - 1\right)\right] * \text{ Section length}$$

If: 0.90 < Dss/C < 1.00

$$\text{Running Time} = \left[(0.3497 \cdot \text{Dss/C}) + 0.7667 + \left(\frac{60}{\text{Free - flow speed}} - 1\right)\right] * \text{ Section length}$$

Figure 6.9
Freeway Running Time Computation Routine - FREQ Based

(1)

$$v_{ideal} = \frac{v_{predicted}}{PHF * f_{width} * f_{heavy\ vehicles} * f_{population}}$$

Where:

v_{ideal}	=	Ideal flow rate to compute speed
$v_{predicted}$	=	Predicted volume (vph)
PHF	=	Peak hour factor
f_{width}	=	Lane width and lateral clearance adjustment factor
$f_{heavy\ vehicles}$	=	Adjustment factor for effect of heavy vehicles
$f_{population}$	=	Driver population adjustment factor

(2)

$$s = \frac{s_f}{1 + a(v/c)^b}$$

Where:

s	=	Predicted mean speed (mph)
s_f	=	Free-flow speed (mph)
v	=	Minimum of v_{ideal} or capacity
c	=	Capacity
a	=	$0.16 + \frac{s_f - 70}{250}$
b	=	$4 + \frac{70 - s_f}{2.5}$

Source: 1994 Highway Capacity Manual

Figure 6.10
Freeway Running Time Computation Routine - 1994 HCM Based

(1)

$$\text{Running time per mile} = \frac{3600}{s_f - a * \exp^{(b*dist)}}$$

Where:

s_f = Free-flow speed (mph)

dist = Average distance between signals (miles)

$$a = 18 + \frac{s_f - 70}{250}$$

$$b = \frac{s_f - 25}{5} - 9$$

(2)

$$D = 1.3 * (d_u * DF + d_i)$$

Where:

d_u = Approach uniform delay (sec/veh)

$$= (0.38) * C * \frac{[1 - (G/C)]^2}{[1 - (G/C) * Min(X, 1.0)]}$$

d_i = Approach incremental delay (sec/veh)

$$= 173 * X^2 * \left\{(X - 1) + \sqrt{(X - 1)^2 + m * (X/C)}\right\}$$

DF = Delay adjustment factor

C = Cycle length (sec)

G = Effective green time for the lane group (sec)

G/C = Green ratio for the subject group

X = Volume/capacity ratio for the subject lane group (if v/c > 1.00, use 1.00)

v = Volume per hour

c = Capacity for the through lane group (vph)

m = Calibration term for incremental delay

D = Approach total delay

Source: 1994 Highway Capacity Manual

Figure 6.11 Arterial Running Time Computation Routine

The arterial running time estimate using this procedure is only valid for volume to capacity ratios (v/c) less than or equal to 1.00. Therefore, if v/c is greater than 1.00, the running time estimated using this process is added to the additional time estimated in the queue analysis routine.

The queue analysis routine is used when the demand to capacity ratio is greater than 1.00. If the demand to capacity ratio is less than 1.00, then the queue delay equals zero. The queue analysis routine is used for both freeway and arterial facilities and is computed separately for the critical sub-section and the remainder of the study section. As shown in Figure 6.12, the queue analysis routine requires data on peaking characteristics to determine the duration of the queue, when the queue occurs, and when the queue clears to estimate the total delay. The graphs in Figure 6.12 show the accumulated volume and queue versus time through the sub-periods. The figure also identifies the model's default values for the peaking characteristics.

Data checks are necessary to verify that the queue will clear during the analysis period. The queue first occurs within the sub-period where the demand rate (V) is greater than the capacity. Next, the sub-period where the queue clears is determined, checking to see if the queue builds again in another period. Total and mean delay are then computed using lane(s) capacities and sub-period lengths and volume rates, using the following equations:

$$\textit{Estimated total delay} = \frac{1}{2}\left[\sum_{i}^{k}(V_i - C_i) * \left[P_i^2 + P_i * \frac{\sum_{j}^{k} P_j * \left(V_j - C_j\right)}{C_{k+1} - V_{k+1}}\right]\right] + R$$

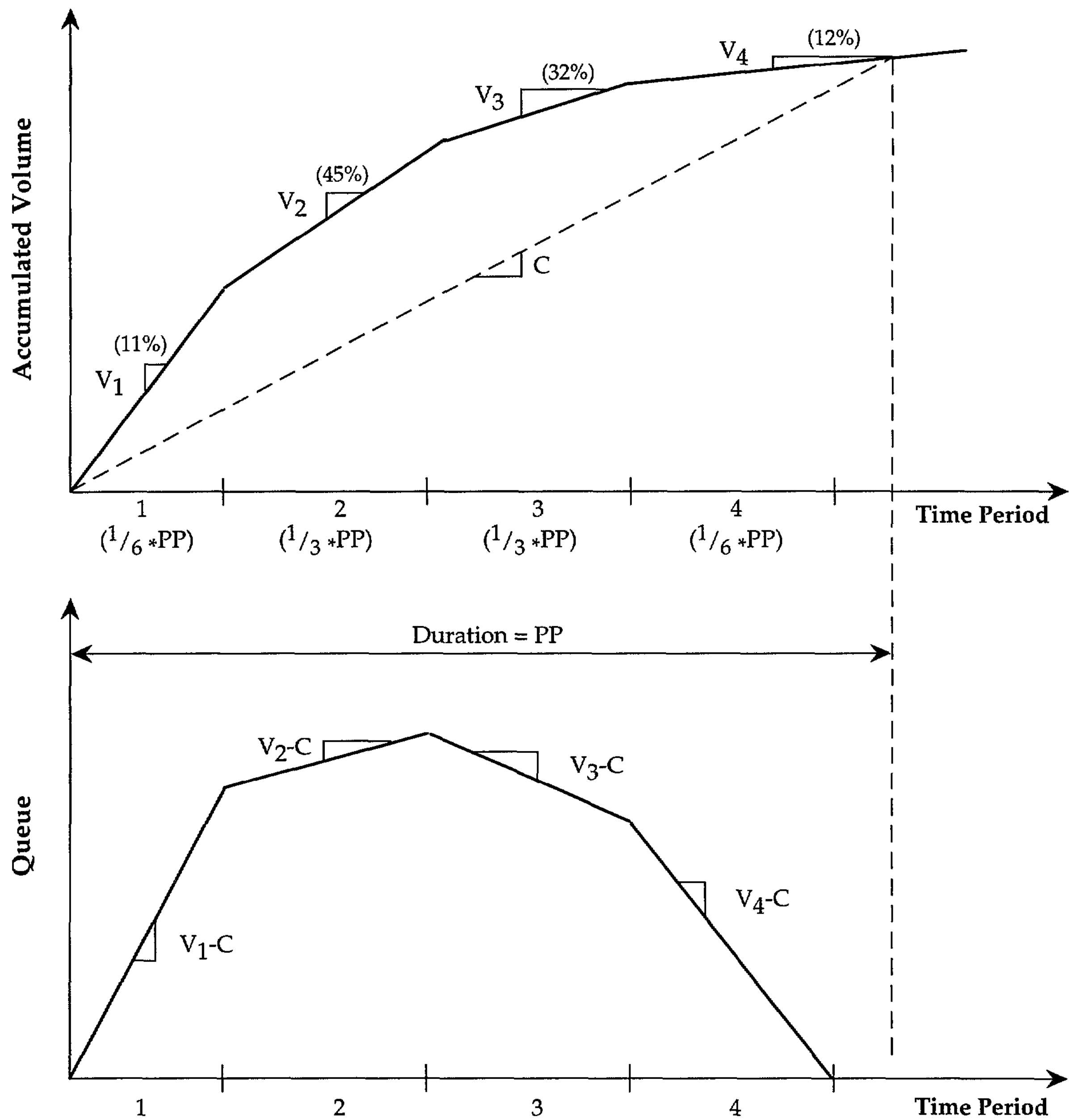
Where: i=j= Number of sub-periods;
P = Length of sub-period in hours;
V = Demand rate;
C = Capacity;

