STATE OF OREGON

DEPARTMENT OF TRANSPORTATION

TRAVEL DEMAND MODEL DEVELOPMENT

AND

APPLICATION GUIDELINES

Prepared for

Oregon Department Of Transportation
Planning Section
Transportation Planning Analysis Unit

Prepared by
Parsons Brinckerhoff Quade & Douglas, Inc.
Portland, Oregon

With Assistance from
Kittelson & Assiciates, Inc.
Portland, Oregon

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1.0
INTRODUCTION

1.1 - Background and Objectives

With passage of the 1990 Federal Clear Air Act Amendments (CAAA), the 1991 Federal Intermodal Surface Transportation Efficiency Act (ISTEA), and the 1991 Oregon Transportation Planning Rule (TPR), a resurgence in the interest and commitment to improving underlying travel demand model behavioral properties and forecasting techniques has been evidenced throughout the country. The state-of-the-practice has improved measurably in the last few years with the advent of fully nested logit mode choice models, incorporation of the LogSum variable (as the impedance measure) in Trip Distribution, feedback loops occurring throughout the process fostering stronger relationships between individual model components, and advances in trip assignment algorithms (i.e., multi-class assignment, conical volume-delay functions, etc.) to name a few. Substantially new (research) approaches are also being funded by FHWA, FTA, EPA, DOE, and the office of the Transportation Secretary, including the Track "C" redesign of the Travel Forecasting Process and the Los Alamos TRANSIMS project.

Simultaneously and consistent with the advent of relatively inexpensive micro-computer hardware and software resources, including transportation planning software (notably emme/2 in Oregon), the need and opportunity to apply travel demand forecasting techniques and procedures to transportation problems at the regional, corridor, and subarea levels have corresponding increased. There is a new challenge confronting state and regional agencies -- the selection and development of appropriate analysis tools for application to the planning problems at hand. To meet this challenge the transportation planner/analyst must possess both a blueprint for developing and applying these tools and the training necessary to implement that blueprint. The intended purpose of these guidelines is to provide that blueprint.

With notable exceptions, Metropolitan Planning Organizations (MPO's), counties, and individual cities within Oregon will require technical assistance and guidance in developing and applying travel demand models to the wide spectrum of planning and design study needs in their purview. With this in mind, it will be important for the Oregon Department Of Transportation (ODOT) to be well-positioned to offer technical support. Separate, parallel efforts have been established within ODOT to provide staff training in both the specific use of emme/2 and, more importantly, in the principles of model development and application.

1.2 - Purpose and Use Of The Guidelines

Guidelines for the estimation, calibration, validation, and application of travel demand models on a statewide basis, must by their very nature, address the appropriate level-of-complexity of mathematical formulation and level-of-detail required for a range of regional sizes, beginning with a region as diverse in transportation infrastructure as Portland, to the three other MPO's within the State (all of whom possess populations in excess of 50,000), and finally to those regions with less than 50,000 inhabitants, stratified into those who are in non-attainment (with respect to one or more of the air quality-defined precursors) and those who are currently in attainment. Similarly, the level-of-complexity must consider the full spectrum of model sophistication ranging from typical or common practice (generally found in most MPO's) to acceptable practice, "best" practice, advanced practice, and finally, to "state-of-the-art", which often borders on academic research. The current travel demand modeling capabilities present within the Portland region generally represent advanced practice, with some of their new initiatives placing the region on the path to "state-of-the-art". These statewide guidelines are intended to support ***"best" practice*** as the yardstick of acceptable practice, while simultaneously supporting, but not requiring nor limiting, extensions of the methodology to advanced or state-of-the-art practices. The specification of model development and application guidelines have been formulated, therefore, in the context of a two-dimensional framework -- region size and model capability. In a number of instances, where applicable, optional (or advanced practice) guidelines are also included.

1.3 - Report Structure And Outline

The Guidelines begin with an overview of the requirements and implications for travel demand modeling based upon applicable Federal and State of Oregon legislation. The inclusion of Chapter 3 (Input Data Assembly and Methodology) is intended to establish and address the critical importance and role of land use, travel survey, and transportation supply data in the modeling process. The heart of the guidelines is contained in Chapters 4 and 5. These model development guidelines have been structured to detail the mathematics of *model formulation*, provide *examples* of fully developed model components, and provide recommendations for *market segmentation* (where appropriate), and generally describe procedures for model *validation and application*. Chapter 4 focuses on the needs and requirements of the Metropolitan Planning Organizations (MPO's) within the state, while Chapter 5 addresses regions and cities which, as a function of population level, are below the MPO threshold (defined for these purposes as 50,000 inhabitants). The often overlooked topic of application guidelines is the subject of Chapter 6. A general description of the use of travel model outputs in a variety post-processing contexts, specifically environmental analyses and traffic simulation methods, is the subject of Chapter 7. Chapter 7 is not intended to describe the analytical details of data output preparation or translation, but rather, the role of individual model component specifications needed to address the requirements of these analysis techniques. And finally, Chapter 8 discusses the emerging directions in the state-of-the-art in travel demand model development and forecasting.

2.0
LEGISLATIVE REQUIREMENTS AND IMPLICATIONS

2.1 - Federal Conformity Rule

Section 51.452 of the December, 1993 Conformity Rule entitled, "Procedures For Determining Regional Transportation-Related Emissions" contains a listing of *attributes* which the network-based transportation demand model must possess in regions with serious, severe, or extreme ozone or carbon monoxide non-attainment. As an introduction, Part 5(b)(1) states that the network-based transportation model must relate "travel demand and transportation system performance to land-use patterns, population demographics, employment, transportation infrastructure, and transportation policies". The first section of Chapter 3 provides a fundamental description of the structure and application principles embodied in the current Oregon models and demonstrates the inherent behavioral connections between the regional land use, demographics, and transportation infrastructure and policy input to the quantification of travel demand levels and patterns and the subsequent measurement of transportation system performance. Building upon this basic tenant regarding the inter-relationship between land use, network supply, and travel demand, the rule outlines 10 additional attributes which the models should endeavor to contain.

2.1.1 - Acceptable Practice

The first attribute requires that the functional relationships in the model correspond to acceptable professional practice and are reasonable for emission estimation. The proposed travel demand model guidelines represent the classical "four-step" process -- trip generation, trip distribution, mode choice, and trip assignment. Each of these model elements are consistent with accepted practice by MPO's, and utilize methodologies which reflect "best" or "advanced" practice. Taken together these model guidelines meet or exceed each of the required attributes outlined in section 51.452.

The most effective tool for judging the adequacy of model estimates for emissions computation, is inherent in the results of model validation for the established base year. Comparisons of observed traffic counts and model estimated link volumes will establish this basis.

2.1.2 - Model Validation

The established base year for model validation will generally be *1990.* This base year and the 1994 conformity determination date represents only a 4 year period, as compared to the maximum of 10 years mandated by the rule, between model validation and conformity. The land use and demographic

forecasts, along with the transportation networks should represent the best available information for a base year which could range in the four year period between 1990 and 1994. It should be recognized, however, that the land use and demographic data, utilized by individual transportation analysis zone, will be created based upon a number of data sources, notably with information obtained from the 1990 U.S. Census files.

2.1.3 - Capacity Sensitive Traffic Assignments

The highway assignment methodology employs the principles of equilibrium capacity restraint. Both peak hour and daily traffic volumes along with corresponding travel speeds emanate from this assignment procedure. The specification of link-specific capacity values is determined by considering a wide range of link attributes including, functional roadway type, posted speed limit, link length, number of lanes, parking type, and geographic location.

2.1.4 - Travel Speed Feedback

The trip-interchange level travel times (and speeds) used in both trip distribution and mode choice are based upon the congested speeds computed in the traffic assignment phase. Initial congested values can be obtained from a prior travel demand model run and adjusted through subsequent iterations of the distribution and mode choice models until there is reasonable agreement between assumed (or input) and capacity restrained speeds.

2.1.5 - Empirically Derived Free Flow Speeds

The procedure used to estimate free flow speed and capacity is a detailed methodology that utilizes the maximum amount of information from the network and "connects" this data with information from the Highway Capacity Manual.

2.1.6 - Provision Of Peak and Off-Peak Travel Demand and Travel Times

Both free flow and congested times and speeds are utilized throughout the trip distribution, mode choice, and trip assignment components. The proposed model guidelines explicitly consider the disaggregation of purpose specific travel into individual time period slices (i.e. peak versus off-peak) in both the distribution and mode choice phases.

2.1.7 - Pricing Sensitivity

The nested logit mode choice model contains the full range of pricing (or cost) variables in the individual utility equation expressions for both auto and transit. These cost variables include destination zone parking cost, rail station parking cost, automobile operating cost (cents per mile), and transit fare. A unique attribute of the Trip Distribution models is use of a composite impedance, also known as the LogSum variable, as the measure of accessibility. The LogSum variable, by definition, includes travel time, travel cost, and the socio-economic characteristics of the traveler for all of the available modes.

2.1.8 - Trip Generation Model Accessibility

The trip production trip generation models typically incorporate variables such as auto ownership, the number of household workers, and household size as the key determinants of trip production behavior. Auto ownership provides a direct measure of accessibility in the estimation procedure.

2.1.9 - Economic and Population Growth & Accessibility

Part 5(b)(1)(x) suggests the need for formal mechanisms which relate regional economic and population growth with accessibility measures derived from the transportation system. In this instance, there is substantial disagreement in the research community regarding the validity or relevance of this relationship. It is coherently argued that overall regional economic and population growth is influenced by factors considerably more global in nature then trip-interchange level accessibility.

2.1.10 - Construction-Related Congestion

As currently structured, the computation of emissions by individual precursor do not explicitly consider potential increases from construction-related congestion. While it can be argued that roadway construction and/or rehabilitation may increase emissions, these increases would likely be non-recurring and subject to significant daily and seasonal variation. The conformity rule, does not however, require consideration of these potential impacts in the travel demand modeling process.

2.2 Oregon Conformity Rule

The Department of Environmental Quality (DEQ) with the assistance of an advisory committee representing diverse interests, developed a proposed conformity rule, OAR Section 340-20-700.[1] This proposed rule as directed under the Clean Air Act as amended in 1990, is specific to the State of Oregon. Oregon's proposed rule mirrors the federal conformity language except in a few areas where the state rule is more stringent. Section 340-20-1010, "Procedures for Determining Regional Transportation Related Emissions," is one area that the state rule is more stringent; primarily in the transportation demand modeling area.

In section 340-20-1010(b), for serious, severe, and extreme ozone and serious carbon monoxide areas, the rules are identical. The attributes for the network based models are outlined in the previous section (2.1) of these guidelines.

Section 340-20-1010(c) is found only in the state rule and is for all metropolitan non-attainment areas not covered under subsection (b). Subsection (c) contains a list of modeling attributes and procedures which must be met. Part (c)(1), states that any procedures or practices that satisfy some or all of the requirements of paragraph (b) that are the current or previous practice of a MPO shall continue to be

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[1] "Criteria and Procedures for Determining Conformity to State and Federal Implementation Plans of Transportation Plans, Programs, and Projects Funded or Approved Under Title 23 U.S.C. or the Federal Transit Act."

used. In other words, this paragraph prevents any area from back sliding on modeling practices that meet or exceed paragraph (c) that are in use by that agency. In addition to this, eight other attributes and procedures are identified.

2.2.1 Network

The first attribute of the state conformity rule requires a network based demand model capture or represent at least 85 percent of the vehicle trips. Transportation networks developed under the "best practice" guidelines, must therefore, include roadway facilities at the collector level. This level of network detail typically captures 90 percent or more of the vehicle trips. Consistency with zone system definition taken together with the need to represent collector level facilities may require the inclusion of selected local streets in the network as well.

2.2.2 Trip Tables

The proposed "best practice" structure of the travel demand models described in these guidelines begin with two key sets of inputs -- land use and demographic data and transportation networks. The creation of trip tables based on current and future land use and demographic forecasts are inherent to this process.

2.2.3 Vehicular Traffic

In general practice, all person trip volumes on an individual link basis are estimated and converted to vehicular equivalencies -- either private automobile, commercial vehicle, or public transit. Use of the multiclass assignment capability of the emme/2 software provides the mechanism to simultaneously consider the contribution of each vehicular mode on the roadway system during equilibrium capacity restraint assignment.

2.2.4 Other Modes

Mode choice models are used to estimate the modal shares of travel given the time and cost of various competing modes and the demographic and socio-economic characteristics of urban residents. The mode choice model structure recommended for use in Oregon's MPO areas is the nested logit model. The nested logit model is capable of representing motorized as well as non-motorized modes including walk and bicycle travel.

2.2.5 Traffic Assignment Calibration

The comparison of the applied base year model with the field observed data serves as the indicator of how well the model replicates existing travel patterns. At each step in the model development process, the model components are subjected to a series of aggregate and disaggregate validation tests following estimation of model parameters. Model validation is strictly an aggregated set of comparisons, and represent the final test of the model's ability to accurately simulate existing travel behaviors.

2.2.6 Emission Calculation

The calculations of emissions is covered in detail under Section 7.2 of these guidelines.

2.2.7 "Off-Model" Emissions

Current practice in Oregon for addressing "off-model" or "off-system" emissions is to globally apply a factor to the total Vehicle Miles Traveled (VMT) for the study area. With 90 percent of the vehicle trips typically represented in the network, this factor can be estimated when the total miles of "off- system" roadway facilities are determined.

2.2.8 Estimates of Future Land Use for Projection of Emissions

Section 2.3 briefly describes the necessity of linking land use to transportation planning. Land use, demographic, and economic data is one of two key inputs to the model. Estimation of future year land use and economic activity is mandatory in the application of forecasting models and is generally based on a comprehensive plan for the region. In forecasting applications, the analyst evaluates the results based on hypotheses and expected results. Where results vary from the expected, an evaluation and determination is made to whether the inconsistency is in the model application data or improper application of the model. Corrections can then be made where applicable. Through this process, reasonable projections of future emissions can be made.

2.3 - Oregon Transportation Planning Rule

The Land Conservation and Development Commission (LCDC) with the support of the Oregon Department of Transportation (ODOT) adopted the Transportation Planning Rule (TPR) OAR 660, Division 12 in April 1991. The TPR is intended to govern transportation planning and project development at local, regional, and statewide levels. Basically, the rule requires ODOT, regional planning bodies, and local governments to link land use and transportation planning efforts. While the TPR does not specifically regulate the structure of travel demand models, it does establish principles that require sensitivity in the development and application of the models.

The TPR requirements vary by urban area as follows:

- The principle requirement of the TPR is for cities, counties, MPOs, and ODOT to prepare and adopt transportation system plans (TSPs). The TSP establishes land use controls and a network of facilities and services to support overall transportation needs.   Transportation needs are defined as the movement of people and goods. From this, the transportation project development process begins.

- Outside of urban areas, the rule indicates what transportation uses are consistent with Goal 3 (Agricultural Lands), Goal 4 (Forest Lands), Goal 11 (Public Facilities and Services), and Goal 14 (Urbanization).

- In cities with a population of less then 2,500 outside of a Metropolitan Planning Organization (MPO) and counties under 25,000 in population, the rule provides for a whole or partial exemption or deferral.

- In urban areas with less than 25,000 population, the rule requires amendments to plans and ordinances requiring residential, commercial, and industrial development patterns to encourage pedestrian and bicycle travel.

- In larger urban areas with a population greater then 25,000, the rule requires development patterns that are transit friendly and carefully considers alternatives to highway expansion. This includes transportation and demand management measures.

- For areas inside Metropolitan Planning Organizations (MPOs) the rule mandates that within 30 years following the adoption of a transportation system plan, total vehicle miles traveled (VMT) must be reduced by 20 percent.

- In the Portland metropolitan area, the rule also requires the evaluation of alternate land use designations, densities, and designs.

2.3.1 - TPR Implications on Transportation Modeling

While the TPR does not regulate transportation modeling, implicit requirements for the travel demand models can be gleamed from the objectives or goals of the rule. The main goals of the rule are to: 1) develop transportation system plans; 2) reduce reliance on single occupancy vehicles; and 3) reduce vehicle miles traveled. Transportation models developed in a manner consistent with these guidelines will posses the level of sophistication necessary to respond to the range of transportation alternatives and policy level strategies.

2.3.2 - Transportation System Plan (TSP)

The TSP is based on the evaluation of potential impacts generated by the proposed system alternatives. It demonstrates or quantifies the impact of land use planning on the transportation system. System alternatives may include improvements to existing facilities, new facilities, and implementation strategies that consider or include alternate modes. These alternatives may also include transportation system management (TSM) and transportation demand management (TDM) measures. The level of analysis that is required for the TSPs is best accomplished using a transportation model developed in a manner consistent with the guidelines outlined in sections 4 and 5.

2.3.3 - Vehicle Miles Traveled (VMT) Reduction

The VMT reduction requirements of the TPR are very aggressive for MPO areas. VMT tracking and testing (estimating) is essential for compliance with the rule. The model can measure the initial baseline conditions, and then be used to track and forecast changes due to transportation system and land use changes.

2.3.4 - Single Occupancy Vehicle (SOV) Reduction

To evaluate system alternatives for SOV reduction, as with VMT reduction, the analysis tool needs to be sensitive to person trip assignment, mode choice, and trip pricing. These guidelines have been developed to assist in developing models sensitive to this type of scenario testing.

2.3.5 - Land Use

The land use, demographic, and economic data is one of the key inputs to the model. Land use scenarios can be examined by modifying the input assumptions and re-running the travel demand models. Land use models can be explicitly incorporated into this loop. The use of land use models would be considered "advanced" practice.

3.0
INPUT DATA ASSEMBLY AND METHODOLOGY

3.1 Land Use And Demographic Data

State and Federal mandates (OTP, 1993 Oregon Conformity Rule, TPR, ISTEA) are the driving force behind improvements in travel demand modeling. Land use and demographic data are essential inputs to the travel demand modeling process.

The level of detail of land use, economic, and demographic data is determined by the relevant requirements of the model formulations and complexities. While the specifics of development process for these critical model inputs will vary from one area to another due to the variations in analysis needs and resource availability, there are common requirements which would apply to any model system in the state.

3.1.1 Land Use Data

Land use information describes and quantifies zoning and development density respectively. Zoning is a general activity designation for a parcel of land. The level of zoning disaggregation typically includes residential (single and multi family), commercial, industrial, etc. Density is simply the measure of development of a parcel of land.

For modeling purposes, zoning information is necessary only to the extent that such density measures as residential density and/or employment density can be computed from available information. Existing land use data can be obtained from a number of sources including:

- US census data
- Tax assessors (building permits)
- Planning and zoning agencies
- Utility records
- Field surveys

3.1.2 Socio-Economic Data

This section contains a list of candidate variables for inclusion in the land use and demographic dataset, based on anticipated model structures. These variables fall into two categories; those that will be used as inputs to the models, and therefore must be forecast for the future, and those that will be used to check or calibrate the models, for which only current year data must be compiled. Table 3-1 lists the candidate

variables, as well as whether they need to be forecast or are for calibration purposes. Table 3-1 also shows which variables are anticipated to be used in trip generation for the household submodel, in the production and attraction models, in the Truck model, and in the creation of the mode split model and submodels.

Table 3-1
Proposed Forecast Variables and Their Use

| Variable | Trip Generation | | | | | |
	Household Submodel	Production	Attraction	Truck Model	Mode Choice	Need to be Forecast?
Population (Residents)	●	●	●		●	Y
Employed Residents		●			●	Y
Average Income	●					Y
Household (SDU, MDU, Group)	●					Y
Household Size	●	●			●	N
Income Level	●	●			●	N
Auto Ownership	●	●			●	N
Total Employment			●	●	●	Y
Retail Employment			●	●	●	Y
Service Employment			●	●		Y
Light Industrial Employment			●			Y
Manufacturing Employment			●	●		Y
Other Employment			●	●		Y
School Enrollment			●			Y
University Enrollment			●			Y
Zonal Area		●	●		●	Y
Recreational Space			●			Y

The household income, number of workers, size, and number of autos are available from the Census Transportation Planning Package (CTPP) and home interview surveys. Sources for employment data include State Employment Department, CTPP (by census tract) and county tax assessors parcel records.

3.1.3 Land Use and Transportation Model Integration

The need to link travel demand and land use forecasting models has become evident with the passage of recent mandates (OTP, 1993 Oregon Conformity Rule, TPR, ISTEA). This link must relate the influence of land use alternatives on transportation system patterns and vice versa. The mechanism for facilitating this interaction can be a set of land use models.

Though many other models exist, the one most often used is the DRAM/EMPAL model. This system contains a Disaggregated Residential Allocation Model (DRAM) and an Employment Allocation Model (EMPAL). One of the principle design features of the DRAM/EMPAL models is the ability to evaluate land use/transportation alternatives. Both are derived from the original Lowry gravity model (the same gravity model found in most trip distribution models). Other land use models include, CATLAS, POLIS, SAM and METROSIM.

3.2 - Travel Survey Data

Travel surveys provide the underlying strength of any model and serve as the fundamental data upon which it is built. While there are a wide variety of surveys that can be designed for this purpose, the primary objective of this data collection activity should be reflective of the data necessary to estimate and calibrate a set of travel models for a region. A Home Interview survey form the centerpoint of any model development project. An On-board transit survey may also be essential to needs of model estimation, specifically in the construction of a choice-based sample for mode choice model estimation. Park-and-Ride Lot surveys may offer additional information regarding the magnitude and distribution of drive access to transit (as well as carpool/vanpool users). And finally, External-Internal vehicle surveys provide data for estimating the external-internal and external-external trip types.

3.2.1 - Home Interview Survey

A Home Interview Survey is used to collect information about the travel characteristics of households in a region. This type of survey is usually the major source of information for developing a set of travel models to estimate travel behavior in a region. This survey is considered essential when a model development process is being under taken. Survey sampling techniques usually require a *minimum* of between 1000 and 1600 households be interviewed. These figures rely on sampling statistics and are generally independent of the size of the region. Larger samples are often necessary to construct models with the full range of explanatory variables. For example, a cross-classification trip generation model may consist of four auto ownership categories cross-classified by five household size and four worker categories. A basic or practical guideline for determining the appropriate number of samples required suggests that a minimum of 30 samples (or households) be present in each cross-classification stratum so that adjacent strata may be compared to gauge statistical significance. In this example, a minimum of 2,400 usable observations would be required. If the available sample size is less than the desired number, compromises with respect to variable inclusion and/or statistical significance of one or more cells will be the result. Zero auto and larger households are typically cells which tend to be missing or under-reported in smaller sample surveys

An *activity-based* survey is the preferred method of design for a Home-Interview Survey, as compared with the more traditional *trip-based* survey method. An activity-based survey collects more detailed and descriptive information about the <u>activities</u> that comprise each end of a trip. Conversely, the information obtained from a trip-based survey is limited to the traveler's interpretation of trip purpose based upon the purpose response obtained for each recorded trip segment. An activity-based survey also recognizes that activities are the fundamental descriptors of trip making. The information reported about each activity, including the type of activity and the corresponding name of the establishment (or activity), is an important key in describing or defining a set of trip purposes based upon traveler behavior rather than simply relying upon a set of predefined trip purposes.

An example can further demonstrate the primary differences between the two types of survey methods. A traveler proceeds from his/her home to a day care facility to drop off his/her child and then continues on to work. Both surveys would define the purpose sequence of the these three activities as "home", "pick-up/drop-off" (or serve passenger), and "work". Both survey methods would also "link" or remove the intermediate day care stop and create a single home-to-work trip. The difference lies in the trip purpose that would ultimately be defined by each survey. The more classical trip based survey would define this sequence of activities as simply a home-based work trip, in the absence of any knowledge regarding the precise activity performed at the pick-up/drop-off location. The activity based survey, however, has more descriptive information (day care facility) to define this sequence of activities as a Home-Based Work Strategic trip (see section 4.2.1). A second example should help to show exactly how a new trip purpose might be defined as a result of having more detailed information on a travelers activities. In this case, a person works at home takes his/her child to school and then returns home. The trip based survey would "link" or remove the intermediate school purpose and produce a home-to-home trip record which is subsequently dropped from the analysis. An activity based survey recognizes the intermediate activity as a school trip, and defines both a home-to-school and a school-to-home trip.

The design and implementation of the Home-Interview survey is another important consideration in the survey administration process. Several types of survey methods have been utilized in the past including:

- Mail Out-Telephone Interview Retrieval
- In-Home Interview
- Mail Out/Mail Back (or Self Administered)

The mail out-telephone retrieval has been used with substantial success due to its cost effective nature and the reliability of the data. It entails the mailing of survey packets to households that have agreed to participate followed by a telephone call where the travel information is collected over the phone. The in-home interview calls for surveyors to gather information based on a personal interview completed in the respondent's home. The quality of the data gathered in this manner is extremely high, however, the method is very costly, and there is intense resistance based upon concerns regarding safety and security of the household and interviewer. The mail out/mail back (or self administered) survey is similar to the mail out-telephone collection survey with the exception that none of the travel survey information is collected over the phone. The completed travel diaries and household questionnaires are completed and then returned via mail to the surveyors. This type of survey is very cost effective, but requires very clear and concise questionnaires. The non-response and incomplete data rates are also very high which can lead to results that severely limit use and applicability.

Home interview surveys provide the primary source of information on which travel behavior and trip making patterns are measured and translated into a set of travel demand forecasting models. The home interview survey is thus a necessity for MPO level analyses. For smaller urban areas, the home interview survey is optional, but strongly encouraged. If a Home-Interview Survey is not available or within the financial capability of the smaller urban area, then the resulting travel demand model constructs and behavior properties reflected in the area's model will need to be based upon on experience elsewhere within the state[1].

3.2.2 - On-Board Transit Survey

On-board transit surveys are often performed to complement and enhance the data and information obtained in a Home-Interview Survey. The data is considered to be "choice-based", rather than random, given the emphasis placed on a single mode. On-Board Survey data can be useful in a variety of contexts including short-term or operational planning exercises as well as model development, calibration, and validation. The sample of households randomly selected for interviews in a Home-Interview Survey may not be able to provide a sufficient number of transit trip observations to reliably develop mode choice models or assist in the calibration or validation of the models.   An on-board survey specifically designed for model development purposes can contribute directly to each step in the model development process.

Designing a sampling plan for an on-board bus survey involves two major considerations. The first consists of determining the total number of bus trips to be sampled. General system characteristics such routes and sub-routes, route direction, and time-of-day should be considered when designing the sample plan. The second consideration consists of selecting the specific bus trips to be sampled balancing surveying efficiency in a consist manner with the overall survey design.

There are two fundamental approaches to the design aspect. One attempts to achieve an equal precision per route, while the second allocates samples as a direct function of individual route ridership, but provides for a minimum precision per route. The former approach is typically followed in instances where the primary use of the data will be for short-range or operational planning. The latter is the method normally employed when model development and application is the primary use of the data.

