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16. Abstract

This research report presents an assessment of the feasibility of validating the Shirley Highway (I-395) High-Occupancy Vehicle (HOV) Lane Demand Model in Texas. The results of the study suggest that the Shirley Model has not been sufficiently developed at this time to warrant additional testing outside the Shirley corridor. In fact, additional testing within the Shirley corridor will be needed to determine whether the preliminary model represents the "best" model that could be estimated from the dataset, and whether the model can accurately replicate travel choice decisions observed in the Shirley corridor. A review of currently available alternatives to the Shirley Model is also presented. While these procedures could be used to develop a range of demand estimates that appear reasonable for many sketch planning applications, they are still fairly crude and more refined estimation procedures are clearly needed. It is recommended that any additional efforts to validate the Shirley Model in Texas be undertaken through a separate research project and that local efforts focus on the development of HOV lane demand estimation procedures based on experiences gained in operating HOV facilities in Texas. These two independent, though clearly complementary, efforts should be closely coordinated to facilitate a possible merging of efforts at some time in the future.

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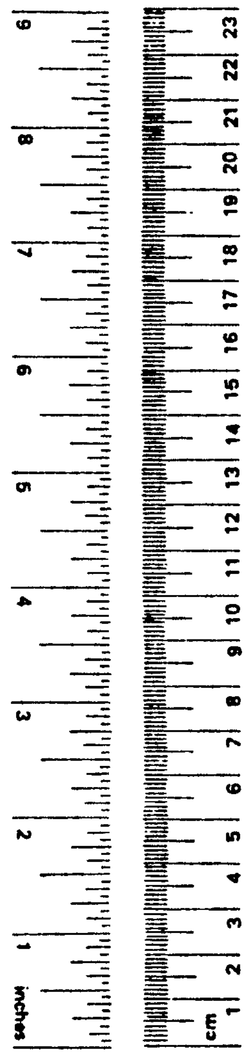
METRIC CONVERSION FACTORS

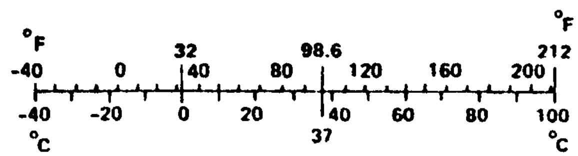
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

FEASIBILITY OF VALIDATING THE SHIRLEY HIGHWAY HOV LANE DEMAND MODEL IN TEXAS

by

Robert W. Stokes
and
Jimmie D. Benson

Research Report 1103-1
Validation of the Shirley Highway HOV Lane
Demand Model in Texas
Research Study No. 2-10-87-1103

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The Texas A&M University System
College Station, Texas 77843

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ABSTRACT

This research report presents an assessment of the feasibility of validating the Shirley Highway (I-395) High-Occupancy Vehicle (HOV) Lane Demand Model in Texas. The results of the study suggest that the Shirley Model has not been sufficiently developed at this time to warrant additional testing outside the Shirley corridor. In fact, additional testing within the Shirley corridor will be needed to determine whether the preliminary model represents the "best" model that could be estimated from the dataset, and whether the model can accurately replicate travel choice decisions observed in the Shirley corridor. A review of currently available alternatives to the Shirley Model is also presented. While these procedures could be used to develop a range of demand estimates that appear reasonable for many sketch planning applications, they are still fairly crude and more refined estimation procedures are clearly needed. It is recommended that any additional efforts to validate the Shirley Model in Texas be undertaken through a separate research project and that local efforts focus on the development of HOV lane demand estimation procedures based on experiences gained in operating HOV facilities in Texas. These two independent, though clearly complementary, efforts should be closely coordinated to facilitate a possible merging of efforts at some time in the future.

Keywords: High-occupancy vehicles, HOV lanes, travel demand estimation, mode choice, mode split, logit model, disaggregate travel demand models

IMPLEMENTATION STATEMENT

The goal of this research study is to assist the Texas State Department of Highways and Public Transportation (SDHPT) in assessing the potentials for using the Shirley Highway HOV Lane Demand Model in Texas. The results of this study will be useful to SDHPT and other transportation planners and policy analysts in planning, evaluating, designing and implementing transitway facilities in the major urban areas of Texas and other states.

DISCLAIMER

SUMMARY

This research report presents an assessment of the feasibility of validating the Shirley Highway HOV Lane Demand Model in Texas. In addition to describing the Shirley Model and reporting on the feasibility of using the model in Texas, the report also presents a brief overview of the state-of-the-art in disaggregate travel demand modeling, and reviews several alternative HOV lane demand estimation procedures.

The results of the study indicate that the Shirley Model, in its current form, suffers from a number of technical problems which raise questions concerning the feasibility of implementing the model in Texas within a reasonable time frame. The Shirley Model will require additional development and testing to insure that the model has been correctly specified and to determine whether the model can accurately replicate travel choice processes observed in the Shirley Corridor. These issues should be addressed prior to the initiation of additional tests outside the Shirley Corridor.

The Shirley Model is based on a "choice-set" that differs from the choice-set(s) available to commuters in the major urban areas of Texas. That is, the Shirley Model predicts mode shares for modes that differ from the modes available to HOV commuters in Texas. It is not clear at this time whether the Shirley Model could be re-estimated to account for these differences in choice-sets.

A basic policy-related issue affecting the feasibility of using the Shirley Model in Texas centers around the fact that the model is intended to be used as a traditional mode-choice model with an HOV component. The Shirley Model would estimate mode shares for traditional modes (e.g., highway, transit), as well as HOV priority lane mode shares. The mode-choice modeling efforts underway in Texas are sufficiently advanced that it does not seem prudent at this time to re-direct these efforts to incorporate HOV priority lane demand estimation capabilities into the mode-choice phase of the modeling process. Prior to attempting to incorporate HOV lane components into established mode-choice models, additional research should be conducted to more clearly define those factors affecting HOV lane demand.

In short, it is the conclusion of this study that the Shirley Model is not ready for testing outside the Shirley corridor. In fact, additional testing within the Shirley corridor will be needed to adequately assess the potentials for using the model elsewhere.

Based on these considerations, the following two recommendations concerning future research directions are offered.

1) Efforts should be initiated to develop HOV lane demand estimation procedures based on experience gained in operating HOV facilities in Texas. At this time, estimation procedures based on HOV lane market area analyses appear to be the most promising. The recommended approach would involve using currently available traffic assignment models to estimate potential HOV lane traffic markets and using observed HOV lane utilization data to develop estimates of the percentage of the traffic market that uses the HOV lane. Specifically, selected "link assignments" could be developed to estimate traffic volumes that could use the HOV link(s) in their trip making. The travel demand models could also be used to access demographic data for the traffic markets identified from the selected link assignments. Actual HOV lane utilization data could then be used to develop relationships between the characteristics of the market areas and observed HOV lane utilization levels.

This recommended re-direction of the study effort is consistent with the existing work plan and should be more clearly defined and initiated during FY 1988.

2) Efforts to validate the Shirley Model in Texas (and/or elsewhere) should be undertaken as part of a separate research project. Given the amount of work likely to be required to complete the development and testing of the Shirley Model, it does not seem prudent at this time to rely solely on the Shirley Highway efforts as the basis for developing HOV lane demand estimation procedures for Texas. Therefore, it is recommended that any local involvement in validating the Shirley Model be undertaken as part of a separate research effort. Given the potential nationwide significance of these possible future testing efforts, it would seem appropriate to pursue FHWA and/or UMTA funding support for these validation tests.

Implementation of these two recommendations should result in the development of reliable HOV lane demand estimation procedures for Texas in a timely fashion. Local efforts directed at developing HOV lane demand estimation procedures should serve the short-term needs of the state. Also, by coordinating local efforts with the continuing development and testing of the Shirley Model, it should be possible to identify a range of estimation procedures for possible use in Texas. This two-stage attack on the problem makes it possible to develop an evolutionary approach to HOV lane demand modeling. The development of local models, for example, could provide the basis for developing/implementing more sophisticated models, such as the Shirley Model, at some future time.

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1. INTRODUCTION

1.1 BACKGROUND

Given the commitment to high-occupancy vehicle (HOV) technology in Texas and other states, there exists a need to develop better methods to estimate the potential use of HOV facilities for ridesharing and transit services. High-occupancy vehicle facilities can be very cost-effective investments that substantially improve the competitiveness of privately and public operated transit services, as well as private carpools and vanpools.

Since very few HOV lanes are currently in operation, no widely accepted procedures for analyzing such facilities are available. Most of the few procedures available are based on a synthesis of general methodologies which were originally developed for purposes other than HOV lane demand estimation. While these "quick response" procedures may be adequate for sketch planning purposes, they do not lend themselves to systems-level analyses, nor are they particularly "policy sensitive". That is, these procedures are not amenable to analyzing the system-wide effects of HOV facilities, and/or analyzing how travel behavior in a particular corridor might change as a result of modifications made to the rules governing use of an HOV facility. A particularly critical problem which has been encountered in recent HOV facility planning activities is the issue of carpool demand estimation, and the associated operational and policy implications of establishing occupancy requirements for carpools.

The Shirley Highway HOV Lane Demand Model, which is currently being developed by the Federal Highway Administration (FHWA) and the Urban Mass Transportation Administration (UMTA), is a significant first-step in attempts to address these limitations in HOV travel demand modeling. In its present stage of development, the Shirley Model is a disaggregate, logit mode-choice model intended to estimate selection probabilities for the following modes:

- Transit;
- 1, 2, 3, and 4+ occupant non-HOV lane modes; and
- Shirley HOV lane modes (4+ occupants).

Ultimately, the model is intended for application within an Urban Transportation Planning System (UTPS) network and would estimate selection probabilities by mode, route, and time of day. Such a model could facilitate the development of a comprehensive and uniform HOV facility planning tool for the major urban areas of Texas. Additionally, successful validation of the Shirley Model in Texas, and/or identification of possible refinements and modifications in the model, could also facilitate use of the model on a nationwide basis.

The Urban Mass Transportation Administration and the Federal Highway Administration are presently evaluating several alternative forms of the Shirley Model and are considering additional work to allow formal validation and testing of the models. This effort would also include coding the model in UTPS in order to apply the model in a forecast mode.

1.2 OBJECTIVES AND RESEARCH APPROACH

The overall goal of the research effort is to assess the feasibility of making the Shirley Highway HOV Lane Demand Model operational in Texas. A three year study has been designed, with the first year of the study directed at familiarizing the research team with the current status, basic logic, and operating features of the models to be used in the study.

The objectives for the first year of the study are to:

1) Review documentation for the Shirley Highway HOV Lane Demand Model and travel demand models currently in use or under development in Texas; and

2) Acquire the Shirley Model and perform an initial assessment of the feasibility of making the model operational in Texas.

The objectives for the second year of the study are to:

1) Investigate refinements and modifications (if any) which may be needed to make the Shirley Model operational in Texas;

2) Assess the compatibility of the Shirley Highway Model with travel demand program packages in use, or being developed, in Texas; and

3) Identify technically and economically feasible refinements and modifications (if any) which can be implemented to consolidate the Shirley Model with travel demand packages in use, or being developed, in Texas.

The objectives for the third year of the study are to:

1) If technically and economically feasible, consolidate the Shirley Model with the travel demand program packages being used in Texas;

2) If the Shirley Model can be made operational in Texas, test the model using historical data from HOV facilities in Texas; and

3) If the Shirley Model can be made operational in Texas, evaluate the model's performance in terms of data requirements, tractability, and ability to replicate historical operating statistics.

This report presents the results of efforts directed at accomplishing the objectives of the first year of the study. Research activities during this initial phase of the study have been directed at familiarizing the research team with the basic logic and operating features of the models to be used in the study. Documentation for the Shirley Model and travel demand models in use, and/or under development, in Texas were reviewed. The review focuses on 1) assessing the status of the Shirley Model in terms of the likelihood of making the model operational in Texas within a reasonable time frame, 2) assessing the compatibility of the Shirley Model with local transportation system characteristics and modeling efforts currently underway, and 3) identifying data required to apply and evaluate the model in Texas.

The research has been phased in such a way that implementation of subsequent research activities are contingent upon the results of the first year of the study. If, for example, the results of the first year of the study indicate that it may not be feasible to pursue further development of the Shirley Model in its present form, the sponsor may elect to terminate the study, or to initiate the development of a new (or substantially modified) HOV lane demand model.

1.3 ORGANIZATION OF THE REPORT

In addition to this introductory section, the report contains the following five major sections.

Section 2: Fundamentals of Disaggregate Travel Demand Models. This section presents a brief overview of the state of the art in the use of disaggregate travel demand models. The discussion summarizes the major issues involved in estimating and applying disaggregate models and provides a general background for subsequent discussions concerning the Shirley Highway Model. Particular emphasis is placed on the use of the logit model in disaggregate travel demand modeling.

Section 3: The Shirley Highway HOV Lane Demand Model. The third section of the report describes the travel behavior dataset developed from the Shirley Highway (I-395) HOV Priority Lanes Corridor and the initial efforts to calibrate a logit work trip mode choice model with this data. The status of the modeling effort is discussed in terms of the following four key questions:

1) Can the dataset support the development of a model that appears "reasonable" in that it adequately explains observed behavior and has properties that are similar to those typically observed in mode choice models?

2) Does observed behavior in the Shirley Highway Corridor indicate that HOV travel on the reserved lanes is perceived by travelers to differ from other ridesharing opportunities only in terms of travel time savings, or are there other perceived differences as well?

3) What are the relative contributions of the reserved HOV facility and other ridesharing incentives (parking priorities, employer-based matching programs, etc.) to ridesharing behavior in the corridor?

4) How transferable might a model developed in this corridor be for other urban areas considering similar HOV facilities?

Section 4: Feasibility of Using the Shirley Model in Texas. A discussion of the issues affecting the use of the Shirley Model in Texas is presented in this section. The exposition proceeds first with the technical aspects of implementing and evaluating the model in Texas. The discussion of the technical issues involved is followed by an evaluation of the policy and political considerations that might have a bearing on the feasibility question. Section 4 concludes with a preliminary assessment of the feasibility of using the Shirley Model in Texas.

Section 5: Alternative HOV Lane Demand Estimation Procedures for Texas. Section 5 of the report presents a general description of four simplified HOV lane demand estimation procedures which have been used by the Texas Transportation Institute in HOV lane studies in Houston. The section also provides a critique of the procedures and a brief discussion of possible modifications that could improve the accuracy and tractability of these procedures.

Section 6: Conclusions and Recommendations. The sixth and final section of the report contains a summary of study findings and puts forward a number of recommendations concerning the future directions of the research effort.

Those readers already familiar with the basics of disaggregate travel demand models and the state of the art in HOV lane demand estimation in Texas may wish to focus on the discussions in Sections 4 and 6 of the report.

2. FUNDAMENTALS OF DISAGGREGATE TRAVEL DEMAND MODELS

2.1 GENERAL

Conventional travel demand models typically involve a four-step sequence: 1) trip generation (travel frequency); 2) trip distribution (where trips go); 3) modal split; and 4) traffic (route) assignment (1). These models are often called aggregate models because they explain the travel of a group of households or individuals. Additionally, aggregate data are used in estimating the models.

In contrast, disaggregate models explain the travel of individuals or households directly. Therefore, data are used at the disaggregate level at which they were collected, rather than averaged into larger aggregates (1). Disaggregate approaches to understanding travel demand are based on the assumption that since travel originates with the decisions of individuals, improved understanding of aggregate behavior can be derived by improved understanding of individual travel behavior.

The following considerations have prompted an increased interest in the use of disaggregate approaches in transportation demand analysis in recent years (1).

1. Economy of Data Collection. Aggregation of data on individuals into group totals or averages, such as averages over travel zones or over metropolitan areas, loses the detailed information about the travel decisions of the individuals composing the groups. To calibrate models of group behavior, observations of many groups are required to obtain reliable estimation results. When the analysis is performed at the level of the individual, detailed information about his/her situation can be explicitly incorporated into the model and its estimation. Thus, with a given number of observations required for model calibration, many fewer individual observations are required when the data on individuals are not aggregated into groups. Furthermore, by avoiding the averaging or, equivalently, the aggregation process, the variability of the explanatory variables is much greater, making the estimation more reliable. Liou and Hartgen (2) found

that disaggregate models permitted considerable savings in data costs as compared with conventional approaches. For these reasons, very substantial savings in data collection costs might be realized.

2. Transferability. Models that describe the behavior of aggregates of individuals are frequently not transferable from one group to another unless the size, composition, or other characteristics of the group are unchanged or controlled. Because models of individual behavior do not have this "aggregation problem," they are more likely to be transferable.

In most applications, predictions of aggregates of individuals are necessary. In these cases the disaggregate models can be calibrated on data collected for the individual, and the level of aggregation (e.g., region, subregion, traffic analysis zone, corridor, etc.) can be taken into account in the analysis. The transferability property is particularly important in using the results of analysis in one area for predicting behavior in other geographic areas. Disaggregate approaches need not apply to an entire region, but can be used for subregions, corridors, or specific market segments. Models that are geographically transferable will also substantially reduce the cost of developing a new model to fit each particular situation.