Case	k	R
A	1	0
B	2	$(V_1 - C_1) * P_1 * P_2$
C	3	$[(V_1 - C_1) * P_1 * (P_2 + P_3)] + [(V_2 - C_2) * P_2 * P_3]$

Case A = Queue clears in second sub-period;
Case B = Queue clears in second sub-period; and
Case C = Queue clears in fourth sub-period.

$$\textit{Estimated queuing delay} = \frac{60 * [\textit{Estimated total delay}]}{[\textit{Estimated volume}]}$$

If the facility has either existing or proposed ramp metering, the user has the option of including ramp meter delay in the travel time computation routine. The user needs to input ramp meter delay, in minutes, for the HOV eligible and non-HOV eligible vehicles. Since the model was not calibrated for ramp metering specifically, a warning is issued to the user to that effect. Also, if there is no ramp metering in the existing (before) case, but there is ramp metering proposed for the future facility, a warning is issued to the user that there will be origin and destination discrepancies since ramp metering tends to favor longer trips.



Where:

() = Default values
V = Demand rate (percentage of peak)
C = Capacity
PP = Duration of peak period

Figure 6.12 Queue Analysis Routine (Dcss/C>1.0)

The existing ramp meter delay input by the user is directly input into the travel time calculation. Ideally, for the estimated (future) travel time computation, the estimated user input ramp meter delay should be adjusted after each run of the model. To do this, the estimated demand (volume) output from the total response model and distributed through the allocation module could be input into FREQ and run. The average ramp delay from the FREQ run could then be used as the input in the HOV model. The procedure would be complete when the average ramp delay output from FREQ is approximately equal to the ramp meter delay input by the user.

The travel time calibration term adjusts the forecasted travel times to account for differences between estimated travel time and the observed travel time (user input). The existing travel time is estimated using the supply module routine described above. This travel time estimation uses existing roadway geometrics and demand input by the user. If the estimated travel time is significantly different from observed travel time (greater than 20%), the user must adjust the input capacity values and/or peaking characteristics to more closely reflect input travel times. This difference between the model's estimated existing travel time and the travel time input by the user is added to the running time, queue delay, and ramp meter delay in each iteration to compute total travel times.

6.3.4 Total Response Module

In this step, the HOV model estimates total traveler response to the proposed HOV facility. Several variables influence the demand for HOV facilities including travel time savings in the HOV lane, trip length, household size, vehicle availability, rideshare programs, parking costs, etc. HOV demand models typically express the demand for an HOV facility (dependent variable) as a function of several tangible explanatory variables.

Because the total response model's parameters are estimated based on actual observations, all carpool formation factors and traveler responses to the HOV lane are assumed to be accounted for within the data used for model estimation. Thus, HOV demand models are typically forecasting the total response to the HOV lane which aggregates spatial, temporal, and modal responses. An implicit assumption in the estimation of the HOV model (and a guide in the selection of observation sites) was that apart from the HOV lane, no other major changes have occurred in the locations used in the statistical estimation of the model.

Based on the HOV literature review, HOV lane travel time savings emerged as the primary determinant of HOV demand. Consequently, the total response model was developed to predict total response to the HOV facility based on travel time savings in the HOV lane relative to the existing (before) traffic conditions and relative to mixed-flow lane traffic performance. The total response estimation procedure was developed using before/after and HOV/non-HOV observations from existing HOV facilities around the United States.

Prior to the total response module, the allocation module uses the estimated travel times by lane type to distribute the HOV eligible vehicles into the HOV and mixed-flow lane(s) as described previously. This input is necessary to compute travel times by vehicle type (HOV eligible or non-HOV eligible vehicles) through weighted averages of volumes. The other necessary inputs include:

- Eligibility type;
- Existing average peak period speeds by lane type;
- Length of study section;
- Existing peak period volumes for the study section by eligibility type;
- Estimated peak period travel times by lane type; and
- Estimated peak period HOV eligible vehicle volumes for the study section by lane type.

The total response module framework is shown in Figure 6.13. Separate model parameters were estimated for facilities with different occupancy requirements (2+ and 3+) and are applicable to the following design and occupancy scenarios:

- Add one HOV lane;
- Add two HOV lanes;
- Extending an HOV lane;
- Convert mixed-flow lane to HOV lane;
- Convert occupancy requirement from 3+ to 2+; and
- Convert occupancy requirement from 2+ to 3+.

The model equations for predicting total response are shown in Figure 6.14. These equations were developed by regressing the percent change in vehicle volumes versus the percent change in travel times from the available data sets. The methodology for estimating total response for 2+ eligibility (HOV and non-HOV eligible) and non-HOV eligible in HOV 3+ facilities use dependent variables that describe percent change in travel times from before to after the HOV facility is implemented. The first equation in Figure 6.14 shows an increment of 0.13 which means that a new or converted HOV 2+ facility will generate a minimum of 13 percent growth in HOVs even in the case of no travel time benefit for HOVs from before to after. This growth is probably due to HOVs diverting from parallel facilities onto the new HOV facility. Total response to HOV 3+ facilities is a function of both before/after and HOV/non-HOV travel times. Figures 6.15 and 6.16 contain the plots and corresponding regression equations for the 2+ eligibility models for HOV and non-HOV vehicles, respectively. Each of the observation points used for the development of the model equations is shown and is labeled according to location, barrier availability, and action type.

The percent HOV and non-HOV volume changes computed through this procedure are applied to the existing HOV eligible and non-HOV eligible vehicle volumes to obtain forecasted volumes by vehicle type. Figure 6.17 presents a comparison of results of the total response model to results from other existing models that are used to predict HOV demand. The new methodology, for similar travel time benefits, estimates HOV 2+ total response close to the mid-to-low range of the other models. This is probably reflecting the reduced car-pool mode shares observed in the 1990 Census. The HOV 3+ total response estimate is greater than for HOV 2+, and is in the mid-to-high range of other HOV model estimates since travel time benefits of 3+ HOV lanes are typically greater than travel time benefits of 2+ HOV lanes.

