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16. Abstract

Implementing transportation improvements requires a significant effort that may involve several levels of planning; social, economic and environmental documentation; geometric and structural design; operations analysis; signalized intersection design; and/or pavement design. Accurate and timely traffic estimates and forecasts are basic to the entire transportation planning process and are essential to enable the Texas Department of Transportation (TxDOT) to effectively meet the mobility needs of the state. This guide provides an introduction to the transportation planning and travel demand forecasting requirements and establishes the policies, processes and methodologies for developing traffic forecasts for the various stages of TxDOT project development.

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TRAVEL FORECASTING GUIDELINES

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IMPLEMENTATION STATEMENT

This guide is intended for use by TxDOT personnel, other public agencies, and/or consultants performing traffic forecasting for TxDOT projects. It explains the internal policies and procedures governing the development of traffic forecasts and describes the forecasting methodologies appropriate for each stage of project planning and development. The information provided by this guide is not intended to replace sound transportation planning judgement. However, deviation from the procedures or methodologies presented herein should be cleared with the TxDOT's Transportation Planning and Programming Division (TPP) prior to performing the traffic forecast.

The chapters in this guide are not designed merely to list traffic forecast requirements or to describe the forecasting methodology appropriate for TxDOT projects. They also provide background information relevant to each planning and/or forecasting stage and provide contextual guidelines for selecting among alternative methodologies.

DISCLAIMER

The contents of this report reflect the views of the authors and the various source documents. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. In addition, this report is not intended for construction, bidding, or permit purposes. George B. Dresser, Ph.D., was the Principal Investigator for the project.

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LIST OF ABBREVIATIONS AND SYMBOLS

AADT	average annual daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	average daily traffic
ATHWLD	average of the 10 heaviest wheel loads daily
ATR	automatic traffic record
AWDT	average weekday traffic
BBR	Bureau of Business Research
BC	U.S. Bureau of the Census
BEA	Bureau of Economic Analysis
BNIP	Bridge Needs Investment Program
BPR	Bureau of Public Roads
C/VM	cost per vehicle mile
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CBD	Central Business District
CMP	Congestion Management Program
CMS	congestion management system
CO	carbon monoxide
COEMP	county employment
COHH	county households
COPOP	county population
CRI	Congestion Relief Index
CTPP	Census Transportation Planning Package
DDHV	directional design-hour volumes
DOT	U.S. Department of Transportation
DRAM	Disaggregated Residential Allocation Model
EPA	Environmental Protection Agency
ESAL	equivalent single axis loads
ETC	estimated year of project completion
FHWA	Federal Highway Administration
FIP	Federal Implementation Plans
HBO	home based other
HBW	home based work
HEEM	Highway Economic Evaluation Model
HGAC	Houston-Galveston Area Council of Governments
HOV	high-occupancy vehicle
HNIS	Highway Network Information System
HPMS	Highway Performance Monitoring System
ISTEA	Intermodal Surface Transportation Efficiency Act
ITE	Institute of Transportation Engineers
ITLUP	Integrated Transport and Land Use Package
LD	latent demand
LOS	level of service
LOV	low-occupancy vehicle
MPO	Metropolitan Planning Organization

MSA	metropolitan statistical areas
NAAQS	National Ambient Air Quality Standards
NAC	Noise Abatement Criteria
NCTOG	North Central Texas Council of Governments
NHB	non-home based
NHS	National Highway System
NO_x	oxides of nitrogen
NPA	National Planning Association
O-D	Origin-Destination
PDP	Project Development Plan
PLUM	Projective Land Use Model
POLIS	Project Optimization Land Information System
RACT	Reasonably Available Control Technology
REIMIS	Regional Economic Impact Model for Highway Systems
RFP	reasonable further progress
SDC	State Data Center
SIC	Standard Industrial Classification Codes
SIP	State Implementation Plan
SOV	single-occupancy vehicle
STP	Surface Transportation Program
TAZ	traffic analysis zones
TCM	transportation control measure
TDH	Texas Department of Health
TIP	Transportation Improvement Program
TLFD	Trip Length Frequency Distribution
TLOG	Roadway Inventory and Traffic Log
TMA	transportation management area
TNRCC	Texas Natural Resource Conservation Commission
TOMM	Time Oriented metropolis Model
TPP	Transportation Planning and Programming Division
TSDC	Texas State Data Center
TSZ	traffic serial zones
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
USGS	U.S. Geological Survey
UTM	universal traverse mercator
UTPS	Urban Transportation Planning System
v/c	volume/capacity
VHT	vehicle hours traveled
VMT	vehicle miles traveled
VOC	volatile organic compound
WIM	weigh-in-motion
WP	Woods and Poole