3. Policy Sensitivity. Traditional aggregate demand models have not been sensitive to many public policy alternatives that affect travel behavior. The disaggregate detail on level of service and individual and household attributes can provide an improved understanding of the determinants of travel choices. Because disaggregate approaches are developed in terms of the behavior of the individual, the evaluation of public policy alternatives is enhanced. The disaggregate approach provides a natural framework for analyzing how a policy alternative affects the decision-making of the individual. If the policy effects are analyzed as they affect the individual, the transportation analyst's recommendations gain credibility because they are more intuitive. Moreover, disaggregate approaches are ideally suited to evaluating the impact of policies on different market segments or interest groups.

4. Flexibility. Disaggregate modeling is a method of analysis that is not a single model or a single "cookbook" approach. By the same token, it takes advantage of data and knowledge at hand and results of previous studies, whether the problem is long-range demand forecasting or short-range analysis of issues such as air quality and energy conservation alternatives.

Conventional urban transportation planning tools have been found satisfactory by many members of the planning community in meeting the needs for which conventional approaches were designed. However, a new generation of planning problems has emerged which requires improved knowledge of how public policy affects the use of existing facilities (e.g., fares and tolls, air quality control programs, energy conservation, exclusive bus lanes, and so forth). Disaggregate approaches can be designed to meet these new needs.

2.2 THE LOGIT MODEL

The logit model of individual choice behavior has been the most prominent methodology used in disaggregate travel demand models. The logit model assumes that each individual makes selections from among a set of alternatives, often referred to as the choice set. From that set he chooses the alternative he prefers. In making the selection, he assigns a utility value to each alternative. The utility of an alternative is a measure of the order of preference (e.g., if one alternative is more preferred, it will be assigned a higher utility). For modeling purposes the utility is composed of two components, a component based on observed attributes, often called the "representative utility," and an unobserved component, called the random utility component. The term "random utility model" is derived from the assumption that although the individual's choice is rational, an observer cannot predict a given individual's choice because of the influence of unobserved determinants of choice as reflected in the random component (1).

Mathematically, assume that each tripmaker assigns some utility to each of his travel alternatives. Let U_{it} be the utility of the i^{th} alternative for the t^{th} tripmaker. Further assume that each utility value can be partitioned into two components, a systematic component, or "representative utility," V_{it}, and a random component, ε_{it}, such that (1),

$$U_{it} = V_{it} + \varepsilon_{it} \tag{1}$$

The systematic component V_{it} is that part of utility contributed by factors that can be observed and measured (the "representative utility") and the random component ε_{it} is the utility contributed by unobserved factors (1).

Tripmakers are assumed to choose the travel alternative that yields the highest utility. Thus, individual t will choose alternative i over alternative j if (1).

$$U_{it} > U_{jt} \tag{2}$$

From Eqs. 1 and 2 it is clear that the alternative i is chosen if (1)

$$V_{it} + \varepsilon_{it} > V_{jt} + \varepsilon_{jt} \tag{3}$$

or, equivalently, if

$$V_{it} - V_{jt} > \varepsilon_{jt} - \varepsilon_{it} \tag{4}$$

One cannot predict with certainty which alternative an individual will choose, i or j, because although V_{it} and V_{jt} can be estimated and compared, it cannot be determined with certainty if $(V_{it} - V_{jt})$ exceeds $(\varepsilon_{jt} - \varepsilon_{it})$. Instead, one seeks to determine the probability with which $(\varepsilon_{jt} - \varepsilon_{it})$ will be less than $(V_{it} - V_{jt})$. This is generally done by assumming that the ε_{it}'s are independently and identically distributed with the Weibull distribution (1-4). Based on these additional assumptions, it can then be shown that the probability that the t^{th} individual will choose the i^{th} alternative is given by (1):

$$P_t(i) = \frac{e^{V_{it}}}{\sum_{j=1}^{J} e^{V_{jt}}} \tag{5}$$

in which

J = the number of alternatives (including the i^{th} alternative); and

e = the base of the natural logarithm.

Equation 5 is the well-known logit model (1).

It was stated above that V_{it} is the component of utility contributed by observed attributes. It is computationally convenient to assume that V_{it} is a linear combination of the observed attributes of the alternative i and individual t (1):

$$V_{it} = \sum_{k=1}^{K} X_{itk} B_k + \sum_{l=1}^{L} S_{tl} \alpha_l \tag{6}$$

in which

X_{itk} = value of the k^{th} attribute (level-of-service) of alternative i for the t^{th} individual;

K = total number of attributes of the alternatives;

B_k = parameter of the k^{th} attribute;

S_{tl} = l^{th} socioeconomic characteristic of individual t;

L = total number of socioeconomic characteristics; and

α_l = parameter of the l^{th} socioeconomic characteristic.

The logit model is often presented in the "log odds" format, where the log of the ratio of the probabilities of two alternatives can be expressed as a function of the difference in attribute levels of the alternatives (1):

$$\ln (P_{jt}/P_{it}) = \Sigma B_k (X_{jtk} - X_{itk}) \tag{7}$$

This algebraic transformation of the logit equation is quite convenient. It has allowed researchers to simply estimate binary choice logit models using ordinary least squares regression packages since the dependent variable can be represented as the natural log of the ratio of selections between i and j for individual (or class) t, and the independent variables become the differences in values of attributes between alternatives i and j (1).

There are four key assumptions in arriving at the logit model given by Equation 5 (1):

1) That individual behavior is random, as a result of unobserved determinants of behavior, but the relative shares of the choice alternatives can be predicted with the estimated model, based on the "representative utilities."

2) Within a group of individuals with identical observed attributes, there are no taste variations (stated differently, the model coefficients (B_k) are fixed and not random).

3) The random components of utility are independent across alternatives (the unobserved attributes of two alternatives vary independently and are as likely to be different as similar).

4) The random utility components and the attributes contributing to that utility are not correlated with the observed attributes.

Collectively, the last three assumptions produce the Independence of (or from) Irrelevant Alternatives property of the logit model. This property is the most controversial issue in disaggregate modeling. It may be demonstrated in several ways. For example, in the "log odds" ratio form (see Equation 7), it is clear that the ratio of the share of two alternatives is not affected by the attributes of a third alternative. Consequently, if two alternatives have equal probabilities of being chosen in a two-way choice (e.g., $P_i = P_j = 0.50$), the introduction of a new "irrelevant" third alternative, k, with attributes identical to alternative j will cause all three alternatives to have equal market shares in a three alternative choice.

This result is counterintuitive, since the new alternative, k, should only divert riders from the identical alternative j, producing shares of 50-25-25 (1).

The most commonly used example of the property is a two-mode choice situation, auto and bus. Each has a 50 percent mode share. If a third irrelevant choice is added to the choice set by painting half the buses blue and the other half red, yielding a three-mode choice set, the logit model will illogically predict that the "new" mode will capture equal shares from auto and bus yielding a 33-33-33 mode split (1).

Most of the specification errors of logit models, and the increasingly sophisticated modeling alternatives designed to correct for these efforts, result from a violation of the last three assumptions (1).

Logit models are generally estimated by one of two alternative procedures. First, data on the calibration sample can be loaded into a maximum likelihood estimation computer package for logit models. (This is generally the preferred approach). Second, the data can be preprocessed into the log odds format and the model estimated using a least squares multiple regression computer routine (1).

The maximum likelihood approach iteratively solves for the set of coefficients, B's and α's, which yields the representative utilities, V's, which generate the best fit to the observed pattern of choices in the calibration sample. The estimation package will iterate through the problem until the estimated coefficients reach a specified convergence criterion or the estimation completes a specified number of iterations. The least squares approach finds the set of coefficients that minimizes the sum of the squared errors between the predicted and observed log odds ratios (1).

2.2.1 Logit Mode-Choice Model Specification Issues

A large amount of research has addressed the issue of appropriate specification of variables in disaggregate models. Tye et al. (1) have summarized the most salient findings. This section presents the results of their review.

Table 1 summarizes explanatory variables that have been used in mode-choice models. Some of the more important variables are discussed below. This discussion is presented in two sections. First, the measurement and specification of socio-economic characteristics are discussed. In the second section, the measurement and specification of level-of-service variables (the attributes of alternatives) are discussed.

Socioeconomic Characteristics

The most important socioeconomic characteristics affecting mode choice include financial considerations (e.g., income, wage, or wealth) and auto availability (e.g., ownership and competition for the family car) (1). Other relevant considerations in some choice settings can include employment type, lifecycle stage, age, and neighborhood setting or location.

Research indicates that after-tax wage is preferred over income as an indicator of the effect of financial considerations in mode choice (see McFadden (5)). Further, research by Train and McFadden (6) indicates that an acceptable specification is "cost divided by wage," which has the effect of linearly relating the value of time to the wage rate. Their research indicated that this specification resulted in a somewhat better fit than did a specification where time was multiplied by the wage rate (which would have the effect of converting time into a money equivalent). However, the goodness of fit of the models differed only slightly, suggesting that the choice between specifications is essentially arbitrary (1).

Despite the superior conceptual appeal of the (after tax) wage rate (at least for worktrip mode choice), only family income is reported in many data sets; therefore, it must be used. Researchers also should be cautioned that the quality of the data on the income variable is often suspect. Many respondents give wrong answers to income questions or skip them on surveys. Finally, there is the issue of whether auto ownership, which is colinear with wage and income, is the true underlying determining factor in mode choice.

Table 1. Explanatory Variables Affecting Mode Choice

Variables with critical explanatory power
Travel Cost
On-Vehicle Time
Walk Time
Transfer Wait Time
Transit Initial Headway
Number of Persons in Household Who Can Drive
Determinants of Alternative Availability (e.g., ability to drive, auto required at work)
Wage
Variables with important explanatory power
Number of Transfers
Respondent's Relation to Household Head
Employment Density at Work Location
Suburban or Urban Residence
Family Composition
Variables with ambiguous explanatory power
Household Income
Residential Population Density
CBD Location of Residence
Number of Workers in Household
Age of Household Head
Reliability of Transportation Mode
Perceptions of Comfort, Safety, Convenience
Variables with low explanatory power
CBD Work Location
Sex of Respondent
Age of Respondent
Work Status of Household Head
General Attitudes Toward Privacy, Delay, Safety

Source: Tye et al. (1).

In any event, financial considerations are theoretically important to individual travel decisions and generally should not be omitted from models (1).

With respect to transferring logit models from one region to another, the importance of explicitly accounting for differences in traveler behavior among different income classes has a direct bearing on the validity of applying disaggregate models estimated on one group of data (e.g., from one city) to forecast travel behavior for another group of travelers. Ignoring income-specific travel behavior when it is important will result in parameter estimates that are dependent on the income distribution found in the estimation sample (1).

Empirical research on disaggregate demand modeling has frequently found that household automobile ownership (AO) significantly influences worktrip mode choice. There are two basic considerations in using household AO variables in mode choice models (1):

1) Travel decisions (e.g., mode choice) are not independent of household mobility decisions (e.g., residential location). As such, parameter estimates of AO variables in disaggregate mode choice models will probably be somewhat biased by these unobserved attributes.

2) It is not so much the number of autos in a household as the availability of an auto at the time of the trip that influences choices on how, where, when, and how often to travel.

Many models for particular choice situations have found other socioeconomic variables to be useful predictors of mode choice. For instance, Ben-Akiva and Atherton (7) found employment type to be a useful variable in analyzing carpool incentives. Lifecycle stages can influence the amount of income available for transportation and the need for an auto at home. For instance, a young working couple may have considerable financial resources available for the comfort and convenience of automobile transportation and be relatively insensitive to costs. A suburban housewife may require an auto to get through her day, thereby successfully competing with her breadwinner husband for the car during the day. Age may be a relevant variable where walking and bicycling are included in the choice set (1).

Level-of-Service Variables

The specification of level-of-service (LOS) variables (travel time, wait time, and travel cost) involves the following considerations (1):

- Generic versus alternative-specific variables
- Level of aggregation
- Network versus observed
- Perceived versus objective

In a generic specification, the estimated coefficient for a variable is restricted to taking the same value across alternatives. With an alternative-specific specification, a separate coefficient is estimated for each LOS attribute of each alternative. In a mode choice modeling framework, for instance, generic LOS representation assumes that an additional minute spent traveling on a bus is valued equally to an additional minute spent traveling by auto. Indeed, if such were not the case - if, for example, additional bus time is found to be more onerous than additional time spent in an auto - it is due to the effects of unobserved modal attributes omitted from the model (such as comfort, privacy, reliability, etc.). Thus, in a well-specified model that explicitly accounts for all attributes that significantly affect choice, the use of generic representations of LOS is justified (1).

In practice, however, it is generally not possible to ascertain initially whether choice models are sufficiently well specified to justify the use of generic LOS variables. Tye et al. (1) have reported estimation results suggesting that mode choice models are not able to distinguish significantly different traveler valuations of travel times and costs between auto and transit. The hypothesis that travelers' valuations of the LOS variables do not differ between modes was tested statistically. The null hypothesis that the time and cost parameters do not differ between modes could not be rejected; suggesting that the use of generic LOS variables is statistically justified.

However, these findings differ from the conclusions of McFadden et al. (5) on the use of generic versus alternative-specific LOS variables. McFadden et al. concluded that although the importance of in-vehicle time did not seem to vary for public transportation modes (bus and BART), auto in-vehicle time was valued differently from in-vehicle time for public transportation (1).

With respect to the aggregation issue, the general rule (see Train (8)) is that data generally should be disaggregated to the lowest level possible. For example:

- Time should be disaggregated into in-vehicle, walk, and transfer components; and

- Variables should be specific to the individual decision maker (individual values are preferred over, say, zonal averages).

However, it should be noted that disaggregate LOS data may be difficult and costly to obtain, especially for alternatives, in the calibration data set and difficult to forecast for the forecast data. In many cases, hand-coded data differ significantly from network data. At minimum, it has a greater variance between respondents. These differences can have significant effects on the estimated model (1).

As disaggregate models have been calibrated and implemented, a considerable amount of attention has been given to the question of use of network zonal averages for LOS data versus data calculated specifically for the individual. An early study (3) made a careful attempt at collecting LOS data specific to the individual traveler, but many studies since then have, by necessity, been required to rely on network averages even when calibrating a disaggregate model. The disaggregate LOS data are obviously preferred, but tedious collection of such disaggregate data mitigates to some extent the purported data economy of disaggregate models (1).

In discussions concerning the aggregation issue, it is assumed that LOS data calculated specifically for the individual (observed data) correctly measures the characteristics of the travel alternatives facing the individual. The network data, which are zonal averages of the LOS variables, are used to approximate the observed variation (1). Two questions, then, can be raised. First, how accurately do network variables approximate observed variables? The second question is how do models estimated with observed and network data differ?

In an attempt to address the first question, Talvitie and Dehghani (9) performed analyses on several LOS variables for auto, bus, and BART modes. Their findings suggest that network data may not always closely approximate observed data.

With respect to the second question, Tye et al. (1) have shown that estimation of a model with network variables replacing the correct observed variables results in a form of specification error that results in biased model coefficients.

In general, then, the research indicates that the use of network data results in biased coefficients. The coefficients of models using network data are quite different from the corresponding coefficients of models using observed data, even though there is very little difference in goodness of fit. It is particularly interesting that network models indicate that out-of-vehicle time is consistently considered more onerous than in-vehicle time, while the models estimated with observed data do not (1).

On a related matter, considerable debate has ensured in the literature over whether "engineering" LOS data, based on sources other than the traveler, or data as "perceived" by the traveler are the appropriate variables (1).

Engineering LOS data are generally derived from computerized "skim trees" representing the travel times and distances between nodes in the transportation network. These data are generally available for most urban areas and were developed during the highway building boom of the 1950s and

1960s. These data, however, may be outdated and may not accurately reflect the LOS for all individuals for all trips (1).

Perceived LOS data can be developed during the travel survey used to collect data on socioeconomic characteristics for model calibration. The argument for the use of "perceived" data is obvious. Since the traveler is responding to the facts he perceives, perceived data are "obviously" superior. On the other hand, if models are to be transferable, there must be an explicit mechanism for translating engineering data to perceived data. As a practical matter, most forecasters have only engineering data available, and developing sufficient perceptual data for both modeling and forecasting purposes would put an unacceptable burden on the interview process. Finally, there is the argument that perceptual data are engineering data weighted or discounted by the model coefficients and therefore should not be weighted again in the model calibration (1).

A major problem with perceived data is that travelers' perceptions of the LOS of the alternatives available relative to their chosen alternatives are likely to be poor. People have enough trouble estimating the time it takes them for the chosen alternative without having to guess how long it would taken them by a rejected alternative (1).

Another major problem with respect to the use of perceived LOS data is the policy variables one can or one wishes to manipulate. Clearly, it is within the scope of public policy to change the objective level of service offered by transit or highway systems. Fares, tolls, headway, and congestion all can be externally controlled. Perceptions of LOS, which may or may not be closely tied to engineering LOS, are not as readily manipulatable. Transportation planners have little experience in making the bus seem faster or the auto feel more expensive. Consequently, for these reasons the use of perceived LOS data for general planning applications is not recommended (1).