Purpose: To Predict Total Response

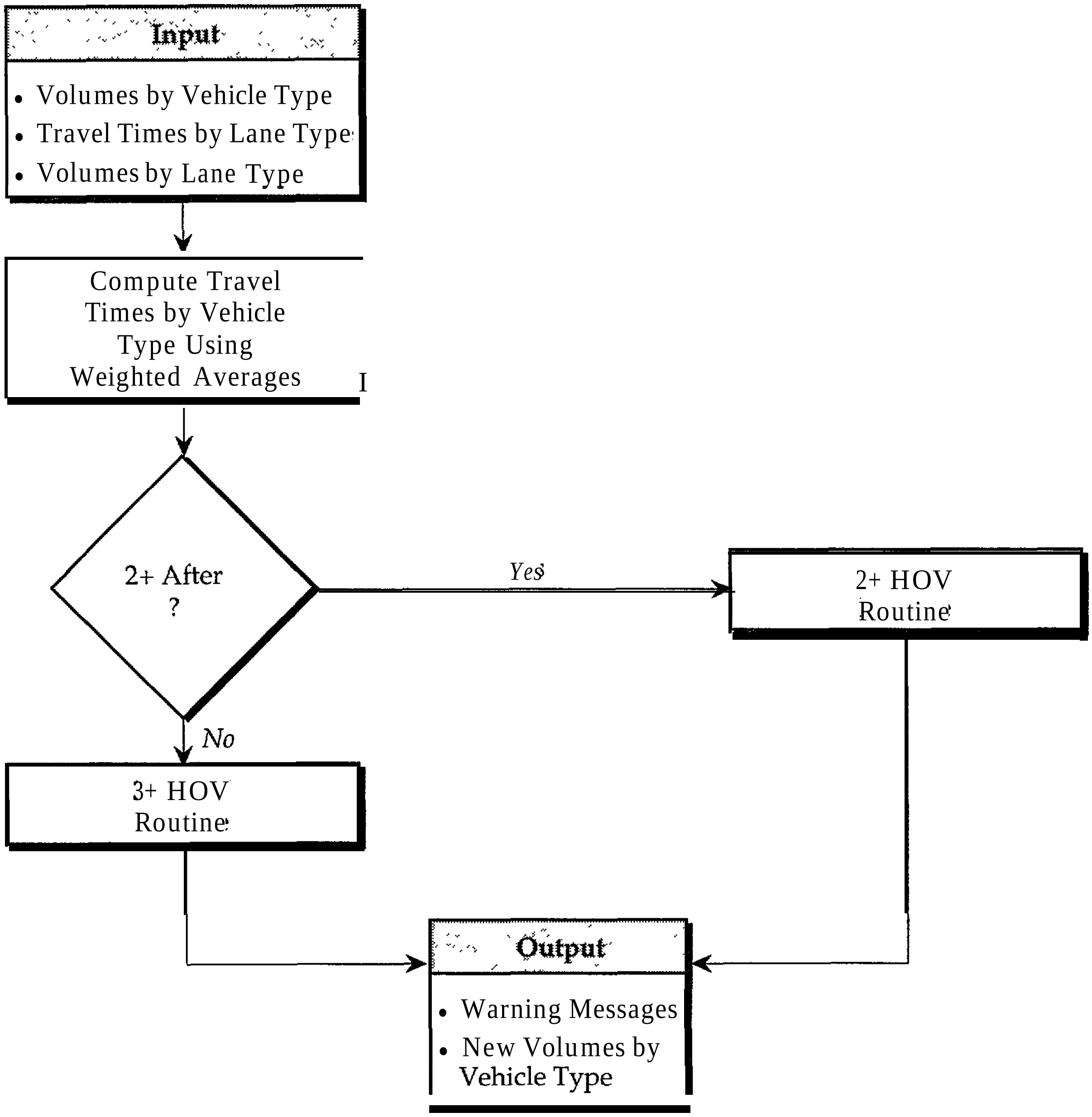


Figure 6.13 Total Response Module

- $Percent\ HOV\ 2+\ Change = 0.13 + 2.11 * \left[\frac{(After - Before)\ Travel\ Time\ for\ HOV\ 2+}{Before\ Travel\ Time\ for\ HOV\ 2+}\right]$
  - T-statistic: (0.50) (2.21)
  - F-statistic = 4.91

- $Percent\ Non\text{-}HOV\ 2+\ Change = 0.48 * \left[\frac{(After - Before)\ Travel\ Time\ for\ Non - HOV\ 2+}{Before\ Travel\ Time\ for\ Non - HOV\ 2+}\right]$
  - T-statistic: (3.24)
  - F-statistic = 6.80

- $Percent\ HOV\ 3+\ Change = 2.72 * \left[\frac{(After - Before)\ Travel\ Time\ for\ HOV\ 3+}{Before\ Travel\ Time\ for\ HOV\ 3+}\right] +$
  - T-statistic: (1.84)

  $$1.41 * \left[\frac{[(Non - HOV 3+) - (HOV\ 3+)]\ After\ Travel\ Time}{Before\ Travel\ Time\ for\ Non - HOV\ 3+}\right]$$
  - T-statistic: (2.42)
  - F-statistic = 3.92

- $Percent\ Non\text{-}HOV\ 3+\ Change = 0.07 + 0.89 * \left[\frac{(After - Before)\ Travel\ Time\ for\ Non - HOV\ 3+}{Before\ Travel\ Time\ for\ Non - HOV\ 3+}\right]$
  - T-statistic: (3.23) (-5.70)
  - F-statistic = 32.54