Transit on-board surveys are highly encouraged in order to get a rich set of transit ridership information. In Oregon, however, the home interview surveys were deliberately structured to elicit information from transit-using households. Given this explicit attempt to capture the behavior of households which make transit trips, an On-Board survey would provide additional insight and understanding as well as an excellent data base for model calibration and validation, but would not be required to establish a "best practice" model set. As such, the on-board transit rider survey should be considered optional.

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[1]Travel Demand Model Development activities within Oregon are expected to consider the *blended* use of Home-Interview survey data from a number of smaller urban areas in an attempt to identify behavior similarities and differences which can be incorporated in model formulation. The successful result of this approach would more easily extend the use of the resulting models to areas which do not have original data sources, such as a Home-Interview Survey.

3.2.3 - Establishment Survey

Establishment surveys, also known as employment or destination surveys, are performed to provide specific and detailed information about trip destinations. This information is also used to supplement what is contained in a home interview survey. This information is particularly useful for estimating and calibrating the trip attraction models. The presence of an establishment survey creates an opportunity to estimate the trip attraction models on a disaggregate rather than an aggregate basis. When designing the sampling frame, factors such as geography, establishment type, and establishment size should all be considered.

In addition to enhancing the trip attraction models, data collected from this survey instrument can be used to develop a parking cost model, and/or to provide information about visitors and commercial vehicle traffic. The parking cost model can be created from this data because detailed information can be collected about the exact location where an employee actually parks and the associated cost. Insight regarding the behavioral trade-offs between cost, parking location, and associated walking distance can become an integral part of the parking cost model. Information regarding employer subsidies for parking can be collected and incorporated in the modeling framework. The survey can also provide information of the volume and characteristics of visitors to an establishment. The final data element, volume and characteristics of commercial vehicle traffic can provide the basis and starting point for developing commercial vehicle models. While establishment surveys are certainly considered optional, they are encouraged where resource permit.

3.2.4 - External Survey

External surveys provide information for travelers that have one end of their trip outside the region or subsequently for travelers that have both ends of their trip outside the region (external-external), but simply pass through. A survey of this nature allows supplementary models to be developed for two trip purposes related to external trip making:

- Internal-External (and External-Internal)
- External-External

The external survey should include a simultaneous external station count so the surveyed vehicles may be expanded properly to the regional total of external trips. Two methods of performing an external survey are:

- License Plate Survey
- Personal Intercept

The license plate survey is more economical but experiences very low response rates (i.e., 5-20 percent). The personal intercept survey is a more costly since surveyors must stop and interview participating vehicles, but the quality of the data is much higher since a wide variety of questions may be asked about the trip being made and the quality of information can be carefully controlled.

External surveys are also optional, but are highly recommended if external travel comprises a reasonable measure of overall regional travel.

3.3 - Transportation Networks

The representation of the transportation system is one of the most important aspects of travel demand modeling. The most direct method for creating a transportation network for modeling is to develop an abstract representation of the system elements. The elements that should be included range from the basic roadways to a depiction of the transit system. A transportation network is developed for each primary travel mode; in most cases this is the private automobile and transit. The auto system is called a highway network and includes those streets, roads, thoroughfares, and freeways that make up the regional highway system. The network is basically a map of these routes, defined in a manner that can be read, stored, and manipulated by the transportation planning computer program - emme/2.

The transit network is interrelated with the highway network. This is especially true in the emme/2 transportation planning software. The transit lines are defined by which highway links they traverse. Although it is possible to code transit only links, this is not usually done unless the transit service being represented utilizes an exclusive right-of-way such as an grade-separated fixed-guideway system or a bus-only street such as a mall.

3.3.1 - Highway Network

The highway network serves several purposes in transportation system analysis. First, it is an inventory of the existing road system, or a catalog of facilities. It is a record for the present and future years, of the physical status of the highway system. Basic information such as miles of roadway, route configuration, capacity, and counted volumes can be stored in the network. Secondly, the network is used in demand analysis to estimate the highway travel impedance between zones in a region. This impedance, or resistance to travel, is usually described as the time or distance associated with each zone pair (or interchange). This information is used primarily in trip distribution and mode choice. The third major use of the network is in the simulation of auto travel and in the estimation of impacts associated with this travel.

3.3.2 - Highway Network Coding

The process of translating the highway system into a computer usable format is known as network coding. The basic elements of the network file are nodes and links. Links are used to represent individual roadway segments. Nodes represent the intersection of roadway segments and are also used as shape points to maintain the true topology of the highway system. In addition to regular nodes and links, the network contains special nodes called centroids. Centroids represent the traffic analysis zones (TAZ) and are located at the center of activity in the zone. They are the point at which trips are loaded on the highway network. External stations are centroids which represent the points at which external trips enter or leave the region.

In historical practice, networks used in travel demand models were defined through a process of tracing highway segments off a set of base maps such as USGS maps. The coordinates of the nodes were entered manually or with a digitizer in the network data base. The face of network development is changing with the introduction of the Bureau of Census TIGER files. These files can be used to develop base maps of a region and these base maps can be exported, thus saving the time of digitizing the networks. Even more important is the consistency and accuracy gained by using the TIGER file data.

3.3.3 - Node Usage and Placement

Nodes indicate specific points in the network. Nodes are identified by a node number, "x", and "y" (Cartesian) coordinates, indicating node location, and multiple user fields which can be used to hold numeric data. Node user fields can be used to hold intersection related data such as intersection controller type, and intersection level of service results. Node types include regular nodes, transit access nodes, dummy nodes, and centroids. Regular nodes, representing street intersections, bus stops, transit stations, and points along highways are the most common node type. Transit stations may be accessed through a transit access node with a walk link representing the movement from the bus stop or parking lot. Transit access nodes serve a dual purpose, because they also act as regular nodes through which auto and bus movements may pass without going to the station.

Centroids are a unique type of node which represent the origin or destination of trips by both auto and transit modes to/from a zone. The coordinates of centroids are defined to facilitate the geographic review of zonal and network data. Travel to/from a zone is not affected by the centroid's location within a zone, since travel characteristics are based on the attributes of links connecting centroids to the network. Centroids for external zones are located adjacent to the major highway they serve. Once all the centroids have been located, their positions are reviewed to insure that none are overlapped by another node or link. This technique makes network plots more readable.

The fields available for the node records are:

- Node label
- X-coordinate
- Y-coordinate
- User defined data (i.e. type of intersection control, junction type, area type, etc.)

3.3.4 - Roadway Links

The highway and transit systems in a region are represented by a system of links connecting pairs of nodes. Each link contains the following information: the nodes that it connects, the modes that may use it, the link length, the link type, the number of lanes, the volume delay function (VDF) identifier, and user fields. One link is coded for each direction of movement on both the highway and transit networks. Therefore, links are usually coded one-way along roadway segments that only allow one-way movement (including freeways and ramps) and on auxiliary transit links that are used in only one direction during the time period that the model is meant to represent. For example, during the AM peak hour only park-and-ride movements that are traveling towards transit stations are allowed. The link type coded for each link can hold any representation of the type of link desired. Numeric values ranging from 1 to 99 are currently allowed in emme/2.

Link impedances are assigned using volume delay functions, which in emme/2 are flexibly defined in a separate file. The volume delay function code assigned to each link should correspond to the appropriate volume delay equation to be used during an assignment. Volume delay function codes are numeric and can range from 1 to 99.

The fields typically used for link records are:

- A-node label of link
- B-node label of link
- Link length
- Link modes
- Link type
- Number of lanes
- Volume-delay function number
- User defined data

Link user defined data fields can be used to store a variety of numeric data. These include data to be used for assignment calibration and validation such as roadway counts, observed speeds, and toll fee information. The user fields may also be used to store information vital to the execution of the assignment model. For example, in congested networks with closely spaced intersections, intersection capacity is usually observed to be more of a constraining factor to smooth, uninterrupted vehicle flow than link capacity. The link capacity used in the volume delay functions in a capacity restrained assignment may therefore be defined in a user field and represent the capacity of the downstream intersection (or B-node of the link.)

The values for capacity to be placed in the user field may come from a look-up table of capacities based on characteristics of the intersection including: intersection control type, functional classifications of approach segments at the junction, and area type. Note that area type may be an important intersection attribute as links in rural areas may have their capacities more appropriately represented as mid-block capacities. This is based on the fact that links with lengths greater than a threshold value, determined with local knowledge of traffic queue generation and discharge tendencies, are flow constrained by link attributes of roadway width, presence of parking, rather than intersection flow constrained.

Since the concept of associating capacity restrained traffic assignment with capacity of downstream inter-sections is recognized as proper, this technique should be adopted as "best" practice. Defining link capacities based only on link characteristics is still regarded as acceptable practice.

3.3.5 - Transit Network

In addition to the highway network which allows bus and express bus modes, the networks also include transit links that are not part of the highway network. The two major categories of these transit-only links are bus-only links and rail links. The bus-only links represent portions of the highway system, usually collector streets, that carry bus routes, but are not important enough to include in the highway network. The lengths of such links are determined by the bus routes that utilize them. Impedances on these links are a function of their length and the default speeds of the bus routes.

In addition to the transit network, it is sometimes necessary to build a network of auxiliary transit links which make it possible to move from the origin zone to a transit network (via walk or park-and-ride), trans-fer between routes (via walk), and move from the transit network to the destination zone (via walk). It is important to keep in mind that the basic transit network uses the same nodes and links as the highway net-work as the two are inherently interconnected in emme/2.

3.3.6 - Centroid Connectors

Centroid connectors are links representing typical access and egress to/from roadways and transit service to/from centroids. Within a network structure, a single link may be used to represent both auto and walk access from a zone to the network, since the network access node is part of the highway network on which transit can be allowed to operate. For most regions, this means that links connecting zone centroids to the highway network allow both vehicle and auxiliary transit modes to use them.

The preferred method for coding centroid links is to connect the zone centroid node to a mid-block node. This method allows greater route choice flexibility by simulating a choice of left versus right turn from a minor approach into a major traffic stream and avoids the difficulty of intersection capacity calculation with large volumes of trips entering an intersection from a zone centroid.

3.3.7 - Park-and-Ride Links

Park-and-Ride links are a special form of centroid connector representing auto access to transit stations. Specifically, the link corresponds to a person driving or getting dropped off at a bus stop or the parking lot of a train station. These links are categorized under auxiliary transit to prevent trips from using the park-and-ride link to access the highway network. Park-and-ride links are typically only coded from the zone in an AM network, for example, in order to prohibit transit users from using park-and-ride to egress from a station. Park-and-ride links should only be connected to transit facilities that have parking facilities. A centroid may be connected to more than one park-and-ride lot allowing a choice to be made as to which lot will be used. The number of park-and-ride links from an individual zone as well as the number of parking facilities to be connected from a zone is normally a function of the structure embodied in the mode choice model.

3.4 - Travel Cost Data and Information

Costs associated with travel are often referred to as exogenous variables because they are derived externally from the basic model set. Travel costs are generally broken down into auto operating costs, transit fares, and parking costs. All costs should be expressed in base year dollars. Given this assumption, only the incremental costs expected to exceed the inflation rate should be added to the base year operating costs to establish future year estimates.

3.4.1 - Auto Operating Costs

The cost of owning and operating a vehicle is usually broken down into two components:

- Costs associated with ownership of the vehicle, and
- Costs of operating the vehicle.

Costs associated with ownership of the vehicle include items such as depreciation, insurance, license fees, and finance charges. These costs are considered fixed costs associated with the decision to own one or more vehicles in a household. Costs associated with operating a vehicle are often referred to as out-of-pocket costs since they are paid on a more frequent basis than ownership costs. Vehicle operating costs

include gasoline, motor oil, tire replacement, maintenance, and repair. The operating costs are variable charges because they vary with the distance traveled.

The use of reports from the Bureau of Labor Statistics (BLS), U.S. Department of Energy, as well as state automobile association surveys can be used to track historical changes in gasoline and non-gasoline costs. The BLS reports are extremely useful for showing national and sub-regional trends in gas prices, changes with respect to consumer price indices, as well as vehicle ownership costs.

3.4.2 - Transit Fares

The cost of riding a transit vehicle is captured in the fare charged by the transit operator. A variety of methods may be applied to calculate transit fares for zonal interchanges. If the complexity of the transit systems warrants, a path based fare should be calculated to properly determine the fare on a zonal interchange. If the data exists, an average fare should be calculated to represent the fact that some passengers pay the adult cash fare, while some pay with discount passes, while youths generally ride for a reduced fare. If this data is not available then the adult cash fare should be used.

3.4.3 - Parking Costs

Parking costs reflect the cost a traveler incurs when parking a vehicle at the destination end of the trip. There are two basic options available in developing parking costs per trip to a destination zone:

- Use the nominal, or posted parking price, or
- Use the partial parking price (accounting for employer subsidies).

The partial parking price is more accurate because the effects of employer subsidies on employee parking can be substantial in certain areas. Data on employer subsidized parking may not be available, requiring that the nominal or posted price be used.

Because drivers do not always park in the zone representing their final destination, the concept of a "floating zone" structure has been developed to help account for this phenomenon. This technique attempts to account for the average parking cost seen by a traveler to a zone as being the   average parking cost for the zone and all adjoining zones within a specified walking distance. The network need not actually be coded with walk links for this purpose. The floating zone distance is typically set between 0.25 and 0.50 miles. Each zone is represented by a centroid and the average zonal cost is obtained by averaging the individual costs in each surrounding zone within the specified floating zone distance. These averages are then weighted by the number of spaces in each of the zones.

Weighted average parking prices should be developed by using the number of parking spaces per facility and the corresponding parking prices. An average maximum daily rate per zone is developed for each destination zone. The maximum daily rate is the maximum amount a person would have to pay to park in a facility for 8-24 hours at the posted rates. Individual parking facilities are aggregated to the zonal level.

Models should be developed to relate the daily and two-hour average parking costs to the trip-end zone characteristics. The primary trip-end data variable should be a measure of density; commonly, employment density is used. The average daily rate should be applied to Home-Based Work trips for an 8-24 hour period to reflect the cost of parking for the entire day in a space and a two hour average parking rate is developed to be applied to other trip purposes that will incur a parking charge such as Home-Based Other. In most models of this type, there is a minimum density level in which the parking cost is set to zero for all values below this threshold.

3.5 - Model Validation Data

Model validation represents the final step in the model development process. The comparison of the applied model in the base year with the observed data serves to indicate how well the model is replicating existing travel patterns. At each step in the travel model development process, each model component is subjected to a series of validation tests following estimation of the model parameters (coefficients, constants, etc.). Model validation is strictly an aggregate set of comparisons, and represents the final test of the model's ability to accurately simulate existing travel behavior. A variety of data sources may be used in the validation of the travel demand models.

3.5.1 - Traffic Count Data

Traffic volume counts are used to compare estimated roadway volumes to observed values. The traffic count data used in the comparison should represent counts taken during the same base year as defined for model development. For example, if the model is being validated based on 1990 socio-economic and land use data, then the traffic counts should be from that same year.

There is often a wide variation in the traffic count data depending on the month and day of week that the individual traffic counts were taken. If a peak hour validation is being performed, it is important to make sure that the traffic count data represents the same hour. Traffic counts taken across multiple days are the best because the data can be summarized and further analyzed to examine any variation that may be present. Traffic counts should also be geared towards the season for which the model is being validated. For example, traffic counts are not often taken in the summer because school is out of normal session and this affects both home-based school trips as well as home-based work trips.

If counts can only be performed at limited locations in the modeled area then screenline locations should be established to strategically cordon the area along major physical barriers. External station counts are always required to ensure the model is properly calibrated at these gateway locations. Traffic count data is a requirement for any area performing travel demand model development.

3.5.2 - Highway Travel Speeds

Link travel speeds are used in the assignment process and fundamentally determine which paths will be used on the network when traveling between zone pairs. There are several reliable methods to collect data on travel speeds. Floating car runs can provide a useful source of information of not only free-flow, but also congested speeds. Pneumatic traffic counters can also be used to collect speed data. The speeds output from a model run can be compared to the observed travel times on a link by link basis to determine if the coded link speeds are accurately reflecting traffic flow conditions. The model estimated link speeds

should be based upon a set of calibrated travel time functions for the region used in concert with an equilibrium capacity restraint assignment algorithm. The function developed by the Bureau of Public Roads (BPR) is a reasonable starting point, although a larger variety of functions are becoming more prevalent in practice including conical functions. Intersection based volume delay functions represent an additional level of sophistification beyond link-based computation of travel speeds and delays, but require significant additional effort to properly implement.

3.5.3 - Trip Length Information

Information regarding the average length of trips by trip purpose is important in determining how the model is reproducing traffic flows on the network. A home interview survey can serve as a primary source for data on trip lengths. The US Census data for Journey-to-Work information can also be used if it is available. Trip length information is most often used to calibrate a set of trip distribution models for a region. Trip length information can also be used in the calibration of the mode choice model. The observed and estimated average trip lengths for each purpose are compared to make a determination of how well the model is currently calibrated. Several factors can influence the average trip length, including the spatial distribution of productions and attractions as well as the initial highway link speeds used in the calibration process. Each of the appropriate factors influencing the estimated trip length should be reviewed if the comparison of the observed and estimated trip lengths is not favorable.

3.5.4 - Vehicle Occupancy

Observed vehicle occupancy data is important for models that are estimating shared ride modal shares. As more metropolitan areas explore the use of high occupancy vehicle lanes to reduce or curtail roadway congestion, the ability of travel demand models to reliably forecast shared ride modes will become increasingly important. A home interview survey can provide a good source of information on vehicle occupancy statistics for a region. When direct observation of vehicle occupancy rates is being made by surveyors the count locations should be selected to provide information for key points in the network. Key points of a network include areas such as external stations, screen line locations, cordons around central business districts, and on freeways. Vehicle occupancy data is optional for developing travel demand models.

3.5.5 - Special Generator Surveys

Special generator surveys or studies can provide area-specific data on trip making characteristics and roadway segment volumes. These type of surveys are usually only done for special generators that might have concentrated development in central business districts. Quite often these special generators are not appropriately handled in the traditional model stream. This is especially true if the demographic characteristics in an area are significantly different than the average. In these cases it may be worthwhile to perform a local trip generation study. Airports are another example of a special generator since the employment for the airport is usually accounted for in the socioeconomic file but the air passenger traffic is not. Special generator surveys are not required for travel demand model development efforts if there are no significant special generators within the modeling area.

3.5.6 - Transit Passenger Volumes

A statistical analysis of 24-hour transit assignments on a route-by-route basis provides the basis for ascertaining the accuracy of the transit validation. Actual transit boardings for each route for an entire weekday can be obtained from on-board rider surveys or other available route level information.   Similarly, for other non-motorized modes such as bicycle and walking, data from an independent source or count data can be used in the model validation process.

4.0
MODEL DEVELOPMENT GUIDELINES

4.1 - Introduction

The model development guidelines presented in this chapter describe the underlying theory and basis for the structure, formulation, and development of each model component comprising *"Best Practice"* for each MPO within the state. It also outlines the series of technical steps required to estimate and implement each model, along with the calibration and validation procedures to be followed in verifying the accuracy and acceptability of the complete model set.

The proposed overall structure of the recommended transportation model system is displayed in Figure 4-1. As shown in this schematic representation, application of the model begins with two key sets of input; the demographic, economic, and land use information (at the transportation analysis zone level), and the multimodal transportation network level-of-service data.

The first model in the sequence is the household auto ownership model. The choice between owning 0, 1, 2, or 3 or more vehicles within a household is a fundamental decision effecting travel. The next model is the trip generation model. Estimation of the magnitude of trip making is considered in terms of the range of possible types of trip purposes (i.e., Home-Based Work, Home-Based Shopping, etc.). Following trip generation, an estimate of the proportion of travel (by trip purpose) occurring in the peak and off-peak (or base) hours is determined by a diurnal factoring model. Although the diurnal factoring model is not explicitly discussed in this chapter, the separation of individual trip purpose travel into discrete time period slices can be obtained from original survey data (for the base year) or taken directly from the trip assignment (i.e., Time of Day) model. The linking of trip origins and trip destinations is accomplished by the Trip Distribution model, while the choice among alternative transportation modes is estimated using a Mode Choice model. The final component of the model system is embodied in the assignment of travel to each respective transportation network.

The recommended "best practice" model, as depicted in Figure 4-1, contains a series of "feedback" loops from lower level decision models to a number of upper level components. These "feedback" loops represent both the interrelationship between individual components (i.e., the representation of time, cost, and the socio-economic characteristics of the traveler from Mode Choice in distributing travel in Trip Distribution) and the opportunity to iterate the entire model set to reach of state of equilibrium between the representation of transportation supply and level-of-service and the resulting demand for travel.
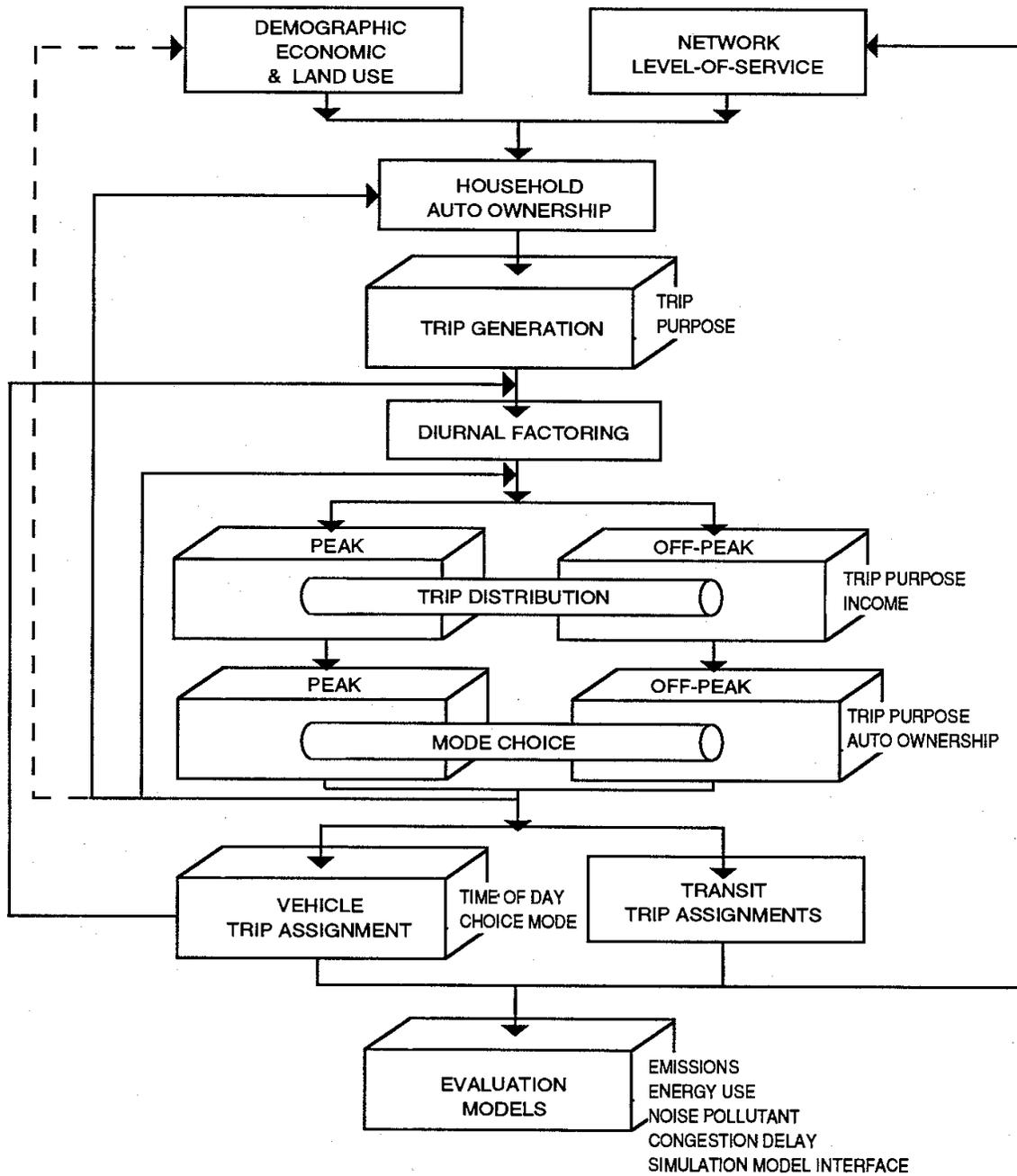
Figure 4-1 - SCHEMATIC REPRESENTATION OF THE REGIONAL TRAVEL FORECASTING MODEL SYSTEM

The chapter concludes with model validation procedures and standards designed to evaluate the ability of the entire modeling system to adequately forecast traffic and transit volumes at an acceptable level of accuracy.

4.2 - Trip Generation

The trip generation model is composed of two basic models -- a production model and an attraction model -- and one or more submodels. The trip generation model estimates the overall magnitude of trip making on a specific geographic basis (i.e., zones). Various submodels are used to support and describe the disaggregation of households (and/or workers) by selected independent variables.

4.2.1 - Market Segmentation Considerations

The trip purposes used in the trip generation model should generally conform to the following definitions: (1) Home-Based Work; (2) Home-Based Shopping; (3) Home-Based Social/ Recreational; (4) Home-Based Other; (5) Home-Based School; and (6) Non-Home Based. Recent research has suggested that the work trip purpose could be further stratified into subcategories as a function of the potential for intermediate trip stops. This categorization scheme would subdivide work trips into (1) Home direct-to-Work, (2) Strategic Home-Based Work, and (3) Tactical Home-Based Work. An example of a strategic Home-Based Work trip would involve the pickup or dropoff of a school age child. In the case of a tactical work trip, the intermediate stop could be a convenience stop such as stopping for gasoline. Furthermore, it is suggested that the Home-Based School trips be subdivided into Elementary/Secondary and University trips, and also that consideration be given to separating Non-Home Based trips into Non-Home Based Other and Non-Home Based Work, and possibly Non-Home Based Work-to-Work. While all these purposes may not be used in this detailed fashion in all subsequent models (i.e., trip distribution and mode choice), this stratification should allow for the development of a better behavioral model at the trip generation stage and the resulting trip ends can easily be combined for the subsequent models.

Beyond stratification by trip purpose, "time-of-day" (peak versus off-peak) considerations are needed to support segmentation in other model components (i.e., trip distribution and modal choice). In the case of trip generation, the reflection of time-of-day is best implemented following the trip generation model computations. This initial diurnal factoring could be based upon a previous iteration of a time-of-day choice model or historical (survey-based) relationships.