2.2.2 Transferability of Logit Mode-Choice Models

Previous works dealing with the transferability problem have sought to answer the questions: Can logit travel demand models be transferred from one city to another without modification? If not, are modifications short of complete recalibration of the models feasible? The answer to the first question appears to be: "No, at least not in general," while the answer to the second question appears to be "Yes, under some circumstances (1)."

The first step in understanding the transferability problem is to identify the reasons why a model would not be transferable (i.e., reasons why a transferred model is a poor predictor in a new forecasting environment or why two models calibrated on different data sets produce entirely different estimates of behavioral parameters). These reasons include the following (1):

1. Model specification differences which may or may not reflect true behavioral differences. Two models may be specified differently even though they purport to forecast consistent behavior. For example, one model may include income; another may include the wage rate; others may include income as a separate additive term; and another may divide it into the cost term. Variables may not be defined consistently. For example, one model may use network (aggregate) level-of-service data; another uses perceived data; a third uses individually measured portal-to-portal values. Model coefficients may also vary with changes in the cost of living.

2. Differences in sampling procedures. Differences in sampling procedures can affect the model coefficients. For example, the corridor sampling in a 1972 study in Pittsburgh produced a mode-specific constant with a "transit bias." That is, the model predicted that more persons would choose transit than auto when the independent (explanatory) variables were identical for both modes. Thus, it clearly was not transferable in the short run. This bias may have resulted from the calibration sample. Corridors with good transit service were chosen for the sample, increasing the share of persons in the sample who chose that residential location for reasons related to the availability of transit and were "biased toward transit." This underlying "taste for transit" in the calibration sample may have reduced the models' applicability to other "unbiased" populations. This, of course, can be a problem with any model calibrated on cross-sectional data.

3. <u>Differences in estimation techniques and sample size, etc.</u> "Outliers" whose behavior cannot be explained in terms of behavioral relationships calibrated for the rest of the population can nevertheless have a large effect on the estimated coefficients. In effect, the estimation procedure strains to make as much sense as possible of this apparently irrational behavior. This properly raises questions as to whether such observations should be included in the calibration sample and what weight should be given to failure to predict the behavior of outliers in judging whether a model passes a test of transferability.

4. <u>True behavioral differences</u>. It may also be that two cities or groups may have different social and economic values influencing their choice behavior. For instance, New York City dwellers may have different values with respect to transportation than rural Midwesterners. These differences in taste may limit transferability from one cultural environment to another. Tests of variations in tastes by Hausman and Wise (<u>10</u>) have demonstrated that they can significantly affect model results.

Atherton and Ben-Akiva (<u>11</u>) tested the ability of a worktrip mode choice model calibrated on Washington, D.C., data to explain travel behavior in Los Angeles and New Bedford, Massachusetts. The authors concluded that the evidence on the transferability of logit demand models is "encouraging," but it is apparent that no model will be perfectly transferable and that procedures for "updating" (or adjusting) the model coefficients are required (<u>11</u>). They then describe and empirically test five update procedures. Similar research in England (<u>12</u>, <u>13</u>) produced results comparable to those reported by Atherton and Ben-Akiva.

Talvitie and Kirshner (<u>14</u>), however, are less optimistic on the transferability of logit mode-choice models. Their research, based on the use of four data sets, indicated that:

1. Outliers can have substantial impacts on the point estimates of some of the coefficients in logit models.

2. Model coefficients are highly sensitive to model specification.

3. Model coefficients do not appear transferable within regions, between regions, or over time.

To summarize the available evidence on the transferability of disaggregate mode choice models, the works reviewed seem to be in close agreement that not all travelers everywhere exhibit the uniformity in their trip-making behavior that one would have hoped for, at least with respect to worktrip choice of mode. However, from the work of Atherton and Ben-Akiva (11) and Daly (12), it appears that the differences that do exist are sometimes amenable to reconciliation by an adjustment of model coefficients and that calibration of separate models for every traveler group is not always necessary, at least for mode split. Other research (14) indicates that logit model estimation may not display robustness with regard to differences in traveler tastes, data collection, or model specification, and can be very unforgiving of errors on the part of practitioners. These difficulties suggest that for many applications the collection of a new data set and the calibration of new models may be required and is a far safer course than attempting to transfer a model, especially for those without advanced training in the use of disaggregate models. Several hundred new observations should be sufficient to test the transferability of the models (1).

2.3 SUMMARY

The major conclusion emerging from reviewing the state of the art in disaggregate modeling is that disaggregate models are a valuable research tool for transportation planners. But they can be subject to significant errors (as can aggregate techniques) and require a relatively sophisticated understanding of the assumptions employed. The researcher must make a relatively heavy commitment to understanding what he is doing if these errors are to be avoided (1).

Disaggregate travel demand models can be (and have been) applied in several different ways. They can replace one or more individual components of the conventional transportation planning process. Alternatively, they can be used for problems that are not easily addressed by conventional planning tools (e.g., analysis of Transportation Systems Management (TSM) actions or the introduction of new transportation modes). They can either be computerized or used as sketch planning tools requiring only hand-held or programmable calculators (1).

While disaggregate demand modeling techniques have made considerable progress in recent years, there has been increasing skepticism regarding the value of disaggregate models. This skepticism is based on a number of concerns. The first concern regards the issue of accuracy. Talvitie and Kirshner (14) found that "outliers" caused by data entry errors or highly unusual behavior can have significant effects on the estimates of the coefficients. The authors tested the transferability of model coefficients within regions, between regions, and over time and rejected it for each case. The authors were also troubled by the sensitivity of the estimated coefficients to model specifications. Finally, the authors were troubled by the fact that 60 to 80 percent of the explanatory power of the models is contained in the alternative-specific constants and only 20 to 40 percent in the LOS and socioeconomic variables. The authors glumly inquire whether disaggregate models have much to offer given the fact that service variables are only slightly affected by most policy transportation changes (1).

Typical of the expression of skepticism regarding the generality of the usefulness of disaggregate models is the attempt by Gomez-Ibanez et al. (15) to transfer disaggregate elasticities to evaluate auto restraint policies in the Boston area. The authors were dismayed to find that different studies produced such greatly differing elasticities, causing doubt about the transferability of models and concern about the sensitivity of the results to model specification (1).

Different researchers using different data have reported significantly different coefficients for time and cost variables. This lack of consistency has greatly troubled some researchers, such as Gomez-Ibanez et al., who consider the lack of uniformity a great shortcoming of the disaggregate approach. On the other hand, others, such as the Office of Technology Assessment, U.S. Congress (16), have found the relative consistency of value of time (after accounting for inflation) to be reassuring despite the differences in coefficient values, and have not hesitated to evaluate nationwide energy policy using the results of disaggregate models (1).

Skepticism has been especially keen regarding the value of large-scale attempts to substitute disaggregate models for the traditional four-step transportation planning process. Shunk and Kollo (17) have criticized disaggregate models on the grounds that such sophisticated models are not appropriate for day-to-day use in the real world, despite their elegance or relative accuracy. The grounds for their complaints were the following (1):

1. Despite the claims that the models represent traveler decision-making, dramatic changes in the estimated constants are required to "validate" the models from the estimation subsample to the aggregate data set.

2. A "distance correction variable" for each of 30 districts was required for trip distribution, reminiscent of "friction factors" in aggregate models.

3. The distribution models required "unique adjustment factors" which had to be adjusted by hand to produce reasonable forecasts, rather than "responding independently."

4. The mode choice models required adjustment of the mode-specific constant which was specific to the interchange.

5. The model is unduly complex and costly to operate.

Despite the early optimism on transferability of disaggregate models, recent evidence suggests that, at a minimum, adjustments to the models must be made before transferring the models from one geographic area to another. Furthermore, different models calibrated on different data have produced behavioral parameter estimates that are not consistent. However, these differences may be explained by factors other than inherent behavioral differences among people (different model specifications, variable definitions, etc.). Therefore, the evidence does not necessarily support the conclusion that a behavioral model is not transferable (1).

The wisdom of transferring an existing model depends greatly on the costs of making forecast errors. If a high level of accuracy is desired, a sample size of possibly as large as several hundred observations is highly recommended to test the reasonableness of transferring an existing model. If less accuracy is required, a forecast based on an existing model with recalibration of the "mode-specific constant" may well be acceptable. Transferability is most likely to be valid when transferring the model to a group of people choosing among a set of alternatives identical to the calibration data set. Furthermore, it must be remembered that while transferring a model saves on the cost of collecting new data to calibrate a new model, it places greater demands on the practitioner to understand fully the assumptions made when applying the model (1).

3. THE SHIRLEY HIGHWAY HOV LANE DEMAND MODEL

3.1 GENERAL

The Shirley Highway (I-395) is an interstate freeway segment connecting downtown Washington, DC with suburban communities in northern Virginia. Two other major employment sites, the Pentagon and the Crystal City Office Complex, are in the corridor on the Virginia side of the Potomac River. The freeway has two reversible, median lanes reserved for the exclusive use of high occupancy vehicles (HOVs), including transit buses, vanpools, and carpools (18).

This section of the report describes the travel behavior dataset developed from the Shirley Highway HOV Priority Lanes Corridor and the initial efforts to calibrate a logit work trip mode-choice model with this data. A general discussion of the status of the Shirley Model development effort is also given. The status of the model development effort is discussed in terms of the following four key questions (18):

1) Can the dataset support the development of a model that appears "reasonable" in that it adequately explains observed behavior and has properties that are similar to those typically observed in mode choice models?

2) Does observed behavior in the Shirley Highway Corridor indicate that HOV travel on the reserved lanes is perceived by travelers to differ from other ridesharing opportunities only in terms of travel time savings, or are there other perceived differences as well?

3) What are the relative contributions of the reserved HOV facility and other ridesharing incentives (parking priorities, employer-based matching programs, etc.) to ridesharing behavior in the corridor?

4) How transferable might a model developed in this corridor be for other urban areas considering similar HOV facilities?

Each of these question is central to the usefulness of any model developed for the corridor, both in assessing policy changes considered for the reserved facility and in transferring the model to other urban areas.

3.2 CALIBRATION DATASET

In order to develop models of travel choice in the Shirley Highway corridor, it was necessary to obtain specialized information on current travel choice behavior in the corridor. As discussed in Section 2, the development and testing of disaggregate mode-choice models requires a direct, observed link between an individual's actual choice of travel alternative with the characteristics of alternatives available to him, his socioeconomic characteristics, and special workplace and other constraints and incentives. The procedures used to obtain information on travel choice behavior in the Shirley corridor are described in the following sections.

3.2.1 Travel Survey

The source of the information on travel choice in the Shirley corridor was a commuter travel survey conducted in February and March of 1984 (18). The survey had two components:

- An auto user survey, including low occupancy vehicles (LOV) and HOV; and

- a transit user survey.

The auto user survey was conducted using license plate sampling techniques and a mailout survey. The transit survey used a virtually identical survey form which was handed directly to transit riders.

The survey attempted to collect the following general information (18):

- trip origin and destination
- trip frequency
- trip purpose
- use of and familiarity with the following alternatives:
  - Shirley HOV (carpool/vanpool)
  - auto drive alone
  - auto, 2 occupants
  - auto, 3 occupants
  - auto, 4+ occupants (not Shirley HOV)
  - bus and/or Metrorail
- the following information for each alternative:
  - arrival/departure time
  - access/egress characteristics
  - cost
  - employer benefits
  - route (highway or transit)
  - differences in return trip
- the following employment characteristics:
  - federal worker
  - number of employees at work site
  - official work hours
  - flexibility in work hours
  - preferential parking for carpools

- demographic information, including:

  - residence and workplace tenure
  - vehicles owned/available
  - number of household members, workers, and drivers
  - age
  - sex
  - annual household income

The sample for the auto survey was developed from a sample of vehicle license plates obtained in a one-day roadside survey. The roadside surveys were conducted from February 29 to March 2, 1984. Sampling sites were set up at 15 entrance ramps or cordon locations on the Shirley Highway and parallel facilities (18).

License plates (Virginia only) were recorded throughout the weekday peak period, 6:00 a.m. to 9:30 a.m., in 15-minute increments. License plates were recorded at a set interval (1 in n), and were teamed with ongoing total vehicle counts at the same site. Computerized license numbers were sent to the Virginia Department of Motor Vehicles for address coding. A sample was retested from the matched list for receipt of the survey, with the sampling rate from the list varying by location, mode, and time of day. The vehicle owner was mailed as many survey forms as occupants observed in the vehicle on the survey day. Approximately 35% of the survey forms were returned (18).

The transit survey was conducted on March 6 and 7. Forms were given to all arriving bus passengers at the Pentagon Metrorail station. Survey crews were positioned at Metrorail gates and issued stamped, self-addressed survey forms to every n^{th} passerby. On another day, forms were given to riders of five private bus lines serving the corridor, whose operations did not pass through the Pentagon. Of 2,600 bus survey forms distributed, 754 were returned usable (18).

3.2.2 Travel Time and Cost Data

While the travel survey requested some limited information from respondents on their reported travel time from home to work or school, estimated trip travel times for each possible mode for each trip in the calibration file were developed "synthetically" using computerized network representations of the highway and transit systems in the corridor. Network derived times are usually utilized in model development efforts for two primary reasons. First, when the travel demand model has been developed, and is applied to forecast travel in a future year, highway and transit networks are typically used to estimate the travel times and costs of future transportation systems as input to the models. Hence, a model calibrated on network derived times and costs will be applied to consistent data. Second, survey respondents may not be able to accurately report the travel times or costs of the mode they utilize, much less the travel time or costs of modes they did not use.[1] Highway and transit networks typically provide the only means by which to estimate the travel times and costs of alternative, unchosen modes, for each specific trip reported in a travel survey (18).

Travel times and costs were developed for each trip reported in the calibration file using highway and transit networks representing the transportation systems in place in the Shirley Highway Corridor in March 1984, the survey period. These networks were based upon those developed and maintained by the Metropolitan Washington Council of Governments (MWCOG) in support of their continuing transportation planning process (18). The development of both highway and transit travel times and costs are discussed below.

Highway Travel Times and Costs

Travel times and costs for auto trips were developed for each trip record in the survey file for two groups of automobile trips: low occupancy

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1 See the discusion concerning specification of level of service variables (Section 2.2.1) for additional comments on this issue.

vehicle (LOV) trips and high occupancy vehicle (HOV) trips. LOV travel times are based upon network estimates of travel conditions on the roadways in the corridor in the a.m. peak period in March 1984, without utilization of the reserved HOV lanes on the Shirley Highway (I-395). The LOV travel times apply to the travel modes of (18):

- drive alone,
- 2 occupant autos,
- 3 occupant autos, and
- 4+ occupant autos not on the Shirley HOV lanes.

The HOV travel times are based upon the same roadway network description as the LOV, but with the inclusion of the Shirley Highway priority HOV lanes into the network, which operate at a higher speed than the parallel mixed traffic lanes of the facility. Hence, for many observed trip origin-destination pairs, HOV travel times will be shorter than corresponding LOV times. However, certain trip interchanges will have no HOV time advantage over LOV paths (18).

The highway network from MWCOG was iteratively adjusted to provide the best possible match between simulated travel times (and speeds) and those observed in a series of speed/delay runs made in the corridor as part of the overall project. The UTPS program UROAD was employed to determine minimum time paths between corridor trip origins and destinations and to "skim" travel times and distances from these paths. Care was taken to accurately represent travel time differences between LOV trips and HOV trips, where the Shirley Highway HOV lanes did offer travel time savings (18).

The standard highway network processing conventions were used, in that each trip's travel time was estimated from the traffic zone centroid of origin to zone centroid of destination. Zone centroid "connector links" represent the average time accessing the highway network from/to each traffic zone, and a separate estimate of time to get from the "front door" out the driveway and to park the car and get to the employment site is represented by each traffic zone's "terminal times." These terminal times were estimated by MWCOG based upon the population and employment density of each traffic zone, and ranged between 1 to 8 minutes. These terminal times are maintained as separate variables in the calibration file, and are not included in the highway network times, which are treated as "in-vehicle" times. Also, no explicit estimate of additional time required to pick up or drop off carpool members has been included in any multi-occupant auto mode time estimates (18).

The LOV and HOV perceived operating costs were estimated for each trip by assuming a cost per vehicle of 15 cents per mile times the trip distance. These costs were then divided by the occupancy of each mode to obtain a cost per person estimate (18).

Transit Travel Times and Costs

Transit travel times were simulated for each trip reported in the survey with the aid of a transit service network developed with the assistance of MWCOG. The network represents a.m. peak period transit services in the Shirley Highway Corridor as of March 1984. These transit services included Metrorail (Yellow and Blue lines), Metrobus, and private contract carriers from the southern reaches of the corridor. Transit service running times and frequencies were based upon schedules provided by WMATA and the private carriers (18).

Transit access coding between traffic zone centroids and bus/rail service was based upon established MWCOG procedures. Most traffic zones in the corridor were connected with walk access/egress links to coded transit lines. Several zones on the outskirts of the suburban areas were connected with auto access links.