Figure 6.14 Models for Prediction of Total Response

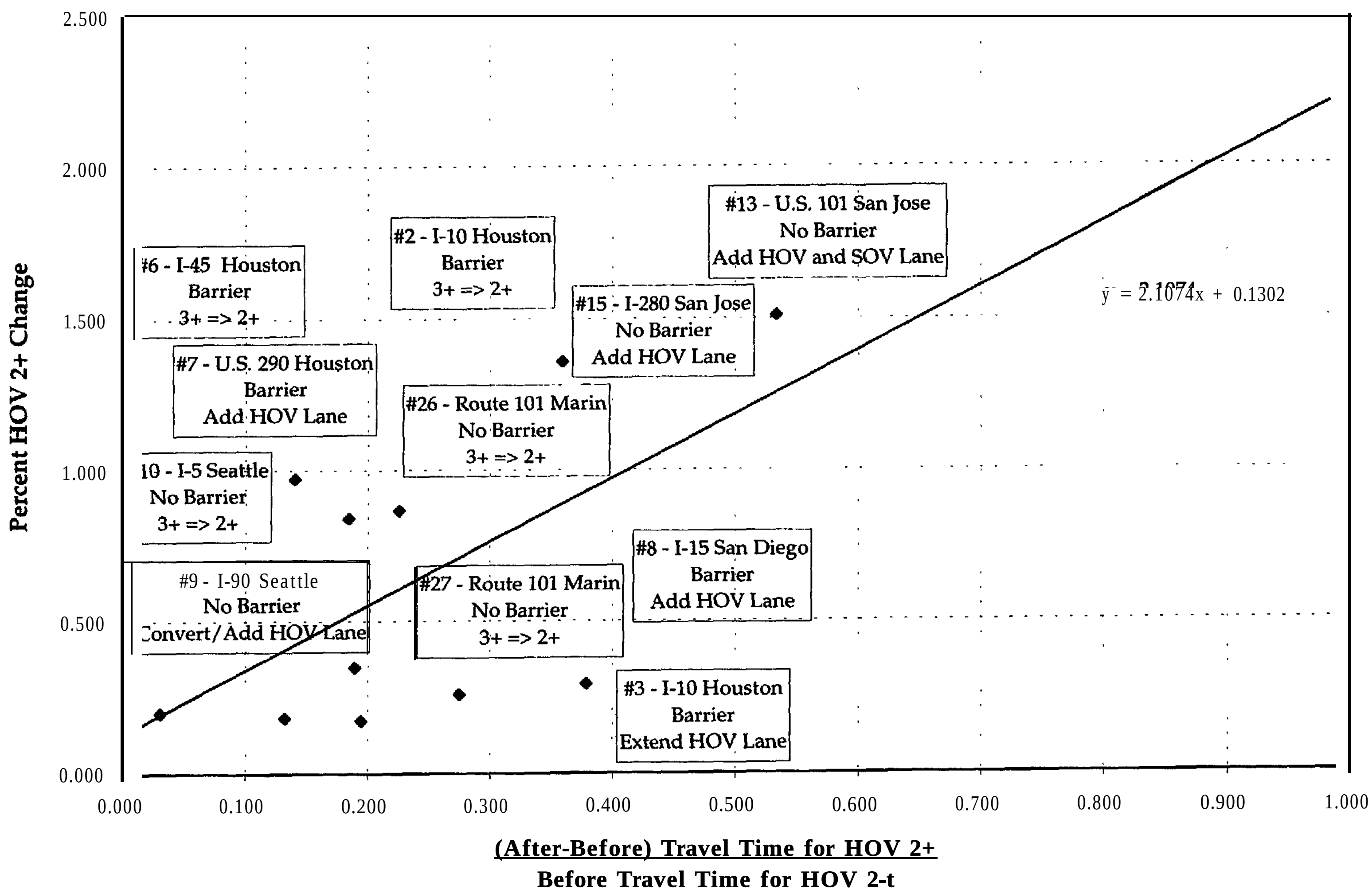


Figure 6.15 Total HOV Eligible Vehicle Response to a 2+ HOV Facility

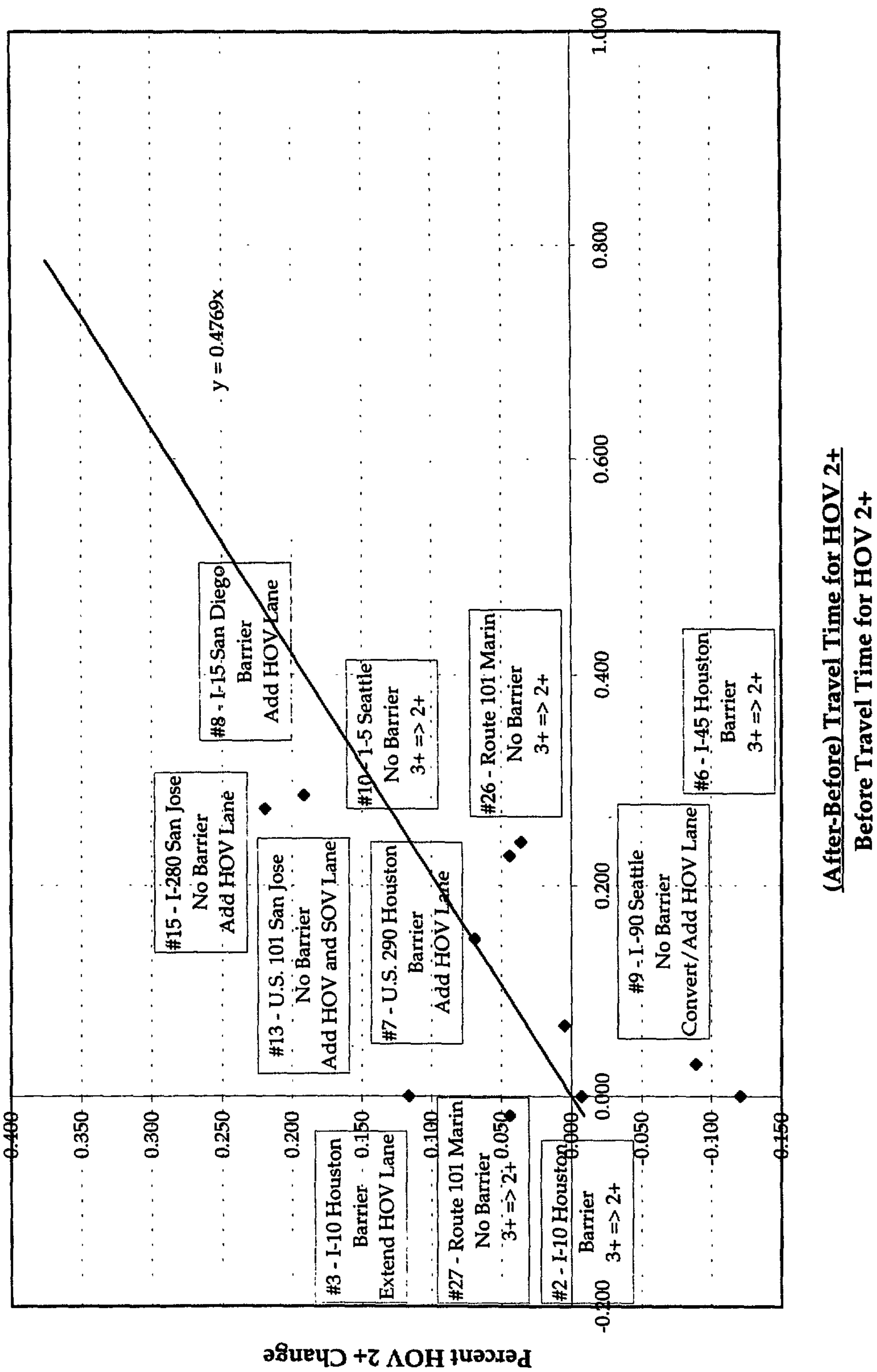


Figure 6.16 Total Non-HOV Eligible Vehicle Response to a 2+ HOV Facility

Figure 6.17 Comparison of Total Response Model to Other HOV Models

	Travel Time Differential (Minutes)			
Model	**Year**	**Before/After**	**HOV/SOV**	**Total HOV Response (Growth)**
Comsis	**1994**	5	---	40%
Shoemaker/Sullivan	1994	---	12	120%
Wesemann (Orange County)	1987	5-9	---	20-30 %
Parody/CRA	1982	**6**	---	**90-230%**
New HOV 2+ Model	**1995**	**6**	**---**	**62-92%**
New HOV 3+ Model	1995	**6**	**6**	**95-155%**

6.3.5 Equilibration Module

Because the estimation of HOV travel time savings is crucial in the prediction of HOV mode shares, and HOV mode shares in turn influence travel times in HOV and mixed-flow lanes, the new HOV model includes an iterative mechanism to couple HOV and mixed-flow total response estimates with traffic performance estimates. Figure 6.18 contains the framework for the equilibration module.

The equilibration module procedure is the same for both freeway and arterial facilities. The data inputs include estimated demand for the study section and iteration closing (stop) criterion. The user is given the flexibility to define a closing criterion that will terminate the loop and proceed with the next step. The closing criterion is expressed in terms of the percent change in vehicle volume by lane type from the previous iteration.

$$\begin{pmatrix} \text{Closing factor} \\ \text{\% difference between} \\ \text{consecutive iterations} \end{pmatrix} = \left| \frac{\begin{bmatrix} \text{Estimated volume} \\ \text{for current iteration} \end{bmatrix} - \begin{bmatrix} \text{Estimated volume} \\ \text{for previous iteration} \end{bmatrix}}{[\text{Estimated volume for previous iteration}]} \right|$$

The criterion must be satisfied (computed percent difference is less than the closing criterion input by the user, or default) for two consecutive iterations before the mode1 proceeds to the next step. If the criterion is not satisfied for both the HOV and mixed-flow lane(s), a weighted average is computed to advance convergence using the following procedure:

$$\left[V_{i+1}\right] = \left(\frac{i-1}{i}\right)V_{i-1} + \left(\frac{1}{i}\right)V_i$$

Where: V = Traffic volume (demand); and
i = Iteration number.

These adjusted vehicle volumes are then used to proceed within the iterative process as inputs into the supply module (see Figure 6.1 – Genera1 Model Structure). If the closing criterion is satisfied then the mode1 proceeds to the spatial and modal response module.