As outlined in Trip Distribution (4.2), stratification of the Home-Based Work trip distribution model by a socio-economic variable could assist in better representing the relationship between worker and workplace. This requires that both the trip production and trip attraction model be stratified in the same manner.

4.2.2 - Trip Production Model

This section discusses the estimation of the trip production model, but does not include any discussion of a school bus or commercial vehicle generation model. That is, the definition of the production model, for purposes of these guidelines, is the model which estimates trip ends generated by the residences at the home end of the trip, including **walk and bicycle** trips.

Development of school bus (vehicle trip) movements are normally taken directly from a Home-Interview Survey data and simply "growth-factored" to the future based upon population estimates. The school trip production model (for all types of school trips) will include *all* school trips. It is anticipated that school bus trips would be removed prior to mode choice model application. In the event that Measure 5 results in the elimination of all or some of the existing school bus service, the opportunity would exist through this mechanism to adjust the school bus trip table accordingly. Commercial vehicle estimates are discussed later in this chapter.

4.2.3 - Mathematical Formulation

The recommended estimation procedure for the production model is a disaggregate cross-classification procedure using Multiple Classification Analysis,[1] with some corrections being made to the basic model using regression and/or hand-fitted curves. The objective of the cross-classification model is to develop a set of relationships which can be used to identify all of the worker and/or household characteristics which generate statistically different trip rates, while minimizing the number of individual cells in the matrix. The use of a disaggregate data base, (i.e. households), reduces the errors due to zonal averaging and the cross-classification methodology and allows the model to be non-linear with respect to the independent variables. The dependent variable should be trips per worker (i.e., employed resident) for the Home-Based Work trip purpose(s) and trips per household for all other trip purposes. The most appropriate and basic independent variables for this model would be either households by auto ownership or income level and household size, although for the Home-Based Work trip purpose, the number of workers should be examined in addition to household size. The choice between auto ownership or income level will be largely dependent upon the decision to construct a auto ownership model and the relative performance of each variable when evaluating the cross-classification model. This use of auto ownership based upon an auto ownership model reflects (to a degree) the implicit effect of accessibility on trip making potential.

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[1] "Trip Generation by Cross-Classification: An Alternative Methodology," Peter R. Stopher and Kathie G. McDonald, Transportation Research Record 944.

An example of a cross-classification model for the Home-Based Shopping trip purpose using household income and size is shown below:

Productions Per Household					
Persons Per	Income Group				
	1	2	3	4	5
1	0.543	0.543	0.603	0.603	0.603
2,3, and 4	1.057	1.057	1.057	1.114	1.114
5+	1.438	1.438	1.560	1.560	1.560

In addition to these independent variables, a series of "land use form" variables should be investigated, after the basic model is developed. These variables could be residential density, employment density, or area type.[2] The intent of such land use form variables is to explore and possibly help explain the differences between geographic areas. In light of the 1990 Clean Air Act Amendments a reflection of transportation supply characteristics should also be considered (primarily for the Home-Based Non-Work and Non-Home Based trip purposes in order to more explicitly examine the impact of accessibility (or lack thereof) on the magnitude of discretionary trip making (beyond that of the basic auto ownership decision). The number of Home-Based Work trips are not likely to be influenced by supply characteristics to any significant degree. Examples of supply characteristic variables could include use of a LogSum term (from mode choice) or alternatively, the amount of retail employment within a pre-specified time contour.

The recommended base data is the Home Interview Survey, without expansion factors. While expansion factors will allow for the determination of total travel in the region, it obscures some of the analysis performed on the disaggregate data and therefore the estimation of the trip production model should be performed without the expansion factors.

The basic strategy for the trip production model is to relate trip generation per worker or per household to income or auto ownership level and household size (or number of workers). From past studies, it has been ascertained that these independent variables are not related to trip generation in a linear form, that is, two-person family households do not necessarily generate twice as many trips as one-person family households. Therefore the estimation strategy for relating trip productions to income or auto ownership and household size is to use cross classification. In addition, the model should also attempt to investigate the influence of single versus multi-family households, land use configurations, and transportation supply[3] on the trip generation rate. The approach for this investigation is to relate the error associated with the cross classification model with land use intensity variables, such as population density, employment density, and area type, and/or with transportation supply indicators, such as employment opportunities within a specified travel time contour or in the case of the non-work purposes, possibly a

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[2]   Use of an area type variable attempts to incorporate both population and employment density in reflecting the effect of land use on trip making rates. An example of a density equation used to define area type would be: Density = (Population + 2.0 * Employment)/Area.

[3]   For Non-Work Trip purposes which would be more sensitive to transportation supply variables, the production cross-classification model may be replaced by a frequency of choice model in a multinomial logit or similar form.

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variable such as autos per worker. The technique for implementing these "corrections" is generally regression analysis and/or hand fitted curve models.

The Multiple Classification Analysis (MCA) technique (which is an extension of the analysis of variance or ANOVA) used in construction of the cross-classification models relies upon the estimation file developed from the Home Interview Survey to produce the basic statistics for each combination of strata in order to analyze the variables selected for inclusion and determine appropriate cell values.

MCA represents an alternative estimation method for cell values (for cross-classification models) that provides substantial improvements to the classical use of the t-ratio to statistically measure the means of adjoining cells as the basis for cell combination. The MCA approach offers statistical goodness-of-fit measures (including the F statistic) that allow for the comparison of alternative classification schemes and an overall assessment of the model fit. Probably, the most important advantage of the MCA method, is its ability to determine reliable cell values, not simply based upon the size of the data sample within a given cell, but rather based upon the overall mean and the applicable class means. This approach provides a greater level of reliability for each cell rate than with the more classical method.

The final step in the analysis is to relate the aggregate error of the cross-classification model to proposed density and/or transportation supply measures. The resulting relationship may or may not be linear. A set of plots should ascertain if the relationship is reasonably linear, or if the relationship is non-linear but can be approximated by a "normal" mathematical function, such as an exponential function, or if the relationship is non-linear and cannot be approximated by a normal mathematical function, but may be approximated by using hand fitted curves, or finally, if the relationship is non-linear and appears to be grouped in such a manner that additional cross-classification variables would appear reasonable. For example, the differentiation between single and multiple dwelling units may provide additional predictive understanding of the differences in trip rates.

As a disaggregate validation of the trip production model, the final set of cross-classification models can be applied to the Home-Interview data set and estimated trips generated. A series of statistical tests can then be performed at three levels of aggregation, household, zone, and district as follows:

Analysis Level	Trip Purpose	Average Trip Rate		Standard Deviation		Standard Error of the Mean		Standard Error of the Estimated		Coefficient of Determination	Linear Regression Coefficients	
		Observed	Estimated	Observed	Estimated	Observed	Estimated	Standard Error	With Respect to Mean		A	B
Household	Work	1.752	1.752	1.781	0.821	0.047	0.021	1.580	90.18	0.2127	0.00016	1.00005
Zone	Work	2.642	2.642	4.596	4.053	0.148	0.130	2.088	79.03	0.7934	-0.02598	1.00997
District	Work	53.333	53.326	47.712	46.364	6.887	6.692	9.643	18.08	0.9583	-0.38622	1.00738

4.2.4 - Trip Attraction Model

This section discusses the calibration of the trip attraction model. For Home-Based trips, attractions are defined as the non-home end of a trip. The attraction model should also include a submodel to estimate non-home based trip ends which could be based upon the number of home-based trip *ends*. In other words, non-home based trip productions could utilize the estimate of home-based trip attractions when considering the number of non-home based trips to be produced within a zone.

The trip purposes used in modeling the attractions should be the same purposes used in the production model. The recommended calibration procedure for the attraction model is regression analysis, at an aggregate level. The aggregation level suggested is a "district." The definition of a district is a group of traffic analysis zones. Although, this is a fairly large spatial area for travel demand modeling, the data normally available for this analysis constrains the investigation to large area analysis (i.e., in the absence of a work place survey). The regression equations developed should be modified so that the models can be applied at the traffic analysis zone level. This modification can be accomplished in one of two methods, both aimed at eliminating the constant. The first would be to allocate the constant to each of the coefficients in the model, while the second would force the Y-Intercept of the regression through zero. In either case, an attempt should be made to minimize the contribution of the original constant. The data base available for this analysis is the home interview data and the land use variables.

The four suggested phases of this analysis are: (1) developing rational districts; (2) preparing a data base; (3) estimation of model parameters; and (4) validation. The first step is to develop a set of rational districts with each district being composed of a set of traffic analysis zones. The data base consists of a record for each district. These records contain the number of attractions, by purpose, for the district and the land use information, such as population and employment, in the district. The estimation of the model parameters is performed using a statistical regression program. Validation consists of estimation of the attractions, using the attraction model, and the comparison of estimated attractions to the actual attractions.

The reason that districts are needed is typically that the only available data set for this calibration phase, is a relatively small sample data set, and therefore, the variation by zone would be too great to allow stable regression analysis. By combining the data at a district level, the variation is reduced and regression analysis made possible. This aggregation is not necessary for the production model, since the individual independent variables are available at the production level.

The strategy is to develop a set of districts which are: (1) large enough that the average attraction trip rate per independent variable is approximately correct; and (2) small enough, so that there are enough districts to allow reasonable regression equations to be estimated. Selecting the districts is a fairly difficult task requiring some subjective judgment. Obviously the districts should have enough attraction trip ends to reduce the unexplained variation and they should also be composed of contiguous traffic analysis zones. Thus the districts will be largest in the suburban area and smallest in the denser activity centers. Hopefully it will be possible to select districts which are reasonably homogeneous with respect to land use, (i.e., mixing major manufacturing and retail areas may obscure the analysis). If possible, it would be advantageous to have approximately the same number of attractions in each district, but this is

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normally difficult. There should be at least 30 records, not expanded attractions, in a district. This requirement may require reducing the number of districts and/or simply removing some of the districts from the calibration file. The approach in developing Non-home based trips is to obtain the average number of trip origins or destinations per district.[4]

4.2.5 - Mathematical Formulation

The basic strategy for the trip attraction model is to relate district attractions to the land use variables using linear regression. The relationship between attractions and land use variables is fairly standard (i.e., work attractions to employment, shopping attractions to retail employment etc.) The standard tests should be applied in evaluating these equations, including the coefficient of determination (the R Square), t-ratio's for the independent variables, and an F ratio for the entire equation. Examples of equations investigated for the Home-Based Other trip purpose are as follows:

	Model Variables						Model Statistics	
	Retail Employment		Households		Other Employment			
Intercept	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	R^2	F Value
6320.05	7.6237	58.71			-0.3427	2.55	0.681	48.01
-1966.27	2.6793	11.38	1.4504	37.75			0.817	100.21

 In addition, the observed and estimated attractions should be reviewed by district to identify the "outliers," attempting to correlate these outliers with a specific land use condition, such as area type, heavy industrial employment, etc. This analysis particularly applies to special generators like major shopping centers and airports. Another evaluation criteria is the value of the bias coefficient. This coefficient or constant term should be as low as possible.

Beyond the basic land use variables, other variables may be best introduced as dummy variables. Area type is one example. Such dummy variables can be used in two ways. The first way is as an additional bias coefficient on the basic equation. If the dummy variables are used in this manner, the coefficients on the independent variables remain constant and the number of attractions for a district are increased or decreased by a certain amount depending on the area type.

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[4]   It should be noted that in the case of Non-Home-Based trips, there is no identifiable production end or attraction end. In estimating Non-Home-Based "attractions," therefore, one-half of the total number of trips are estimated to have their origin or destination end at a particular zone (intrazonal trips being counted twice toward this total). In applying the model for Non-Home-Based trip "attractions," this estimated number of trip ends is doubled, and then split 50-50 between productions and attractions, for purposes of distributing these trips to specific interchanges. A regional control total for Non-Home Based trips is derived from the production model and subsequently used to normalize the total attraction value obtained in the attraction model.

Travel Demand Model Development and Application Guidelines

The second method of using dummy variables is as modifiers on the independent variable coefficients. In this case, the hypothesis is that the independent variable attracts a different number of trips per unit of measure, depending upon the location in the region. For example, it can be hypothesized that retail employees may attract more shopping trips per employee as the urban area becomes less dense or suburban. That is, the retail employees in the CBD will attract less shopping trips per employee than retail employees in the suburban areas. In this case, the use of the dummy variable would be a multiplier on the independent variable coefficients.

The general approach in calibrating the attraction models is to first investigate the "normal" independent variables, such as employment and households. Only after these variables have been tested, should dummy variables be considered. When dummy variables are investigated, the bias type of approach should be implemented first. If the bias dummy variables are fairly large and significant, the second approach should be considered, since a basic criteria is to reduce the bias coefficient values. A general rule of thumb for the coefficients being too large is if the bias coefficients contribute more than 15 to 20 percent to the entire model. That is, if the product of the bias coefficient and the number of districts, which are included in the bias coefficient, is greater than 20 percent of total regional trips, then the bias coefficient is too large and the model should be revised. It is suggested that the most efficient strategy for this approach is to apply the dummy variable technique to the "strongest" independent variable first and then proceed to the next strongest independent variable, until the dummy variables stop adding significance to the equation.

4.2.6 - Trip Generation Submodel Development

While the previous sections have discussed the production and attraction models, they have accepted as a given some of the input data which cannot be immediately available for future year forecasts. The most important set of input data for which this might be true, is households stratified by income group or auto ownership level and household size (or possibly the number of workers for Home-Based Work).

The submodel to stratify households by a socio-economic variable (income or auto ownership) and household size is typically performed as a "two pass" model. For illustrative purposes, the following discussion assumes that income is selected as the socio-economic variable. If an auto ownership model is constructed then the distribution of households by auto ownership would be obtained directly from the model and would not require a submodel as described here. An auto ownership model (as discussed in the next section) provides a behavioral basis for predicting auto ownership levels, while an auto ownership submodel relies upon an input estimate of average autos per household within a zone to estimate the proportions of households by individual categories.

The first pass is to model the income and household size distribution separately, using census data as the observed data and relating the distribution of the income and household size to the average values of these variables. For income groups this is a fairly simple task, consisting of producing a set of curves which relate the percent of households for a given income group to the average income of the area. For a four group income stratification (i.e., quartiles) this model would include four curves, one for each income group and the constraint on the curves is simply that for any average income the group percents

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must sum to one (one hundred). In order to maintain a reasonable set of relationships for future forecasts, the average income is usually specified as the ratio of the average zonal income to the average regional income. The household size model is similar to the income model in that it consists of a curve for each household size. Unlike the income model, the household size model contains two constraints; the first being that the size percents must sum to one for any average household size, while the second is that the size percents must mathematically produce the correct average household size.

The technique used to calibrate these first pass models is typically a curve fitting exercise. That is, the data is grouped by the ranges of average income and household size and the curves are plotted using the constraints previously described. While this technique appears to be fairly unsophisticated, the data usually is very well behaved and reasonable hand-fitted curves can be developed fairly easily. Normally these first pass models are developed using the latest census data and are calibrated using census tract information. Since the models use averages and ratios as the independent variable and percents or proportions as the dependent variable, the models can be applied at the traffic analysis zone level without any modifications. An example of a household size submodel is shown in Figure 4-2.

The second pass model is to use the individual distribution models, from the first pass, and to estimate the joint distribution. The typical technique used in this modeling process is to hold the individual distributions while attempting to "match" the joint distribution for the region. Obviously for any given zone or census tract the regional joint distribution is incorrect, but this distribution is a reasonable starting point and the zone distribution should approach the regional distribution when the zonal averages are equal to the regional averages. When applying this technique, care must be taken to insure that the regional totals are conserved; that is the correct number of regional households by income group is maintained and the regional average household size is maintained.

4.2.7 - Special Trip Purpose Treatment

There are a number of special or unique trip purposes which may be of prime importance to the MPO regional travel market. One is the air passenger and related visitor travel to the regional airport. The approach to this aspect of the travel could be to employ a set of model relationships developed elsewhere or to estimate the generation and distribution of air passengers (and related visitors) based upon actual survey data (if available).

Other special generators may be any set of activities which the basic models do not address adequately including sports complexes, major recreational areas, hospitals, and major regional shopping centers.

HOUSEHOLD SIZE SUBMODEL
FIGURE 4-2
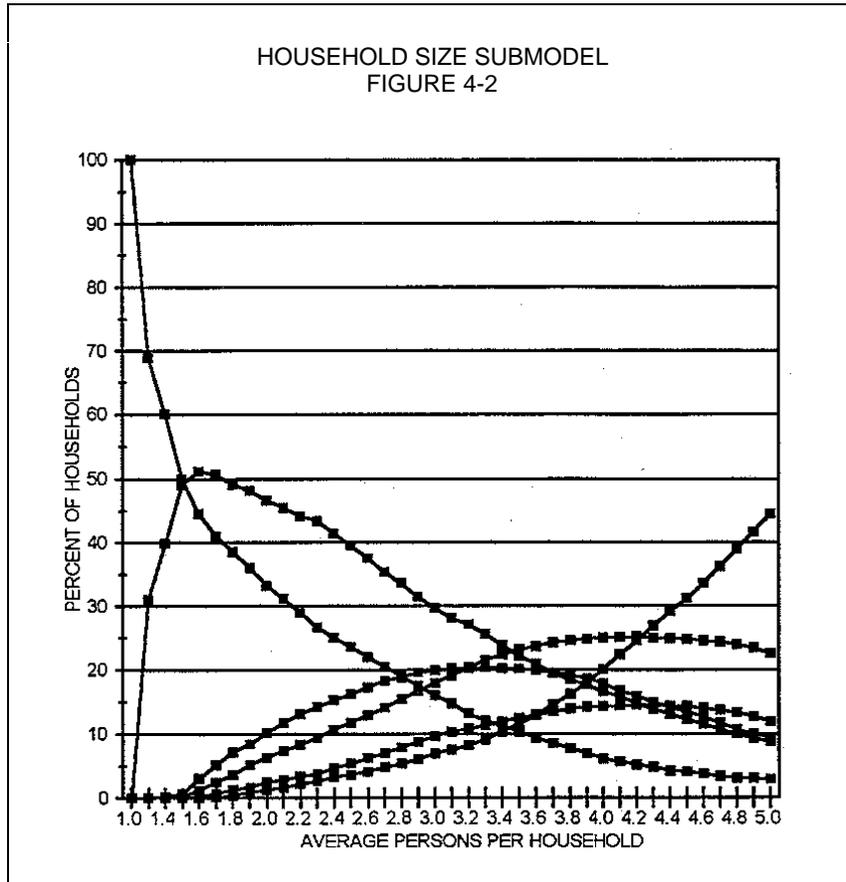
4.2.8 - Application Strategy

The production and attraction models do not necessarily estimate the same number of regional trips.
Typically, it is necessary to present the distribution model with the same number of regional productions
and attractions. The application strategy, therefore, is to control the totals by either balancing production
to attractions or attractions to productions.

The suggested "controls" for use in balancing the productions and attractions are as follows:

| | Model Controlling |
Trip Purpose	Regional Total
Home-Based Work	Production
Home-Based Shopping	Production
Home-Based Other	Production
Home-Based Social/Recreational	Production
Home-Based Elementary/Secondary	Production
Home-Based University	Attraction
Non-Home Based Other	Production
Non-Home Based Work	Production

The only exception to the above would be for Home-Based Elementary/Secondary school if enrollment data were available, in which case, the attraction model would be used for the control value.

4.3 - Auto Ownership

The forecasting results or output from a regional Household Auto Ownership Model play a central role in a number of the other basic model components. It may form the basis for market segmentation or serve as an explanatory variable in the Mode Choice Model, serve as a cross-classification variable in the Trip Generation Trip Production model , or be used as a socio-economic stratification variable in construction of the Home-Based Work Trip Distribution Model.

The Auto Ownership model is functionally the first model in the forecasting sequence (following the Land Use/Demographic forecasting mechanism and the representation of transportation supply in computerized network form). There are, however, a series of lower level linkages between subsequent model components (i.e., the mode choice models) in the form of a "feedback" mechanism using composite or accessibility variables to represent the attributes of the transportation system in the auto ownership decision choice. As a result, estimation and calibration of the auto ownership model is dependent upon the structure and coefficient values of the mode choice model.

4.3.1 - Mathematical Formulation

The intended purpose of the Household Auto Ownership Model is to predict the number of autos by category (0, 1, 2, and 3+). The general structure of the model is the standard logit formulation which is used to reflect the probabilistic choice nature of the auto ownership decision:

$$P_n = \frac{e^{U_n}}{\sum_m \left(e^{U_m} \right)}$$

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where $U_n \quad = \quad a_n + b_i * SE_i + c_i * LogSum_i$

$\qquad$ n $\quad = \quad$ number of autos owned

The b_i coefficient represents the set of coefficients on socio-economic or household characteristics, while the c_i coefficient represents the set of coefficients on the denominators of the Home-Based Work and Home-Based Non-Work mode choice models (see section 4.5.1). If the Home-Based Non-Work mode choice model is embodied in more than one model (i.e., disaggregated beyond a single Non-Work purpose), then the LogSum from each model could be included in the utility function. The a_n bias coefficient (for three of the four auto ownership choices) represent remaining "unexplained" behavior. The mathematical formulation of the LogSum variable is discussed in the section on Mode Choice Model guidelines.

4.3.2 - Explanatory Variable Considerations

There are a large number of socio-economic (or land use) variables that could be considered in the utility expression. The most important is a representation of *income*. In the (San Francisco Bay Area) MTC[5] regional travel demand models, income is represented as the natural logarithm of remaining (or disposable) income. Other possible socio-economic variables include housing type, the number of workers in the household, and household size. From a truly behavioral perspective, the most meaningful variable beyond household income would be the number of licensed drivers. Unfortunately this variable is difficult to forecast and can not be expected to be available in the future. Another land use variable, employment density, could be used to adversely impact the probability of choosing more than one auto. In general, as income and household size increase, the probability of owning more than one auto should increase.

The LogSum variable from the mode choice model represents the travel accessibility from the residence zone, summed over the available modes, stratified by the number of autos owned (assuming the mode choice model is stratified in the same manner). The generalized LogSum variable summed over all modes, however, would not directly respond to the notion that as transit accessibility increases, auto ownership would decrease. The ratio of the exponentiated utility for transit divided by the exponentiated utility for auto would more appropriately respond to this concept and therefore, would be the more appropriate formulation for including the logsum term.

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[5] "Home-Based Work Trip Models, Final Disaggregate Version," Metropolitan Transportation Commission, December, 1987.

4.4 - Trip Distribution

The Trip Distribution model links or connects trip ends (production and attractions) estimated in the trip generation model to determine trip interchanges between each zonal pair. Beyond estimates of the magnitude of activity in each analysis zone, the model employs (or considers) the effects of impedance or accessibility on destination choice. The measurement of accessibility is a critically important aspect in the formulation of this model component. The trip distribution model is a recipient of direct feedback from both upper and lower level model components, including mode choice and trip assignment.

The trip distribution model structure recommended for all MPO's within Oregon is the standard **gravity model formulation**, as opposed to generalized growth-factoring techniques. However, the *logit form* of the trip distribution model is equally acceptable and strongly encouraged where resources and time permit an investigation of this structure. The discussion in this section concentrates on the gravity form of the model, with only a brief reference and description of the logit form.

4.4.1 - Mathematical Formulation

In general, the "gravity" model postulates that the number of trips from one analysis zone to another is proportional to the attractions at the attraction zone and inversely proportional to the travel impedance between the two zones.

The general formulation of the model can be described as follows:

$$T_{i,j} = P_i * \frac{A_j * F_{i,j} * K_{i,j}}{\Sigma_j^1 (A_j * F_{i,j} * K_{i,j})}$$

where:

$T_{i,j}$	=	the number of trips between zone i and zone j
P_i	=	the trip productions for zone i
A_j	=	the trip attractions for zone j
$F_{i,j}$	=	is an accessibility factor associated with the measure of travel impedance from zone i to zone j
$K_{i,j}$	=	is the socio-economic or physically related factor for all movements between zone i and zone j

The normal calibration process followed in developing each purpose specific model is to mathematically fit the accessibility factors ($F_{i,j}$) to the frequency distribution of trips stratified by the defined impedance measure and then to explore the need for K-Factors. In general, proper model specification attempts to avoid the use of K-Factors, the validity of which may be questionable when applied in a future year. K-Factors should only be considered when an underlying physical or geographic barrier can be associated

with the error in estimation (i.e., river crossing) or when a distinct socio-economic or land use characteristic introduces the error (i.e., mismatch between worker and job features).

Calibration of the Trip Distribution models attempt to:

- match average impedance values within three percent;
- calculate the coincidence ratio and match the observed and estimated trip length frequency distribution curves (impedance, time, and distance) within reason;
- calculate the coefficient of determination at a district interchange level for use in the possible inclusion of K-Factors.

4.4.2 - Logit Model Formulation (Optional)

This form of the trip distribution model follows the traditional form of the standard logit formulation:

$$T_{i,j} = P_i * \frac{e^{U_{i,j}}}{\Sigma_j^I e^{U_{i,j}}}$$

where:

$T_{i,j}$	=	the number of trips between zone i and zone j
P_i	=	the trip productions for zone i
$U_{i,j}$	=	the set of linear function parameters describing the utility for zone i choosing zone j as a destination.

The utility expression for each production/attraction zone pair is specified as a linear function which incorporates trip attractions as a *size* variable[6] and, at a minimum, a measure of accessibility between zones. As described in Composite Impedance Development section (4.4.3), this accessibility measure is specified as the natural logarithm of the denominator of the mode choice model[7]. A substantial strength of the logit form of the model is the (completely flexible) opportunity to incorporate other explanatory variables. For example, these additional variables could include measures of urban form (density measures or area type descriptors), other size variables (i.e., recreational area for Home-Based Social/Recreational trips), or other socio-economic indicators.

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[6] Variables describing quantity, or the number of attractions, appear in the logit model in a different way from those variables describing quality or level-of-service and cost. The ALOGIT program provides a mechanism to simultaneously permit estimation of the logit distribution model considering the influence of one or more *size* variables.

[7] The natural logarithm is derived from the mode choice model for each individual trip purpose and may need to be the "weighted" sum of the probabilities of each socio-economic stratification level (i.e., auto ownership or income) multiplied by the natural logarithm for that level.

The form of the logit model distribution model lends itself directly to disaggregate estimation, followed by aggregate calibration. This form of the model must be applied in a doubly-constrained manner to insure a balance between desired and obtained productions and attractions, respectively.