Transit wait times were estimated as one-half the headways of transit lines being boarded for each segment of a transit trip. No caps were coded on waiting time computations, for either the first line boarded or any subsequent transit lines transferred to. Additional time penalties of between one to two minutes were coded at Metrorail stations to reflect additional time spent in accessing/egressing trains within stations.

Finally, transit paths were determined by weighting all out-of-vehicle time components at 2.5 times in-vehicle time (18).

Transit fares were simulated using MWCOG's process which replicates WMATA's complex fare structure. These fares represent a.m. peak period fares in effect in March 1984. Different fare values were determined based upon whether a transit trip would require bus only service, rail service only, or a combination of both. The separate fare structure of private carriers in the corridor was also represented (18).

3.2.3 Final Calibration Dataset

Table 2 documents the contents of the final version of the Shirley Highway Corridor model calibration file. The file contains 2,757 records containing 66 variables; each record represents an a.m. peak period, inbound, work trip. These records represent only those trips for which values of all of the 66 listed variables were available from both individual survey returns and highway transit networks (18).

The data in the file are primarily derived from responses recorded from the Shirley Highway Commuter Survey. However, the survey data have been augmented with data from other sources, as described above. Transit fares, and access, egress, and in-vehicle travel times have been obtained from transit network and fare matrices. Automobile travel times and distances have been taken from the highway networks simulating the roadway system in the corridor (18).

Table 2. Summary of Contents of the Shirley Highway Corridor Final Calibration Dataset

Location (Columns) Begin	End	Variable Name (ULOGIT file)	Variable Label	Code	Variable Description
2	7	SEQNUM	Record ID number	Open	
8	12	ORIGIN ZONE	COG TAZ of trip origin	Open	

Table 2. Summary of Contents of the Shirley Highway Corridor Final Calibration Dataset (Cont.)

Location (Columns) Begin	End	Variable Name (ULOGIT file)	Variable Label	Code	Variable Description
13	17	DESTINATION ZONE	COG TAZ of trip destination	Open	
18	19	DA IND	Drive-along indicator	0	Not drive-alone trip
				1	Drive-alone trip
20	21	TWO OCC IND	Two-occupant auto trip indicator	0	Not two-occupant trip
				1	Two-occupant trip
22	23	THREE OCC IND	Three-occupant auto trip indicator	0	Not three-occupant trip
				1	Three-occupant trip
24	25	SHIRLEY HOV IND	Shirley Highway HOV lane trip indicator	0	Not Shirley HOV lane trip
				1	Shirley HOV lane trip
26	27	OTHER HOV IND	Four-plus occupants, non-Shirley Highway HOV trip indicator	0	Not four-plus occupant, non-Shirley HOV lane trip
				1	Four-plus occupant, non-Shirley HOV lane trip
28	29	TRANSIT IND	Transit trip indicator	0	Not transit trip
				1	Transit trip
30	33	FREQ DA	Drive-alone mode frequency	0-100	Reported frequency (percent of time over past year) of drive-alone trips
34	37	FRQ 2OCC	Two-occupant mode frequency	0-100	Reported frequency (percent of time over past year) of two-occupant trips
38	41	FRQ 3OCC	Three-occupant mode frequency	0-100	Reported frequency (percent of time over past year) of three-occupant trips
42	45	FRQ SHIRLEY HOV	Shirley Highway HOV lane mode frequency	0-100	Reported frequency (percent of time over past year) of Shirley HOV lane trips

Table 2. **Summary of Contents of the Shirley Highway Corridor Final Calibration Dataset** (Cont.)

Location (Columns) Begin	End	Variable Name (ULOGIT file)	Variable Label	Code	Variable Description
46	49	FRQ OTHER HOV	Four-plus occupants, non-Shirley Highway HOV mode frequency	0-100	Reported frequency (percent of time over past year) of four-plus occupant, non-Shirley HOV lane trips
50	53	FRQ TRN	Transit mode frequency	0-100	Reported frequency (percent of time over past year) of transit use
54	55	GVT IND	Government employee indicator	0	Not a Federal Government employee
				1	Federal Government employee
56	57	LRG EMPL IND	Employee of large employer indicator	0	Employee of employer with fewer than 500 employees at work site
				1	Employee of employer with 500 or more employees at work site
58	59	FLEX WORK IND	Flexible work hour indicator	0	Employer does not offer flexible work hours
				1	Employer offers flexible work hours
60	61	PREF PARK IND	Preferential parking indicator	0	Employer does not offer preferential parking for carpools
				1	Employer does offer preferential parking
62	65	TENVREH	Months at present home address	Open	
66	69	TENVREW	Months at present work location	Open	

Table 2. Summary of Contents of the Shirley Highway Corridor Final Calibration Dataset (Cont.)

Location (Columns) Begin	End	Variable Name (ULOGIT file)	Variable Label	Code	Variable Description
70	72	NO VEHS	Number of vehicles owned or available to the household	Open	
73	76	DRIVERS	Numbers of licensed drivers in household	Open	
77	78	OWNS VEH IND	Indicator of household vehicle ownership	0	Household owns no vehicle
				1	Household does own at least one vehicle
79	82	ADULTS	Number of adults in household	Open	
83	86	INCOME	Annual household income (1983 Dollars)	1	Under $5,000
				2	$5,000 to $14,999
				3	$15,000 to $24,999
				4	$25,000 to $34,999
				5	$35,000 to $49,999
				6	$50,000 or more
87	90	AGE	Age of survey respondent	1	Under 21 years
				2	21 to 31 years
				3	31 to 40 years
				4	41 to 50 years
				5	51 to 64 years
				6	65 years or older
91	92	SEX	Sex of survey respondent	0	Female
				1	Male
93	94	INC1	Income group one indicator	0	Income greater than $15,000 per year
				1	Income less than $15,000 per year

Table 2. Summary of Contents of the Shirley Highway Corridor Final Calibration Dataset (Cont.)

Location (Columns) Begin	End	Variable Name (ULOGIT file)	Variable Label	Code	Variable Description
95	96	INC2	Income group two indicator	0	Income not between $15,000 and $34,999
				1	Income between $15,000 and $34,999
97	98	INC3	Income group three indicator	0	Income not more than $35,000
				1	Income $35,000 or more per year
99	100	AGE1	Age group one indicator	0	Respondent age not under 21 years
				1	Respondent age under 21 years
101	102	AGE2	Age group two indicator	0	Respondent age not between 21 and 30 years
				1	Respondent age between 21 and 30 years
103	104	AGE3	Age group three indicator	0	Respondent age not between 31 and 40 years
				1	Respondent age between 31 and 40 years
105	106	AGE4	Age group four indicator	0	Respondent age not between 41 and 50 years
				1	Respondent age between 41 and 50 years
107	108	AGE5	Age group five indicator	0	Respondent age not between 51 and 64 years
				1	Respondent age between 51 and 64 years

Table 2. Summary of Contents of the Shirley Highway Corridor Final Calibration Dataset (Cont.)

Location (Columns) Begin	End	Variable Name (ULOGIT file)	Variable Label	Code	Variable Description
109	110	AGE6	Age group six indicator	0	Respondent age not more than 64 years
				1	Respondent age more than 64 years
113	120	VEH PER WORKER	Household vehicles per worker	Open	
123	130	VEH PER DRIVER	Household vehicles per driver	Open	
138	145	SAMPLE WEIGHT	Sample weight	Open	Bayseian weight to normalize sample to universe
151	152	LOV IND	Multi-occupant automobile, not on Shirley HOV lanes, indicator	0	Chosen mode not multi-occupant (2+ persons) vehicle not on Shirley HOV lane
				1	Chosen mode multi-occupant vehicle not on Shirley HOV lanes
153	158	LOV TIME	In vehicle automobile travel time, not using Shirley HOV lane (min.)	Open	Determined from highway network
159	164	LOV DIST	Automobile travel distance, not using Shirley HOV lanes (tenths of miles)	Open	Determined from highway network
165	170	HOV TIME	In vehicle automobile travel time using Shirley HOV lanes (min.)	Open	Determined from highway network
171	176	HOV DIST	Automobile travel distance using Shirley HOV lanes (tenths of miles)	Open	Determined from highway network

Table 2. Summary of Contents of the Shirley Highway Corridor Final Calibration Dataset (Cont.)

Location (Columns) Begin	End	Variable Name (ULOGIT file)	Variable Label	Code	Variable Description
177	182	TRN OUT VEH	Total out-of-vehicle transit travel time (minutes)	Open	Includes access/egress time, wait time and transfer time (if any) from transit network
183	188	TRN AUTOCONN	Total time required to access transit by automobile, in zones where automobile access is possible (minutes)	Open	From transit network
189	194	TRN RUN	Total transit in-vehicle travel time (minutes)	Open	From transit network
195	200	TRN WGHT	Total weighted transit travel time (minutes)	Open	In-vehicle time plus 2.5 times out-of-vehicle time
201	206	FARES	Total transit fare per trip (cents)	Open	Determined from transit network
207	210	ZONE			
211	218	POP DENSITY	Origin TAZ population density (persons per square mile)	Open	From MWCOG data files
219	226	EMP DENSITY	Destination TAZ employment density (workers per square mile)	Open	From MWCOG data files
227	229	PROD TERMTIM	Time to access automobile at trip origin TAZ (minutes)	Open	From MWCOG data files
230	232	ATTR TERMTIM	Time to park and egress from automobile at trip destination TAZ (min.)	Open	From MWCOG data files

Table 2. Summary of Contents of the Shirley Highway Corridor Final Calibration Dataset (Cont.)

Location (Columns) Begin	End	Variable Name (ULOGIT file)	Variable Label	Code	Variable Description
233	238	PARK COST	Average zonal parking cost per vehicle (cents per day)	Open	
239	244	PARK COST DA	Average zonal parking cost per person, single occupant automobiles (cents per day)	Open	
245	250	PARK COST TWO	Average zonal parking cost per person, two occupant automobiles (cents per day)	Open	
251	256	PARK COST THREE	Average zonal parking cost per person, three occupant automobiles (cents per day)	Open	
257	262	PARK COST HOV	Average zonal parking cost per person, high occupant (average occupancy of 5.5612 persons per vehicle) automobiles (cents per day)	Open	
264	271	HOVO OPERATING COST	Vehicle operating cost per person, per trip, high occupancy vehicles not using the Shirley HOV lanes (calculated from LOV DIST at a rate of $0.15 per mile)(cents)	Open	

Table 2. Summary of Contents of the Shirley Highway Corridor Final Calibration Dataset (Cont.)

Location (Columns) Begin	End	Variable Name (ULOGIT file)	Variable Label	Code	Variable Description
274	281	DA OPERATING COST	Vehicle operating cost per person, per trip, single occupant vehicles (calculated from LOV DIST at a rate of $0.15 per mile)(cents)	Open	
284	291	TWO OPERATING COST	Vehicle operating cost per person, per trip, two occupancy vehicles (calculated from LOV DIST at a rate of $0.15 per mile)(cents)	Open	
294	301	THREE OPERATING COST	Vehicle operating cost per person, per trip, three occupant high vehicles using Shirley Highway HOV lanes (calculated from HOV DIST at a rate of $0.15 per mile)(cents)	Open	
310	317	LOV WEIGHT	Sample weight, records corresponding to LOV trips only	Open	Can be used to select sub-sample of file of LOV trips (2, 3, 4+ non-Shirley lanes)
334	341	HOVS OPERATING COST	Vehicle operating cost per person, per trip, high occupancy vehicles using Shirley Highway HOV lanes (calculated from HOV DIST at a rate of $0.15 per mile)(cents)	Open	

Source: Comsis Corp. (18).

3.3 PRELIMINARY MODEL RESULTS

The US DOT's ULOGIT calibration software was used to estimate a multinominal logit[1] mode choice model from the Shirley Highway Corridor calibration dataset. The model given by Equation 8 was chosen to best represent the travel choice processes occurring in the Shirley Highway corridor (18). Table 3 presents the calibrated values of the model coefficients.

$$P_m = \frac{e^{-U_m}}{\sum_{i=1}^{n} e^{-U_n}} \qquad (8)$$

Where:

P_m = probability of selecting mode m

$U_{transit}$ = A1 x IVTT + A2 x OVT + A3 x FARE + C2 x VPW + B6

$U_{drive\ alone}$ = A1 x IVT + A3 x (PARKCOST1 + OPCOST1)

$U_{2\ occupant}$ = A1 x IVT + A3 x (PARKCOST2 + OPCOST2) + B2

$U_{3\ occupant}$ = A1 x IVT + A3 x (PARKCOST3 + OPCOST3) + B3

$U_{4+\ non\text{-}Shirley}$ = A1 x IVT + A3 x (PARKCOST4 + OPCOST4) + C1 x PREFP + C4 x LRGEMPL + B4

$U_{Shirley\ HOV}$ = A1 x HOVT + A3 (PARKCOST4 + OPCOSTHOV) + A4 x HOVDIST + C1 x PREFP + C2 x VPW + C3 x FLEX + C4 x LRGEMPL + B5

A1-A4 = level of service coefficients

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[1] Refer to Section 2.2 for a general discussion of the logit model.

B2-B6 = mode specific bias coefficients

C1-C4 = tripmaker and workplace characteristic coefficients

IVTT = transit in-vehicle time

OVT = transit out-of-vehicle time

FARE = transit fare in cents

VPW = vehicles per worker in the household

IVT = LOV in-vehicle time

PARKCOST1-4 = average traffic analysis zone destination parking cost divided by occupancy

OPCOST1-4 = perceived operating cost per person of LOV trip at 15 cents per mile

PREFP = 0/1 variable, where 1 indicates employer provides preferential parking treatment for carpools

LRGEMPL = 0/1 variable, where 1 indicates employer has more than 500 employees at work site

HOVT = in-vehicle travel time for HOV trips using Shirley HOV lanes

OPCOSTHOV = perceived operating cost, per person, of HOV trip using Shirley HOV lanes at 15 cents per mile

HOVDIST = distance (miles) of trip using Shirley HOV lanes

FLEX = 0/1 variable, where 1 indicates employer provides flexible work hours

Table 3. Calibrated Model Coefficients, Shirley Highway HOV Lane Demand Model

Coefficient	Value	t-Ratio
A1	0.0286	7.55
A2	0.0355	6.29
A3	0.0022	5.13
A4	-0.0830	-9.88
C1	-1.0673	-8.12
C2	0.2806	3.58
C3	-0.0546	-0.46
C4	-0.6078	-4.22
B2	1.5636	16.71
B3	3.4739	20.61
B4	5.0149	21.20
B5	3.6565	17.40
B6	-0.4808	-3.00

Source: Comsis Corp. (18)

3.4 DISCUSSION

The model given by Equation 8 represents the results of initial model specification efforts. This "candidate" specification has a number of shortcomings that will need to be resolved before attempting to use the model in other urban areas. For example, the model builders have expressed concern regarding the estimation of the model's parameters. Due to the problems encountered with the ULOGIT software, the modelers recommend additional calibration tests using logit fitting software other than UTPS program ULOGIT.

The ULOGIT software was initially selected for this effort because of the consultant's experience with its use and its demonstrated ability to fit regional models. It was discovered during the course of this analysis that

ULOGIT is extremely sensitive to the order in which variables are specified in the fit equations. In fact, in one instance a model form that was successfully calibrated by the program on one day was unable to be fit by ULOGIT during a subsequent trial. The only difference between the two runs was the specific order in which the variables were listed in each specification. Staff at UMTA indicated that ULOGIT is coded with only single precision program variables rather than double precision and that this is a likely cause as to why the program had such difficulty in fitting the rich and complex travel behavior data represented by the Shirley Highway Corridor calibration dataset. If further research is pursued with this dataset, it is strongly recommended that a different logit model calibration program be utilized (18). The QUAIL (19) logit fitting program has been suggested as an alternative to ULOGIT.

In addition to the model specification issue, the candidate model has not been validated. Consequently, it is not known with any degree of certainty whether the candidate model is the "best" model, or whether the model can accurately replicate the travel choice processes occurring in the Shirley Highway corridor. As a result, additional development and testing of the model will be necessary prior to the initiation of validation tests elsewhere.

A third concern that must be addressed if the model is to be evaluated in Texas is the time period modeled. As noted earlier, the Shirley model is a peak-period model. The travel demand programs currently in use in Texas are 24-hour models. The Texas models will need to be modified to incorporate peak-period assignment capabilities if the Shirley Model is to be utilized.

Finally, the model must be coded in UTPS in order to apply and evaluate the model. While coding the model itself is a fairly straight-forward procedure, the coding and skimming of the transit, HOV, and highway networks may pose some difficulties.

The concerns outlined above indicate that the results of the initial modeling effort must be viewed with a great deal of caution. The results do, however, provide some insight into the problems of understanding and predicting travel choice behavior in the presence of HOV priority facilities and workplace carpooling incentives.

The first general conclusion that can be drawn from the candidate model is that the travel time and cost variables found in most mode-choice models (See Table 1, p. 15) are significant in the Shirley Model as well. The Shirley Model, then, seems "reasonable" in that it has properties (variables) similar to those typically observed in mode-choice models.