Purpose: To Find Equilibrium

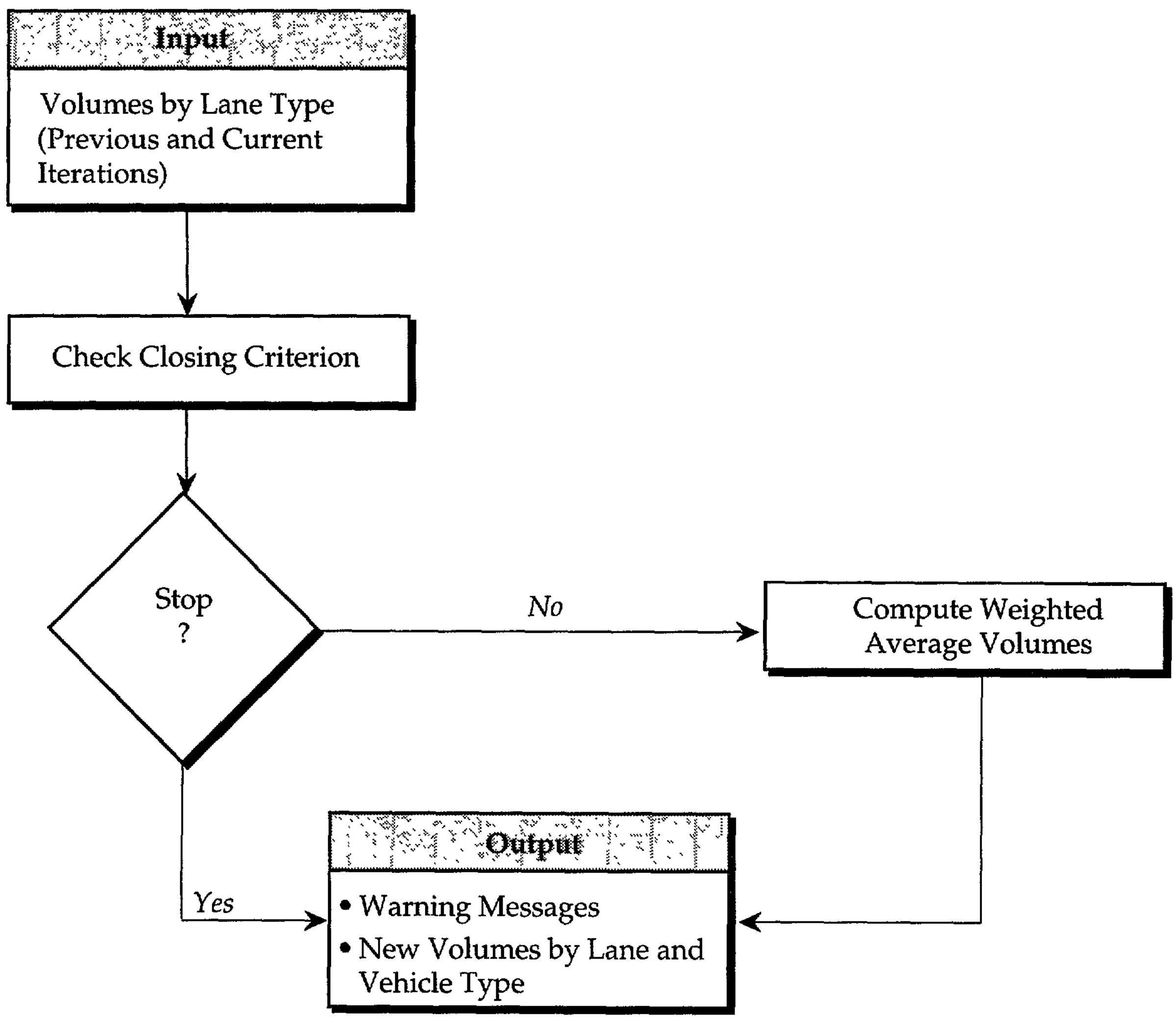


Figure 6.18 Equilibration Module

6.3.6 Spatial and Modal Response Module

The HOV model methodology estimates the total traveler response to the HOV facility including travelers that came from or go to parallel facilities and other modes. Since the model methodology is applied to the peak period, it is assumed that the estimated total response to the HOV facility includes only spatial and modal components but no temporal response. The model addresses the shift between the proposed facility and the parallel route(s) for non-HOV eligible vehicles, HOV eligible vehicles, and buses. The purpose of this module, is to produce a quick estimate of the allocation of the forecasted new HOV demand into spatial and modal components. An overview of the module's framework is contained in Figure 6.19.

Based upon the data available, the model estimates the percentage of HOV lane demand that came from or diverts to another route. The inputs to the spatial and modal response module are:

- Existing peak period vehicle volume by vehicle type;
- Average vehicle occupancies by vehicle type;
- Estimated peak period vehicle volume by vehicle type;
- Spatial and modal response trip table allocation percentages;
- Violation rate; and
- Percent of HOVs in the HOV lane(s).

The module estimates the spatial and model response using a trip distribution type methodology that allocates the estimated trips by their existing mode of travel. A trip matrix is developed which distributes the existing non-HOV, HOV, and bus trips to the estimated (after) non-HOV, HOV, and bus trips on both the facility and the parallel route(s). Table 6.5 presents the spatial and modal trip matrix.

Table 6.5 Spatial and Modal Response Trip Matrix

			After						
			Facility			Parallel Facilities			
			Non-HOV	HOV	Bus	Non-HOV	HOV	Bus	Total
Before	Facility	Non-HOV							
		HOV							
		BUS							
	Parallel Facilities	Non-HOV				0	0	0	
		HOV				0	0	0	
		Bus				0	0	0	
		Total							

The vehicle trips input by the user and estimated in the total response module are converted to person trips using the average vehicle occupancies (AVO) by vehicle type input by the user or the default values. The existing (before) person trip volumes by mode for the facility are input into the row totals. The estimated (after) person trip volumes by mode are input into the column totals. Since there is no information on the trips which remain on the parallel facilities and the methodology needs not to predict them, the cells shown in Table 6.5 with a "0" represent those trips which are on the parallel facilities in both the before and after scenarios.

Purpose: **To *Allocate Response into Spatial and Modal Components***

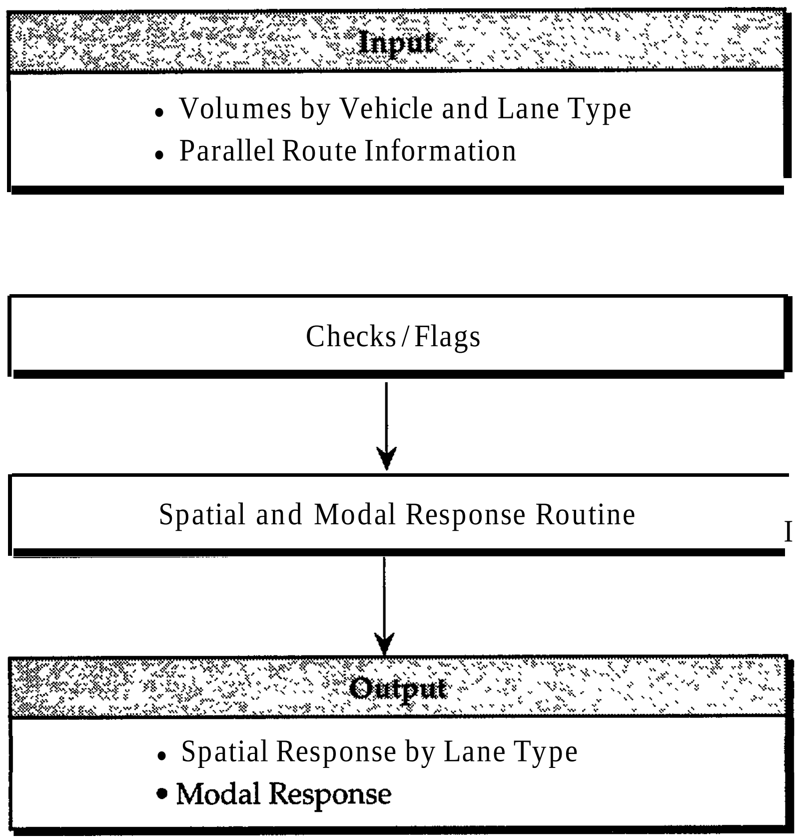


Figure 6.19 Spatial and Modal Response Module

The row and column totals are then be distributed within the trip matrix. The row and column totals for the parallel facilities are then estimated based on the following assumptions:

- If the estimated (after) person trips is greater than the existing (before), the difference is from the parallel facility, and the number of trips going from the facility to the parallel route(s) is zero (see Table 6.6 for the default distribution percentages). If the existing (before) person trips is greater than the estimated (after), the difference went to the parallel facility, with zero trips coming from the parallel route(s) and going to the proposed HOV facility. Table 6.7 presents the default allocation percentages for diversion away from the proposed HOV facility. The estimated (after) parallel facility person trips are distributed among the existing (before) modes using the existing (before) mode split for the proposed facility.
- Total trips going to or coming from the parallel facilities are distributed according to the mode split on the proposed facility. The greater of the existing (before) or the estimated (after) HOV mode split is used.