4.4.3 - Composite Impedance Development

In the Trip Distribution model, all modes and all components of travel (i.e., cost, time, and distance) should be used in the model as independent variables affecting the distribution of travel. Historically, the impedance measure has been defined to be the peak period highway network travel times (updated to include intra-zonal and terminal time) for the Home-Based Work trip purpose, and base period (or off-peak) travel times for each on the Home-Based Non-Work and Non-Home Based trip purposes. In a small number of Home-Based Work models, *generalized price* has been used as the impedance measure where the shared-ride and/or transit modes have the potential to affect trip distribution patterns. This composite measure of accessibility is obtained directly from the denominator of the mode choice model (at the upper level nest). Although the shared-ride and transit modes may not capture a very substantial share of the person trip market, particularly in trip purposes other than Home-Based Work, the primary value of a composite impedance for **all** trip purposes is the inclusion of cost.

The basic objective, therefore, of utilizing composite impedance to develop the trip distribution model using the functional form of the gravity or logit model, is to develop a model form which is:

- sensitive to all modes of travel.
- sensitive to both travel times and costs.
- sensitive to the income or auto ownership of the traveler.

The composite impedance (or LogSum) measures the spatial separation between zones giving adequate consideration to travel time, travel cost, and other measures, such as the number of transit transfers (depending upon the variables contained in the mode choice model). At the same time, the impedances give weight to the socio-economic characteristics (i.e., income, auto ownership) of the traveler, through inclusion of the income or auto ownership bias coefficients.

The (utility) values resulting from the mode choice model equation must be combined in such a way that:

- the combined values fall within a reasonable range
- the combined value decreases as any mode improves (i.e., as the time or cost decreases)
- the combined values increases if any mode is unavailable.

Based on previous models of this type, two formulations meet each of the above criteria. One formulation is a variation of the Harmonic Mean formula:

$$I = \frac{K}{\Sigma(1.0/(A_i + C))}$$

where:

I	=	is the composite impedance
A_i	=	is the mode choice utility function for mode i
C	=	is a constant chosen to make all A_i's a positive value
K	=	is a constant chosen to scale the results

The second formulation uses the exponential function of the utility expressions, sums their values, and takes the natural logarithm of the result. This LogSum formulation is expressed as:

$$I = K * \ln\left[\frac{C}{\Sigma\left(\frac{1}{e^{A_i}}\right)}\right]$$

where:

I, K, C, A_i are defined as above

In addition to meeting the criteria defined earlier, the Harmonic Mean Formula is simplistic in form and computation. However, the manner in which this measure combines the impedances of each mode lacks a theoretical basis. The LogSum formula takes advantage of the decision rule implied by the calibrated logit-form mode choice model[8], and can be used with either the gravity or logit model form of the model. It is logical, therefore, that all else being equal, the probability of selecting a particular destination should be proportional to the sum of these values for all available modes. The presence of the natural logarithm scalar is simply to spread out the resulting values of impedances, which would be concentrated very narrowly at the low end of range otherwise. The constant C can be adjusted to insure that the logarithms will have positive values by using the following relationship:

$$C \succ \max\left(\frac{1}{e^{A_i}}\right)$$

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[8] The probability of selecting a mode i is proportional to $\quad e^{-U_i}\left(=\frac{1}{e^{U_i}}\right)$

The constant K can then be used to scale the impedance values to range between reasonable limits. Calculation of the composite impedance is dependent upon specification of the mode choice model for each applicable trip purpose.

4.4.4 - Market Segmentation

Separate trip distribution models should be developed for each trip purpose defined and used in the Trip Generation Model. Each of the models should be calibrated by individual time period (i.e., peak and base), with all models relying upon composite impedance (or LogSum) as the measure of accessibility.

The Home-Based Work model(s) should also be stratified (or segmented) by a socio-economic variable (i.e., income), which increases the number of model calibrations required for each time period. Stratification of the Home-Based Work trip distribution model(s) requires the development of a Trip Generation model stratified in the same manner (or able to translate the generation results to obtain consistency).

4.4.5 - Model Calibration

Calibration of the trip distribution model is essentially a four-step process. Following calculation of a composite impedance matrix and using the production and attraction vectors output from the trip generation model, the calculation of accessibility factors (F-Factors) represents the first step in the procedure. An initial set of values for model calibration could be a uniform value (i.e., one) or any reasonable set of coefficients from a similar model developed elsewhere[9].

The second step involves the actual execution of the trip distribution model utilizing the gravity model algorithm referenced earlier. In the initial calibration effort, the K-Factors are all set to 1.0 After each iteration of model application, revised attraction values are calculated in order to properly balance the estimated trip attractions with the desired input values. Typically, this attraction balancing process is conducted three times, after which the desired and estimated attractions should be in relatively close agreement. The fourth, and final step in the calibration process is to compare the observed and estimated trip length (i.e., impedance measure) frequency distributions and estimate a revised set of F-Factor values until an acceptable level of agreement is achieved.

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[9] To the extent that the initial values are well chosen, the number of calibration iterations will be minimized.

4.4.6 - F-Factor Estimation Process

In general, it has been observed that there are a relatively small number of mathematical functions which adequately approximate a typical accessibility factor curve as can be developed using conventional curve fitting methods. Among these are the gamma function, the bessel function, and a third-order exponential function. The primary difference in these functions is the general steepness of the slope of the curve. The gamma function best approximates the characteristics of the desired F-Factor relationship. The general formulation of the gamma function is:

$$F_i = A * I^B * e^{G*I}$$

where:

F_i	=	is the accessibility factor for impedance value I
A,B,G	=	are the gamma function coefficients
I	=	is the impedance value (LogSum)
e	=	the exponential function

Normally, both the B and G coefficients will be negative, while the G coefficient may initially be positive. Examples of gamma function coefficients for individual trip purposes are as follows:

F Factor Curves - Gamma Function Coefficient Values			
Trip Purpose	Alpha (A)[10]	Beta (B)	Gamma (G)
Home-Based Work	13.89772	-0.949458	-0.0547358
Home-Based Shop	13.97188	-2.214257	-0.0150434
Home-Based Other	13.90257	-1.712110	-0.0594423
Home-Based University	13.87314	-2.973638	-0.0390154
Home-Based School	1.71056	+8.706363	-0.7878427
Non-Home Based	13.91389	-1.898889	-0.0506704

A graphical representation of these curves[11] are displayed in Figure 4-3.

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[10] These values are expressed as the natural logarithm of the estimated value.

[11] F-Factors do not possess a unit of measure, in fact, they have no meaning. Their use is in relation to each other. As a result, F-Factors can be scaled by any value and retain the same mathematical meaning in the model.

EXAMPLE FRICTION FACTOR CURVES
FIGURE 4-3
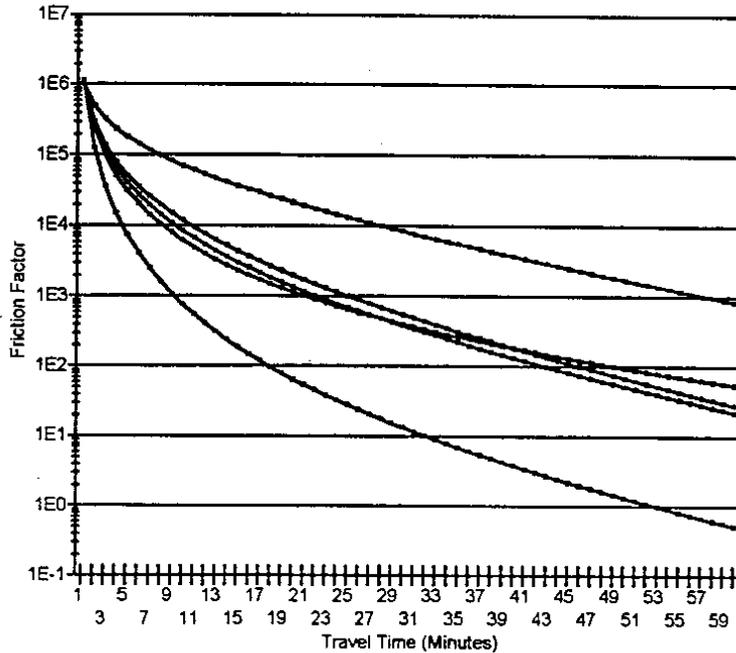
4.4.7 - Evaluation Of Results

The key criterion for calibration of the trip distribution model is the ability to match the mean and general shape of the impedance-based trip frequency distribution curve. A basic additional test is to examine time and distance based frequency distributions at the same time to insure that the model is not systematically biased with respect to either measure. An example of some of the statistical comparisons derived from this analysis would look like the following:

| Comparison of Estimated and Observed Trip Length Distributions								
	Mean Trip Length			Standard Deviation of Trip Length				
TRIP PURPOSE	Survey (min)	Model (min)	Model/ Survey	Survey (min)	Model (min)	Model- Survey	Coincidence Ratio	District r^2 Value
Home-Based Work	19.863	19.881	1.0009	11.090	11.680	0.590	0.874	0.916
Home-Based Shop	10.642	10.670	1.0026	6.825	6.648	0.177	0.895	0.967
Home-Based Other	13.359	13.480	1.0090	8.874	8.729	0.145	0.869	0.962
Non-Home Based	13.800	13.829	1.0021	9.319	9.144	0.175	0.859	0.980

A comparison of the observed and estimated trip matrices at a district level is essential to review the possible need for K-Factors. Any set of district-to-district movements which are estimated poorly, should be investigated to ascertain if there is a logical or systematic reason for the difference. Physical barriers are traditional causes of such relatively large differences. In other instances, socio-economic relationships (i.e., income) may be associated with a particular travel movement. In this latter case, linear regression, cross-classification, or fitted curves can be used to determine appropriate K-Factor relationships to correct for the estimated error in the distribution. The logit form of the model would obviate the need for K-Factors by providing the opportunity to include additional explanatory variables directly in the utility expression. In the event, K-Factors are used, the F-Factor coefficients must be re-estimated and the set of evaluation criteria re-examined until the model satisfactorily meets the criteria.

4.5 - Mode Choice

Mode Choice models are mathematical expressions which are used to estimate the modal shares of the travel market given the time and cost characteristics of the various competing modes and the demographic and socio-economic characteristics of the urban residents. Mode choice models are designed to be an integral link in the travel demand chain, with direct feedback mechanisms to a number of related model components -- auto ownership, trip generation, trip distribution, and (modal) trip assignment.

The mode choice model structure recommended for Oregon MPO's is a *nested logit model*, as opposed to a hierarchical or multinomial model (see Figure 4-4). The classical multinomial logit model, which still represents "acceptable" practice, is the prevalent model form currently found in a vast majority of regional modeling sets throughout the country. The multinomial logit model, however, assumes equally competing alternatives (among all modal alternatives considered), which in turn, results in the "shifting" of trips to and from all competing modes in proportion to the initial estimates of these modes. A common problem typically associated with the multinomial structure is the potential for violation of the Independence of Irrelevant Alternatives (IIA) axiom. Violation of this key model property has been best illustrated in the Shirley Highway Corridor (a major commute corridor between suburban Virginia and downtown Washington D.C.) which has a significant number of 4+ occupancy and public transit users. These travelers receive substantial preferential treatment, as compared with the general traffic lanes, with corresponding measurable savings in travel time. Travel survey data in the corridor clearly demonstrated that travelers using one of the shared ride modes (2-person or 3-person autos) were *much more likely* to switch to the carpool lane level (4+), than those driving alone or using public transit. The mathematics of the multinomial model, however, dictates that each mode contribute to the new mode increase in direct proportion to their existing shares prior to the implementation of (4+) carpool improvements.

The hierarchical logit model is a variation of the multinomial that allows for a subsequent splitting or allocation of trips to a set of submodes. In most structures of this type, a LogSum variable (or the denominator of the lower level choice, described in more detail later in this section) is used in the upper level choice (with an implicit LogSum coefficient of 1.0) together with other (generally socio-economic) explanatory variables. In this manner, the lower level submodes are reflected in the upper level choice, but as if they were independent equally competing modes with the other primary mode(s).
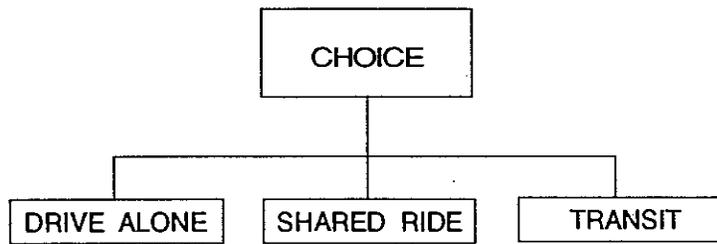
Simple Multimodal Logit Model
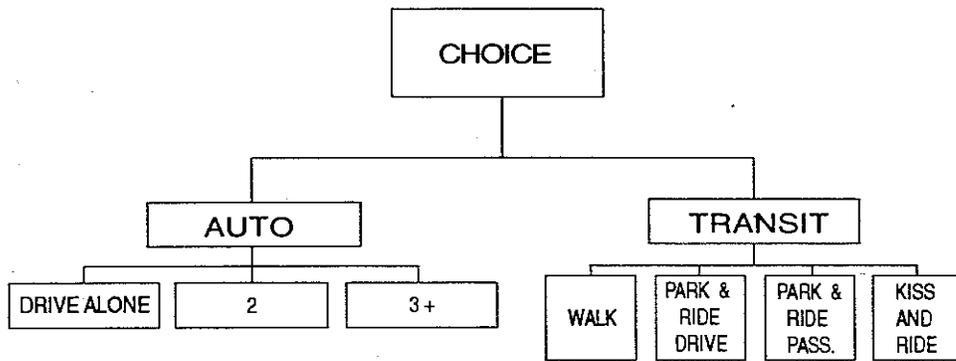
Heirarchical Logit Model
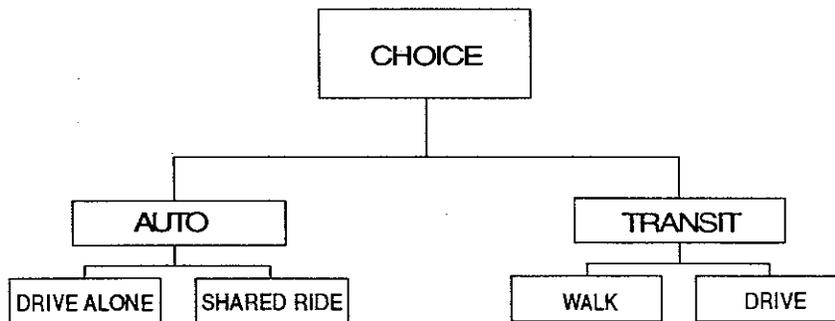
Nested Logit Model

Figure 4-4 - ALTERNATIVE LOGIT MODEL FORMULATIONS

A <u>nested logit</u> model recognizes the potential for something other than equal competition among modes. This structure assumes that modes, submodes, and access modes are distinctly different types of alternatives that present distinct choices to travelers. Its most important departure from the multinomial structure is that the lower level choices are more *elastic* than they would be in the multinomial or hierarchical structures. Thus an improvement in walk access to transit (refer to Figure 4-4) would alter the existing diversions between walk and drive to transit the most. This same improvement in walk access would also shift travelers from auto to transit, but with elasticities that are equal to the elasticities found in multinomial logit models; therefore the elasticities for access choice are higher. This increased sensitivity is reasonable if the modes included in a single level of the nest are logically related. It seems intuitive that a person who had already decided to use transit would be more sensitive, with respect to accessing the transit system, to a change in transit travel time or cost, than would be a person who was deciding between transit and auto.

4.5.1- Mathematical Formulation

The standard logit formulation is:

$$P_i = \frac{e^{U_i}}{\sum_m e^{U_m}}$$

where: P_i = the probability of using mode i
U_i = the utility of mode i
e = the natural logarithm

The utility expression for each available mode (i) is specified as a linear function which incorporates a range of variable types, including time, cost, locational measures, and the socio-economic characteristics of the traveler; for example:

$$U_i = \beta_1 * Time_i + \beta_2 * Cost_i + \beta_3 * Location_{Var} + \beta_4 * SE + \beta_0$$

The travel time variables are typically disaggregated into in-vehicle and out-of-vehicle time at a minimum, with out-of-vehicle time stratified by walk time, initial wait, and transfer wait time (the later two categories applicable to the transit mode(s)). Similarly, travel cost is often disaggregated into the more general out-of-pocket costs (i.e., automobile operating costs and transit fare) and destination parking cost. Locational variables in utility expressions are used to reflect a set of unique geographically based characteristics (i.e., Central Business District) or, alternatively, may be represented in the form of land use variables such as employment and/or population density. A wide variety of variables are possible in the Socio-Economic category (SE) including variables that measure the relative wealth of the trip maker (income or auto ownership) or reflect other household characteristics (i.e., workers per household, licensed drivers per household, etc.). And finally, a mode specific constant reflects the

unexplained behavior. The individual coefficients associated with each variable reflect the relative importance of each attribute.

The nested model structure (as shown in Figure 4-4) employs three multinomial logit models, one for the primary choice of mode among auto and transit, a second level choice among auto submodes (drive-alone and shared-ride) and another second level choice among transit access modes (walk and drive access). In application, the model independently addresses auto submode and transit access choice first. This is expressed as:

$$P_{DA} = \frac{e^{U_{DA}}}{e^{U_{DA}} + e^{U_{SR}}} \text{ and,}$$

$$P_w = \frac{e^{U_w}}{e^{U_w} + e^{U_D}}$$

A composite of the utilities of the auto submode and transit access choices then represent auto and transit respectively in the upper tier of the model structure. This composite measure is the natural logarithm of the denominator of the logit model, often termed the "LogSum". The LogSum term is effectively the total utility provided by the submodes of a particular primary mode. A LogSum is calculated for each of the second level nests as:

$$LogSum_A = -\ln[\ e^{U_{DA}} + e^{U_{SR}}\ ]$$
and,

$$LogSum_T = -\ln[\ e^{U_w} + e^{U_D}\ ]$$

The LogSum terms for the auto submodes and transit access choice then appear in the utility expression for the primary mode level as:

$$P_T = \frac{e^{\beta_T * LogSum_T}}{e^{\beta_T * LogSum_T} + e^{\beta_A * LogSum_A}}$$

The value of the LogSum coefficients in the upper tier of the model (i.e., auto versus transit), is an indicator of the degree to which the lower level choices form a subchoice that is distinct from the primary mode alternatives. A value of 1.0 indicates that the lower level modes are not a subchoice but rather are full options equally competitive with the primary modes. In this instance, these lower level choices can be simplified or included directly in the upper level. A value of 0.0 would indicate that the lower level choices are perfect substitutes for each other. Values between 0.0 and 1.0 indicate the extent to which the lower level choices represent a subchoice.

The nested structure also enables the exploration of a large number of possible nests. Figure 4-5 presents three such *examples*. The first example is one (of a large number) of alternatives proposed for Los Angeles. The second example is based upon on-going mode choice model development efforts in the Chicago Metropolitan region. The third, and final example, is representative of the most prevalent structure embodied in recent nested model estimations.

These three examples of possible nested structures (see Figure 4-5) do not reflect an explicit consideration of *walk or bicycle trips* (i.e., non-motorized travel). The trip generation section discussed the inclusion of walk trips in the trip generation model formulation. Treatment of the walk (only) and bicycle travel in mode choice could take the form of either a post-distribution model separation or as an additional primary mode in any of the nested structures.

4.5.2 - Market Segmentation Considerations

Traditionally, a larger number of trip purposes are maintained in the trip generation and trip distribution models then in mode choice. Common practice has been to compress the subset of non-work purposes into a single purpose, resulting in three basic purposes for mode choice modeling -- Home-Based Work, Home-Based Non-Work, and Non-Home Based. This simplification stems from the notion that household and individual travel behavior properties, as translated into elasticities, are relatively similar when considering the choice of mode. However, serious consideration should be given to separating Home-Based School trips from Home-Based Non-Work, and possibly separating Non-Home Based into Non-Home Based Work-Related and Non-Home Based Other. And finally, the formulation and structure of the 1994 Activity and Travel Survey instrument provides an opportunity to separate and distinguish, in the Home-Based Work trip purpose, between (1) Direct to Work , (2) Strategic Work, and (3) Tactical Work trips (for additional discussion of trip purpose definition refer to the earlier section in this chapter).

The Home-Based Work purpose has typically been associated with peak levels of service and cost, while the Home-Based Non-Work and Non-Home Based purposes have been associated with off-peak or a base period level-of-service. This simplification has become increasingly less appropriate as the effects of congestion have lead to an increased spreading of the peak period and a corresponding re-distribution of trip purpose contributions. Changes in labor force participation rates have also fundamentally impacted household travel decisions and resulting trip-making patterns. Recognition of these phenomenon suggest that each trip purpose considered in mode choice (in addition to Trip Distribution) be stratified by time period (i.e., peak and off-peak).
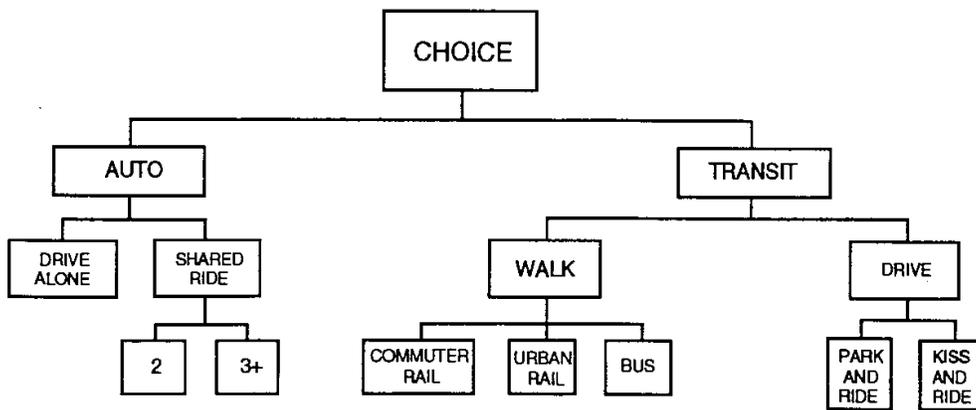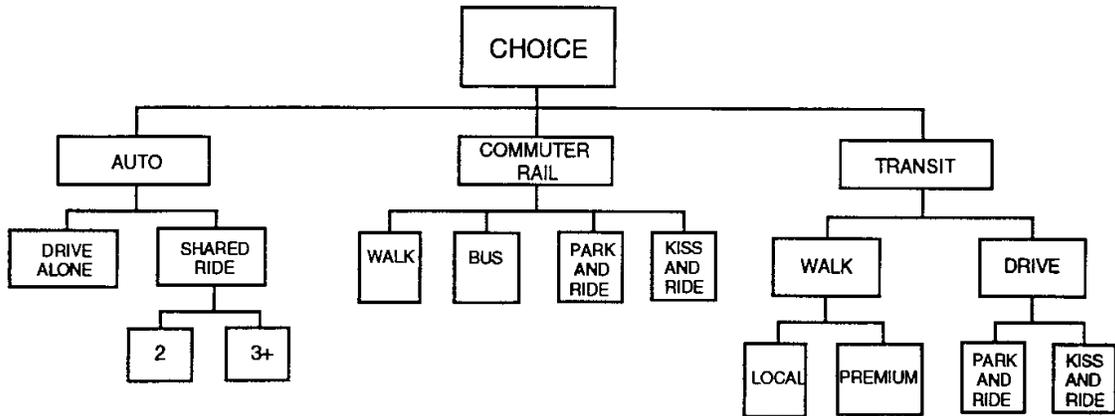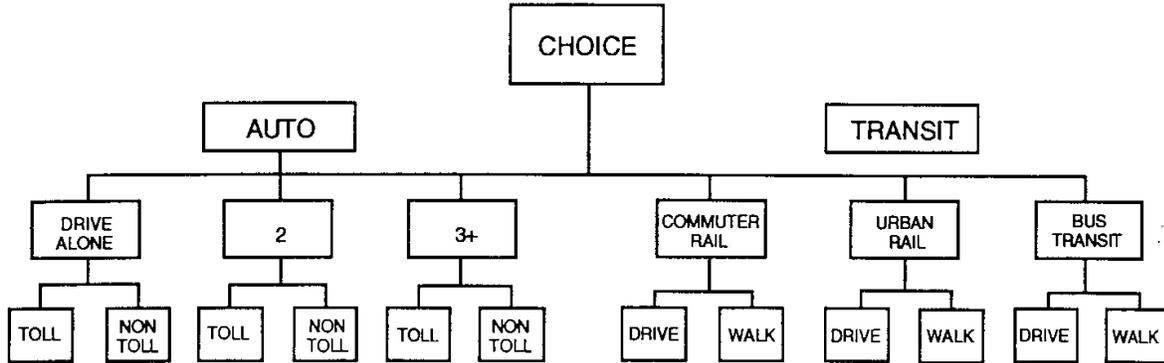
Figure 4-5 - CHOICE STRUCTURE EXAMPLES

This stratification would allow the estimation of each purpose specific (not time period specific) model to utilize the appropriate level-of-service characteristics for the time period in which the sampled trip actually occurred.

A final element with regard to market segmentation is the stratification of alternative specific constants (i.e., bias coefficients) by an indicator of wealth or socio-economic status. Historically, either auto ownership or income has been used for this purpose. Auto Ownership is generally represented by classifying households into 0-car, 1-car, and 2+ car households, while income stratification takes the form of a relative set of income groups (i.e., tertiles, quartiles, etc.). Auto ownership tends to be a stronger indicator in mode choice, but requires construction of an auto ownership model in order to estimate future conditions. Most regional agencies attempt to estimate income changes over time, but deliberately (and understandably) avoid projections of changes in auto ownership. In light of the emerging requirements of the Clean Air Act Amendments of 1990 (see Chapter II), use of auto ownership with the corresponding requirement to construct network sensitive auto ownership models is recommended.

A variation for inclusion of auto ownership from that of a simple market segmentation technique, is to separate (or segment) car-owning households from non-car owning households (i.e., 0-car versus 1+ car households), and utilize an auto ownership variable (i.e., autos per household, autos per worker) in the utility expression at the appropriate levels of the nest.

4.5.3 - Estimation Strategy

There are a number of alternative options for developing the mode choice model coefficient estimates (for each of the modal utility expressions) for an MPO within the state. The four basic alternatives are:

- Completely estimate the model using disaggregate data and statistical programs such as ALOGIT, LIMDEP, TROMP, or ULOGIT.

- Augment or enrich the Home-Interview Survey data with data and information from other travel surveys within the region, most notably a Transit On-Board Rider Survey.

- Estimate the model using information from other regions to specify the system coefficients for specific individual levels of the nest and then use statistical estimation techniques to estimate the remaining levels.

- Create the model using information from other regions to specify the system coefficients for all levels of the nest.

The first option may not be entirely possible, as all desired modes in the nested model may not currently exist within the region (i.e., rapid transit, 2 or 3+ carpool facilities or incentives), or given the relatively limited amount of mode usage (for any particular mode), it may not be possible to adequately represent one or more choices. And finally, although one or more modal options may currently exist (i.e., local and premium public transit), there may not be a sufficient number of cases (observations) where multiple choices exist (i.e., when a trip maker can *choose* between local and premium service).