The second travel behavior issue that the candidate model provides insight into is the hypothesis that more than travel time differences explain differences in mode choice for use of HOV priority facilities. Prior to discussing the results of the tests of this hypothesis in the Shirley Corridor, a brief digression is in order.

Because there are few major HOV facilities in the United States, there has been little opportunity to assess the specific nature of travel behavior in corridors with HOV lanes. As a result, studies on proposed new HOV facilities typically rely on an assumption that travel on an HOV facility available to, for instance, 4+ occupant vehicles is different from currently observed travel in 4+ occupant vehicles absent the reserved lane only in terms of travel time. This assumption implies that all travel characteristics not specifically included in the model are the same in both situations, an assumption that may well be quite wrong. Such unmeasured characteristics as reliability and avoidance of stop-and-go traffic may both be significant determinants of mode choices and significantly different between HOV-lane and non-HOV lane travel (18). A common situation, then, is one in which the researcher has "left-out" variables either because he is unaware of their presence in the true specification or because he does not have data for including them in the model (20).

These unmeasured variables are captured in the mode-specific constants, often called bias constants. These constants usually play a major role in the predictions generated by a mode choice model. For example, the Twin Cities mode choice model considers five modes (transit plus auto occupancy levels 1 through 4+) and uses income-specific bias constants. For a middle-income traveler, these constants are (18):

Occupancy	Bias Constant	Equivalent In-Vehicle Minutes	Difference Versus 1-Occupant Mode (Minutes)
1	-1.818	-59	-
2	-0.717	-23	36
3	+0.233	+8	67
4+	+0.846	+27	86

where the "equivalent minutes" of in-vehicle travel time are computed by dividing the bias constant by the in-vehicle time coefficient (0.031, in this example). This indicates that the effect of important but unincluded variables is equivalent to large differences in travel times. For 4+ occupancy, for example, the influence of unincluded variables is equivalent to 86 additional in-vehicle minutes compared to driving alone (18). These results suggest that there exists a significant "dis-incentive" to use the 4+ mode. A major concern, therefore, is whether this very large "penalty" should be applied to 4+ occupant autos on an HOV facility. If the HOV facility changes (improves) some of the unincluded variables substantially, the continued use of the 86 minute penalty would result in a significant underestimate of HOV volumes on the facility (18).

This concept of "equivalent minutes" is a useful one for examining the relationship between travel time savings and mode choice in the Shirley Model. For example, the mode specific bias constant for the Shirley HOV mode (B5) is 3.6565, and the bias constant for HOVs not using the priority lanes (B4) is 5.0149 (Table 3). This indicates that carpoolers in the corridor have an additional propensity to use the Shirley HOV lanes that is not explained solely by travel time and cost differences and workplace descriptors. This propensity can be expressed in terms of an equivalent travel time difference of 47 minutes per trip (B4/A1 - B5/A1) (18). There appears to be "something", other than travel time and cost differences and workplace characteristics, that provides an incentive to use the HOV lanes that is equivalent to a travel time savings of 47 minutes. These other incentives may be related to the reliability (consistency) in travel time resulting from the higher level-of-service provided by the HOV lanes. This preliminarily indicates that other urban area modal split models which attempt to estimate HOV priority facility use based solely on time and cost savings will be underestimating the attractiveness of these facilities (18).

A third issue addressed by the Shirley Model is whether, and to what extent, workplace incentives for ridesharing contribute to the success of that mode compared with travel time savings offered by the Shirley HOV facility. The candidate model indicates that workplace incentives are important inducements for ridesharing over and above those offered by the Shirley HOV lanes. Table 3 indicates that the availability of preferential parking for carpools (coefficient C1) offers a strong inducement to carpool with or without the use of the Shirley HOV lanes, the equivalent of 37 minutes of travel time savings (C1/A1). Similarly, being employed at a work site with more than 500 employees (most likely a Federal Government work site), generates other positive inducements to ridesharing, the equivalent of 21 minutes of travel time savings (C4/A1). Flexible work hours, while included in this model, do not appear to be a separate, strong explanatory variable for ridesharing, with a t-ratio of less than 1.00 (18).

A final issue regards the potential transferability of any model developed from the Shirley Highway Corridor dataset. This requires the inclusion of all significant determinants of ridesharing behavior. In addition to the travel time and cost, workplace, and sociodemographic variables in the Shirley HOV mode equation, a trip distance variable was included to represent the reliability of travel time offered by the HOV lanes over the mixed traffic lanes and other roadways in the corridor. The distance variable (HOVDIST) has a strongly significant coefficient (A4) with a negative sign indicating that the longer a trip, the more likely a commuter will choose to use the Shirley HOV lanes, all other factors held constant. Ten extra miles of trip length is the equivalent of 29 minutes of travel time savings for HOV lane users (A4/A1 = -2.9 miles/minute). Isolating this effect is important in enhancing the ability of the model to be transferred to applications in other travel corridors (18).

The candidate model discussed in this section suggests a number of interesting relationships which could prove useful in efforts to understand and predict travel choice behavior in corridors with HOV priority facilities. However, additional research is required to better refine modal choice models that can accurately predict travel choices for alternative transportation improvements which include HOV priority facilities and workplace ridesharing incentives. The developers of the Shirley Model recommend that these additional calibration tests utilize other logit fitting software than UTPS program ULOGIT. These refined model forms should then be rigorously validated in the way they would be used to forecast travel using aggregate inputs, both in the Shirley Corridor and in other HOV facility corridors around the nation (18).

4. FEASIBILITY OF USING THE SHIRLEY MODEL IN TEXAS

4.1 GENERAL

This section presents an assessment of the feasibility of using the Shirley Model in Texas. The assessment is based on a number of technical and policy-related issues which have a direct bearing on the feasibility question.

The technical issues addressed include: 1) the variables in the Shirley Model and their potential significance in Texas; 2) the modes modeled by the Shirley Model as compared to modes utilizing HOV facilities in Texas; 3) data requirements for implementing and evaluating the Shirley Model; and 4) the mechanics of implementing the Shirley Model within the travel demand modeling structures currently in place in Texas.

In addition to these technical considerations, a number of policy-related issues are also discussed. The basic theme of the discussion involving these policy issues revolves around the feasibility and desirability of attempting to introduce a new mode-choice model to replace those currently in use or under development in the major urban areas of Texas.

4.2 TECHNICAL CONSIDERATIONS

The key technical issues that must be considered in assessing the feasibility of using the Shirley Model in Texas are the following.

1) Calibration/Validation. Due to problems encountered with the ULOGIT software, the developers of the Shirley Model have recommended that the parameters of the model be re-estimated using the QUAIL (19) logit fitting program. Additionally, the candidate model has not been validated against Shirley Highway Corridor data. Consequently, it is not known with any degree of certainty whether the candidate model is the "best" model, or whether the model can accurately replicate the travel choice processes occurring in the Shirley Corridor. As as result, additional development and testing of the

model will be necessary prior to the initiation of validation tests elsewhere. Although additional model development and testing efforts have been proposed, the model has not been sufficiently refined for testing outside the Shirley Corridor.

2) Mode-Choices Modeled. The Shirley Model considers the following mode choices:

- Transit;
- 1, 2, 3, and 4+ occupant non-HOV lane modes; and
- Shirley Highway HOV lane modes (4+ occupants).

High-occupancy vehicle facilities in Houston, on the other hand, accept buses, vanpools and, in one case, 2+ occupant carpools. The modal alternatives available to HOV commuters in Houston, then, differ from those available to Shirley Highway commuters. As a result, the Shirley Highway dataset cannot be used to re-estimate a model that predicts 2+ or 3+ HOV lane usage because these are not modal choices available to Shirley Highway commuters; i.e., there are no Shirley Highway data available to estimate a model for 2+ or 3+ HOV lane modes. In short, the Shirley Model is based on a "choice-set" that differs from the choice-set(s) available to commuters in major urban areas in Texas.

3) Model Variables. The candidate Shirley Model given by Equation 8 (p. 43) contains several variables that may be of questionable significance in modeling mode-choice processes in Texas. For example, the work site size (LRGEMPL), parking cost (PARKCOST), carpool incentives (PREFP), and flexible work hours (FLEX) variables are probably not significant determinants of mode-choice in Texas. All of these except the parking cost variable have been specified as dummy (0/1) variables. These dummy variables could be assigned zero-values for applications in Texas. The parking cost variable, on the other hand, may need to be re-evaluated in terms of its potential significance in Texas, where these costs are relatively low.

The basic concern with these variables is that it is not known how comparable the ranges of values for the variables are between urban areas in Texas and the Shirley Corridor. It is quite possible that the upper end of the range for these variables in Texas is near the lower end of the ranges observed for the Shirley Corridor. How well the Shirley Model performs for observations in the "tails of the data" is not known.

4) Time Period Modeled. Another issue that must be addressed if the Shirley Model is to be evaluated in Texas is the time period modeled. The Shirley Model is a peak-period (6:00 a.m. - 9:30 a.m.) model. The travel demand programs current in use in Texas are 24-hour models. As a result, the Texas models will need to be modified to incorporate peak-period assignment capabilities if the Shirley Model is to be utilized in Texas.

5) Data and Coding Requirements. Given the preliminary nature of the candidate model, it is not possible at this time to identify precisely the data needed to apply and evaluate the Shirley Model in Texas. It appears, however, that the following general data would be needed.

- highway skim files (time and distance) for non-HOV and HOV paths,
- transit skim files (as required by the calibrated model),
- zonal data (e.g., parking costs, autos/worker, transit fares)
- home based work (HBW) person trip tables, and
- mode usage data and traffic counts (for model validation).

The model results should be compared both on an aggregate and disaggregate basis. Aggregate results should compare:

- corridor modal shares,
- cutline and screenline modal shares,
- CBD versus non-CBD modal shares,
- cutline and screenline traffic volumes, and
- Root Mean Square Error (RMSE) by roadway facility type.

Disaggregate comparisons should be made for:

- volumes by freeway entrance location,
- HOV facility volumes,
- specific link volumes, and
- trip length frequencies by mode and level of service variables.

The majority of these data are standard UTPS data and should be available for the major urban areas in Texas. However, several issues will need to be resolved in the development of these data. These include:

- which traffic zone system to use (highway or transit),
- which person trip table to use (daily HBW vs. peak HBW), and
- which "rules" to follow in the coding and skimming of the transit network and highway network.

4.3 POLICY ISSUES

The basic policy issue affecting the feasibility of using the Shirley Model in Texas centers around the fact that the model is intended to be used as a traditional mode-choice model with an HOV component. The Shirley Model would estimate mode shares for traditional modes (e.g., highway, transit), as well as HOV priority lane mode shares. The mode-choice modeling efforts underway in Texas are sufficiently advanced that it does not seem prudent at this time to re-direct these efforts to incorporate HOV priority lane demand estimation capabilities into the mode-choice phase of the modeling process. Prior to attempting to incorporate HOV lane components into established mode-choice models, additional research should be conducted to more clearly define those factors affecting HOV lane demand in Texas.

In the short term, then, it would appear that what is needed is a procedure for estimating HOV lane demand using information extracted from travel demand models and HOV lanes currently in use, rather than attempting to reformulate existing models to estimated potential HOV lane demand directly. The development of HOV lane demand estimation procedures that are not components of existing mode-choice models, yet draw upon elements of these and other travel models, would seem to be more appropriate at this time.

As the factors affecting HOV lane demand become more clearly defined, efforts could be directed at re-structuring existing mode-choice models to include an HOV lane demand component.

4.4 SUMMARY

The Shirley Model, in its current form, poses a number of technical problems which raise questions concerning the feasibility of implementing the model in Texas within a reasonable time frame. The Shirley Model will require additional development and testing to insure that the model has been correctly specified and to determine whether the model can accurately replicate travel choice processes observed in the Shirley Corridor. These issues should be addressed prior to the initiation of additional tests outside the Shirley Corridor.

The Shirley Model is based on a "choice-set" that differs from the choice-set(s) available to commuters in the major urban areas of Texas. That is, the Shirley Model predicts mode shares for modes that differ from the modes available to commuters in Texas. It is not clear at this time whether the Shirley Model could be re-estimated to account for these differences in choice-sets.

Given the preliminary nature of the Shirley Model, it is not possible at this time to define precisely the data and coding requirements of the model. However, it appears that additional data would be needed to validate the model in Texas, and that a substantial effort would be required to code the model in the existing travel demand model structure.

In addition to these technical issues, the desirability of attempting to introduce a new mode-choice model to replace those currently in use or under development raises a number of policy-related questions that have a direct bearing on the feasibility question. Mode-choice modeling efforts in Texas have advanced to the point that attempts to re-direct these efforts may not be prudent at this time; particularly in light of the "preliminary nature" or the Shirley Model.

The technical issues outlined above suggest that additional development and testing of the Shirley Model will be needed prior to the initiation of validation tests outside the Shirley Corridor. This assessment of the implications of the technical issues raised makes the policy issues of secondary importance in the overall feasibility question.

The overall indication from this preliminary assessment, then, is that it is not feasible at this time to implement the Shirley Model in Texas. Which is not to say that the research effort should be abandoned. Preliminary results from the Shirley modeling effort look promising and should prove useful in modeling HOV lane demands. Given the need for reliable HOV lane demand estimation procedures in Texas (and elsewhere) and the insights into HOV lane travel choice behavior provided by the Shirley Model, a re-directed, incremental research approach appears warranted. This re-directed effort might involve the development of an HOV lane demand estimation procedure based on empirical data from HOV lane facilities in operation in Texas. Such a procedure could be supplemented with network information extracted from travel demand programs currently in use in Texas. This approach should lead to an identification and quantification of the factors affecting HOV lane demand and provide the basis for the subsequent development of more refined HOV lane analysis techniques.

The suggested re-direction of the research effort should remain closely coordinated with the continuing development and testing of the Shirley Model. This coordination is important for several reasons. For example, continued monitoring of the Shirley effort could provide valuable insight into the factors and relationships affecting HOV lane demands. Additionally, efforts to develop an HOV lane demand estimation procedure for Texas cities could provide an independent (though indirect) validation of the significance of the variables identified in the Shirley Model. Finally, given the UMTA and FHWA sponsorship of the Shirley Model project, it is possible that the Shirley Model could evolve into the preferred method of analysis for federal funding support of HOV lane projects. Therefore, the coordination of any local HOV modeling efforts with the Shirley project could greatly expedite the implementation of future HOV lane projects in Texas.

As noted earlier, the modified research approach suggested above should not be viewed as an abandonment of the original study objectives. Once the Shirley Model is more fully developed, it would be extremely useful to attempt to validate the model in Texas. These validation tests could facilitate the development of a comprehensive and uniform HOV lane planning tool for the major urban areas of Texas. Additionally, successful validation of the Shirley Model in Texas, and/or identification of possible refinements and modifications in the model, could also facilitate use of the model on a nationwide basis. Preliminary indications are that there may be federal funds available to conduct these validation tests. In the meantime, however, local, short-term needs indicate that alternatives to the Shirley Model need to be identified and evaluated. This study approach is within the scope of work outlined in the research agreement.

A preliminary inventory and assessment of alternatives to the Shirley Model is presented in the following section of this report.

5. ALTERNATIVE HOV LANE DEMAND ESTIMATION PROCEDURES FOR TEXAS

5.1 GENERAL

Since very few HOV lanes are currently in operation, no widely accepted procedures for estimating HOV lane demand are available. Consequently, current procedures for estimating the demand for these facilities are based upon a synthesis of several methodologies. In recent years, the Texas Transportation Institute (TTI) has utilized the following four techniques to estimate the demand for HOV facilities in Houston: 1) The findings from a recent Federal Highway Administration (FHWA) study (21); 2) A mode-split analysis of home-based work trips in the Houston-Galveston area (22); 3) The findings from a recent TTI study that developed guidelines for sizing park-and-ride lots (23); and 4) An analogy to the contraflow lane operation on I-45N in Houston (24). A feature which all of these techniques have in common is their "quick response" capability. Nevertheless, preliminary test applications of these quick response estimation procedures have, in some instances, yielded results beyond the accuracy typically associated with sketch planning techniques.

This section presents a general description of the four estimation procedures listed above. The section concludes with a brief critique of the procedures and a discussion of possible modifications and extensions that could improve the accuracy and tractability of these procedures.

5.2 FHWA PROCEDURE

5.2.1 Background

A 1982 study (21) sponsored by the FHWA evaluated existing HOV lane projects in the U.S. in an effort to develop simplified techniques to predict travel volumes due to the implementation of priority treatment for HOVs on freeways. The review of current procedures revealed that no existing travel demand models have been estimated using actual before-and-after data from the broad cross-section of HOV demonstration projects sponsored by USDOT over the past 10 years. Consequently, a new model formulation was proposed and estimated using empirical before-and-after data from HOV sites across the U.S.

5.2.2 Applicable HOV Treatments

The existing HOV sites that were used to develop the estimation procedure shared the following basic characteristics (21):

1. The HOV lanes operate on (or adjacent to) major radial freeways serving a central city or central business district;

2. The HOV lanes ranged from 2.5 to 9 miles in length;

3. All study sites experienced force-flow or severe capacity constraint conditions on the general purpose lanes in the periods prior to implementation of the HOV lane(s); and

4. Among the HOV sites used in model estimation, many network conditions and alternative links existed, allowing different route diversion effects.