Table 6.6 Spatial and Modal Trip Table Allocation Percentages for Diversion to the HOV Facility

			After		
			Non-HOV	**HOV**	**Bus**
Before	Facility	Non-HOV	**75%**	**27%**	10%
		HOV	**9%**	**37%**	**35%**
		Bus	1%	**12%**	**50%**
	Parallel Facilities	Non-HOV	13%	**12%**	1%
		HOV	1%	**8%**	1%
		Bus	1%	4%	**3%**
		Total	100%	100%	100%

Table 6.7 Spatial and Modal Trip Table Allocation Percentages for Diversion Away From the HOV Facility

			After						
			Facility			Parallel Facilities			
			Non-HOV	**HOV**	**Bus**	**Non-HOV**	**HOV**	**Bus**	**Total**
Before	Facility	Non-HOV	**75%**	**9%**	1 %	13%	1%	1%	100%
		HOV	**27%**	**37%**	**12%**	**12%**	**8%**	**4%**	100%
		Bus	10%	**35%**	**50%**	1%	1%	3%	100%

The user has the option of overriding these values. The HOV percentages contained in Table 6.6 are based on the Houston North Freeway Survey (1990) and are similar to the results from a Minneapolis survey conducted in 1989.

The estimated trip table is then revised so that the sum of cell values add up to the correct before row totals. A FRATAR row and column factoring process is used until the cell entries sum to the desired row and column totals.

The closing criterion for the FRATAR factoring process is 1% of 1 .00 (ratio of current value over previous iteration value).

Once the closing criterion for the FRATAR factoring process is satisfied, the resulting person trip table is converted back to vehicles using the average vehicle occupancy values by mode. The resulting vehicle trips are then distributed by lane type according to the percentage of HOV eligible vehicles in the HOV lane computed in the allocation module.

6.3.7 Output Module

In this step the model computes, summarizes, and reports final measures of performance as shown in Figure 6.20. Figure 6.2 1 presents an overview of the output module structure. The measures of performance estimated within the model framework include:

- Vehicle and person volumes;
- Travel time;
- Vehicle and person miles of travel;
- Vehicle and person hours of travel;
- Vehicle and person delay;
- Air quality/emissions; and
- Fuel consumption.

Each of these measures is estimated by lane type (HOV and mixed-flow lane(s)) and by analysis period (existing, short-term and/or long-term) in either English or metric units. In addition, spatial response by lane type is evaluated for the air quality/emissions and fuel consumption performance measures to provide a means to effectively assess the net effect of the proposed HOV facility.

The inputs required for the output module include:

- Air quality calculation option (EMFAC or MOBILE 5a);
- Average speed on parallel roadways;
- Analysis period;
- Average annual temperature (EMFAC option only);
- Percentage of total vehicles which are trucks (gas versus diesel), buses, and motorcycles;
- Average vehicle occupancy for HOV3+ and buses;

Vehicle Volumes	Before			Short-Term			Long-Term		
	HOV Lane(s)	Mixed-Flow Lanes	Total	HOV Lane(s)	Mixed-Flow Lanes	Total	HOV Lane(s)	Mixed-Flow Lanes	Total
SOVs									
HOV 2									
HOV 3+									
Buses									
Trucks									
Motorcycles									
Total									

Person Volumes	Before			Short-Term			Long-Term		
	HOV Lane(s)	Mixed-Flow Lanes	Total	HOV Lane(s)	Mixed-Flow Lanes	Total	HOV Lane(s)	Mixed-Flow Lanes	Total
SOVs									
HOV 2									
HOV 3+									
Buses									
Trucks									
Motorcycles									
Total									
AVO									

Measure of Performance	Before			Short-Term			Long-Term			Spatial Response			Net Effect	
	HOV Lane(s)	Mixed-Flow Lanes	Total	HOV Lane(s)	Mixed-Flow Lanes	Total	HOV Lane(s)	Mixed-Flow Lanes	Total	HOV Lane(s)	Flow Lanes	Total	Short-Term to Existing	Long-Term to Existing
Vehicle Volume														
Person Volume														
Travel Time (min)														
VMT														
PMT														
VHT														
PHT														
Vehicle Delay (hrs)														
Person Delay (hrs)														
HC (kg)														
CO (kg)														
NOx (kg)														
Fuel (gallons)														

Figure 6.20 Output Tabulations

Purpose: To ***Compute Outputs***

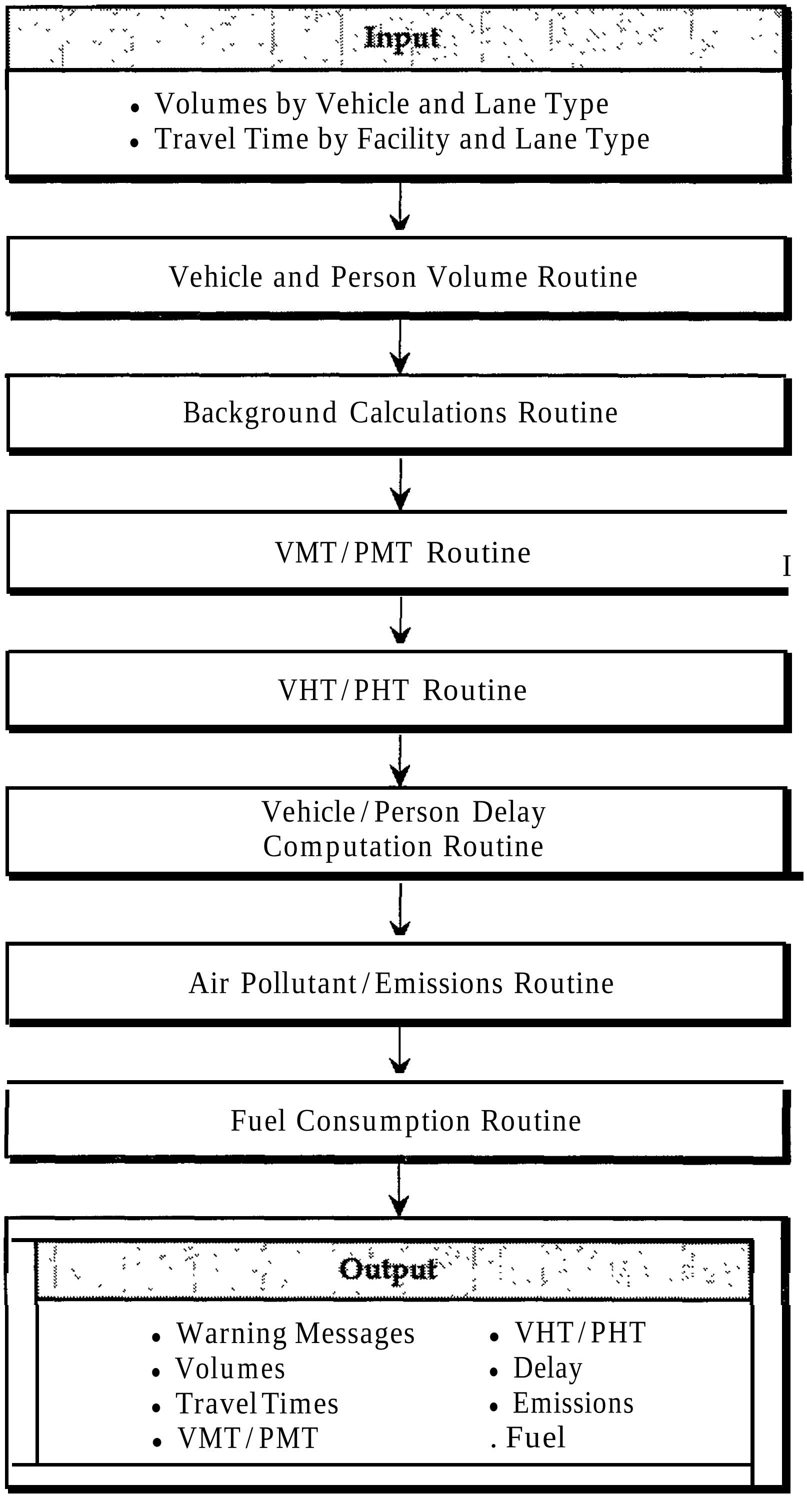


Figure 6.21 Output Module

Existing and estimated (future) peak period vehicle volumes by lane and vehicle type;