The second option is a realistic strategy for most regions within the country where public transit and/or ride-sharing capture relatively small market shares. The 1994 Revealed Preference Household Activity

and Travel Behavior Surveys ongoing in each of the four MPO's has been designed specifically to capture these important travel markets in the design of the sampling framework. If successful, the potential need to employ this strategy would be obviated.

To the extent necessary (and as a result of the model estimation process), lower levels of the nest can be *synthesized* using experience from other regions throughout the state or country. Given the availability of Home-Interview Survey data for each of the four MPO's, resorting entirely to the last option will be unnecessary.

The last option, however, represents a very viable option for regions which have not been designated an MPO, but which require the use of a mode choice model.

4.5.4 - Model Calibration and Validation Tests

Following estimation of the models, a key element of the overall mode choice model development process is to insure that the resulting models are able to accurately simulate travel behavior character-istics and patterns within the region.

It is essential that the mode choice model set be able to estimated observed modal trips within a reasonable degree of accuracy. Following successful estimation of coefficients for each mode choice model (i.e., trip purpose), the models must be applied at the aggregate (zone) level and the mode specific constants adjusted to match observed control values. Applying the models at the aggregate level utilizes the full set of network based travel times and costs, zonal level socio-economic and other related data (i.e., parking costs) and the person trip tables resulting from the trip distribution models. In this manner, the models are applied as they would be in forecasting future year trips.

Essentially in the calibration and validation phase, the following type of comparisons should be developed and analyzed:

- The accuracy of the models with respect to total trips, stratified by the pertinent socio-economic strata, submodes. and major geographical areas.

- The accuracy of the models with respect to the transportation system characteristics.

- The accuracy of the models with respect to the assignment of trips to the network, particularly the transit trips as the auto vehicular assignment validation is of itself a considerably more extensive analysis which is the subject of the section on Trip Assignment/Time Of Day Choice Models.

The models should forecast modal trips accurately when these trips are aggregated by the pertinent socio-economic strata, such as income or auto ownership. The individual submodes or access modes are also important, as is the correct modal shares by major geographical district. The comparison of results with respect to the transportation system characteristics can be performed by plotting the distribution of observed and estimated trips by each key characteristic. And finally, an assignment of trips to the network may reveal other systematic problems with the model.

4.5.5 - Sensitivity Examinations

The final step in the development of the regional mode choice models is the performance of a series of sensitivity tests and a comparative review of the model coefficients with experience elsewhere.

Sensitivity tests lend confidence in the use of the estimated, calibrated, and validated models. Nested logit mode choice models are fairly complex mathematical structures, and it is not easy to ascertain the significance of any individual variable and its relative effect upon travel patterns. The basic methodology for the sensitivity tests are as follows:

- Utilize the base year data as the primary data for the examination of sensitivity.
- Evaluate only one independent variable at a time.
- Perform the tests at the aggregate level rather than the disaggregate level.
- Plot the results as a function of the existing probability to gauge the range of sensitivities on a regionwide scale and evaluate the impacts on a geographic basis (i.e., CBD versus non-CBD).

Evaluating only one variable at a time, provides sensitivity tests which are better able to determine the shape of the curve relating change in the modal share to change in an independent variable (i.e., elasticity).

4.5.6 - Comparative Review

An extremely valuable final exercise in the process is to compare the independent variable coefficient values and relationships with experience nationwide. This tabular review can also provide supporting evidence and confidence when lower levels of the nest must be synthetically developed.

There is a substantial number of Home-Based Work Logit Models for other urban areas. Most of these models are multinomial logit models, but there is increasing experience with the nested logit form. Table 4-1 summarizes a series of Home-Based Work models for a number of urban areas with the calibration year (i.e., survey year) ranging from 1960 to 1984. There are considerably fewer Home-Based Non-Work and Non-Home Based models. Tables 4-2 and 4-3 present the coefficients for a number of cities for these purposes.

Table 4-1
Review Of Mode Choice Coefficients For The Home-Based Work Purpose

Coefficients on Service-Level Variables from a Sample of Home-Based Work Mode Choice Models

		Travel Time Coefficients								Travel Cost Coefficients		
City/Region	Survey Year	In Vehicle	Drive Access	Out-Of Vehicle	Auto Terminal	Transit Walk	Transit 1st Wait	Transit Txfr Wait	General	Auto Operating	Transit Fare	Parking Cost
New Orleans	1960	-0.015	-0.100		(M)	-0.033	-0.077	-0.032	-0.0080			
Minneapolis	1970	-0.031			(M)	-0.044	-0.030	-0.044	-0.0140			
Chicago	1970	-0.028			-0.030	-0.114	-0.023	-0.114	-0.0121			
Los Angeles	1975	-0.020		-0.112					-0.0144			
Seattle	1977	-0.040	-0.286		(M)	-0.044	-0.030	-0.044	-0.0140			
Cincinnati	1978	-0.019		-0.028					-0.0045			
Washington	1980	-0.017		-0.058						-0.004	-0.004	-0.009
San Francisco	1980	-0.025		-0.058					-0.0039			
Dallas	1984	-0.030	-0.055		-0.055	-0.059	-0.055	-0.059		-0.005	-0.005	-0.012
Shirley (Low)	1984	-0.022		-0.035					-0.0037			
Shirley (High)	1984	-0.034		-0.044					-0.0046			

Relative Importance Of Travel Time Coefficients

City/Region	Survey Year	C(ovt) / C(ivt)	C(walk) / C(ivt)	C(wait) / C(ivt)	C(xfer) / C(ivt)
New Orleans	1960		2.200	5.133	2.133
Minneapolis	1970		1.419	0.968	1.419
Chicago	1970		4.127	0.844	4.127
Los Angeles	1975	5.600			
Seattle	1977		1.100	0.750	1.100
Cincinnati	1978	1.456			
Washington	1980	3.381			
San Francisco	1980	2.300			
Dallas	1984		1.862	1.851	1.993
Shirley (Low)	1984	1.018			
Shirley (High)	1984	2.000			

Value Of Time with the CPI Adjusted to 1979

City/Region	Survey Year	CPI Index	C(ivt) / C(cost)	C(ivt) / C(oper)	C(ivt) / C(fare)	C(ivt) / C(park)
New Orleans	1960	29.6	2.76			
Minneapolis	1970	38.8	2.48			
Chicago	1970	38.8	2.56			
Los Angeles	1975	53.8	1.12			
Seattle	1977	59.5	2.09			
Cincinnati	1978	65.2	2.84			
Washington	1980	82.4		2.61	2.08	0.97
San Francisco	1980	82.4	3.47			
Dallas	1984	103.9		2.68	2.68	1.07
Shirley (Low)	1984	103.9	2.29			
Shirley (High)	1984	103.9	3.74			

Values Of Time As Percent Of Median Income

City/Region	Survey Year	1979 Median Income	C(ivt) / C(cost)	C(ivt) / C(oper)	C(ivt) / C(fare)	C(ivt) / C(park)
New Orleans	1960	$18,933	30.31			
Minneapolis	1970	$24,897	20.77			
Chicago	1970	$24,301	21.92			
Los Angeles	1975	$22,041	10.60			
Seattle	1977	$21,000	20.31			
Cincinnati	1978	$21,552	27.43			
Washington	1980	$27,885		19.49	15.50	7.26
San Francisco	1980	$24,599	29.36			
Dallas	1984	$22,033		25.25	25.25	10.11
Shirley (Low)	1984	$27,885	16.75			
Shirley (High)	1984	$27,885	27.36			

Table 4-2
Review Of Mode Choice Coefficients For The Home-Based Non-Work Purpose

Coefficients on Service-Level Variables from a Sample of Home-Based Work Mode Choice Model

City/Region	Survey Year	Travel Time Coefficients					
		In Vehicle	Drive Access	Out-Of Vehicle	Auto Terminal	Transit Walk	Transit 1st Wait
New Orleans	1960	-0.0066		-0.0165	-0.3400		
Minneapolis	1970	-0.0080		-0.0200			
Seattle	1977	-0.0080	-0.2000	-0.0200			
St. Louis		-0.0238		-0.0595			
Honolulu						-0.1010	-0.0410
San Juan		-0.0050				-0.0600	-0.0610

Relative Importance Of Travel Time Coefficients

City/Region	Survey Year	C(ovt) C(ivt)	C(walk) C(ivt)	C(wait) C(ivt)	C(xfer) C(ivt)	C(ivt-work) C(ivt-nwk)	Minutes/ Transfer
New Orleans	1960	2.5				2.27	
Minneapolis	1970	2.5				3.88	40.8
Seattle	1977	2.5				5.00	6.8
St. Louis		2.5				0.96	
Honolulu							
San Juan			12.0	12.1	12.1	2.60	

Value Of Time using the Original Coefficients

City/Region	Survey Year	CPI Index	C(ivt) C(cost)	C(ivt) C(oper)	C(ivt) C(fare)	C(ivt) C(park)	C(work) C(nwk)
New Orleans	1960			0.33	0.33	0.12	0.67/0.25
Minneapolis	1970		0.40				1.17
Seattle	1977		0.14				0.40
St. Louis			0.79				0.46
Honolulu							
San Juan			0.60				0.48

Table 4-3
Review Of Mode Choice Coefficients For The Non-Home Based Purpose

Coefficients on Service-Level Variables from a Sample of Home-Based Work Mode Choice Model

City/Region	Survey Year	Travel Time Coefficients					
		In Vehicle	Drive Access	Out-Of Vehicle	Auto Terminal	Transit Walk	Transit 1st Wait
New Orleans	1960	-0.0131		-0.0328	-0.2420		
Minneapolis	1970	-0.0100		-0.0250			
Seattle	1977	-0.0200	-0.1980	-0.0250			
St. Louis		-0.0230		-0.0575			
Honolulu						-0.1260	-0.0400
San Juan		-0.0100				-0.1190	-0.0260

Relative Importance Of Travel Time Coefficients

City/Region	Survey Year	C(ovt) / C(ivt)	C(walk) / C(ivt)	C(wait) / C(ivt)	C(xfer) / C(ivt)	C(ivt-work) / C(ivt-nwk)	Minutes/ Transfer
New Orleans	1960	2.5				1.14	2.29
Minneapolis	1970	2.5				3.10	
Seattle	1977	2.5				1.40	
St. Louis		2.5				0.99	
Honolulu							
San Juan			11.9	2.6	2.6	1.30	

Value Of Time using the Original Coefficients

City/Region	Survey Year	CPI Index	C(ivt) / C(cost)	C(ivt) / C(oper)	C(ivt) / C(fare)	C(ivt) / C(park)	C(work) / C(nwk)
New Orleans	1960			15.72	15.72	0.27	1.6/0.275
Minneapolis	1970		1.50				3.50
Seattle	1977		0.39				0.45
St. Louis			1.25				0.76
Honolulu							
San Juan							2.00

4.6 - Commercial Vehicles

In general practice, truck travel is usually combined with private automobile vehicle trip estimates and converted to automobile equivalencies on an individual link basis, or the non-home based trip purpose is used as a surrogate for estimating truck travel trip matrices. These methods typically increase link level vehicular volumes by anywhere from 5 to 15 percent. The percentage of trucks assumed on a link is classically a function of facility type and area type. This practice does not accurately reflect the actual origins and destinations of trucks nor the wider range of variation of resultant volumes on individual roadways. This forecasting scheme also tends to ignore facilities where trucks are prohibited by ordinance. The truck travel forecasting process should consist of four components: trip generation, trip distribution, peak-hour factoring, and trip assignment. The basic highway networks are used as the truck network as long as the links where trucks are prohibited are removed or identified (use of the multi-class assignment technique in emme/2 facilitates this identification). Truck trips can be stratified in a variety of different manners, but it has been found that three primary categories are the most descriptive -- two-axle, three-axle, and four-or-more axle vehicles. These truck types are more descriptive of commercial vehicle trip making characteristics, then truck weight for example. Four general trip purposes can be defined -- internal-internal trips, external-external trips, external-internal trips, and internal-external trips. In this context "external" refers to an origin or destination outside the region.

To date, relatively little information has been collected throughout the country as compared with the amount of information available for personal travel. Several areas throughout the country have collected information via surveys and detailed vehicle counts. Where possible local data should be drawn upon to develop estimates of truck traffic flows to create a truck (or commercial) vehicle model, although this can be a substantially added cost.

4.6.1 - Trip Generation

The first model in the travel demand forecasting chain for commercial vehicle travel is the trip generation model.   This model relates the origins and destinations of trips to land use and socioeconomic characteristics of the region.   Employment is a strong variable when estimating truck trip production/attraction equations. Stratification of employment into several employment categories such as manufacturing, business services, and other employment will add definition to the trip generation relationships.

There are two primary surveys that can be used to develop trip generation equation rates. An employer survey and/or a roadside intercept survey. The employer survey provides information that can be directly used to develop the trip generation rates for internal-internal and internal-external trips. The intercept survey, which is typically performed near external stations in a region, supplements the employer survey to provide information for internal-external and external-external trips.

Data from an employer survey can be used to represent all truck trips garaged in a region and can be used to create an internal-internal travel model. Consequently, any trip recorded in an employer survey with an external origin or destination can be accounted for in an intercept survey data and would not be included in the internal-internal model.
Variables in the trip generation equations should be developed initially based on the disaggregate regional survey data. Based on validation comparisons at the link level, adjustments in the mode form or coefficient values may need to be made. Some regions have adjusted the final trip generation equations by calculating

ratios of estimated-to-observed link volumes and adjusting the equations accordingly in an iterative process, although at a very aggregate level such as the total magnitude of travel.

Surveyed trips with origins and/or destinations outside a region can be obtained from the intercept surveys conducted at locations on regional freeways and other major facilities near external stations. Internal-external trips are then estimated by regressing the expanded survey trips against regional socioeconomic data.

External-external trips passing through a region are estimated from survey data collected at selected intercept stations. Local truck counts on selected roadway links are used in expanding the trips to match region totals.

Some business operations generate enough truck traffic that they should be considered as special generators. Where possible, counts on roadways outside the special generators should be taken so trip generation rates can be estimated and calibrated. Examples of a special generator might be a port or concentrated commercial freight site.

4.6.2 - Trip Distribution

Trip distribution comprises the second submodel in the commercial vehicle travel demand forecasting process. The gravity model trip distribution technique is considered "best practice" in this specialized trip purpose. The trip-length distribution obtained directly from the survey data should be used to calibrate friction factors for each trip purpose. Rather than composite impedance, highway travel time would represent the most logical measure of impedance for this trip segment.

4.6.3 - Peak-Hour Factors

The discussion of the model has, to this point, focused on estimating 24-hour truck volumes on streets and highways in the study area. However, the basis for alternative analyses and highway design projects is usually the peak-hour forecast for a roadway link. The following paragraphs describe the third submodel of this travel demand forecasting model, peak-hour factoring. The 24-hour trip tables developed through trip generation and trip distribution are factored to develop time period specific trip tables.

Previous studies have found that the proportion of daily trips occurring during the typical morning and evening peak periods is significantly lower for trucks than automobiles. An iterative process should be followed to adjust the initial peak-hour factors. Peak-hour factors are initially developed for each trip purpose using a combination of the surveys and the classification counts, and the 24-hour trip tables factored accordingly. These trips are then assigned to the highway network (see section 4.6.4) and the estimated peak-hour trips are compared with the observed volumes. The factors are adjusted and the new trip table is iteratively assigned until the estimated vehicle miles traveled (VMT) is within five percent of the observed VMT[12].

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[12] Observed VMT is calculated by multiplying link distance by the observed travel volume for those links which contain a valid observed count.

4.6.4 - Network Refinements & Trip Assignment

The network to be used for a truck model should be a modified version of the street and highway network utilized in the highway models. Truck speed and capacity values are assigned to network links using lookup tables by area type (CBD, residential, rural, etc.) and facility type (freeway, arterial, collector, etc.). Furthermore, trucks over a certain weight may be prohibited on selected routes. The emme/2 mutli-class assignment capability provides for a separate modal designation for trucks, thereby easily identifying prohibited truck facilities. Trip tables created for two-axle, three-axle, and four or more axle truck trips are then assigned to the street and highway network as the fourth step in the travel demand forecasting process.

4.6.5 - Model Validation

The final step in the commercial vehicle travel demand forecasting is assignment validation, which involves a statistical comparison of observed and estimated truck traffic volumes. This comparison is an evaluation of the complete truck model system's ability to simulate actual travel. From the trip assignments, the estimated VMT and percent root mean square error (RMSE) can be calculated, and adjustments made to the model as necessary.

4.7 - External Travel

External travel[13] has been historically treated in a very analogous fashion as commercial vehicle travel. A base year trip table is created from actual survey data and simply growth factored to the future or a basic three-step model (trip generation, trip distribution, and modal choice) has been developed. In the case of external travel, either modeling approach is considered acceptable for forecasting purposes, however, the basic three-step approach would reflect best practice if data is available to develop and/or calibrate the model relationships. Fortunately, external travel is typical a very small portion of overall travel, but should not be ignored.

4.7.1- Trip Generation

A "best practice" set of trip production and trip attraction equations would differentiate between axle type (2, 3, and 4+) and type of facility (freeways, state highway, and local facilities). The trip production estimates are based upon growth-factored roadway counts, while trip attractions are a function of households and employment by type.

A example set of attraction equations are summarized below:

External Stations on Freeways

- 2-Axle Vehicles

$$A_j = 0.000662 * HH_j + 0.0760 * EMP_j^I + 0.127 * EMP_j^R$$

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[13] The discussion in this section focuses entirely upon external-internal travel. The treatment of external-external travel is not addressed in the guidelines. Given the typical lack of data with respect to external-external travel, each region is expected to employ the best available data and techniques in this regard. The availability of external survey data can contribute significantly in this regard.

- 3-Axle Vehicles

$$A_j = 0.000832 * HH_j + 0.00144 * EMP_j^I + 0.000842 * EMP_j^R$$

- 4+ Axle Vehicles

$$A_j = 0.0278 * EMP_j^I + 0.00658 * EMP_j^R$$

External Stations on State Highways

- 2-Axle Vehicles

$$A_j = 0.000295 * HH_j + 0.0203 * EMP_j^I + 0.0539 * EMP^R + 0.0251 * EMP_j^O$$

- 3-Axle Vehicles

$$A_j = 0.00065 * HH_j + 0.0008 * EMP_j^I$$

- 4+ Axle Vehicles

$$A_j = 0.00456 * EMP_j^I + 0.00218 * EMP_j^R$$

External Stations on Local Highways

- 2-Axle Vehicles

$$A_j = 0.0000898 * HH_j + 0.0185 * EMP_j^O$$

- 3-Axle Vehicles

$$A_j = 0.000534 * HH_j$$

- 4+ Axle Vehicles

$$A_j = 0.00162 * EMP_j^I$$

where: HH_j Number of Households
         EMP^I Industrial Employment in zone j
         EMP^R Retail Employment in zone j
         EMP^O Other Employment in zone j

4.7.2 - Trip Distribution and Trip Assignment

The trip distribution model employs the gravity model form and typically utilizes a uniform set of F-Factors to distribute productions and attractions. In trip assignment, external trips are combined with internal vehicle trips prior to model execution.

4.8 - Trip Assignment and Time-Of-Day Choice Models

The assignment of automobile trips in travel demand modelling has traditionally relied upon the use of a single, static trip table representing daily vehicle trips, or perhaps a factoring of daily trips representing a peak period or peak hour. This vehicle trip table is then assigned to the roadway network using a variety of techniques, most commonly, Equilibrium Capacity Restraint. With the growth of HOV (High Occupancy Vehicle) lanes and Toll facilities this methodology has been extended through the creation of separate LOV (Low Occupancy Vehicle), HOV, and/or Toll vehicle trip tables (still static demand for a specific time period) that were assigned iteratively (using equilibrium capacity restraint) onto the network. Due to the multiplicity of policies, HOV is sometimes split into HOV2 (two occupants) and HOV3+ (three or more occupants). This iterative assignment of modes allowed for the expression of network attributes unique to a single mode, e.g. less congestion for HOV vehicles on HOV links that are forbidden to LOV vehicles, while preserving the interaction of the separate modes on mixed-flow facilities. This technique greatly expanded the range of facilities and policies that could be explored, but suffered from a poor understanding of the importance of the order of assignment of modes, and of how to measure the degree of equilibrium. Recent advances in assignment methods have lead to simultaneous multi-class assignment. Using simultaneous assignment, each iteration assigns all of the various modes while still allowing for the expression of mode specific attributes on individual links.

Vehicle trip tables for assignment have been static representations of a fixed portion of the total daily demand. Daily trips are usually converted to peak hour (or peak period) trips using global factors (diurnal distribution factors) for each direction (e.g. home-to-work and work-to-home) and trip purpose. For every zone the same assumption is made as to the percentage of trips occurring in the peak. If daily trips are converted to peak period trips, then a global assumption is also made as to how the peak period assignment relates to the peak hour volumes.

Along with the development in assigning multiple modes, there have been advances in dynamically assigning demand. Rather than relying on a single set of peaking factors, the portion of the daily demand

occurring during the defined peak can be described as a function of peak versus off-peak service, trip purpose, distance, and value of time (amongst other variables), for each zonal interchange. An extended period (e.g. 5 hour A.M. period) trip table can then be used as input to assignment, and the peak period or peak hour volume can be dynamically determined and updated (uniquely for each zonal interchange) during assignment after each iteration. With the use of such a Variable Demand assignment, the competition for the limited peak hour capacity can be reflected, and the proportion of trips in the peak (e.g. morning trips occurring in the A.M. peak hour) can be calculated on a zone-by-zone basis based on the demand for the facilities and the characteristics of the tripmakers.

Transit assignment has evolved more slowly. This is due in part to the fact that transit route choice is virtually independent of rider demand, allowing for a less sophisticated analysis of route choice. Transit route choice has been typically assigned using the shortest path strategy. Using this strategy, the rider is assumed to take the shortest single set of available transit lines from his or her origin to destination.

Other transit strategies are beginning to find implementation in transit assignment. One such strategy is to assign trips to the transit network using a multi-path strategy. With the multi-path strategy, multiple paths are chosen in such a way that the decrease in wait time (due to the fact that more routes are being used) is greater than the increase in average travel time, yielding a total (weighted) travel impedance that is better than the shortest path strategy. This strategy (like the shortest path strategy) can be applied to any subset of modes. The volumes loaded to the paths chosen are typically based on a strategy such as I'll take the first bus among those in the (multiple) paths. This results in loadings that split amongst parallel (competing) lines based on their relative headway.

The multi-path strategy tends to avoid wild fluctuations in route choice due to small changes in transit service. With the shortest path strategy two or more paths may differ by only a small fraction of a minute, but all of the zone-to-zone demand is assigned to one path. If, for instance, the run time of a route changes by a fraction of a minute all of the riders may be assigned to an entirely different path. This is less of a problem with the multi-path strategy, where small fluctuations in travel time are less likely to effect the set of acceptable paths within the strategy.

4.8.1 - Highway Assignment

With the potential, largely in the future, for toll roads and an HOV network, and with the traversal of I-5 (as a regional and statewide carrier of goods) through the state, the assignment techniques used must be sensitive to a large number of unique modes. As a result of the nested logit mode choice model structure, up to seven unique modes may be present within the highway network. These are:

> LOV w/Toll
> HOV2 w/Toll
> HOV3+ w/Toll
> LOV w/o Toll
> HOV2 w/o Toll
> HOV3+ w/o Toll
> Truck

With seven possible modes, iterative assignment of modes would be nearly unworkable given its complexity and a simultaneous assignment is required. The foundation for a simultaneous assignment can be created by the definition of a specific attribute on the network links identifying the "class" of the link. Since the

HOV2, HOV3+, and Truck Prohibited links will have unique codes, the set of links that are allowed or prohibited can easily be defined for the simultaneous assignment procedure within EMME/2.

4.8.2 - Volume Delay Functions

Since the impedances for the transit modes and the computation of emission estimates are related to the highway link impedances, it is important to have realistic highway impedances (in absolute terms) in order to accurately model these phenomenon. It is for that reason that alternative function sets (i.e., BPR, conical, etc.) should be explored.

4.8.3 - Transit Assignment

Transit assignment should be performed as a set of cumulative assignments using the multipath route choice strategy. Each of the modes identified in mode choice should be assigned separately. Much as the highway assignment segregates trips from the links that some modes are prohibited from using, transit assignments use path parameters (weighting factors) for elements of the transit travel impedance to discourage paths from using selected modes, or prohibit modes from being used. For instance, when assigning local bus trips the weights for rail impedances and express bus impedances should be set to discourage usage of those modes. The segregation of walk access from auto access will be much simpler, since there are separate walk access and walk egress modes. When assigning walk access trips, only walk access and walk egress modes will be active. When assigning auto access trips, only the auto access and walk egress modes will be active. The path parameters should be developed during network testing and should rely on the results of the mode split model estimation for some values.

4.8.4 - Time Of Day Choice Model (Optional)

As the transportation system in Oregon regions becomes more and more saturated, a larger segment of the tripmaking population may be shifting the time of their trip, not to fit a work or shopping schedule, but to avoid peak period congestion. The effect of this peak spreading varies across the region depending on the performance of the transportation network, often at network "chokepoints". As a result, global diurnal distribution factors or global peaking factors can fail to describe travel behavior and the reaction of travellers to the deterioration of performance of specific portions of the transportation network.

A time of day choice model may be developed to determine which portion of the morning or evening trips may be made during the AM or PM peak hour. The morning and evening periods will be large (perhaps 5 hour) periods during which diurnal distribution factors should be stable. The time-of-day model could use a logit type model to determine, on an interchange basis, the probability that a period (morning or evening) trip will occur during the peak hour. The time-of-day model would be sensitive to such variables as trip purpose, trip distance, and travel time This would result in unique peaking factors for every zone to zone pair. These peaking factors are a measure of peak spreading for that zonal interchange. This model would ideally be implemented as a logit choice model as part of a Variable Demand assignment. Use of a Variable Demand assignment guarantees that the results of the time-of-day model are in accord with the congestion resulting from the assignment. Such an implementation would use a variable demand assignment to calculate/assign AM peak hour vehicles. A second variable demand assignment would be done to calculate/assign PM peak hour vehicles. The Off-Peak vehicle trips would be calculated and assigned using a static demand assignment.

4.9 - Model Validation Procedures and Standards

Model validation represents the final step in the model development process. Execution of the complete model system, as it will be applied in any future forecasting setting, provides assigned estimates of travel volumes on both the highway and transit networks. Comparisons are then made against observed volumes that, with the possible exception of transit route level volumes, are independently obtained from the basic (survey) data base.