Thus, if the corridor being analyzed is atypical with respect to these basic characteristics, the models may not yield reliable results.

The FHWA procedure considers the following five travel modes (21):

1. Nonpriority Automobiles - the volume of automobiles traveling in the peak hour on the general purpose lanes in either the before or after time periods;

2. Priority Eligible Automobiles - the volume of automobiles traveling in the peak hour on the general purpose lanes in the before period that could be eligible to use the HOV lane(s) in the after period;

3. Carpools on HOV Lane(s) - the volume of automobiles traveling in the HOV lanes in the before period that would be allowed on the HOV lanes in the after period;

4. Priority Eligible Buses - the number of buses traveling in the peak hour on the general purpose lanes that would be eligible to use the HOV lane(s) in the after period; and

5. Buses on HOV Lane(s) - the number of buses traveling in the peak hours on the HOV lane(s) in the before period that would use the HOV lane(s) in the after period.

The procedures can be used to forecast travel demands for the following four HOV strategies (21):

1. Dedicating a new or existing lane for bus-only HOV operations;

2. Dedicating a new or existing lane for bus and carpool operations;

3. Allowing carpools onto an existing bus-only HOV lane; and

4. Allowing carpools with lower occupancy levels onto an existing bus and carpool HOV lane.

5.2.3 Data Requirements

The following four types of data are needed to implement the FHWA estimation procedures (21):

1. Peak-Hour Volumes. In the before period, a.m. peak hour volumes are required for the following modes (see definitions above): 1) nonpriority automobiles; 2) priority eligible automobiles (note that for bus-only HOV strategies, this volume will be zero); 3) carpools on HOV lanes (if no carpool HOV lane exists, this volume will be zero); and 4) the number of buses and passengers either eligible to move onto the HOV lane or already on the HOV lane (note that this is an either/or situation). These volumes are

measured at a screen line located within the boundaries of the beginning and end point of the proposed (or existing) HOV lane(s). This screen line is also the reference point for all other measurements. Consequently, this line will indicate the location of the forecasted volumes.

Of the four peak hour volumes that may be required for a particular analysis, the one likely to be the least readily available is the volume of priority-eligible automobiles. Typically, permanent or temporary counting stations will provide good data on the total number of vehicles traveling inbound in the morning peak. However, if the proposed strategy being analyzed is to allow 3+ person carpools onto an existing or new HOV lane, the volume of 3+ person carpools is needed along with the combined volumes of two-person carpools and single occupant vehicles. If these volumes by auto occupancy are not immediately available, one could, as a first-cut approximation, use system wide auto occupancy proportions obtained from ridesharing studies (or even Census data), or more accurately conduct a special vehicle occupancy count during the morning peak commuting period.

2. Peak Hour Travel Times. For each travel mode that is pertinent to the HOV strategy being evaluated, an estimate of average door-to-door travel time is required. As indicated above, this estimate is determined for vehicles passing the screen line. Since travel times "saved" or reduced by using or not using the HOV lane are calculated as a proportion of these total door-to-door travel times, small errors in the latter will not introduce large errors in the proportions input to the model. Therefore, it is not necessary that they be determined precisely. They can be obtained from the output of existing computer models or by using information on average trip lengths and route sections having different average travel speeds.

3. Average Peak Hour Travel Speeds. Average peak hour travel speeds are required for vehicles on the general purpose lanes and, if they are present in the before period, vehicles on the HOV lane(s). The speeds are those required to travel either the length of the HOV lane(s) or the length of the general purpose lanes adjacent to the existing or proposed HOV lane(s). These speeds should be estimated more precisely than the total travel time data since they are used to estimate travel times, and changes in

travel times, over the (typically) shorter section of the freeway bounded by the HOV lane. If not already available from secondary sources, these speeds could be determined through actual measurement (e.g., by conducting a floating car travel time study).

4. Existing Freeway Supply and Capacity. The number of lanes and capacity must be specified for both the existing general purpose freeway lanes and, if they exist, for the HOV lane(s). The capacity, if not readily known, can be computed using accepted estimation procedures.

For the forecasting procedures presented here, capacity is defined as the maximum number of vehicles moving by a particular point in a given one-hour period. Thus, if empirical data should yield peak hour travel volumes that are higher than those determined through a formal application of capacity calculation procedures, the higher value should be used as the measure of capacity.

5.2.4 Estimation Procedure

The basic estimation procedure involves using five regression models to forecast demand volumes, and with the aid of supply relationships, obtaining equilibrium travel flows on the general purpose freeway and HOV lane(s). The procedures can be used to predict peak hour flows for: 1) Automobiles on the general purpose lanes; 2) Carpools that are already on or that will be allowed to use the HOV lane(s); and 3) Bus passengers on the HOV lane(s). Since the demand models were developed using actual before-and-after data, the models reflect the net change in volumes due to mode shifts, time-of-day changes, trip generation, and route diversion effects.

A supply model, using speed-flow relationships, is used in an iterative fashion with the predicted demand volumes to reach equilibrium travel volumes. The supply model is used to determine equilibrium speeds on the general purpose lanes (if it is possible for free-flow conditions to exist on the general purpose lanes in the after period). An examination of existing HOV facilities revealed that free-flow conditions are sometimes possible when buses and carpools are allowed to use the HOV facility and a general purpose lane is not taken away. Under all other circumstances, forced-flow conditions continued to prevail in the after period (21).

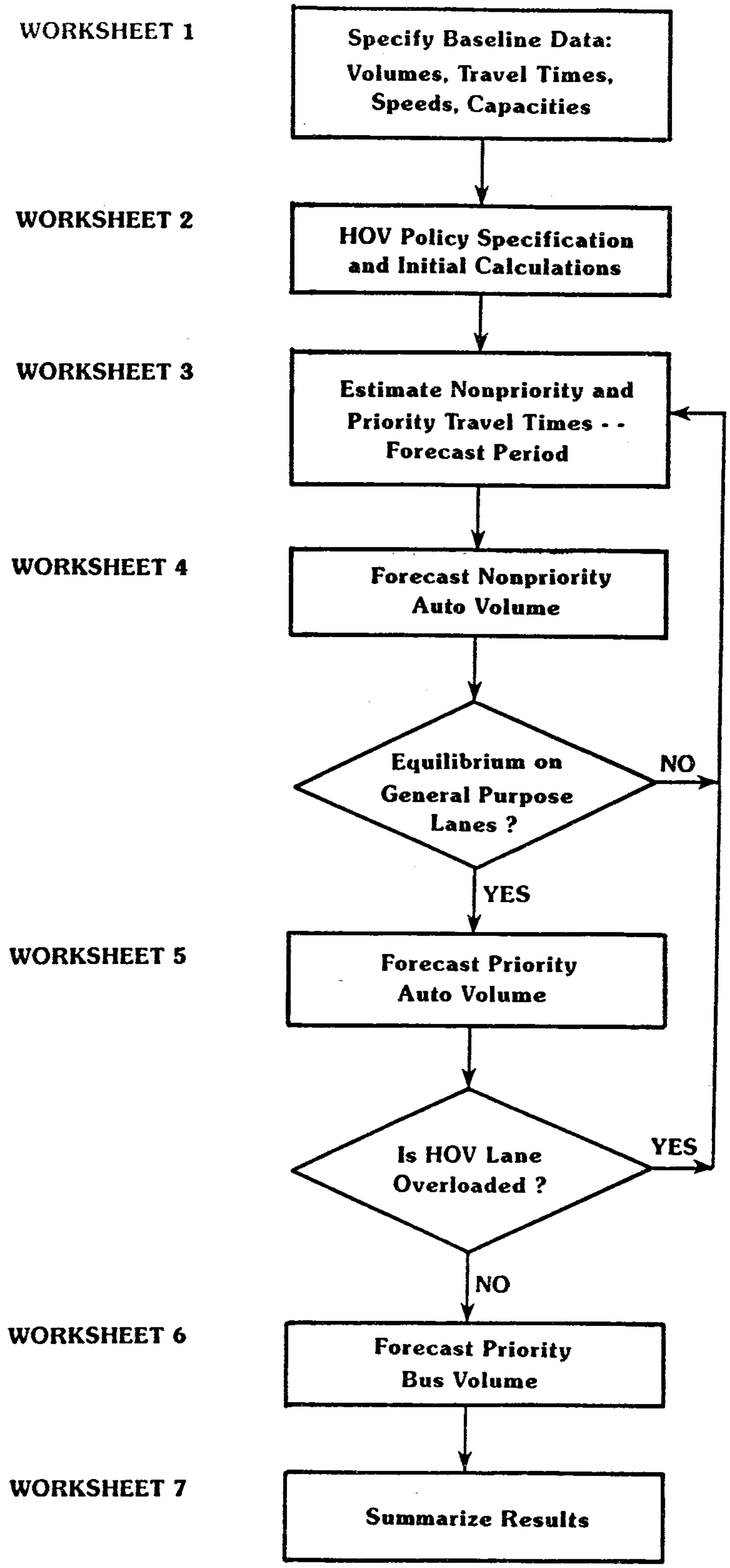
5.2.5 Application

The FHWA procedures have been reduced to a set of seven worksheets that are used in a sequential and, if necessary, iterative fashion to reach equilibrium. The flow chart in Figure 1 highlights the major activities for each worksheet. The general procedure and use of the worksheets is discussed below. A detailed description of the estimation procedure and sample worksheets can be found in References 21 and 25.

First, baseline travel data consisting of before volumes, travel times, speeds, and capacity (as defined above) are assembled and listed on Worksheet #1. Next, the proposed HOV strategy to be evaluated is defined on Worksheet #2. This consists of specifying the modes that will be allowed to use the HOV lane(s), the length of the HOV lane(s), and the proposed capacity of the general purpose and HOV lanes (21).

With the information presently specified, various initial calculations are performed using Worksheet #2 to disaggregate the baseline travel time data into two components -- travel time on and off the freeway section bordered by (or adjacent to) the HOV lane(s). Worksheet #3 is used next to derive initial estimates of travel time changes, and therefore "after" travel times, that will be needed to forecast demand volumes in subsequent worksheets. The before and after travel times now known for each mode are input to a demand equation contained on Worksheet #4 to estimate the after peak hour volume of nonpriority automobiles. If it has been assumed that free-flow travel conditions are possible, a check is made to determine if the initial estimated travel times (and thus speeds) are in close agreement with the model's estimated volume (and thus travel speed and times). If these equilibrium conditions are not satisfied, revised or updated estimates of travel time are computed and the procedure is repeated (21).

When equilibrium volumes are obtained on the general purpose lanes, Worksheet #5 is used to forecast the volume of carpools (including priority



Source: (21)

Figure 1. Flow Chart of FHWA HOV Demand Estimation Procedures

eligible autos and existing HOV carpools) that will use the HOV lane(s). If carpools are not allowed on the HOV lane(s), this worksheet is not used. However, if this worksheet is used, the predicted volume of carpools on the HOV lane is compared to the capacity of the HOV lane(s) to determine whether the initial estimate of speed is valid. This check also determines whether the volume of carpools will exceed the HOV lane capacity, indicating that a more restrictive HOV strategy should be evaluated (21).

Worksheet #6 is used to predict the volume of priority bus users. A similar equilibration procedure is not employed, since bus volumes on the HOV lanes are not likely to exceed HOV capacity. (If necessary, however, the analyst can perform a simple test patterned after those used for nonpriority and priority eligible automobiles.) Finally, Worksheet #7 summarizes the forecasted peak hour travel volumes, speeds, and times that have been obtained from the previous worksheets (21).

5.3 MODE SPLIT ANALYSIS OF HOME-BASED WORK TRIPS

This estimation methodology is based on a generalized mode-split analysis of home-based work (HBW) trips. Data required for implementation include the following:

1) Estimates of existing and design year HBW trip tables;

2) Estimates of existing and design year network travel times, or network traffic assignments; and

3) Estimates of mode splits (% person or vehicle trips on the HOV lane) for the activity centers served by the HOV lane.

The existing and design year trip tables provide estimates of traffic volumes (by trip purpose, mode, or other classification) between specific analysis (or traffic) zones of a metropolitan area. For the purpose of estimating HOV demands, a trip table depicting metropolitan travel patterns in terms of person-trips is preferable.

Estimates of network travel times can be used to determine the specific roadway facilities (links) which are likely to be used to complete the trip interchanges depicted in the trip table.

The key to the effectiveness of this estimation procedure is the availability of reliable estimates of HOV mode-splits. While most standard transportation planning computer program packages can estimate trip tables by travel mode, the resulting trip tables do not explicitly account for the mode shifts which can result from the implementation of an HOV priority treatment strategy. Consequently, the primary disadvantage of this methodology is the lack of data on HOV mode-splits.

With the exception of data on HOV mode-splits, the data needed to implement this estimation procedure should be available from local transportation planning agencies. Most metropolitan areas in Texas have calibrated and implemented transportation planning computer program packages and can provide detailed information on existing and forecasted traffic volumes by origin and destination for the major highway facilities in a particular urban area. By applying estimates of HOV mode-splits, the analyst can then estimate potential HOV demands.

The basic estimation procedure can be summarized as follows:

1) Define the freeway corridor to be analyzed;

2) Tabulate peak period HBW trips between those traffic zones in the freeway corridor and the major activity centers which will be served by the HOV lane;

3) Assign the major activity center trip demands to the freeway and arterial networks on the basis of peak period travel times (If available, network assignments performed using standard computer assignment algorithms may also be used); and

4) Apply mode-split distributions to the HBW trips to estimate potential HOV demands. In the absence of local data, the mode-split distributions shown in Tables 4 and 5 may be used as general guides.

Table 4. Bus Mode Split at Park-and-Ride Lots With and Without Transitways, Houston

Park-and-Ride Lot/Priority Treatment	Percent of Travel by Bus
North Shepherd (with priority treatment)	33%
Addicks (without priority treatment)	15%

Note: Mode split is defined as the percent of park-and-ride lot market area population working in downtown that uses the park-and-ride service.

Source: (24).

Table 5. Mode Splits Associated with Selected Transitway Projects

Project	Mode Split
I-45 Contraflow, Houston	
Bus	33%
Vanpool	19
TOTAL	52%
El Monte Busway, Los Angeles	
Bus	25%
Carpool	20
TOTAL	45%

Note: Mode split as defined in Table 4. For I-45N, these are trips from the park-and-ride market areas to downtown. For El Monte, these are trips from the east end of the busway to downtown.

Source: (24).

5.4 PARK-AND-RIDE DEMAND ESTIMATION

The third technique for estimating HOV demand is based on procedures developed by TTI for estimating park-and-ride lot patronage (23). These techniques include a market area population technique, a modal split technique, and two regression procedures. The procedures are outlined below.

5.4.1 Market Area Population Technique

Analysis of survey data from park-and-ride lots in Texas indicates that the population of the park-and-ride lot market area can be used to estimate the number of park-and-ride patrons destined for the CBD. The percentage of the market area population that is represented by ridership varies between Texas cities. However, within Texas cities, a general range appears to exist. Table 6 summarizes these data.

From the data shown in Table 6, it is not possible to identify what the "ultimate" demand for park-and-ride might be (i.e., ridership that might be generated from a highly congested corridor with priority treatment). The Houston lots on I-45N are filled to capacity, restricting additional lot usage. As such, the value for Kuykendahl may represent a minimum value for that type of service. It is known that this minimum value holds for at least one park-and-ride space per 0.028 market area population. Careful definition of the actual market area, taking into account overlapping market areas in the I-45N corridor, suggests that Kuykendahl, at present, may be serving as much as 2.4% of the market area population. If more parking spaces and buses were provided, it is not unreasonable to assume this percentage would be greater. Indeed, based on today's demand, Kuykendahl may easily be able to serve demand representing 2.5% to 3.0% of the market area population. As a general guide, it is suggested that a market share of 2.5 - 3.0% be used to estimate park-and-ride lot patronage in heavily traveled corridors which have a high attraction to the CBD.