- Length of study section;
- Free-flow speed;
- Existing and estimated (future) peak period travel times by lane type;
- Percentage of HOV eligible vehicle volume in the HOV lane(s); and
- Estimated peak period spatial and modal response.

Vehicle volumes estimated by the total response model are first allocated by vehicle and lane type according to the input (or default) percentages of trucks, buses, and motorcycles. SOV, HOV2, and HOV3+ volumes by lane type are then determined according to the equations in Figure 6.22. The procedure for distributing the total volumes by lane type is different for 2+ versus 3+ eligibility. The 0.86 and 0.88 factors shown in the equations are percentages estimated from actual data collected and utilized in the total response model.

Occupancy rates for computing person volumes are based upon the following values:

Table 6.8 Occupancy Rates by Vehicle Type

Vehicle Type	Occupancy (Persons per Vehicle)
SOV	1
HOV2	2
HOV3 +	User input or default (3.4)
Truck	1
Bus	User input or default (32)
Motorcycle	1

Impacts are estimated as follows:

- Vehicle miles of travel (VMT) is computed by lane type and for the total study section, as shown in **the** following equation:

$$VMT = [Vehicle\ volume] * [Length\ of\ study\ section]$$

- Person miles of travel (PMT) is computed by multiplying the estimated VMT by the average vehicle occupancy.
- Vehicle hours of travel (VHT) by lane type and for the total study section is estimated according to the following equation:

$$WIT = [Vehicle\ volume] * \frac{[Travel\ \ time]}{60}$$

The 60 value in this equation converts the travel time from minutes to hours.

For 2+ eligibility

- $\left[Total\ SOV\ volume\right] = \left[Non - HOV\ eligible\ vehicle\ volume\right] - \left[Total\ truck\ volume\right]$

- $\left[SOV\ volume\ in\ the\ HOV\ lane(s)\right] = \left[HOV\ lane(s)\ volume\right] - \dfrac{\left[HOV\ lane(s)\ volume\right]}{\left[1 + \dfrac{Violation\ rate}{100}\right]}$

- $\begin{bmatrix} SOV\ volume\ in\ the \\ mixed - flow\ lane(s) \end{bmatrix} = \left[Total\ SOV\ volume\right] - \left[SOV\ volume\ in\ the\ HOV\ lane(s)\right]$

- $\left[Total\ HOV2\ volume\right] = \left[\begin{bmatrix} HOV\ eligible \\ vehicle\ volume \end{bmatrix} - \begin{bmatrix} Total\ bus \\ volume \end{bmatrix} - \begin{bmatrix} Total\ motorcycle \\ volume \end{bmatrix}\right] * 0.88$

- $\left[HOV2\ volume\ in\ the\ HOV\ lane(s)\right] = \left[Total\ HOV2\ volume\right] * \left[\dfrac{\%\ HOVs\ in\ the\ HOV\ lane(s)}{100}\right]$

- $\begin{bmatrix} HOV2\ volume\ in\ the \\ mixed - flow\ lane(s) \end{bmatrix} = \left[Total\ HOV2\ volume\right] - \left[HOV2\ volume\ in\ the\ HOV\ lane(s)\right]$

- $\begin{bmatrix} Total \\ HOV3+ \\ volume \end{bmatrix} = \begin{bmatrix} Total \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ truck \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ bus \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ motorcycle \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ SOV \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ HOV2 \\ volume \end{bmatrix}$

- $\begin{bmatrix} HOV3+volume\ in \\ the\ HOV\ lane(s) \end{bmatrix} = \begin{bmatrix} HOV\ lane(s) \\ volume \end{bmatrix} - \begin{bmatrix} Truck\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix} - \begin{bmatrix} Bus\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix} - \begin{bmatrix} Motorcycle\ volume \\ in\ the\ HOV\ lane(s) \end{bmatrix} - \begin{bmatrix} SOV\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix} - \begin{bmatrix} HOV2\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix}$

- $\begin{bmatrix} HOV3+volume\ in\ the \\ mixed - flow\ lane(s) \end{bmatrix} = \left[Total\ HOV3+volume\right] - \left[HOV3+volume\ in\ the\ HOV\ lane(s)\right]$

Figure 6.22
Equations for Distribution of Volumes by Vehicle and Lane Types

For 3+ eligibility

- $$\left[Total\ SOV\ volume\right] = \left[\left[Non-HOV\ eligible\ vehicle\ volume\right] - \left[Total\ truck\ volume\right]\right] * 0.86$$

- $$\left[SOV\ volume\ for\ the\ HOV\ lane(s)\right] = \left[\left[HOV\ lane(s)\ volume\right] - \frac{\left[HOV\ lane(s)\ volume\right]}{\left[1 + \frac{Violation\ rate}{100}\right]}\right] * 0.86$$

  $$\begin{bmatrix} SOV\ volume\ in\ the \\ mixed-flow\ lane(s) \end{bmatrix} = \left[Total\ SOV\ volume\right] - \left[SOV\ volume\ in\ the\ HOV\ lane(s)\right]$$

- $$\left[Total\ HOV2\ volume\right] = \begin{bmatrix} Non-HOV\ eligible \\ vehicle\ volume \end{bmatrix} - \left[Total\ truck\ volume\right] - \left[Total\ SOV\ volume\right]$$

- $$\begin{bmatrix} HOV2\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix} = \left[\left[HOV\ lane(s)\ volume\right] - \frac{\left[HOV\ lane(s)\ volume\right]}{\left[1 + \frac{Violation\ rate}{100}\right]}\right] - \begin{bmatrix} SOV\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix}$$

- $$\begin{bmatrix} HOV2\ volume\ in\ the \\ mixed-flow\ lane(s) \end{bmatrix} = \left[Total\ HOV2\ volume\right] - \left[HOV2\ volume\ in\ the\ HOV\ lane(s)\right]$$

- $$\begin{bmatrix} Total \\ HOV3+ \\ volume \end{bmatrix} = \begin{bmatrix} Total \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ truck \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ bus \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ motorcycle \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ SOV \\ volume \end{bmatrix} - \begin{bmatrix} Total \\ HOV2 \\ volume \end{bmatrix}$$

- $$\begin{bmatrix} HOV3+volume\ in \\ the\ HOV\ lane(s) \end{bmatrix} = \begin{bmatrix} HOV\ lane(s) \\ volume \end{bmatrix} - \begin{bmatrix} Truck\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix} - \begin{bmatrix} Bus\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix} - \begin{bmatrix} Motorcycle\ volume \\ in\ the\ HOV\ lane(s) \end{bmatrix} - \begin{bmatrix} SOV\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix} - \begin{bmatrix} HOV2\ volume\ in \\ the\ HOV\ lane(s) \end{bmatrix}$$

- $$\begin{bmatrix} HOV3+volume\ in\ the \\ mixed-flow\ lane(s) \end{bmatrix} = \left[Total\ HOV3+volume\right] - \left[HOV3+volume\ in\ the\ HOV\ lane(s)\right]$$

Figure 6.22 (continued)
Equations for Distribution of Volumes by Vehicle and Lane Types

- Person hours of travel (PHT) is estimated similar to PMT, by multiplying VHT by average vehicle occupancy.