At each step in the model development process, each model component is subjected to a series of disaggregate and aggregate validation tests following estimation of model parameters. Model validation, however, is strictly an aggregate set of comparisons, and represents the final test of the model's ability to accurately simulate existing travel.

4.9.1 - Auto Vehicle Assignment Validation

There are two basic types of comparisons made when comparing actual traffic counts to estimated auto vehicular volumes; screenline or cordon line validation, and link level validation.

Early in the network development process, a series of screenline locations will need to be established that serve a variety of purposes. Screenlines should be established at locations within the region where physical barriers may suggest the need for K-factors (in the trip distribution model), and other locations which attempt to measure major corridor or subregional flows. In the event that the comparison between observed and estimated screenline volumes are not within acceptable tolerance limits, an analysis of the source of the error may require adjustments to one or more of the upper level models (i.e., trip generation, etc.).

At the link level, two types of comparisons should be made. First is an evaluation of the estimated to observed Vehicle Miles of Travel (VMT) by each of the geographical locations established for analysis in the trip distribution model comparisons (i.e., area aggregations of traffic analysis zones).

The following Table is an example of these comparisons:

Ratio of Estimated/Observed Vehicle-Miles Traveled (All Districts)

Facility Type	Area Type					All
	1	2	3	4	5	
Freeway	0.824	1.202	1.111	0.935	0.785	1.045
Expressway	0.0	0.912	0.826	2.834	0.057	1.000
Collector	1.143	1.200	1.003	1.938	1.222	1.078
Six-leg Arterial	0.878	0.918	1.020	0.906	0.0	0.964
Arterial	1.063	1.019	0.914	1.042	1.119	0.993
Ramp	0.694	0.683	0.732	0.903	1.089	0.744
Total	1.039	1.076	0.949	1.031	1.018	1.004

A second type, is the calculation of percent root mean square error by facility type/area type and a range of volume categories. In the context of model validation, percent root mean square error is computed as follows:

$$\% RMSE = \frac{\sqrt{\frac{(V_o - V_E)^2}{N} * N}}{\frac{\sum_N V_o}{N}}$$

where: V_o Observed Volume for link n
V_E Estimated Volume for link n
N   Number of Observations or number of links

The following tables are examples displaying the results of this type of comparison:

Calculation of Percent Root Mean Square Error (All Districts)

Facility Type	Area Type					All
	1	2	3	4	5	
Freeway	25.803	30.468	16.803	16.247	25.233	25.470
Expressway	0.0	10.120	24.726	193.668	48.675	44.088
Collector	61.395	54.710	43.645	80.785	126.315	62.686
Six-leg Arterial	18.264	16.097	25.925	15.403	0.0	21.835
Arterials	29.203	27.658	30.046	45.740	82.555	38.474
Ramp	50.226	53.751	57.651	63.889	63.665	59.177
Total	34.080	35.476	30.663	45.340	75.531	40.599

Link Volume					% RMSE	

0 to 4999	115.757
5000 to 9999	43.141
10000 to 19999	28.272
20000 to 39999	25.383
40000 to 59999	30.252
60000 to 89999	19.199

4.9.2 - Aggregate Validation Targets

Aggregate validation targets for vehicle trips are measured primarily for the AM and PM peak hours. Twenty-four-hour volumes are computed from the peak and off-peak period volumes and are statistically fitted, and as a result, are of less value in determining model adequacy.

The total AM and PM peak-hour volumes crossing each cordon or screenline should be within 10 percent of the AM and PM peak-hour counts, respectively. On an individual link basis, the following tolerances should be applied:

- 75% of freeway link volumes within +/- 20%

- 50% of freeway link volumes within +/- 10%

- 75% of major arterial link volumes with 10,000 vehicles per day within +/- 30%

- 50% of major arterial link volumes with 10,000 vehicles per day within +/- 15%

4.9.3 - Transit Assignment Validation

A statistical analysis of 24-hour transit assignments on a route-by-route basis provides the basis for ascertaining the accuracy of the transit validation. Actual transit boardings for each route for an entire weekday can be obtained from on-board rider surveys or other available route level information. The observed and estimated boardings can be compared using regression.

5.0
MODEL DEVELOPMENT GUIDELINES FOR NON-MPO AREAS

5.1 - Introduction

The previous chapter presented a set of model development guidelines for Oregon MPO areas that comprise "best practice" travel demand forecasting model components and evaluation techniques. These guidelines were specified in consideration of Oregon State and federal transportation planning rules to enable travel demand models applied in Oregon to address essential issues related to air quality conformity analyses, transportation system plan development and various land use and transportation policies aimed at improving the quality of life in Oregon metropolitan areas. The goal of this chapter is to similarly specify a "best practice" set of travel demand forecasting model components suitable for areas of population less than 50,000 and therefore outside of the planning jurisdiction of any MPO; these areas shall hereafter be referred to as non-MPO areas.

The non-MPO areas, in general, are faced with similar responsibilities as the MPO areas with respect to the planning requirements in the statewide Transportation Planning Rule (TPR). Whereas the MPO areas certainly require a comprehensive travel demand forecasting capability specifically developed for their metropolitan area, the travel demand modeling techniques employed by non-MPO areas may in many cases be much less rigorous while maintaining an appropriate level of quality and reliability. This chapter will present the recommended features of travel demand model components for non-MPO planning applications.

The following section identifies the model development issues unique to non-MPO areas. Following that, model guidelines will be specified for non-MPO areas, first for areas classified as nonattainment, then for areas classified as attainment, for carbon monoxide and ozone. The approach taken is to compare the individual model components for non-MPO areas with those specified for MPO "best practice." This set of model components will constitute the "best practice" for non-MPO areas. The model components specified in this chapter may be considered as a subset and in some cases a relaxation of the specification for MPO areas. Therefore, the details of the underlying theory, modeling framework, and calibration and validation procedures for the individual model components found in Chapter 4 apply to the non-MPO specification as well.

## 5.2 - Travel Demand Modeling in Non-MPO Areas

In addition to the technical validity of travel forecasting techniques, the specification of "best practice" model components for small urban areas must be sensitive to the technical and financial resources of these areas. In areas of low population meeting National Ambient Air Quality Standards (NAAQS,) minimal, if any, model development requirements exist. In contrast, non-MPO areas in nonattainment of NAAQS

may be faced with travel demand modeling requirements approaching the complexity of those required of MPO areas. Note that for the purpose of these model guidelines, nonattainment refers to nonattainment of NAAQS for carbon monoxide (CO) and for ozone (O_3). Areas in Oregon in nonattainment of NAAQS for particulate matter only, such as LaGrande, Lakeview, and Oakridge, are faced with no explicit travel forecasting related conformity analysis requirements and therefore will be considered to be classified as attainment areas for the purpose of these guidelines.

Figure 5-1 is a diagram relevant for non-MPO areas depicting a typical relationship between model complexity, available information, and air quality status. This figure shows the expected level of effort involved in model development depending on their available data and air quality status. The diagram shows that for nonattainment areas, a high level of travel survey and traffic monitoring information is expected to be available and that a more rigorous set of model components utilizing disaggregate choice models may be possible. For those nonattainment areas with minimal existing data and limited resources for collecting data, models may have to be synthetically derived by transferring parameters, model coefficients, and model structures from models developed elsewhere in Oregon or in other areas of the country. For attainment areas, the diagram shows that minimal observed data and low efforts in model development are to be expected. For areas with no conformity analysis requirements, model development effort will be dictated by the types of policy issues of interest and the resources of the local area to perform data collection and model development.

Figure 5-1
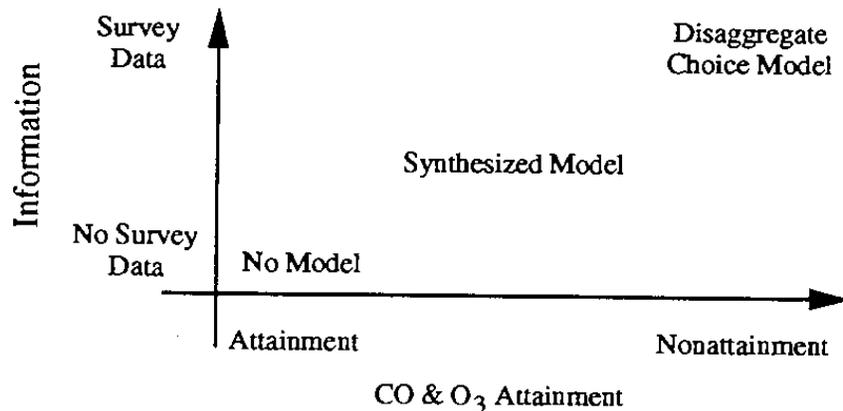
In the guidelines presented in the next two sections, a set of recommended model components will be specified. Whether a model is synthetically derived or calibrated on locally collected observed data will depend on the attainment status, the resources, and the policy questions being asked in the non-MPO area.

5.3 - Guidelines For Areas Classified As Non-Attainment

Areas classified as nonattainment are required to prepare transportation plans consistent with state implementation plans to achieve air quality standards. They must quantify their air quality problem and evaluate measures to reduce mobile source emissions as prescribed in the SIP. For these reasons, areas in Oregon classified as nonattainment must have a capability to reliably and defensibly forecast future traffic, regardless of their population. This section presents the "best practice" set of travel demand forecasting model components and model development guidelines relevant to nonattainment areas with population less than 50,000.

Of at least equal importance to air quality conformity analysis is the need for non-MPO areas in Oregon to comply with their TPR in preparing transportation system plans, evaluating potential regulations for land use policy implementation, and meeting goals to reduce vehicle miles traveled and automobile use. The travel demand model components described in this section are sensitive to these needs while recognizing that appropriate simplifications to the methodologies employed by MPO areas can be made for models used in non-MPO areas without compromising the reliability of their results.

The model components described in this section represent the "best practice" set of models to meet the air quality conformity analysis and local planning analysis needs of the non-MPO areas. In some cases, the guidelines may call for models which require more development effort than a non-MPO planning staff can reasonably be expected to expend. For example, the development of a disaggregate mode choice model addressing non-motorized, transit, and auto modes may be a considerable hardship for a non-MPO area, but "best practice" must include the model. In this case the guidelines will recognize the option for an area to synthesize part or all of the model as necessary given their local constraints on staff to develop models and collect data.

In so doing, the model guidelines will define a "best practice" model development framework which will consist, in some cases, of model components representing best effort of the local area under prevailing conditions. When the non-MPO is faced with a need to develop models estimated on local data due to a new specific focus, their new model components will replace their older synthesized model components within the modeling framework being specified. The non-MPO areas anticipating growth which will move them to within MPO planning jurisdiction in the future or facing new priorities in policy evaluation thus have a migration path for their model development.

5.3.1 - Trip Generation

The trip generation model is used to relate travel activity, measured in trips, to spatially referenced measures of land use and socioeconomic characteristics of the potential trip makers. The trip generation model, in current practice, is the link between travel intensity and land use, and is thus a necessary component of any travel forecasting effort. The trip generation model consists of two models to estimate total trips produced by a zone (trip production model) and total trips attracted by a zone (trip attraction model). In support of these models are various submodels for describing the disaggregation of the basic source of trip production, the household, or the basic source of work-related trip attraction, the worker, by selected independent variables. Details regarding the trip generation model components can be found in Section 4.2.

A number of differences exist between the trip generation model guidelines for MPO areas and the guide-lines for non-MPO areas. In general, market segmentation for non-MPO areas can adequately be accounted for with the following trip purpose definitions: (1) Home-Based Work; (2) Home-Based Other; and (3) Non-Home-Based. Additional stratification of Home-Based Other trips for school-related, recreational, or shopping purposes may be warranted based on the availability of attendance data and retail employment information. If reliable data exists, additional stratification in the trip generation model may result in a more behaviorally sensitive estimate of trip activity. Stratification of Home-Based Work trips by potential for intermediate stops or by socioeconomic variables is anticipated to require too much effort for little additional fidelity.

The recommended method for generating trip productions is the method of cross-classification of disaggregate travel decision making units, i.e. households, by independent socioeconomic variables as was recommended for MPO areas. The result of this model is a set of <u>person trip</u> rates for each combination of values of independent socioeconomic variables. In light of the current focus on multimodal transportation modeling and the emphasis on increasing mean vehicle occupancies for air quality conformity analysis and as a primary goal in the TPR, a person trip production model is recommended for these guidelines.

The recommended method for generating trip attractions is the method of district level regression analysis where a district is an aggregation of traffic analysis zones. The result of this model is a relationship (often linear) between independent socioeconomic variables and trips attracted to a district (see section 4.2.5). This relationship is then applied to traffic analysis zonal data resulting in person trips attracted to a zone.

The socioeconomic stratification submodels described in Section 4.2.6 are required for each of the independent socioeconomic variables in the cross-classification submodels. The model application approach recommended is also as described in Section 4.2.8. Note that the application strategy for non-MPO trip generation models will always be to balance productions and attractions on regional production totals unless Home-Based Other trips have been further stratified by school trip. In this case it is presumed that the decision to stratify is based on the availability of school enrollment or attendance data. In this case school-based trips should be balanced on the more reliable control total which would be regional trip attractions.

5.3.2 - Auto Ownership

For non-MPO areas in nonattainment status, transportation alternatives aimed at increasing the mean vehicle occupancy and the number of vehicle miles traveled are in need of analysis. A disaggregate mode choice model is therefore essential and an essential component of this type of mode choice model is an auto ownership model. The auto ownership model is therefore recommended as a component of the non-MPO model set. Section 4.3 describes the details of this model's formulation and estimation.

The information provided by an auto ownership model is critically important to the non-MPO travel demand model set when faced with air quality conformity analysis. For areas not capable of developing or estimating this model, a synthetic derivation approach may be feasible. A synthetically derived model uses the structure, i.e. specification of model variables, functional form, and model coefficients, of models developed with disaggregate data in other areas. The local values of socioeconomic variables and accessibility to different modes then determine the estimates of zonal auto ownership.

5.3.3 - Trip Distribution

Trip distribution is the method used to relate trip productions to trip attractions to determine the spatial interaction of trips calculated during trip generation. The result of the trip distribution procedure is a set of traffic analysis zone to zone trips linking the trip productions to trip attractions. The MPO guidelines call for use of the standard gravity model as the method for trip distribution. This model is likewise recommended for non-MPO areas. Section 4.4 provides a detailed presentation of the gravity model formulation, calibration and validation.

The gravity model is a spatial allocation model, allocating trips between zones based on the attractiveness of the attraction end of the zone and some measure of separation between zones. Market segmentation is therefore important as it is a way to improve the model's ability to link workers with work places and shoppers with shopping centers, for example. Market segmentation refers to allocating trip interchanges by using a separate trip distribution model for each trip purpose used in trip generation. The idea behind market segmentation is to use work related trip attractions as the measure of attractiveness and peak period network separation measures as the bases for allocating work related trip productions for each zone. A similar argument can be made for other trip purposes to use the appropriate attractiveness and separation measures.

Where MPO models may further segment work trip distribution by some socioeconomic measure, non-MPO areas may generally not be concerned with this additional level of effort. The segmentation of non-MPO trip distribution models by trip purpose is usually quite adequate. Similarly, the segmentation of individual trip purposes by time period (i.e., peak and base) is another area which would not be warranted in non-MPO areas given the general lack of congestion and its corresponding impact on trip timing.

The separation measure used is typically network travel times reflecting the time period for which the particular trip distribution model is intended to represent. That is, peak period times for work related trips and off-peak times for other trips. As outlined in Section 4.4.3, composite impedance is a separation measure that includes the cost of travel on each mode. Use of composite impedance in trip distribution results in an allocation model that is sensitive to modes other than automobile.

The composite impedance measure is readily available from a mode choice model. Use of this measure may be considered as an option if the mode choice model is of such a structure to warrant its use. In other words, a composite impedance measure is only warranted where transit and shared ride alternatives exist and the accessibility they allow may potentially impact travel patterns represented by zone to zone trips.

5.3.4 - Mode Choice

Mode choice models are used to allocate trips determined by trip distribution models between competing modes available to the trip maker to satisfy the zone to zone trip movement. Network sensitive mode choice models have become particularly important as air quality conformity analysis and multimodal transportation planning have risen in importance. It is not acceptable for a transportation analyst to view transit and shared automobile trips as insignificant due to low usage and therefore to ignore their impact or their potential impact on a transportation system.

For this reason, non-MPO areas classified as nonattainment areas should include a network sensitive mode choice model in their travel demand modeling process. A network sensitive mode choice model is distinguished here from a general mode choice model to highlight the importance of having transportation network derived measures of travel time, travel cost, waiting time, and other measures of disutility associated with traveling on a particular multimodal route. Mode choice analysis by aggregate sketch planning methods are too insensitive to subtle differences between, for example, shared ride automobile and drive alone automobile alternatives to effectively model the choice of mode.

The structure of the mode choice model will be dependent on the choices available at the local level and on the data available for calibrating the model. Where insufficient data exists to build a choice structure necessary to address the policy questions of interest in an area, portions of models developed elsewhere may be synthesized to the local model to provide a more broad based mode choice model.

As with the MPO areas, the mode choice models recommended for non-MPO areas are nested logit models. Logit models have proven to be reliable choice models as evidenced by their ability to emulate choices based on measured characteristics of the choices and their sensitivity to changes in these characteristics. Nested logit models are becoming understood to be the theoretically appropriate methodology as opposed to simple multinomial logit models as discussed in Section 4.5. A nested logit mode choice model is necessary to analyze the reductions of automobile vehicle miles and single occupant automobile trips for air quality conformity analysis and to evaluate many local area policies in light of the Oregon TPR goals and requirements.

Recall that when describing trip generation models, an emphasis was placed on modeling person trips rather than vehicle trips. Person trips include trips on all modes, including non-motorized modes. Since estimates of individual facility usage (trip assignment) by travelers using non-motorized modes is typically not of interest, trips using non-motorized modes are usually separated from trips using motorized modes. This separation may come from either a separate nest for non-motorized modes in the nested logit structure, or more typically, by applying non-motorized mode choice proportions by purpose to the set of trip interchanges resulting from the trip distribution procedures. The decision is entirely based on the type of local policies to be evaluated. For example, if walk and bicycle trips are of significant importance, then it may be appropriate for a non-MPO area to collect data and to calibrate a nest of a logit mode choice model specifically for these travel choices to evaluate the impacts of service level changes for other modes on these non-motorized trip makers.

Mode choice model development has far reaching secondary benefits. Mode choice models enhance the analysis of accessibility to travel through use of the LogSum variable (see section 4.5). This has implications in trip generation, auto ownership, trip distribution, and the whole interaction between travel demand analysis and land use.

5.3.5 - Commercial Vehicle Travel Demand

Commercial vehicle trips contribute substantially to overall traffic volumes and must be accounted for accordingly in non-MPO travel demand modeling procedures. For nonattainment areas especially, estimates of vehicle miles traveled by vehicle type are important in accurately computing mobile source emissions.

Section 4.6 describes a methodology for modeling commercial vehicle travel demand. These methods may be considered by areas which have commercial vehicle or work place survey data. Non-MPO areas are likely to not have sufficient data or resources for collecting and processing commercial vehicle data for building a model set. For this reason the method often used in general practice of adjusting highway link volumes based on measured vehicle classification counts is recommended. In other words, modeled volumes on a link are adjusted upward by anywhere from 5 to 15 percent, depending on the percentage of

commercial vehicles observed on the link. This adjustment is made following the trip assignment procedure, yet to be described.

For areas specifically concerned with commercial vehicle travel and especially of heavy truck routing, link volume adjustment will be insufficient. In this case, a truck or commercial vehicle travel demand model should be developed as described in Section 4.6 or synthesized from another similar urban area. The travel demand estimates may then be evaluated with truck trip assignment to alternative highway networks representing different truck route designations or travel policies.

5.3.6 - External Travel Demand

External travel demand accounts for trips by persons traveling into or through the study area from outside the study area, or trips from inside the study area to locations outside the study area. These are referred to as external-internal, external-external, and internal-external, respectively. For some non-MPO areas these trip movements may be a more significant portion of total travel within the region than for larger regions, and therefore, of more interest in the model development effort. Internal-internal trips represent the remainder of trips in a transportation demand model and are determined by the usual person trip estimation methodology described in Sections 5.3.1 through 5.3.4.

External trips are measured at *external stations* located at major ingress and egress points for a metropolitan area. External stations are typically located at the intersections of the study area boundary and interstate highways, state highways, and intercity railroad lines. Estimates of trip productions and trip attractions are often based simply on vehicle classification counts for the links intersecting the study area boundary. In other cases, regression analysis is applied to disaggregate data collected from external station surveys. An example of this type of model was given in Section 4.7.1. A non-MPO area may wish to either apply vehicle count data with growth factors for future years, or to "import" a model such as shown in Section 4.7.1 from another similar urban area. Given the potential impact of external travel on smaller communities, the need for specific origin/destination travel survey data may be needed in addition to vehicle classification counts.

5.3.7 - Trip Assignment and Time-Of-Day

The trip assignment model involves the allocation of trip interchanges to available routes connecting the zone pairs. Trips assigned are usually a combined set of trip interchanges for each mode, where all trip purposes, external trips, and commercial vehicle trips (if determined by a separate commercial vehicle travel demand model) are combined prior to the assignment procedure. These combined modal trip interchanges are then assigned to their respective modal networks where restrictions on vehicle occupancy, vehicle weight, etc. may preclude certain routes from being used.

The preferred method of highway trip assignment is a multipath equilibrium assignment. A multipath assignment concurs with the observed behavior that when several routes exist between a pair of zones, travelers between those zones are dispersed among several of the available routes. The equilibrium paradigm ensures that trips are assigned to the multiple routes in such a way that the solution to this trip assignment problem satisfies the behavioral rule that each traveler is traveling on his "best" route for that pair of zones based on prevailing traffic conditions.

Time period of travel is an important consideration when traffic volumes and travel demand are not uniform throughout the day. The recommended method for accounting for time of day is to determine the proportions of trips by purpose occurring in predefined time periods, such as morning and afternoon peaks, and other times, and apply these proportions to the trip interchanges. Then if 35 percent of daily work trip travel occurs during the morning peak period, 35 percent of the work trip interchanges would be assigned to a network which adequately represents the supply characteristics of the highway network during that time period. The time of day factors, one for each time period, must sum to 100 percent so that all daily trips are accounted for. If sufficient data exists from a household travel survey, time of day factors may be determined on a zonal or district level interchange basis.

Transit networks in small markets, as may be found in non-MPO areas, are unlikely to have much parallel service. Transit assignment algorithms in such instances are typically simple all-or-nothing assignments of transit trips to the transit route of least impedance between pairs of zones. Transit path impedance is a function of path measures such as time waiting to board, time waiting to transfer, in-vehicle time, fare, etc. Weights used in these impedance functions may be taken from a calibrated mode choice model.

5.3.8 - Model Validation

The modeling framework described in the previous seven sections of this chapter is designed to allow non-MPO planning studies to be based on "best practice" modeling procedures. If validated to observed base year data, this methodology can be reliably used as a forecasting tool for evaluating impacts of future transportation and land use policies.

As it is such a vital analysis, the validation guidelines for non-MPO areas are the same as defined for MPO areas. These analyses and validation targets are described in Section 4.9. Note that link level analysis is predominant and may therefore require a non-MPO area to initiate data collection efforts to provide adequate validation data if it does not already exist.

5.4 - Guidelines For Areas Classified As Attainment

The focus of the model guidelines presented in the Section 5.3 was with respect to air quality conformity considerations due to the necessity for employing sound modeling techniques with particular emphasis on multimodal personal travel demand. For non-MPO areas classified as attainment areas, the requirements of their models are only that they conform to the Oregon TPR; that is, that the models are capable of addressing policy issues, supplying information for plan development, and comparing quantitative travel measures with stated evaluation standards and objectives.

The types of analyses a non-MPO attainment area may wish to undertake within the TPR are varied. Transportation system plans for roads, public transit, non-motorized modes, non-passenger modes, parking, land use, congestion mitigation, and financing must be developed. New facilities, improved facilities, transportation system supply management, transportation demand management and "do nothing" alternatives must all be considered to address the needs of the transportation disadvantaged, the transportation system's ability to facilitate movement of goods, and the need to reduce Oregon's reliance on personal automobile travel. Land use regulations are of interest to evaluate appropriate ways to encourage

land development to foster public transportation, walk, and bicycle utilization in place of automobile trips. F inally, stated objectives of reducing vehicle miles traveled by target dates, increasing average automobile occupancy, and increasing transit and non-motorized mode shares must be evaluated and in some cases quantified by travel demand modeling procedures.

To address these issues, the modeling framework could be similar or identical to that for non-MPO areas classified as nonattainment and for MPO areas. The difference is in the application of model components where the local area policy concerns and air quality status afford them the ability to use model components developed in perhaps less detail than may be necessary for other areas.   These non-MPO areas may therefore have more discretion in deciding whether to apply straight forward procedures, for example person trips divided by vehicle occupancies to generate vehicle trips, or to develop more detailed models such as mode choice models to generate vehicle trips. The decision is based on the problems the local area is attempting to address in their analysis and the policies to be evaluated.

Given this common framework, the local areas may decide the level of detail necessary for their model components to address their local needs given their local resources. As their needs change, or their requirements change due to growth or attainment status, the local areas may enhance their individual model components as necessary within the "best practice" modeling framework described in these guidelines.

For attainment areas of *very low population,* development of travel demand models is entirely discretionary. For the purpose of these guidelines, areas of population less than 2,500 and classified as attainment areas will be considered very low population and will have no explicit definition of "best practice" travel demand models. These areas are however advised to follow the non-MPO guidelines for best practice when using travel demand models to evaluate transportation projects or policies so as to strengthen their technical analysis.

The approach taken in the following sections will be to compare travel demand modeling guidelines for non-MPO attainment areas with those of non-MPO nonattainment areas described in Section 5.3. The travel demand model components will be described in reference to their potential use in consideration of the Oregon TPR.

5.4.1 - Trip Generation

Trip generation models are necessary for any travel demand model set as these models link travel analysis to land use. The only requirement for trip generation models is that they estimate person trips. A person trip generation model is useful in the analysis of land use policies such as changes in residential densities, mixed residential and service or retail uses, etc. The person trip generation model relates personal travel activity to socioeconomic characteristics of the different land use scenarios. Finally, the person trip generation model includes trips made by non-motorized modes based on the values of the independent socioeconomic variables.

The need for market segmentation of trip generation models is dependent on the travel characteristics and local data of the specific area. Are there identifiable peaks in travel demand by time of day ? Is there sufficient data to separate trip makers by purpose and to evaluate the results of the estimates? Where data and conditions warrant the use of segmentation by trip purpose, the estimates usually reflect travel behavior

better, which lends more credibility to forecasts of future trips. The methodology for producing trip ends and applying trip generation estimates is as discussed in Section 5.3.1.