The basic steps in applying the market area population technique to estimate HOV demands are outlined below:

Table 6. Ridership as a Percentage of Population in the Park-and-Ride Market Area

City and Park-and-Ride Lot	Ridership as a % of Market Area Population	"Guideline" for City
Austin		
North Park-and-Ride	0.6	
US 183 North[a]	0.3	0.3 to 0.6
Dallas Area		
Garland South	0.8	
Garland North	1.3	
North Central	0.4[b]	0.4 to 1.3
Las Colinas	0.8	
Redbird	0.7	
Pleasant Grove	0.4	
El Paso		
Montwood[c]	0.4	
Northgate[d]	0.07	0.07 to 0.4
Fort Worth		
Meadowbrook	0.05	
College Avenue	0.3	0.05 to 0.3
Houston[e]		
Champions	0.9	
Kuykendahl	2.1	
N. Shepherd	1.0	
Edgebrook	0.8	0.7 to 2.0
Clear Lake	0.8	(constrained due
Beechnut (both lots)[f]	0.9	to size of lots
Sharpstown	0.3[g]	currently avail-
Alief	0.9	able)
Westwood	1.1	
Katy/Mason	0.7	
Kingwood	1.4	
Lots serving contraflow lane		2.5 to 3.0
San Antonio		
Windsor Park	0.5	
McCreless	0.2[h]	varies up to 1.2
South Park	0.1	
Lackland	1.1	
Wonderland	1.2	
Nacogdoches[i]	0.2	

[a] Includes 3 lots served by the same bus-US 183 North #1, #2 and #3.
[b] Riderhip is lower than would be expected due to paid parking, competing local bus service, poor lot access/accessibility and lot not located upstream of congestion.
[c] Includes 2 lots served by the same bus-Montwood and Vista Hills.
[d] Includes 2 lots served by the same bus--Northgate and Rushfair.
[e] Ridership at most of the Houston lots is constrained by parking spaces available.
[f] Includes 2 lots served by the same bus--Meyerland and Sage.
[g] Low percentage due to small lot size.
[h] Lot located in an uncongested corridor and relatively close to activity center.
[i] Includes 2 lots served by the same bus-Broadway and Bitters.

Source: (23).

1) Define Market Area. It is suggested that the HOV lane market area be estimated by assuming that park-and-ride facilities will be located at the upstream and downstream ends of the facility. Any intermediate gaps in the market area can then be filled by drawing lines tangent to the upstream and downstream market areas. Typical market area shapes are shown in Figure 2.

2) Estimate Market Area Population. Census data and/or population projections prepared by local planning agencies can be used.

3) Estimate CBD Patrons. Estimates of CBD patrons are obtained by multiplying market area population by ridership as percent of market area population (values in the range of 2.5 - 3.0% appear reasonable for heavily traveled corridors in major urban areas of Texas).

4) Account for Non-CBD Patrons. In the absence of local data it may be assumed that CBD patrons account for roughly 85% of total patronage with the balance (15%) destined to non-CBD locations.

5) Estimate HOV Lane Vehicle Demands. The ridership (persons) estimates derived from Step 4, can be converted to peak period vehicle demands by applying vehicle occupancy and authorized vehicle distribution factors. Based on experience from the I-45N contraflow lane in Houston, the following factors would appear to be reasonable for most planning applications:

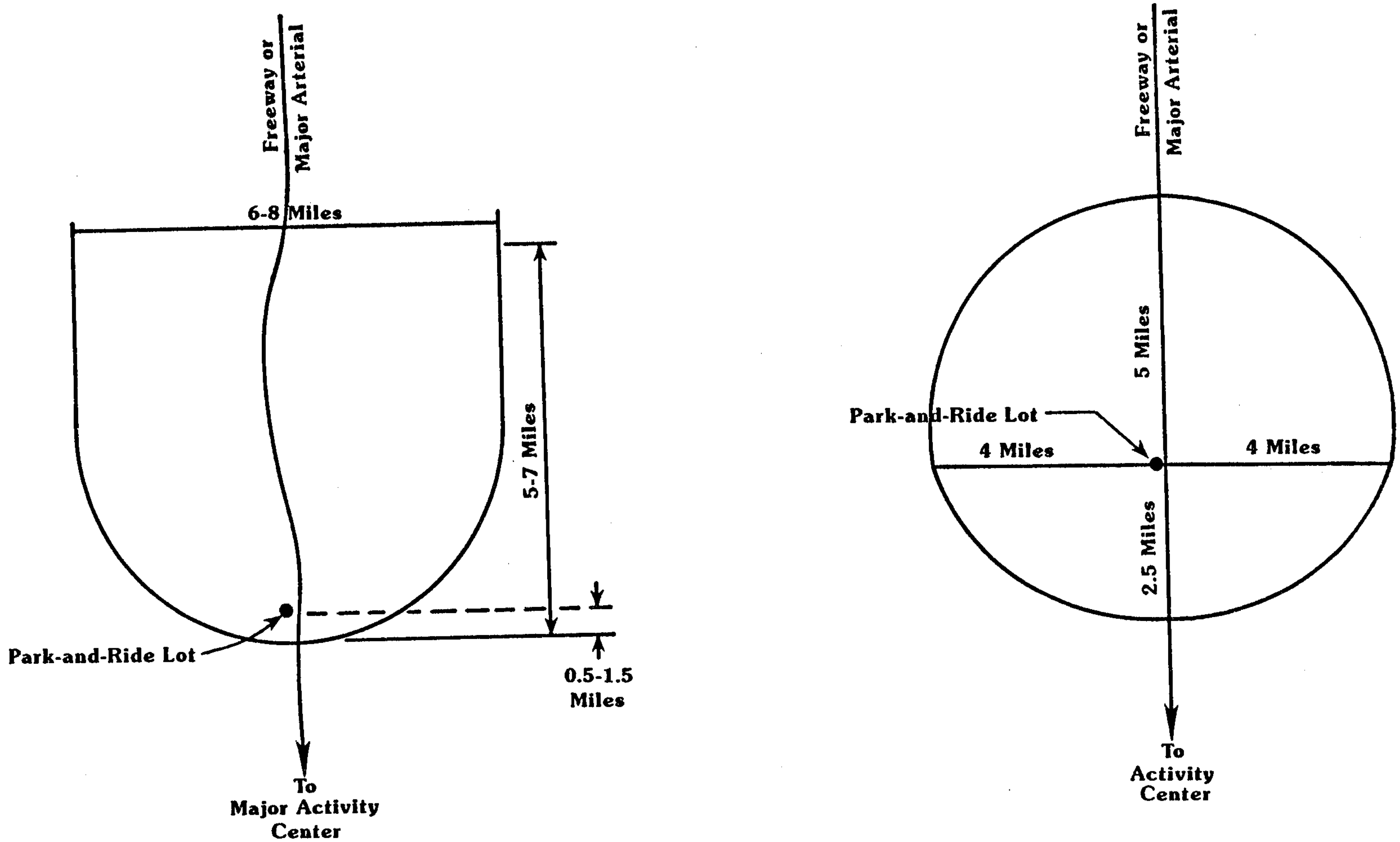
a) 65% of total ridership can be assumed to be on buses;

b) Bus occupancy = 50 persons/bus; and

c) Vanpool occupancy = 9 persons/vanpool.

5.4.2 Mode-Split Technique

The market area analysis previously described assumes that all market areas have an equal affinity to the activity centers being served by park-and-ride. While that approach is simple to apply and uses the most readily available data, it does not account for the fact that different parts of a



(a) Dallas, Garland and Houston, Texas

(b) San Antonio, Texas

Source: (23).

Figure 2. General Shapes of "Typical" Park-and-Ride Lot Market Areas in Texas

corridor or urban area can have different attraction rates to the activity centers being served.

To use the modal-split procedure it is necessary to identify that component of the market area population that works in the activity center served by park-and-ride. This information is not always readily available and, as a result, the attractiveness of this approach is diminished due to data availability concerns. Table 7 summarizes the available modal split data for Texas park-and-ride lots.

The following guidelines--recognizing constraints imposed by lot sizes or lots that have not been properly located -- might be used for park-and-ride analysis.

- Dallas area lots. 10% to 20% modal split.

- Houston area lots. 15% to 30% modal split, with some modal-splits in the range of 50%.

Perhaps Table 7 is most helpful in estimating potential modal-split. Data shown in Table 7 suggest that, if a lot is located properly and a sufficient number of parking spaces is provided, modal-splits in the range of 50% could be attained. That value might be useful in identifying the "upper end" of potential lot size (and demand).

Application of the mode-split technique consists of the following steps:

1) Define Market Area. Same as for Market Area Population Technique previously presented.

2) Estimate Market Area Population Working in Activity Centers. Census data and/or local survey data may be used.

3) Estimate Park-and-Ride Patrons. Estimates of patrons are obtained by multiplying the estimates of market area population working in the activity centers by the activity center mode splits. CBD mode splits on the

Table 7. Estimated Modal-Split for Texas Park-and-Ride Lots

City and Lot	Modal Split[a]	Procedure to Estimate Modal Split[b]
Dallas/Garland Area		
Dallas North Central	7% to 8%	TTI Surveys and Census Analysis
Pleasant Grove	8%	Census Analysis
Oak Cliff	4%	Census Analysis
Garland, North & South	21%	TTI Surveys
Houston		
Clear Lake City	52%	Census Analysis
Gulf Edgebrook	24%	Census Analysis
Westwood	10%	TTI Surveys
Champions	23%	TTI Surveys
N. Shepherd	27%	TTI Surveys
Kuykendahl	22%	TTI Surveys
Kingwood	29%	Census Analysis
Beechnut (2 lots)	13%	Census Analysis
Alief	28%	Census Analysis
Sharpstown	4%	Census Analysis
Katy/Mason	50%	Census Analysis

[a] Modal split is defined as the percent of the market area population working in the activity center served by the park-and-ride service.

[b] In using census data, the percent of the population working in the CBD was obtained from 1970. Due to the massive growth in many of the areas being considered, applying the 1970 percentage to the 1980 market area may result in sizeable errors.

Source: (23).

order of 25%, and non-CBD mode splits on the order of 10% would appear to be reasonable for most planning applications.

4) Estimate HOV Vehicle Demands. Same as for Market Area Population Technique.

5.4.3 Regression Analysis

The data for 35 park-and-ride lots in Texas were analyzed to develop equations that can be used to predict park-and-ride patronage. The following represent some of the more applicable equations.

$$RIDERS = -160 + 204CI + 0.0034MAPOP \quad \textbf{(9)}$$

$$RIDERS = -86 + 0.8MIN + 0.002MAPOP \quad \textbf{(10)}$$
(for $CI \geq 1.3$)

$$RIDERS = 61 + 0.1MIN + 0.001MAPOP \quad \textbf{(11)}$$
(for $0.9 \leq CI \leq 1.2$)

$$RIDERS = 7 + .43MIN \quad \textbf{(12)}$$
(for $CI \leq 0.9$)

where:

RIDERS = Average daily ridership (round trip);

CI = Freeway congestion index (defined as Delay (min)/10 min + (AADT/Lane)/20,000);

MAPOP = Park-and-ride lot market area population; and

MIN = A control based on service provided (i.e., the minimum of the following 2 variables: 1) auto parking spaces x 1.5 persons/auto; or 2) peak-period bus seats). The variable adjusts for the fact that at many existing lots, demand is controlled by facilities or services provided.

While the equations using the variable MIN do a good job of "predicting" ridership at existing lots, their use in estimating demand at new lots requires estimating the value of MIN. Since MIN can vary considerably between lots in a given urban area, the best approach might be to locate an existing lot that is similar to the proposed lot in terms of congestion index, distance to the activity center, and market area population. Using this approach, the value of MIN for an existing lot can be used in the appropriate regression equation to estimate ridership at the new lot. Table 8 presents values of MIN at a number of park-and-ride lots in Texas.

In the absence of a comparable existing lot that can be used to determine the MIN value, one of two approaches might be used. First, the typical values in Table 9 can be applied. These values were obtained for each urban area by averaging the numbers shown in Table 8. It should be noted that, due to the large variation in MIN values for a given urban area, use of the "typical" value may affect the accuracy of the estimate.

Alternatively, since MIN is somewhat related to variables such as market area population, distance to activity center, and congestion index, those values for the proposed new lot can be used to estimate a value of MIN (Figure 3).

The equations using the MIN variable accept the fact that current park-and-ride patronage is often controlled by either facilities (i.e., parking spaces available) or service (i.e., number of buses serving to the lot). These equations, in most instances, predict ridership at existing lots within 25% of actual ridership.

Table 8. Estimated Values of the Variable MIN at Selected Texas Park-and-Ride Lots

Lot	No. of Peak Buses X Seats =	Parking Spaces X 1.5[a]	MIN
Austin			
North Park-and-Ride	3 X 45 = 135	260 X 1.5 = 390	135
US 183 North[b]	2 X 43 = 86	239 X 1.5 = 359	86
US 183 Express	1 X 43 = 43	146 X 1.5 = 219	43
Dallas Area			
Garland South[c]	20 X 50 = 1000	440 X 1.5 = 660	660
Garland North[c]	13 X 50 = 650	320 X 1.5 = 480	480
North Central	11 X 50 = 550	1300 X 1.5 = 1950	550
Las Colinas	3 X 50 = 150	150 X 1.5 = 225	150
Redbird	7 X 50 = 350	315 X 1.5 = 473	350
Pleasant Grove	7 X 50 = 350	624 X 1.5 = 936	350
El Paso			
Montwood[d]	4 X 47 = 188	75 X 1.5 = 113	113
Northgate Express[e]	4 X 47 = 188	209 X 1.5 = 314	188
Fort Worth			
Meadowbrook	2 X 48 = 96	25 X 1.5 = 38	38
College Avenue	6 X 48 = 288	185 X 1.5 = 278	278
Houston			
Kingwood	12 X 47 = 564	950 X 1.5 = 1425	564
Champions	10 X 47 = 470	349 X 1.5 = 524	470
Kuykendahl	29 X 47 = 1363	1300 X 1.5 = 1950	1363
N. Shepherd	21 X 47 = 987	750 X 1.5 = 1125	987
Gulf Sage	10 X 47 = 470	230 X 1.5 = 345	345
Clear Lake	10 X 47 = 470	325 X 1.5 = 488	470
Beechnut Express[f]	12 X 52 = 624	487 X 1.5 = 731	624
Sharpstown	7 X 47 = 329	200 X 1.5 = 300	300
Alief	12 X 47 = 564	300 X 1.5 = 450	450
Westwood	16 X 47 = 752	600 X 1.5 = 900	752
Katy	5 X 47 = 235	170 X 1.5 = 255	235
San Antonio			
Windsor	6 X 47 = 282	167 X 1.5 = 251	251
McCreless	5 X 47 = 235	117 X 1.2 = 140	140
South Park	3 X 47 = 141	64 X 1.2 = 77	77
Lackland	5 X 47 = 235	136 X 1.5 = 204	204
Wonderland	13 X 52[h] = 676	474 X 1.5 = 711	676
Nacogdoches[g]	5 X 47 = 235	123 X 1.2[i] = 148	148

[a] 1.5 - assumed maximum average auto occupancy.
[b] Includes 3 lots served by the same bus-US 183 North, Covenant and NW Hill.
[c] Since the buses from Garland North also stop at Garland South, parking spaces are used to establish the MIN values for Garland.
[d] Includes 2 lots served by the same bus-Montwood and Vista Hills.
[e] Incldes 2 lots served by the same bus--Northgate and Rushfair.
[f] Includes 2 lots served by the same bus--Meyerland and Sage.
[g] Includes 2 lots served by the same bus--Bitters and Broadway.
[h] Bus capacity inflated to account for numerous standees.
[i] Auto occupancy lower than state average.

Source: (23).

Table 9. "Typical" MIN Values for Urban Areas in Texas

Urban Area	"Typical" MIN Value[a]
Houston	600
Dallas	425
San Antonio	250
Austin, El Paso, and Fort Worth	125 to 175

[a] Obtained by averaging the values in Table 8.

Source: (23).

The regression equation using the CI variable (Eq. 9), while somewhat easier to apply, is generally less accurate in predicting ridership than the equations using the MIN variable. In most instances, the CI equation has been found to predict ridership at existing lots within about 50% of observed ridership. In using Eq. (9), or in selecting the appropriate MIN equation, the analyst may find the CI values given in Table 10 useful.