The output module then computes vehicle hours of delay which is measured as the difference between the estimated travel time from the model and the free-flow speed travel time. Vehicle hours of delay is calculated as follows:

$$\text{Vehicle hours of delay} = VHT * \frac{VMT}{\text{Free - flow speed}}$$

- Person hours of delay is the vehicle hours of delay times the average vehicle occupancy.

Emissions impacts are estimated by lane type, for the total study section, and for spatial shift through one of two options. The user has the option of using EMFAC or MOBILE 5a emission rates. The emission rates included within both options are in grams per mile and include hydrocarbons (HC), carbon monoxide (CO), and nitrous oxides (NO_X). The EMFAC option emission rates are based on travel speeds; existing (19 95) versus long-term analyses (2010); various ambient temperatures (55°F to 95°F); and separate vehicle types (autos, gas trucks, and diesel trucks). Interpolation may be required for analysis years or temperatures which fall between the values available. The MOBILE 5a option includes separate emission rates based on speed and vehicle type (autos versus trucks/buses). The emission rates for both EMFAC and MOBILE 5a are shown in Appendix E.

The methodology for computing the emissions assumes that there are no trucks in the HOV lane(s). Emissions are computed in kilograms based upon the following equations:

$$[\text{HOV lane(s) emissions}] = \frac{[[\text{HOV lane(s) VMT}] * [\text{Emission rate for autos}]]}{1000}$$

$$\begin{bmatrix}\text{Mixed} - \text{flow} \\ \text{lane(s) emissions}\end{bmatrix} = \frac{[\text{Length of study section}] * \left[\begin{matrix}\left[\begin{pmatrix}\text{Autos in the mixed} - \\ \text{flow lane(s) volume}\end{pmatrix} * \begin{pmatrix}\text{Emission rate} \\ \text{for autos}\end{pmatrix}\right] + \\ \left[\begin{pmatrix}\text{Total gas} \\ \text{truck volume}\end{pmatrix} * \begin{pmatrix}\text{Emission rate} \\ \text{for gas trucks}\end{pmatrix}\right] + \\ \left[\begin{pmatrix}\text{Total diesel} \\ \text{truck volume}\end{pmatrix} * \begin{pmatrix}\text{Emission rate} \\ \text{for diesel trucks}\end{pmatrix}\right]\end{matrix}\right]}{1000}$$

$$\begin{bmatrix}\text{Emissions for} \\ \text{spatial responders}\end{bmatrix} = \frac{[[\text{Spatial response}] * [\text{Emission rate for autos}]]}{1000}$$

If vehicles divert from parallel facilities to the proposed HOV facility, a reduction in emissions can be taken after implementation of the new HOV facility. If vehicles divert away from the proposed HOV facility, some of the decrease in demand on the facility went to parallel roadways. Therefore, the emissions for spatial responders should be added to the after case to reflect the shift of autos now traveling at parallel facility speeds.

Fuel consumption is estimated similar to emissions. Fuel consumption rate tables, in gallons per mile, are provided in Appendix F. Fuel consumption rates are based upon facility type (freeway or arterial), vehicle type (autos, gas trucks, and diesel trucks), and travel speeds. Fuel consumption values are computed for HOV lane(s), mixed-flow lane(s), the total facility, and for spatial response.

6.4 Implementation

The research results of this report have been implemented in a software product known as Quick-HOV, which provides an analysis and planning tool for HOV facilities based on the model developed herein. The Quick-HOV software model is designed to provide a quick analysis of HOV lane demand and operations.

The program is designed to evaluate the impacts of:

1. Constructing new HOV lane(s)
2. Extending existing HOV lane(s)
3. Changing the eligibility requirements of existing HOV lane(s).

The program is a "quick response" method that evaluates the impacts of HOV lanes for a single direction of travel over a single peak period for arterials and freeways. To analyze both directions of travel, the model is simply run again for the opposite travel direction. The procedures allow the user to predict and evaluate the impacts of HOV lanes on person demand, vehicle demand, auto occupancy, congestion, delay, and air quality. The program produces detailed tabulations of vehicles, persons, vehicle-miles traveled (VMT), vehicles-hours traveled (VHT), delay, delay per vehicle, fuel consumption, and air pollutants. The detailed tabulations show the number of persons or vehicles by vehicle type for the HOV lane(s) and the mixed-flow lane(s) for the before, opening day, short range, and long range conditions. A summary table aggregates these values for all vehicles on the entire study section.

6.4.1 Program Input Data

The program allows two modes of input. The data can be entered interactively or as an ASCII batch file. The interactive form allows the user to provide a minimum set of data or a more complex set of data. The program uses defaults to create a complete data set from the minimum data set.

Regardless of the input mode, the user needs to provide a project description and the project demand data. The project description includes

General Facility Data

- Facility Type
- Length
- Number of Through Lanes
- Capacity/Lane (vphpl)
- Free-Flow Speed
- Average Peak Period Travel Time (optional)
- Barrier-separated?
- HOV Lane Eligibility by vehicle type

Arterial Facility Data

- Lane Width
- Shoulder Width
- Terrain Type
- Ramps per mile
- Barrier Entry/Exits per mile
- Percent RVs
- Signals Per Mile
- Cycle Length (sec)
- Green/Cycle
- Quality of Progression
- Exclusive Left Turn Lanes?
- Percent Turns from Exclusive Lanes

The facility data is supplied for both the HOV lane(s) and the mixed-flow lane(s). The data for the study section can be divided into a critical subsection and the rest of the study section. These data are needed for both the existing and the proposed conditions. The critical subsection is the portion of the study section that has the highest demand to capacity ratio and functions as the "controlling" subsection. The user does not have to specify a critical subsection, if the demand or capacity across the study section does not differ by more than ten percent.

The user must also provide the existing demand data for the study section. The demand data can be entered as a summary demand data set or a complete demand data set. The complete data set includes the demand by vehicle type for each lane type in the critical subsection and the rest of the study section. The demand data also includes information on the following:

Length of peak period

Ramp meter delay by vehicle type

Mean trip length by vehicle type

6.4.2 Summary of Model Components

The Quick-HOV model is a "quick response" tool for predicting order-of-magnitude HOV and mixed-flow demand and traffic performance. The Quick-HOV software can be considered a screening tool used to evaluate traffic performance and impacts on opening day, short-term (six months to a year) and long term (after one or more years).

The model is divided into seven distinct modules. Each module is briefly described below.

Input Module	Accepts and edits data
Lane Allocation Module	Allocates vehicles to the HOV and mixed-flow lanes.
Travel Time Module	Calculates the travel time for the HOV and mixed-flow lanes.
Weighted Travel Time Module	Calculates the average weighted travel time by vehicle type.
Response (Demand) Module	Determines the growth in HOV and mixed-flow traffic due to the travel time savings of the proposed HOV project.
Equilibration Module	Checks closing criteria
Output Module	Calculates the measures of performance for the proposed HOV project.

6.4.3 Hardware Requirements

Minimum computer hardware needed to run the Quick-HOV program includes the following:

- An IBM-compatible micro-computer with at least a 386/486 microprocessor
- MS-DOS version 3.0 or later
- At least 0.5 Mb of hard disk space for the program files.

The software is a stand-alone MS-DOS™ program which runs either in the MS-DOS™ mode or under the Windows™ environment. All input and output files are stored on the hard disk in ASCII format, which allows interfacing with other traffic analysis software.