5.4.2 - Auto Ownership

One intended use of an auto ownership model for non-MPO areas is to provide information to other model components such as to cross-classification trip production models where autos per household is an independent variable and to mode choice models. These two models are sensitive to automobile accessibility and are thus important for analyzing non-motorized travel and reduced dependence on automobiles within the non-MPO area.

Auto ownership model development was discussed in Section 4.3. For non-MPO attainment areas that use some other independent variable such as family income for their trip production model or that use a very simply mode choice procedure, auto ownership models may not be necessary and may be omitted without affecting the overall travel demand modeling methodology. As needs change, the model component can be added within the specified framework.

5.4.3 - Trip Distribution

The gravity model, as described in Sections 4.4 and 5.3.3, is the preferred method for determining trip interchanges given trip production and trip attraction estimates. For non-MPO attainment areas, trip generation estimates are likely to be stratified by only three trip purposes: Home-Based Work, Home-Based Other, and Non-Home-Based. The trip distribution models will thus be similarly stratified.

The spatial separation measure used may in most cases simply be highway or automobile network travel time between zones. Where a non-MPO area is specifically concerned with non-motorized travel patterns, for example land use policies which affect the separation measure for non-motorized trips independent from motorized trips, a composite impedance separation measure may be in order. In this case, a nested logit mode choice model with non-motorized choices in the structure should be developed, from which the composite travel impedance may be derived.

The effect of this example would be to enhance the attractiveness of designated spaces by lowering the separation measure for non-motorized modes while maintaining the same separation measure for automobile and transit modes. This would result in a shift of some of the trip makers from motorized to non-motorized modes depending on the relative difference in impedance and the propensities of the travelers measured by their socioeconomic characteristics.

5.4.4 - Mode Choice

The mode choice model for non-MPO attainment areas could be very simple. The purpose in most instances will be to separate non-motorized trips from the set of trip interchanges and to determine vehicle trips. When this is the only concern, non-motorized trips may be separated from motorized trips by applying a global proportion of non-motorized travel to the total trips between each zone pair or by developing a set of simplified relationships that estimate the proportion of non-motorized travel. Vehicle trips by mode can be calculated from the resultant motorized person trips by dividing those person trips by

the average vehicle occupancy stratified by mode or by zonal or district interchange level average vehicle occupancy stratified by mode if such data exists.

Where more detailed consideration of mode choice is desired, a network sensitive nested logit model is the correct procedure to use. Where sufficient information is lacking, the model may be synthesized as described in Sections 4.5 and 5.3.4.

5.4.5 - Commercial Vehicle And External Travel Demand

Commercial vehicle and external trips are required in travel demand models so that when added to estimates of personal travel within the study area, all travel in the modeled transportation system is accounted for. The estimation of commercial and external vehicle trips from vehicle classification counts and external station counts as described for other modeling studies in Sections 4.6, 4.7, 5.3.5, and 5.3.6 are also recommended for non-MPO attainment areas.

5.4.6 - Trip Assignment and Time-Of-Day

Trip assignment is a necessary component of travel demand models as it is the method for relating utilization of transportation facilities to the demand for travel determined in earlier model steps. Equilibrium capacity restraint is recognized as the correct methodology for highway trip assignment. For areas with transit networks, simple all-or-nothing assignment of transit trips to the transit network is recommended.

Trip assignment by distinct time period is usually not necessary for non-MPO policy evaluation and plan development analyses, except in areas which are expected to grow rapidly and where significant congestion is an expected future condition. Models which estimate daily traffic on the network serve these areas quite well. The exception would be where a specific policy to spread peak period trips to a longer peak period was of interest. In this case diurnal (or time of day) factors as discussed in Sections 5.3.7 and 4.8 may be applied to evaluate traffic flow impacts and facility service levels due to the "peak spreading".

5.4.7 - Model Validation

As mentioned in Section 5.3.8, model validation is such an important part of travel demand model development that thorough consideration, such as described for MPO areas in Section 4.9, must be given to this analysis. Data collection, as necessary, must be performed to ensure that adequate model validation information exists. The "best practice" modeling methodology must be accompanied by diligent model validation with quality data to produce reliable and defensible travel model estimates and future forecasts.

6.0
TRAVEL DEMAND MODEL APPLICATION GUIDELINES

6.1 - Introduction

Studies in urban transportation systems planning, urban transportation systems evaluation, and urban transportation facilities planning and design depend on reliable and accurate information from travel demand model applications. These applications produce quantitative estimates of urban travel used in cost/benefit analysis, capacity analysis, and are relied upon for characterizing future conditions of the urban transportation system. It is therefore essential to integrate quality assurance evaluations into the model development process and to diligently apply checks and balances to model components and model outputs during model application.

A number of proven methodologies for ensuring quality travel demand model components exist. This chapter focuses on application consistency, reasonability evaluations, and sensitivity examinations. These tests, comparisons, and analyses must be applied throughout the model development and model application stages.

6.2 - Application Consistency

Consistency, as used here, refers to correspondence among model components, analysis requirements, theory, and expected results. Application consistency is a qualitative measure of coherence that should be strived for during model development. Consistency in model construct and selection of model variables, and their relationships within the overall model application framework determine the application consistency. Some specific guidelines are noted below.

Model construct must be consistent with the requirements of the analysis. For example, sketch planning models are appropriate for analyses to select a subset of transportation alternatives for further analysis but would be inconsistent with the analysis requirements for estimating urban VMT by facility. The latter requires detailed network representation, detailed consideration of speed/flow relationships, and detailed attention to travel behavior in deriving travel demand given the largely heterogeneous characteristics of travelers in an urban area.

Another example might be the consistency between model construct and choices. Specifically, in mode choice models, the available modes determine the choice model construct. A nested logit choice construct reflects the importance of lower level choices on upper level choices. To put this idea into some context, access to transit versus access to other modes is a factor in the primary choice between transit and the

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other modes. When such secondary choices exist, a nested construct is appropriate to ensure consistent treatment of choice attributes.

Consistent use of model variables such as transportation supply variables is another requirement. A classic example of inconsistent use of supply variables is to use distance or travel time based upon posted speed to measure spatial separation for a trip distribution model. A more consistent method of calculating spatial separation would be to use a function of congested travel time since a choice of home location is likely to be based on travel time estimates under prevailing traffic conditions, not on estimates of travel time based on posted speed limits or on distance.

Consistency between model framework and analysis requirements is necessary to ensure that the model is not used outside the scope of the theory on which it is founded. One such example is the use of traffic assignment models' volume/delay curves to estimate speeds for emissions evaluations. These volume delay curves were developed specifically for equilibrium traffic assignment models, given the mathematical requirements of equilibrium assignment (travel time strictly increasing with flow, continuous, differentiable, and a diagonal matrix of second partial derivatives.) Considerable care must be taken when developing speeds based upon this approach, which may include a post-processing step following the assignment phase.

This last item in parentheses says that travel time on a link must only depend on flow on that link alone. This property of the equilibrium assignment speed/flow relationships requires that speed on a link not be dependent on any other link (i.e. opposing volumes at an intersection are assumed not to affect flow on the link). This simplifying assumption cannot possibly result in observable link speeds. Thus to use link speeds, unaltered, from a traffic assignment, is to use the model outside of its theoretic framework.

Application consistency can be achieved with the aid of a detailed model specification. In a specification, each component of the model process is identified along with very detailed descriptions of its input requirements and its outputs. Where linkages exist between model components, consistency measures should be defined and checked for. Identified inconsistencies should be corrected before continuation to later model development stages occurs.

6.3 - Reasonableness Evaluations

The complexity of travel demand models and their application computer software underscore the necessity to check model component results for reasonability. One cannot accept the results without careful scrutiny due to the many opportunities for introducing erroneous data, omitting information, and simply misunderstanding the applications and analyses being undertaken. Checks for reasonableness can indicate problems which can simply be corrected as well as problems which require major changes in the model application design.

There is no substitute for previous experience with other studies for forming reasonability judgments. Raw data, model results, and knowledge of local factors can all be considered in comparing travel model results between urban areas. If differences in results cannot be explained, an indication of a problem exists. Direct model output, intermediate model output, and hypothesized model results must all be considered throughout the model development and application processes in search for unreasonable model results. This section discusses   evaluations   which   are   necessary   to   ensure   reliability   of   the   models   based   on

believability of model results. It is not the intent to prescribe threshold values or rules-of-thumb for summary statistics, but to identify information which may be examined and compared to known relationships or relationships in published literature.

Base Data Integrity:
Travel models rely heavily on travel survey data, land use and socioeconomic data, and transportation network data. These data are inventoried as part of the travel model specification development and are assembled early in the model development process.

Travel surveys provide the basis for relating individual travel behavior to zonal aggregations of socioeconomic and land use information for the purpose of generating trip activity at the zonal level. Surveys also provide observations of actual travel choices made by individuals and individual households and are thus vital for model calibration and validation. Survey data must be based on statistically valid samples and sample designs and should be tested for such.

Furthermore, survey data must be tested for correctness of processing and completeness. The model specification process will help identify the specific elements of the survey data required for further modeling analyses. Each survey data record must have complete and logical information for the data elements expected to be used, or that record must be omitted.

The methods for checking the survey data are very dependent on the survey design. Redundancy in questioning may be used to cross-check survey information if included in the original survey instruments. Completeness of data records and coding errors in the electronic survey files may be checked for by searching each data field for values outside the range of acceptable responses. Illogical values may be found by cross-tabulating combinations of fields. For example, a household summary of home-based work trips by number of employed residents that revealed many households with more employees than work trips would cause one to suspect either a data error or some special circumstance occurred on the day the survey was administered that caused many workers to stay home. Finally, survey data geocoding must be diligently checked since geocoding is the method by which household travel behavior information is spatially referenced. A GIS is beneficial in this check as trip patterns can be visualized by plotting lines between trip end locations and inconsistent trip sequences can be readily identified.

Beyond checking survey data for data entry related problems, the survey must be checked for biases among, for example, socioeconomic or geographically based groups of respondents. A highly biased sample may require supplemental surveying or exclusion from further consideration in model development and application. These checks may be made by summarizing and comparing expanded survey data to regional socioeconomic and land use data from local planning data bases such as US Census information.

Base network data must be checked for completeness and logical attributes. The networks used in assignment models must be connected, meaning that at least one network path can be determined between every pair of network nodes. The network attributes used in modeling analyses must also be logical. Attributes utilized to determine minimum cost (i.e. travel time, travel impedance, etc.) must be strictly non-negative. Some attributes may carry any value, such as uncongested travel speed, capacity, bus headway, etc. These values must be correctly assigned, however, to have assignment models produce reasonable travel volumes and congested speeds.

Network attribute coding errors can be recognized most readily with a GIS. A set of matrices called skim matrices can be generated which hold values of interzonal separation such as time, distance, cost, impedance, etc. These interzonal values are determined by summarizing network attribute values along the shortest path (as determined by the specific separation value) between zone centroid pairs. Ranges of values in these skim matrices can be plotted in different patterns or colors in a GIS for individual zones. For example, for a specific zone, the operating cost for traveling to all other zones can be shown by coloring the polygon representing a destination zone based on which range the zone's interzonal cost fell in, and overlaying the highway network onto these colored zones. The result is a display resembling a contour map. The displays can be examined for atypical patterns.

Calibration Data Integrity:
Calibration data bases are typically assembled from survey data and other planning data sources. A calibration file is a collection of data from many sources and is used as a convenient single source of calibration information and to protect the integrity of original data bases. The calibration data base, for a specific travel model, is an assembly of data specifically required for that model. All unrelated survey data, socioeconomic data, and land use data are excluded from this data assembly.

The calibration data bases are further used for creating calibration variables based on calibration data but generalized or transformed in some way. For example, a home-based work trips variable may be created from trip purpose information and verified with employment status and workers per household information. Given this variable, employment status may be no longer necessary and omitted from the final calibration data base.

It is thus necessary to check the consistency and integrity of the calibration data to ensure proper processing has occurred. Simple tabulations and cross-tabulations of base and calibration data should be compared for correctness.

Intermediate Results Evaluations:
Quality of model results are typically judged at the end of the model application process. Intermediate results evaluation however can point to problems in early model application stages which should be addressed before time is invested in later stages. For example, trip production and attraction models estimate trip activity out of and into zones based on observed relationships between individual travel behavior and zonal land use and socioeconomic characteristics. Trip productions and attractions are then processed such that total trip productions and total trip attractions balance by trip type. Evaluation of raw trips, prior to balancing, as compared to Census trips, employment by category, school enrollment, and land use areas, can indicate specific problems in the disaggregate travel/aggregate planning data relationships.

Final Model Results Evaluations:
All model results must be evaluated and compared to basic knowledge of results from other studies. This may be first hand knowledge from previous local experience or previous experience in other settings, or may be knowledge of reported findings in literature. The following list includes information which should be summarized and evaluated for reasonableness:

- trips per household by purpose
- trips per person by purpose
- trips per worker by purpose
- mean and variance of trip length by purpose

- mean and variance of trip time by purpose
- mean and variance of trip cost by purpose
- mean and variance of trip composite impedance
- primary and secondary mode shares
- trip length statistics by mode
- trip accessibility statistics by mode
- person miles, hours, cost, impedance of travel by mode by facility type
- grams of speciated emissions per person mile, hour, cost, impedance

The values of base data can be compared to model results easily. Observed versus estimated values can be effectively compared by linear regression where a regression line with slope and correlation coefficient equal to 1.0 and intercept equal to 0.0 represents a perfect fit. Graphical representation of these comparisons using scatter diagrams with overlaid regression lines are effective for visual evaluation.

In forecast applications, the analyst must evaluate results based on hypotheses and expected results. Cases where results deviate from what is expected must be evaluated and a determination made as to whether the results are curiously counter-intuitive (but accurate), the results are based on an error in the model application data, or the results are based on an improper application of the models.

6.4 - Sensitivity Examinations

Sensitivity tests evaluate the responsiveness of models to systematic changes in input values. A measure referred to as elasticity is often used to describe the sensitivity of model results to changes in input. Elasticity is defined as the ratio of the percentage change in output to the percentage change in input. It is usually measured for one independent value at a time. For example, the relative change in modal share due to a relative change in some travel time input is the elasticity or sensitivity of modal share to that particular change in travel time.

Elasticities of model coefficients are frequently studied and are subjects of research papers. Sensitivities of model inputs may thus be compared to readily available elasticities to evaluate common relationships in different urban areas between travel choices and independent variables that affect these choices.

In addition to reasonability checks on model sensitivities, this analysis helps to identify independent variables of significant sensitivity as well as variables of insignificant sensitivity. This information is important to an analyst seeking changes in transportation supply likely to achieve some desired goal. The model elasticities relate isolated changes in transportation supply variables to the expected responsiveness of the model. Model sensitivities also add credibility to the model results as the model is not only replicating base travel conditions, but is sensitive to a number of key model components.

7.0
TRAVEL DEMAND MODEL IMPACT EVALUATION TECHNIQUES

7.1 - Introduction

In many transportation planning and engineering studies, travel demand model applications provide the requisite information for engaging in further technical analyses. For example, turning movement percentages and vehicle composition through an intersection may be considered in traffic analyses of intersections. Microsimulation of freeway operations require traffic arrival distributions at entry points and departure distributions at exit points of the freeway segments under study. Lastly, environmental models which estimate emissions caused by moving vehicles require measures of the amount of travel per geographic location.

It is important to consider the analyses for which travel demand model results will be used to ensure that sufficient detail of information and consistent assumptions are maintained throughout the model development and application process. The focus of this chapter is on the application of output from travel demand models as required for further analyses. Specifically, the first section of this chapter will be a discussion of emission estimation models as they pertain to mobile sources and their relationships with the individual travel demand model components which are used to estimate travel related inputs to total emission calculations. Following that will be a discussion of traffic models used to perform analyses of transportation facilities and their data requirements which can be addressed by travel demand models and analyses.

This chapter is not intended to specify guidelines for the use of emissions and traffic operations models. It is intended to provide completeness to the scope of travel demand model development by outlining applications of the models that go beyond the conventional uses for comprehensive urban transportation planning.

7.2 - Evaluation Of Emissions

7.2.1 - The Necessity of Mobile Source Emissions Modeling

The primary impetus for estimating mobile source emissions has been a greater public awareness of environmental damage caused by unchecked urban growth and development and increased utilization of motor vehicles. Such public concerns have been partially addressed through legislative mandates, such as the Clean Air Act Amendments of 1990 (CAAA), which require more comprehensive consideration of the impacts of transportation plans on air quality and the inventory and tracking of traffic intensity by

metropolitan planning organizations (MPOs,) state departments of transportation, and local governments. The charge of travel demand model developers is to develop dependable and defensible model components which satisfy the requirements of emission estimation analyses without overstating the capabilities of travel demand forecasting models.

The CAAA impose specific requirements for which regional travel model output is integrally important. Among these requirements are evaluation and implementation of mandated control measures for heavily polluted metropolitan areas, estimation of baseline and projected emissions for emission budgeting, estimation of baseline and projected vehicle miles of travel (VMT) for comparison with actually measured VMT, and analysis of conformity of transportation plans, programs, and projects with state implementation plans for achieving clean air State Implementation Plan (SIPs).

Responsible agencies have abundant incentive to comply with and satisfy the quantitative requirements of the CAAA as they are subject to citizen initiated legal action as well as Environmental Protection Agency (EPA) sanctions for approving incomplete or inadequately evaluated plans. To guard against legal action from those challenging their findings, responsible agencies must ensure that their models are technically sound, comprehensive, accurate, and reasonably current in comparison to travel models used throughout the profession. It is also in the best interest of agencies to accurately represent their current and projected air quality in models so that new projects thought to be compliant do not unexpectedly force them into a more serious air quality classification which carries with it closer scrutiny, more extensive requirements, and more difficulty in reverting to a less severe air quality classification.

Apart from legislative requirements, a further incentive to develop concise estimates of facility utilization is due to more local flexibility in allocating Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) funds between highway, transit, and non-motorized transportation projects to best serve the needs of the local area in meeting their air quality goals. More accurate and detailed travel models required for emissions estimation will also aid in project level, corridor, and subarea studies as consistency is easier to achieve when there is greater detail in the regional models.

7.2.2 - The Uses for Mobile Source Emissions Modeling

Every metropolitan area with population of 50,000 or more, designated an urban area by the US Bureau of the Census, must have a designated metropolitan planning organization (MPO) responsible for the development of comprehensive transportation plans and transportation improvement plans (TIPs). The MPO must at a minimum consider the existing urbanized area and the area expected to be urbanized within their 20 year forecast period. In nonattainment areas, the MPO must consider the entire nonattainment area, where portions of the area are subject to exclusion upon mutual agreement between the MPO and the Governor of the state.

Under planning regulations published jointly by the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA), the MPO's planning process must include a linkage between transportation and environmental planning. Thus MPOs, without regard to attainment of National Ambient Air Quality Standards (NAAQS,) are required to consider air quality as part of the evaluation of their transportation plans.

Areas in nonattainment for ozone (without regard to population) are required to define their emissions problem by developing an emissions inventory and emissions budget for transportation hydrocarbons (HC) and to revise their state's SIP accordingly. The emissions budget is a plan to reduce emissions to allowable levels by the attainment date determined by the severity of their existing 1-hour concentration of HC pollutants. Similarly, areas in nonattainment for carbon monoxide (CO) must define their emissions problem and update their SIP to reflect their emissions inventory and resulting emissions budget.

Areas described as outlined above are the ones affected by the CAAA. The targeted audience for these guidelines is thus diverse and includes people in agencies responsible for transportation plan development, transportation project programming, emission inventorying, transportation service operators, state departments of transportation and environmental protection, interested general public, and other concerned parties.

7.2.3 - Mobile Source Emissions Estimation Models

Mobile source emissions for a region are estimated by applying an emission rate, typically in units of grams per mile, to an estimate of vehicle activity for the region, or vehicle miles of travel (VMT.) This statement of emissions modeling is deceptively simple as development of the input requirements for emission factor estimation and the procedure for estimating VMT can be considerably complex. This section considers the transportation related variables required to estimate emission factors, while the following section focuses on specific requirements for estimating VMT for emissions calculations.

The emission factor model required by most states is the EPA's MOBILE model (latest release MOBILE5a) with the exception being California which uses its own EMFAC7EP model. As such, Oregon's use of MOBILE5a is acceptable practice. The MOBILE model requires a considerable amount of information which allows the analysis to be localized to the specific metropolitan area being modeled. Much of the required information has default values taken from national averages. In many cases, the default values are not representative of a particular area and must be replaced by local data. In this case, example data sources are: fuel sales information, vehicle registration data bases, traffic monitoring programs, and regional travel model output. The following list summarizes the information which may be specified for MOBILE5a:

- alternate tampering rates
- alternate VMT mixes
- mileage accumulation rates
- vehicle registration distributions by age
- basic exhaust emission rates
- modified evaporative emissions test procedure start and phase-in dates
- inspection/maintenance (I/M) programs
- anti-tampering program
- emission control system checks
- vapor recovery systems on refueling
- local information on temperature range, fuel volatility, and reformulated gasoline
- trip length distributions
- average speed by vehicle classification
- percent VMT for each mode (cold-start no catalyst, hot-start catalyst, cold-start catalyst)

For emissions inventories and conformity analysis, the emission factors should be computed using consistent values and assumptions for the above list with those used to prepare the SIP for air quality attainment. In many cases, MOBILE5a default values are required unless supporting evidence warrants use of alternate values.

California has developed its own emission factor estimation procedures and therefore does not use the MOBILE model. One of the major differences between EMFAC7EP and MOBILE is that the former goes a step further in developing its relationship between speed and emission rates by separating trip end related emissions from hot stabilized running emissions. There is considerable evidence that trip starts, both cold and hot, contribute significantly to total vehicle emissions. To combine their effect into a single average operating speed leading to a composite grams per mile emission rate will most certainly result in the neglect of high acceleration and deceleration periods and thus underestimate the higher emissions which result during these periods.

Some users have accounted for this MOBILE model deficiency by estimating cold and hot start emissions by using the following procedure. Run MOBILE with 0% cold start and 100% hot start operating modes. Then run MOBILE with 0% cold start and 0% hot start operating modes. The difference in emission rates between the two runs is the estimate for the hot start emission factor due to trip starts. A similar procedure may be used to estimate a cold start emission factor.

In addition to the straight forward calculation of total emissions by application of MOBILE emission rates, MOBILE output may be used as input to a photochemical grid model such as the Urban Airshed Model. This model requires hour-by-hour grid cell, or temporally and spatially resolved speciated emissions estimates. This information can be obtained by using MOBILE and calculating link estimates of emissions from hourly VMT estimates and summarizing by grid cell by hour. This analysis is obviously well suited to a geographic information system (GIS) given its capability to perform spatial analysis with many types of spatially referenced data.

The Lake Michigan Ozone Study provides a good example of this type of analysis. It is intended and required for areas in serious and greater ozone nonattainment status.

7.2.4 - VMT Estimates for Emission Modeling

As mentioned above, emission factors are produced by the MOBILE model in units of grams per mile. Therefore this emission rate by vehicle type is multiplied by vehicle miles traveled (VMT) by link, link classification, grid cell, or region by vehicle type to generate total emission estimates by those categories. A number of sources for VMT may be available including:

- regional travel models
- statewide travel models
- Highway Performance Monitoring System (HPMS) and other state and local traffic monitoring programs
- USDOT annual *Highway Statistics publication.*

The data sources above are listed in order of preference. Travel models are most preferred because of their versatility in developing emissions forecasts and analyzing the effects of transportation control measures (TCMs,) land use changes, and transportation facility related alternatives. HPMS data alone is usually insufficient to obtain reliable traffic count and vehicle classification information required to estimate VMT. HPMS data supplemented with more extensive traffic count programs can provide sufficient information to estimate current VMT. However, without a travel model, forecasted VMT required in TCM analysis and TIP conformity analysis, for example, must be estimated based on trend analysis and growth factor methods which are limited in their behavioral basis. Finally, VMT based on aggregate statistics published annually may be sufficient in areas where the scale of the urban area and their air quality status and the lack of resources for developing more comprehensive modeling techniques dictate such methods be used.

For urban areas with the resources to model regional travel, special considerations related to eventual emissions modeling are necessary in the development of urban travel demand models. These considerations include:
- detailed multimodal consideration
- validation of <u>both</u> link volumes and link speeds
- validation by <u>all</u> link classifications
- validation by vehicle classifications
- validation by time of day
- estimates of "off-model" travel activity

Each of these items will be discussed as to their relevance to urban travel demand models.

Detailed multimodal consideration is necessary to provide a sufficient framework for considering ISTEA funded projects and TCM alternatives and their impacts on total emissions for a region. Detailed representation of transit services including fare policies, routes, schedules, and parking facilities, automobile usage costs including tolls, congestion pricing, and parking, and travel demand including employee commute options and employer sponsored flex hours and transit subsidies are all important elements of defining transportation levels-of-service and cost.

Multimodal transportation choices must be represented throughout the travel demand modeling process with obvious emphasis on mode choice and less obvious emphasis on trip generation and trip distribution. Trip generation models can enhance the modeling process simply by determining person trip generation rates. Trip distribution models are enhanced by utilizing multimodal impedance measures which represent the entire range of mobility options in the destination choice.

Multimodal network assignment procedures should be used to give appropriate attention to network related travel costs or impedance's by mode. These detailed network attributes should then be used in the network sensitive models of trip distribution and mode choice. Therefore, a minimum of two passes through the modeling process may be necessary to produce consistent travel demand estimates based on multimodal travel opportunities and travel impedance's.

Validation of both link volumes and speeds represents a more rigorous approach to travel model validation than has been used in the more historical applications of modeling analyses to study major transportation facilities. Speeds on the roadway network are vitally related to mobile source emissions and must

obviously be represented accurately in a travel model to provide reliable emissions estimates. In past practice, speed has been relatively ignored as part of travel model validation as the metric for a quality model has been goodness-of-fit measures of link volume compared to traffic count data.

The reasons for focusing on link volumes are both pragmatic and theoretical. Traffic count data is relatively easy to collect and maintain. In many cases, data is available for travel modelers from parallel studies or traffic count reporting programs. Theoretically, a unique set of link volumes define a single solution to the equilibrium traffic assignment problem. Thus when an equilibrium traffic assignment model produces flows which represent observed traffic counts at an acceptable level of accuracy, a high degree of reliability may be associated with that particular traffic assignment model formulation.

Validation of link speeds requires speed run data for links representing the roadway system. Speed run data is collected by a person driving through the network while noting times at which landmarks are passed which help relate the vehicle's locations to the model network links. Average speed is thus the link distance, usually measured from downstream stop line at an intersection to the downstream stop line at the downstream intersection represented by each network link, divided by the time to traverse that distance. Freeway speeds are typically determined by measuring distance between successive exit ramps.