Having developed ridership estimates from the appropriate regression equation(s), the analyst can convert the ridership estimates to peak period HOV vehicle demands on the basis of the following general planning factors:

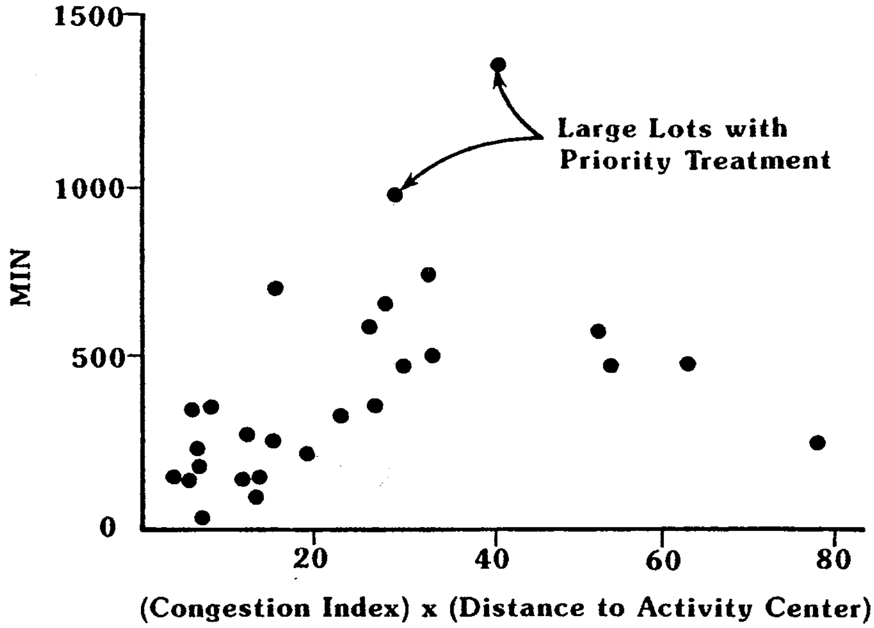
a) 65% of total ridership can be assumed to be on buses;

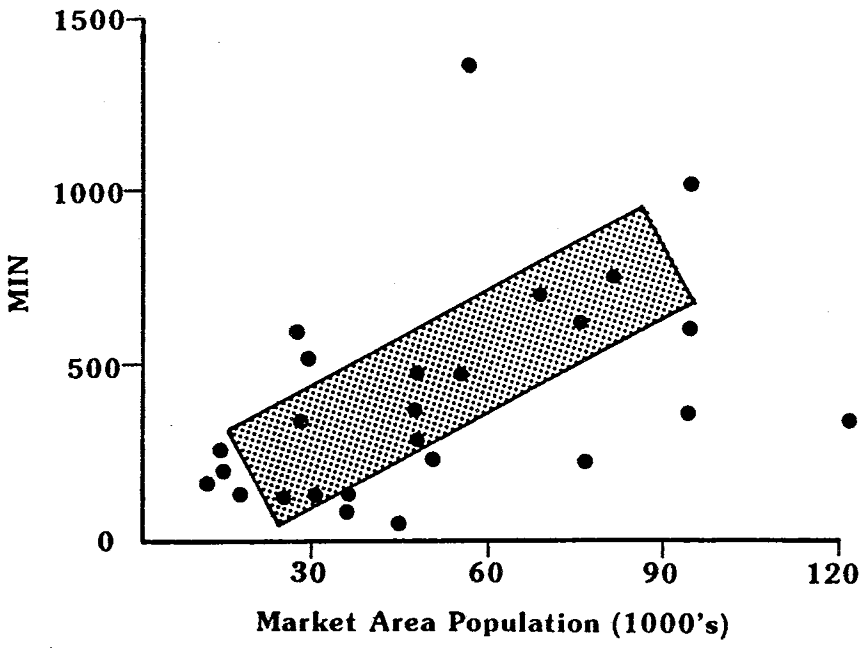
b) Bus occupancy = 50 persons/bus; and

c) Vanpool occupancy = 9 persons/vanpool.

5.5 CONTRAFLOW LANE ANALOGY

The fourth technique which has been used by TTI to estimate HOV lane demands is based on an analysis of travel data from the I-45N contraflow lane (CFL) in Houston.





Source: (23).

Figure 3. Relationship Between the Variable MIN and Selected Descriptors of Park-and-Ride Lots in Texas

Table 10. Congestion Indices (CI)

City and Facility	AADT/Lane	No. of Lanes	Delay in Minutes	CI
Austin				
US 183 N	7,925	6	1.5	0.5
Mo Pac	6,466	6	1.0	0.4
I-35 N	7,188	8	1.5	0.5
I-35 S	18,367	6	2.0	1.1
Dallas				
Stemmons (I-35 E North)	13,210	10	5.0	1.2
N. Central (US 75 N)	20,517	6	18.0	2.8
Thornton East (I-30 E)	13,400	8	15.0	2.2
Thornton South (I-35 E South)	12,800	8	1.0	0.7
LBJ or North Side (I-635)	20,363	8	2.0	1.2
US 175	6,550	6	2.0	0.5
US 67	7,500	6	2.0	0.6
El Paso				
I-10 E	11,780	10	3.0	0.9
US 54	8,817	6	1.0	0.5
I-10 W	12,775	4	1.0	0.7
Fort Worth				
West (I-30 W)	22,675	4	8.0	1.9
South (I-35 W South)	13,900	6	3.0	1.0
East (I-30 E)	8,888	8	2.0	0.6
Houston				
Southwest (US 59 S)	21,633	9	11.0	2.2
Katy (I-10 W)	24,457	7	15.0	2.7
North (I-45 N)	19,000	8	15.0	2.5
Eastex (US 59 N)	15,225	8	11.0	1.9
East (I-10 E)	14,863	8	5.0	1.2
Gulf (I-45 S)	24,443	7	15.0	2.7
West Loop (I-610)	25,363	8	8.0	2.1
San Antonio				
S. Pan Am (I-35 S)	20,425	4	4.0	1.4
I-10 W	21,450	4	9.0	2.0
N. Pan Am (I-35 N)	20,110	4	3.0	1.3
US 281 N	10,062	8	2.0	0.7
I-37 S	8,725	8	0.0	0.4
US 90 W	8,775	8	0.0	0.4

Source: Ref (23).

In using the observed usage of the I-45N CFL to estimate potential demands for comparable facilities on other radial freeways, the procedure used by TTI has been to simply factor the CFL volumes by the ratio of CBD work trips served on the freeways being considered for HOV treatment relative to those served on I-45N. Implementation of this procedure requires information on the number of CBD work trips on the freeways being analyzed. Table 11, which shows estimates of CBD work trip usage for selected radial freeways in Houston, illustrates the type of data required.

Analogies based on operating statistics from other HOV facilities (e.g., Katy Transitway) could also be used to estimate the demand for facilities being considered in similar corridors.

Table 11. Estimated Percentage of Total 1985 CBD Work Trips Using Selected Radial Freeways in Houston

Freeway	No. of CBD Work Trips Assigned to Each Freeway	Percent of Total CBD Work Trips Assigned to Each Freeway	No. CBD Work Trips Served Relative to North Freeway
Eastex	13,500	9	0.6
Gulf	21,500	15	1.0
Southwest	23,000	16	1.1
Katy	23,500	17	1.1
North	22,000	15	1.0
Total 5 Freeways	103,500	72	-

Source: (26).

5.6 RELATIVE ACCURACY OF THE ESTIMATION PROCEDURES

In order to provide an indication of the relative accuracy of the estimation procedures presented in the previous sections, the procedures were used to estimate potential demands for the I-10W (Katy Freeway) transitway in Houston. The estimates were compared with observed usage and relative estimation errors were calculated. Table 12 summarizes the results.

Table 12. Observed and Estimated 1985 Peak-Hour Vehicle Demands, Katy Transitway Houston

	Peak Hour Vehicles			Percent Error (Relative to observed)		
Estimation Method[a]	Bus	Vanpool	Total	Bus	Vanpool	Total
FHWA Procedure	45	30[b]	75	13%	-77%	-56%
HBW Trip Mode-Split	72	247	319	80	90	88
Park-and-Ride Estimation[c]	33	123	156	-18	-5	-8
Contraflow Analogy	60	240	300	50	85	76
Average	52	160	212	30	23	25
Observed[d]	40	130	170	-	-	-

[a] Assumptions are: (1) Buses account for 65% of total person movement; (2) 50 persons/bus, 9 persons/vanpool; (3) Existence of three park-and-ride lots; and (4) Mode-splits of 25% bus and 15% vanpool for CBD, and 10% bus and 7.5% vanpool for non-CBD activity centers.

[b] These are actually 4+ person carpools.

[c] Demands are average values developed from the market area population, mode-split, and regression techniques (equations 9 and 10).

[d] Observed volumes are from only six months of operation. Due to the short utilization period, the observed volumes are probably a conservative measure of potential utilization.

As shown in Table 12, the bus demand estimates developed from the FHWA and park-and-ride procedures are in fairly close agreement with the observed values. Likewise, the vanpool demand estimates developed using the park-and-ride procedures do not differ substantially from the observed demands. Also, simply averaging the demand estimates developed from the four procedures appears to produce results that may be adequate for most planning applications.

In assessing the relative accuracy of the procedures summarized in Table 12, it should be noted that the observed values shown are from a time period when only buses and vanpools were authorized to use the transitway. Recently, 2+ occupant carpools have been permitted to use the facility. This introduction of carpools has substantially altered demand levels and traffic composition on the transitway. For example, average peak-hour vehicle volumes for June 1987 were on the order of 30 buses/hour, 30 vanpools/hour, and nearly 1100 carpools/hour.

The estimation of carpool demands, and the effects of carpool occupancy requirements on transitway usage, have been (and continue to be) significant problem areas in HOV lane demand estimation.

5.7 SUMMARY

The Texas Transportation Institute has used several relatively independent procedures for estimating demands for transitway facilities in Houston. These procedures differ in the amount of data and manpower required for implementation and each technique has certain advantages and disadvantages. Consequently, no single procedure is clearly superior to the others.

While the FHWA estimation procedures appear to provide reasonably accurate estimates of bus demands, the procedures have two significant shortcomings. First, the procedure tells how much existing transit and carpool utilization will increase due to provision of an HOV lane. This causes problems in corridors where little to no transit service exists prior to implementation of the priority lane.

The second major drawback of the FHWA procedures is that they estimate bus and carpool utilization. Vanpooling, which is extremely popular in Texas, is not considered.

Several of the estimation procedures discussed require information concerning HOV mode-splits; information which is not typically readily available. However, "default" mode-split values based on a rather limited amount of data from Houston are available and may be factored for use in other areas in Texas. Additionally, the estimation procedures based on TTI research do not explicitly address carpool demand estimation.

In short, procedures for estimating HOV demands are still fairly crude. While the procedures discussed in this section can be used to develop a range of demand estimates which should be reasonable for "sketch" planning applications, more refined estimation procedures are clearly needed.

The Shirley Model represents one of the more promising recent developments in the area of HOV lane demand modeling. However, much work remains before the Shirley Model will be fully operational. What is needed is a procedure that lies somewhere between the sketch planning techniques used in Houston and the elaborate mode-choice model being developed from the Shirley corridor dataset. Such a procedure could be developed by refining the quick-response techniques discussed in this section in such a way that the resulting procedure(s) could not only meet current local needs of reliable HOV demand estimation procedures but could also serve as an interim step towards validating and implementing the Shirley Model in Texas.

In this regard, the estimation procedures based on market area analyses appear particularly promising. A general extension of these market area analyses that should be explored might involve using currently available traffic assignment models to identify potential HOV lane traffic markets and using observed HOV lane utilization data to develop estimates of the percentage of the traffic market that actually uses the HOV lane. Selected "skims" of the highway and transit networks, for example, could be used to estimate traffic volumes that could use the HOV link in their trip making. Additionally, the travel demand models currently in use in Texas could be modified to access various demographic data for the traffic markets identified from the selected link assignments.

The Texas Transportation Institute has maintained a high-level of involvement in the area of priority treatment for high-occupancy vehicles for well over ten years. During that period, substantive research efforts have been performed for sponsors at the federal, state, and local level. As a result, TTI has access to a wealth of information that could be used to explore the relationships between HOV lane markets and actual HOV lane utilization. References 27-48 provide an indication of the extent of the data base that is currently available for use in this effort.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The Shirley Model, in its current form, suffers from a number of technical problems which raise questions concerning the feasibility of implementing the model in Texas within a reasonable time frame. The Shirley Model will require additional development and testing to insure that the model has been correctly specified and to determine whether the model can accurately replicate travel choice processes observed in the Shirley Corridor. These issues should be addressed prior to the initiation of additional tests outside the Shirley Corridor.

The Shirley Model is based on a "choice-set" that differs from the choice-set(s) available to commuters in the major urban areas of Texas. That is, the Shirley Model predicts mode shares for modes that differ from the modes available to HOV commuters in Texas. It is not clear at this time whether the Shirley Model could be re-estimated to account for these differences in choice-sets.

A basic policy-related issue affecting the feasibility of using the Shirley Model in Texas centers around the fact that the model is intended to be used as a traditional mode-choice model with an HOV component. The Shirley Model would estimate mode shares for traditional modes (e.g., highway, transit), as well as HOV priority lane mode shares. The mode-choice modeling efforts underway in Texas are sufficiently advanced that it does not seem prudent at this time to re-direct these efforts to incorporate HOV priority lane demand estimation capabilities into the mode-choice phase of the modeling process. Prior to attempting to incorporate HOV lane components into established mode-choice models, additional research should be conducted to more clearly define those factors affecting HOV lane demand.

In short, it is the conclusion of this study that the Shirley Model is not ready for testing outside the Shirley corridor. In fact, additional testing <u>within</u> the Shirley corridor will be needed to adequately assess the potentials for using the model elsewhere.

The overall indication, then, is that it is not feasible at this time to implement the Shirley Model in Texas. Which is not to say that the research effort should be abandoned. Preliminary results from the Shirley modeling effort look promising and should prove useful in modeling HOV lane demands. Given the need for reliable HOV lane demand estimation procedures in Texas (and elsewhere) and the insights into HOV lane travel choice behavior provided by the Shirley Model, a re-directed, incremental research approach appears warranted. This re-directed effort might involve the development of an HOV lane demand estimation procedure based on empirical data from HOV lane facilities in operation in Texas. Such a procedure could be supplemented with network information extracted from travel demand programs currently in use in Texas. This approach should lead to an identification and quantification of the factors affecting HOV lane demand and provide the basis for the subsequent development of more refined HOV lane analysis techniques.

The suggested re-direction of the research effort should remain closely coordinated with the continuing development and testing of the Shirley Model. This coordination is important for several reasons. For example, continued monitoring of the Shirley effort could provide valuable insight into the factors and relationships affecting HOV lane demands. Additionally, efforts to develop an HOV lane demand estimation procedure for Texas cities could provide an independent (though indirect) validation of the significance of the variables identified in the Shirley Model. Finally, given the UMTA and FHWA sponsorship of the Shirley Model project, it is possible that the Shirley Model could evolve into the preferred method of analysis for federal funding support of HOV lane projects. Therefore, the coordination of any local HOV modeling efforts with the Shirley project could greatly expedite the implementation of future HOV lane projects in Texas.

As noted earlier, the modified research approach suggested above should not be viewed as an abandonment of the original study objectives. Once the Shirley Model is more fully developed, it would be extremely useful to attempt to validate the model in Texas. These validation tests could facilitate the development of a comprehensive and uniform HOV lane planning tool for the major urban areas of Texas. Additionally, successful validation of the Shirley Model in Texas, and/or identification of possible refinements and modifications in the model, could also facilitate use of the model on a nationwide basis. Preliminary indications are that there may be federal funds available to conduct these validation tests in an independent (though clearly complementary) research effort.

In the meantime, however, local, short-term needs indicate that alternatives to the Shirley Model need to be identified and evaluated. A review of currently available alternatives to the Shirley Model was presented in Section 5. While these procedures could be used to develop a range of demand estimates that may be reasonable for many "sketch" planning applications, they are still fairly crude and more refined estimation procedures are clearly needed.

6.2 RECOMMENDATIONS

The goal of this phase of the research was to assess the feasibility of validating the Shirley Highway HOV Lane Demand Model in Texas. The results of the assessment indicate that the Shirley Model has not been sufficiently developed to warrant testing in Texas at this time. Contingent upon the results of additional development and testing efforts that have been proposed in the Shirley Corridor, the feasibility of validating the model in Texas and elsewhere should be re-assessed at some future date. Given the potential nationwide significance of these validation tests, it would be appropriate to pursue FHWA and/or UMTA funding for this effort. In the meantime, local, short-term needs indicate that there exists a need to develop HOV lane demand estimation procedures based on local transportation system characteristics and actual operating statistics from HOV lane facilities currently in operation in Texas.

Based on these considerations, the following two recommendations concerning future research directions are offered.

1) <u>Efforts should be initiated to develop HOV lane demand estimation procedures based on experience gained in operating HOV facilities in Texas</u>. At this time, estimation procedures based on HOV lane market area analyses appear to be the most promising. The recommended approach would involve

using currently available traffic assignment models to estimate potential HOV lane traffic markets and using observed HOV lane utilization data to develop estimates of the percentage of the traffic market that uses the HOV lane. Specifically, selected "link assignments" could be developed to estimate traffic volumes that could use the HOV link(s) in their trip making. The travel demand models could also be used to access demographic data for the traffic markets identified from the selected link assignments. Actual HOV lane utilization data could then be used to develop relationships between the characteristics of the market areas and observed HOV lane utilization levels.

This recommended re-direction of the study effort is consistent with the existing work plan and should be more clearly defined and initiated during FY 1988.

2) <u>Efforts to validate the Shirley Model in Texas (and/or elsewhere) should be undertaken as part of a separate research project</u>. Given the amount of work likely to be required to complete the development and testing of the Shirley Model, it does not seem prudent at this time to rely solely on the Shirley Highway efforts as the basis for developing HOV lane demand estimation procedures for Texas. Therefore, it is recommended that any local involvement in validating the Shirley Model be undertaken as part of a separate research effort. Given the potential nationwide significance of these possible future testing efforts, it would seem appropriate to pursue FHWA and/or UMTA funding support for these validation tests.

Implementation of these two recommendations should result in the development of reliable HOV lane demand estimation procedures for Texas in a timely fashion. Local efforts directed at developing HOV lane demand estimation procedures should serve the short-term needs of the state. Also, by coordinating local efforts with the continuing development and testing of the Shirley Model, it should be possible to identify a range of estimation procedures for possible use in Texas. This two-stage attack on the problem makes it possible to develop an evolutionary approach to HOV lane demand modeling. The development of local models, for example, could provide the basis for developing/implementing more sophisticated models, such as the Shirley Model, at some future time.

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