Traffic assignment models which represent acceptable practice use multipath, capacity restrained techniques such as the equilibrium assignment method. Capacity restraint refers to the usually nonlinear increase in link travel time as link volume increases. These link travel time/volume relationships typically work very well in estimating network link volumes, but do not typically reflect measured network speeds very well. For this reason, traffic assignment results are often post-processed to compute link speeds from the assigned link volumes using a more reliable relationship between travel time and flow than is used in the assignment process. One such relationship is found in the Highway Capacity Manual (HCM) and may be used to adjust network travel times, and thus speeds, based on assigned link volumes.

Validation by all link classifications refers to the consideration of all network assignment links as opposed to just the major links in the urban area. In the past, links considered to serve regional travel were the focus of validation procedures and many links serving as local, collector, and minor arterials were not examined. A highly significant number of these lower functional class links exist in most modeling networks and can provide a great deal of VMT data if modeled accurately.

This additional validation requirement is likely to translate into a substantial requirement for traffic count data. The HPMS is not intended to collect data at such a fine level and thus is of no use for local streets. A program of local traffic monitoring is thus required to collect vehicle classification counts and speed data for validation.

Validation by vehicle classifications will ensure that the traffic assignment model and corresponding urban travel demand models accurately reflect the spatial allocation of vehicle types to the region's roadway system. Different vehicle types from light duty autos to heavy duty trucks have different rates of emissions at different operating speeds and thus require separate consideration in computing total mobile source emissions.

Traffic assignment models available for commercial use, most notably EMME/2, have the capability to represent a multimodal transportation system. This feature can be utilized to specify a separate network by

vehicle type, where some vehicle types share network links and others are restricted from use. Separate estimates of origin/destination travel demand by vehicle types may then be assigned to these networks, and VMT estimates by vehicle type summarized. These model outputs may then be validated with HPMS and supplemental vehicle classification counts.

In urban areas using traffic assignment models without this built in capability, VMT by vehicle type can be estimated by post-processing the assignment results. One method is to apply vehicle classification factors determined by traffic monitoring programs to estimates of link vehicle equivalent volumes. Another method is to apply the proportions of trips assigned in each iteration of an equilibrium assignment to the separate vehicle type trip tables for each link utilized in that assignment iteration. This method involves storing paths built for each zone during each assignment model iteration and is a fairly involved post-processing analysis procedure. The end result, though, is VMT by vehicle type.

Validation by time of day utilizes traffic count and speed data obtained during different time periods for a typical day. Time periods are usually morning peak, mid-day, evening peak, late-night. For major facility analysis, peak period travel results were sufficient for operational analyses and alternative analyses. However, different operating characteristics exist during these different time periods including average speed, travel demand, vehicle mix, and trip length distribution. All of these effect emissions estimates. Thus VMT should be estimated within these time periods to reflect the different operating and demand conditions.

Trip tables by vehicle type by time period can be determined by factoring the 24-hour trip matrix determined from the trip distribution model by time-of-day trip frequency distributions summarized from household and commercial vehicle travel surveys. In areas where such survey data is not available and is unfeasible to collect, US Census journey to work data can be used to factor work trips at a minimum.

Estimates of "off-model" travel activity are required to account for VMT which occurs on roadways not represented in the model network. Some examples include residential streets, entrances to parking lots and park-and-ride facilities and pollutant emitting transit vehicles. VMT estimates are required for all emitters not represented at the travel model scale. Special attention is required as this number can be quite significant and can affect the accuracy of emission estimates.

7.3 - Evaluation Of Traffic Operations

7.3.1 - The Necessity for Traffic Analyses

Traffic analysis involves the study of capacity, vehicle delay, volume to capacity (V/C) ratios, level-of-service (LOS,) and system performance of transportation facilities. These studies are performed by traffic engineers who specialize in optimizing the performance of individual intersections, series of intersections, freeway corridors, and large scale systems of freeways and surface streets. Performance is often measured in terms of the following measures both singularly and in composite:

- V/C ratio
- delay (stopped delay and total delay)
- bandwidth (number of vehicles likely to pass through an intersection)
- level-of-service

These analyses are performed to study the traffic carrying capabilities of facilities under varying assumptions and provide information useful in implementing improvements and planning, and design of new facilities.

As with emission modeling, traffic analysis has become an important component of MPO's analytical responsibilities given legislative requirements related to the CAAA, TPR, OTP, and the ISTEA. The CAAA requires that an urban area generate a TIP in coordination with the SIP and that the projects programmed in a TIP be supported by sufficient funding. TIPs must therefore be developed based on accurate estimates of project costs and environmental impacts of specific projects on local areas and the region's entire transportation system. In more serious nonattainment areas, the MPOs must implement TCMs, some of which involve traffic operations improvements. The ISTEA, TPR, and OTP requires that a multimodal focus be given to consideration of transportation alternatives analyses. The TPR and OTP require the development and analysis of transportation system and corridor plans to reduce the dependence on single occupancy vehicles (SOV). So, the ability to evaluate transportation improvement options and to estimate air quality impacts of these improvements is necessary.

7.3.2 - Traffic Analyses

The operation of a signalized intersection is a very complex process. Consideration must be given to distribution of traffic movements, distribution of vehicle mix, geometric attributes and time allocation. The first three in the list, movements, mix, and geometry, determine the expected number of vehicles to move through the intersection during each signal phase. This value is then used to determine the allocation of time to each phase. The allocation of time is further complicated by separate phases giving exclusive right-of-way to certain movements at specified times while other phases give simultaneous right-of-way to other movements at times. The goal is to find the optimal configuration of phase sequence and phase length for the typical traffic patterns that traverse the signalized intersection.

The operation of a series of signalized intersections is more complex yet. In addition to the considerations just outlined, a series of intersections along a street is typically coordinated to allow traffic traveling through the entire way to pass through all intersections, to the extent possible, without encountering a red signal indication. This type of operation must consider a trade-off between maximum throughput (bandwidth) along the direction of coordinated signals and delay encountered by vehicles stopped at cross streets.

Signalized intersections may be pretimed and fixed, semiactuated, full-actuated, or pretimed computer controlled. The decisions on which type are selected, take into account the scale of traffic problems, demand patterns, and cost of installation, operation, and maintenance.

Traffic operation analysis as discussed above is best suited for existing applications or short term projections. For planning applications the use of the critical V/C ratio for an entire intersection is most applicable. The purpose of using V/C ratios is to consistently provide the infrastructure to allow signalized intersection to be properly timed and coordinated through operational analysis. The importance of providing adequate reserve capacity at signalized intersection through critical movement analysis cannot be stressed enough.

Unsignalized intersections require an analysis of gaps in the traffic stream and thus are dependent on distribution of movements. Two-way stop and yield controls are located on the minor approaches of an unsignalized intersection and require gaps in the major traffic stream for vehicles to discharge. Thus capacity and delay are very dependent on the frequency distributions of gaps and gap sizes as well as on the distribution of driver tolerances. Four-way stop controlled intersections rely more on a convention of rotational transfer of right-of-way based on arrival sequence. Delay and capacity are therefore more dependent on arrival headway's by approach.

Freeway facilities provide uninterrupted flow opportunities absent of signal and stop control. They are accessed and egressed usually through ramps designed for high speed merging with minimal disruption to through moving traffic. Traffic analyses of freeway facilities involve the study of basic freeway segments, weaving areas, entry and exit ramp junctions, and metered control of entry ramp segments. Freeway operations are highly dependent on geometric attributes of the freeway components, traffic flow patterns, and traffic composition.

Another type of analyses related to freeway operations involve high occupancy vehicle (HOV) facilities which often are tightly coupled with freeway facilities. HOV facilities may be implemented as exclusive use lanes on a freeway facility, as an exclusive facility within a freeway right-of-way, or as a separate facility altogether. HOV analyses involve basic HOV sections, entry and exit junctions, and are dependent on specific attributes of the facility including geometry and channelization, locations of transit boarding and alighting sites, and traffic flow pattern and composition.

Related to HOV operations analyses are transit capacity analyses. These studies consider the effects of transit vehicles on freeway and signalized arterial operations, the total person carrying capability of a roadway characterized by mixed automobile and transit usage, a generalized notion of capacity for transit vehicles operating on arterial streets, business district streets, freeways, and busways, and requirements for boarding and alighting sites for transit vehicles operating on these facilities.

Consideration of non-motorized modes of transportation, such as bicycles, are specifically called for in the TPR, OTP, ISTEA related projects and as possible CAAA transportation control measures. Typical analyses related to bicycles include studies of the effects of bicycles on roadways including intersection and mid-block operations, and the operations of designated bicycle facilities which include exclusive and shared right-of-way facilities.

Analysis of pedestrian facilities is required both for their impact on signalized intersection and for their person carrying capability in business district areas, parking facility access and intermodal facility access. Pedestrian operations are determined by many of the same considerations that characterize motor vehicle operations including geometric attributes of pedestrian facilities and presence of obstructions, patterns of pedestrian activity, and control of motorized traffic.

Site impact analysis studies are required to evaluate the local impacts of specific development projects. These studies look at projected traffic created by new developments and determine the improvements needed to accommodate the new developments. They are also used to help communities relate land use to traffic, assist in decisions for land uses and driveway permits, monitor traffic and maintain traffic data, and provide input to metropolitan planning.

7.3.3 - Traffic Operations Analysis Application Software

This section is concerned with describing several traffic analysis tools used by traffic engineers. Included are several software packages. *The list is by no means exhaustive, rather is intended to be illustrative of typical analyses and tools for applying relevant analytical methods. Included are discussions of signalized intersections both isolated and in groups, freeway, and HOV analyses.*

The study of signalized intersections is undertaken to evaluate characteristics and to determine improvements to improve traffic flow through the intersection. Special purpose software exists for computing capacity and signal operating parameters given the physical characteristics of the intersections and relevant traffic and preferred optimization criteria. A common input to each software program is geometric information to describe the number of lanes, allowed turning movements, length of protected turn bays, width of lanes, pedestrian activities, and network connectivity. In all cases, design traffic volumes and/or capacity are required. In some cases, signal timing parameters and phase sequences are also required.

Planning analysis for an individual intersection to compute volume to capacity ratio is usually performed based on the methodology from NCHRP Circular 212. Using the critical movement methodology to maintain an adequate reserve capacity at intersection for future years is an important exercise in traffic analysis. Providing the necessary reserve capacity at intersections creates the infrastructure for traffic engineers to apply the more detailed operational analysis when appropriate for optimization. The V/C ratio can also be used to estimate the amount of existing and future capacity that site specific traffic will consume. These measures can be used to quantify impacts of land use changes and site developments. An example of software to do this type of analysis is SIGCAP.

Software may be applied to study operations of isolated intersections in which case the optimal phase sequence, length of phase intervals, and cycle length are desired based on some optimality criterion. These signal timing parameters may be selected to either maximize intersection bandwidth or minimize stops, delay, or a combination of stops and delay. Example software programs for isolated intersection analysis are: Highway Capacity Software (and HCM worksheets,) PASSER III (signalized diamond interchanges,) SIDRA, and SOAP.

The analysis of isolated intersections assumes that the traffic arrives in a uniformly random way. When a series of coordinated traffic signals are of interest, different methods considering progressive signal control within the series of signals and the dependence of vehicle arrival distributions are required. These programs seek to determine the above signal parameters along with phase offsets to once again either maximize bandwidth or minimize stops, delay, or a combination of stops and delay for the groups of coordinated signalized intersections. Software with these capabilities include: MAXBAND, PASSER II, and TRANSYT-7F.

For area wide traffic control, usually over relatively small networks of intersections, signal timing parameters and phase offsets are desired to optimize traffic operations over the area. This requires the capability to optimize signals in grids with directional flows in more than one direction. MAXBAND and TRANSYT-7F have this capability for pretimed signals. TIMACS provides information related to timing designs for coordinated actuated controllers and for non-coordinated computer controlled pretimed controllers.

Freeway analysis involves the study of traffic operations on basic freeway segments, ramp segments, weaving segments, merge and diverge segments, drop-lane segments, and HOV lanes. These studies may be conducted under varying assumptions on driver characteristics, incident occurrences, and incident management practices. The most common method used in practice for performing level-of-service, capacity, and delay analyses for freeway sections is to apply the *1985 Highway Capacity Manual methods.*

The HCM outlines calculations of service flow rates given adjustments for vehicle mix, grade, roadside obstructions, roadway dimensions, and percentage of familiar or regular drivers in the traffic stream. The service flow rates, along with observed (or estimated) traffic can be transformed into volume to capacity ratios, densities, and average speed. These measures then correspond to a level-of-service rating (A, B, C, D, or E) for qualitatively describing the freeway section's operations.

For design of freeway segments, known design elements of number of lanes, widths, known obstructions, etc. are used along with estimated design volumes, peaking characteristics, and traffic composition to evaluate level-of-service and the other operational performance measures. The design elements may be systematically modified to evaluate the effect on traffic operations until a preferred design is determined. Design analysis may also include detailed specification of TCMs as part of the freeway section studied, in which case the analysis will provide information relevant to subsequent air quality analysis.

For planning freeway sections, less information is typically given regarding detailed design elements, and these features are thus assumed for the operational analysis. This type of study may be useful, for example, to determine the number of freeway lanes required to satisfy a specified desired level-of-service or capacity.

The physical conditions for which HCM methods for freeway analysis are known to be rather idealized and therefore limited in scope. For example, complex weaving patterns associated with freeway to freeway interchanges and freeway segments separated by closely spaced entrance and exit ramps result in weaving configurations and traffic arrival distributions which do not justifiably correspond to the implicit assumptions in the HCM. For operational studies concerned with complex freeway sections, simulation techniques are often prescribed.

In such instances, freeway microscopic simulation may be the most appropriate analysis tool. One such computer software package is FRESIM, part of the FHWA TRAF family of traffic simulation models. Microscopic simulation refers to the detailed consideration of individual vehicle movement within a traffic system. A fixed time interval simulation, such as used with FRESIM, updates each vehicle's position, operating characteristics, and summary statistics once each time interval. The position of a vehicle, in a freeway simulation, is modified as necessary based on interactions with the roadway and with other vehicles using mathematical relationships known as car following and lane changing algorithms. The heading a vehicle follows is either determined from a user specified origin/destination matrix of entrance ramp to exit ramp flows or determined during the simulation based on entrance ramp and exit ramp volumes.

Traffic composition and flow patterns for the freeway system being studied may come from regional travel models. A likely analysis might include the application of a regional model to consider the travel demand expected by some service level modification to a freeway, represented as increased capacity in the

regional traffic assignment model. Given the traffic composition and flow patterns into and out of the free-way system determined by the regional model, simulation can be used to study the resulting detailed traffic operations on the facility. Selected link analysis, from the regional traffic assignment model, is another possible procedure which will provide regional origin/destination flow patterns for specific links, such as freeway entrance and exit ramps. This information may be used for reasonableness checks on traffic patterns generated by the microscopic simulation.

Results from FRESIM, including average speed, delays, VMT, and emissions estimates may be used to evaluate operational level-of-service and air quality measures. Different freeway designs may be studied as lane configurations, geometries, etc. are modified and the simulation is rerun. For operational analysis of design features that may have an effect on regional traffic patterns, the regional travel models must be reapplied. This may be necessary if ramps are relocated or eliminated in a design or if other features cause capacity changes for the regional network freeway links.

Like the HCM methods, microscopic simulation methods may be limited in scope for certain desired analyses. For example, FRESIM has no direct capability to handle HOV and bus operations on the freeway. When HOV operations are the specific focus of a study, a more specialized program such as FREQ may be required.

FREQ is a macroscopic simulation program with imbedded features for evaluating the benefits of HOV lane operations. Like FRESIM, origin/destination flows may be specified by the user. FREQ may utilize information from regional travel models such as origin/destination flow patterns, vehicle occupancies, and mode shares. The other major application for FREQ is for analysis of ramp metering and prioritized entry on metered ramps. FREQ provides similar output information to FRESIM, sufficient to evaluate operational characteristics of the modeled facilities.

Freeway simulation is by no means the only type of simulation applied. Simulation of surface street traffic operations is probably the most frequently applied microscopic simulation technique. The popular software from FHWA, TRAF-NETSIM, provides microscopic simulation of intersections, groups of intersections, and area wide street networks. This software is known most notably for its ability to store simulation information and later play back this information through post-processing animation software. The animation allows users to visualize traffic operations through groups of signalized intersections, thus allowing for visual identification of readily apparent operational problems.

TRAF-NETSIM provides for a highly detailed representation of streets, intersections, and traffic controls. The simulation is a fixed time interval simulation, as with FRESIM, and employs sophisticated car following and lane changing algorithms. TRAF-NETSIM has no feature for specifying origin/destination traffic patterns. Vehicle direction is determined by a stochastic process dependent on turning movement traffic volumes at intersections. The program does have a feature which allows the user to specify random number seeds so that the stochastic process may be duplicated to recreate identical traffic streams for a given set of turning movement volumes. This feature allows the analyst to evaluate the response of a given, fixed traffic stream to changes in intersection or intersection control designs.

This microscopic simulation program is useful for evaluating intersection operations under scenarios not particularly suited to other intersection analysis methods described earlier due to their implicit assumptions. For example, an analysis for a single intersection affected by adjacent intersection activity, but not

in a coordinated way. In this case the arrival patterns of traffic cannot be assumed to be uniformly distributed as is the case in most isolated intersection analysis methods.

7.4 - Concluding Remarks

Regional travel demand modeling has expanded in scope in recent years to include a necessary interface to other analysis procedures. Emissions and traffic analyses have historically tended to be considered as separate procedures, independent from regional analyses. They have, in the past, been more focused on current conditions and have thus based their traffic pattern input requirements on traffic counts and traffic growth projections. Furthermore, applications of regional travel models produced results of questionable precision for all but major, regional serving facilities. A loosely coupled process of applying these results to minor classification facilities was therefore sufficient and well within the " ball park" for analyses in a planning context.

A greater focus on accuracy of regional model results at all levels of facility types, initiated partly by environmental groups seeking to gain better information for their emission estimation methods, has led to a greater awareness of the problems by the travel demand modeling community. This awareness has in turn led to programs for fixing obvious problems and developing better methodologies.

With these model improvements has come applications of regional travel models for forecasting travel characteristics to be used in emissions models and operations models as discussed in this chapter. These developments are important as they bring a travel behavior capability to facility design and planning. For example, HOV facility design may consider the entire assumed travel behavior implicit in the four step modeling process; that is, application of regional models prior to studying the detailed operations of HOV facilities allows the usage of the facilities to be determined as part of the entire origin/destination, mode, and route choice. Changes in traffic operations due to modified facility service level designs are then studied subject to the changed travel demand patterns which may result from the different service levels.

Regional travel models may likewise be used to estimate emissions impacts due to planned facilities. This capability allows TIP development and conformity studies to be based on more accurate representations of proposed projects and their air quality impacts.

8.0
DIRECTIONS IN THE STATE-OF-THE-ART

In general, the status of travel demand forecasting procedures in Oregon parallels the situation found in most states and urban areas in the United States. These procedures were developed using a basic structure typical of models developed from the 1970's and early 1980's. As in other urban settings, these procedures and models have become dated because of at least three trends:

- First, significant changes have occurred in the area for which the models are supposed to describe land-use and travel patterns. Most urban areas in Oregon have evolved rapidly in terms of population, employment, transportation facilities, land use policies, socio-economic characteristics, housing costs, and the travel patterns that result from this broad range of influences.

- Second, the requirements placed on the forecasting procedures have grown. Where travel forecasting once focused on predicting the necessary capacity for new highway facilities, they are now asked to deal with a much broader set of issues. High Occupancy vehicle lanes, land-use controls and incentives, transportation demand management (TDM) strategies, and transportation system management (TSM) programs are primary examples. Requirements of the Intermodal Surface Transportation Efficiency Act and, to a lesser extent in an attainment area, the Clean Air Act Amendments have further expanded the range of questions that the forecasting procedures must address -- multimodal alternatives, a very broad range of evaluation criteria, maintenance of air quality standards, etc.

- Third, methods for travel forecasting have advanced substantially over the last 10 years. Where the typical model set developed in the early 1980's consists of a series of more-or-less independent models that share information only very loosely, newer methods do a much better job of using information on the transportation system and the travelers on the system. Many of the technical improvements that have been made in the procedures are crucial in the useful analysis of the new, broader set of issues faced by transportation agencies. Emerging methods that are under discussion today promise -- at least eventually -- to significantly improve the ability of forecasting procedures to deal with underlying causes of travel patterns and the forces that are changing these patterns.

Over the past year of two, a rising chorus of criticism has highlighted what has been know for some time -- typical applications of the sequential model approach to travel forecasting have many undesirable features.

Three general themes stand out in these critiques:

- *Typical applications of the sequential process do not use information consistently throughout all of the steps.* For example, highway speeds used in trip distribution to represent accessibility to alternative destinations are typically not the same as the highway speed computed later in the process when auto trips are finally loaded onto the highway network. Socio-economic characteristics (income, household size, etc) are used in trip generation and mode choice but ignored in trip distribution. Transit service levels are considered explicitly in the mode choice model, but play no role in trip distribution to predict the destination of trips made by each household. Block-level census data on households is aggregated to much larger "zones" that limit the ability of the models to understand walk distances to transit services and to examine site-specific impacts of new developments.

- *Important influences on travel patterns are entirely absent from the models.* For example, although parking availability (a free employer-provided space versus a full-price commercial lot) is an enormous influence on the decision to drive alone, carpool, or take transit, this information is rarely -- if ever --used in mode choice models. Although the availability of transit service to work can be an important factor in the choice of residence location (particularly for lower-income households), nearly all models of home-to-work travel consider only travel time on the highway system between home and work. Even though the presence of young children in the household can introduce a number of new activities that require travel -- getting children to school or to day care -- information on households in the models typically omit any indication of the presence of children.

- *Important choices are ignored, or represented very crudely*. For example, the basic element of travel considered by the model -- the "trip" -- masks all sorts of choices made by the household: does the trip to/from work include a stop at school to drop off a child ? Are visits to non-work activities chained together to minimize the total travel time necessary to complete these activities ? and so forth. Typical model sets also use simple factors to represent the distribution of travel across the day and are therefore insensitive to the variety of influences (congestion, trip chaining, part-time employment) that continue to "spread" the peak periods across larger parts of the day.

8.1 - "Best Practice" Model Development

All of these criticisms are legitimate when they are applied to the "typical" implementation of the sequential model set. They are not necessarily fatal flaws; rather they serve to highlight the components of the sequential model set that must be done better in future applications. In practice, recently developed model sets have, in fact, made significant strides in overcoming many of these limitations:

- New model sets include several additional components to deal directly with other travel-related decisions that households must make -- the locations of the residence and workplaces of the household, the time-of-day for specific trips, the number of occupants of auto trips, and the mode of access to transit services.

- Measures of the combined accessibility provided by both auto travel and transit have been introduced in trip distribution models to represent the influences by both modes in the decision on where to travel.

- "Nested" models represent the interactions among choices and the common influences on these choices: single models now address the highly inter-related choices of travel mode, auto occupancy, access to transit (walk or auto), and transit path (local or express).

- Geographic information systems are being used to maintain data in less aggregate and more flexible ways that are being tapped to provide input data for models of both land use and travel behavior.

- Market Segmentation is increasingly used to consider the specific conditions and influences on specific groups in the population -- workers with company-provided parking spaces versus workers who must use commercial parking, higher income versus lower income households, travelers who have a car available versus travelers who do not.

- Rapid increases in computing power have made possible a shift toward more detailed calculations that are better able to understand the individual travel markets found in an urban area, in contrast to the highly aggregate approaches that have been used in the past.

While no single urban area currently has models that include all of these improvements, they can be found in one or more of the recently developed model sets in the United States -- Portland, Dallas/Ft. Worth, Atlanta, Minneapolis/St. Paul, Hartford, Northern New Jersey, Chicago, and San Francisco.

Together, these new model sets demonstrate the full range of refinements that are being made to the sequential approach to travel forecasting. The prescription of "best practice" outlined earlier in this report attempts to address most, if not all, of these refinements.

8.2 - Innovative Approaches

Within the last year there have been a number of innovative approaches offered that stem from new efforts to completely rethink the entire approach to travel forecasting. Initial research sponsored by the Federal Highway Administration has produced four proposals[1] for new approaches. One is based on probabilistic simulations of specific trips by individual household members. The second considers choices faced by households in "hyper-networks" that would be analyzed analogously to the way that highway assignments are handled in conventional models. The third uses choice models to represent explicitly all of the choices with careful attention to the identification of alternatives that households consider for each choice. The fourth bases the analysis explicitly on the activities that households must accomplish and the strategies they employ - including travel - to satisfy these requirements.

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[1] A summary of these proposals is provided in "The Next Generation of Transportation Forecasting Models" by Bruce D. Spear, National Transportation Systems Center, Cambridge, MA, August, 1993.

Travel Demand Model Development and Application Guidelines

The first approach -- probablistic microsimulation -- has received funding for a pilot implementation at the Metropolitan Washington Council Of Governments in Washington, D.C.[2] This work will conduct a survey of activity patterns and travel of a sample of households and develop computer software that simulates these patterns. Changes in influences on activities and travel -- a child who enters school, better transit service, etc -- will be introduced to the simulation and the software will predict the changes in both activity patterns and resulting travel.

A similar approach, but on a much larger scale, is being pursued at the Los Alamos National Laboratories. With funding from the U.S. Department of Transportation, staff at Los Alamos are using Cray supercomputers to simulate the activity patterns and travel behavior of individuals and households, with a case-study application for Albuquerque, New Mexico. With the speed and memory available from this high-powered computing capability, the objective of this work is to simulate explicitly all influences on travel -- ranging from such broad region-wide effects as congestion levels on the highway system to such narrow effects as the signal timing at specific intersections.

While the appeal of all of these ideas is clear, the large risks are equally obvious. None of these ideas has yet been implemented in a setting similar to MPO. Most of these ideas exist only as very broad outlines that may be turned into a significantly improved travel forecasting process.

This is not to say, however, that it is impossible to introduce some of the elements of these emerging ideas into new regional models. A stronger recognition in the models of household activities, for example, may well offer improvements in the prediction of the travel patterns generated by different kinds of households. Explicit treatment of trip-chaining effects, combined with the household activity approach, may significantly improve the ability of the models to predict the travel patterns of workers who drop children off at school and day-care on the way to/from work. These and other insights provided by the emerging ideas on travel forecasting may offer ways to restructure some of the details of conventional models without the risks associated with an attempt to develop an entirely new approach to travel forecasting in the near term.

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[2]This work is being funded by a grant from the Environmental Protection Agency.