SUMMARY

Implementing transportation improvements requires a significant effort that may involve several levels of planning, social, economic and environmental documentation; geometric and structural design; operations analysis; signalized intersection design; and/or pavement design. Accurate and timely traffic estimates and forecasts are basic to the entire transportation planning process and are essential to enable the Texas Department of Transportation (TxDOT) to effectively meet the mobility needs of the state. This guide provides an introduction to the transportation planning and travel demand forecasting requirements and establishes the policies, processes, and methodologies for developing traffic forecasts for the various stages of TxDOT project development.

Chapter 1, *Introduction and General Information*, discusses the purpose and application of the Traffic Forecasting Guide and describes the procedures for requesting a traffic forecast from the TPP Division. The chapter concludes with a section describing the organization and functions of the five sections of the TPP Division.

Chapter 2, *Context (ISTEA and the Clean Air Act Amendments)*, presents an overview of the provisions of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the Clean Air Act Amendments (CAAA) of 1990. The implications of these stipulations for transportation planning and traffic forecasting are also discussed.

Chapter 3, *Input Data and Assumptions*, is divided into sections which review the various input data requirements for traffic modeling and forecasting. These sections also address the relationship between data requirements and a model's objective and the tradeoff between data quality and inevitable budget and time limitations.

Chapter 4, *Travel Demand Modeling Overview*, lists the four steps involved in travel demand modeling and presents an overview of the process itself. This chapter also defines model specification, calibration, and validation and serves as a cursory introduction to the modeling procedures delineated in Chapters 5 through 8.

Chapters 5-8, provide a detailed description of the four travel demand modeling steps: trip generation, trip distribution, mode choice, and trip assignment. Each of these chapters discusses the objectives and, the model specifications as well as the calibration and validation

techniques that apply to those four steps.

Chapter 9 covers "advanced topics" in travel demand modeling such as time-of-day distribution, forecasts, and feedback mechanisms. Brief discussions of the importance of model documentation and several applications for traffic models close out this chapter.

Chapter 10 focuses on urban area transportation forecasting in the state of Texas. It provides an overview of travel modeling in Texas based on a summary of the Texas Package.

Chapter 11, *Forecasting Input Data*, reviews and analyzes two important aspects of estimating and predicting urban travel demand: obtaining the input data and projecting the input data. Specifically, this chapter discusses these topics as they relate to the design and implementation of urban travel surveys in Texas.

Chapter 12, *Rural Area Transportation Planning*, describes the traditional trend projection methodology and delves into the more experimental elasticity-based traffic forecasting models. The latter half of this chapter is designed to provide general background information about these elasticity models, and the example provided is intended as a potential supplement to the already widely used trend-based projection techniques.

Chapter 13 presents a discussion of the traffic forecasting requirements and methodologies for feasibility studies, and the advanced planning stage of project development. This chapter also includes a discussion of forecasting for environmental documentation.

Chapter 14, *Traffic Forecasting for Project Design*, describes the methodology involved in geometric, pavement and bridge design. The last sections of this chapter illustrate these procedures through explicit examples.

Chapter 15 discusses the relevance of current and forecast traffic data to TxDOT's policy and administrative functions. Traffic estimate and forecast methodologies are discussed for both urban and rural areas.

Chapter 16 summarizes the standardized methodology for intercity route studies in Texas. This chapter also illustrates the sensitivity of such studies to traffic characteristics, economic development, and system connectivity.

CHAPTER 1: INTRODUCTION AND GENERAL INFORMATION

PURPOSE OF THE TRAFFIC FORECASTING GUIDE

Implementing transportation improvements requires a significant effort that may involve several levels of planning: social, economic, and environmental documentation; geometric and structural design; operations analysis; signalized intersection design; and/or pavement design. Accurate and timely traffic estimates and forecasts are basic to the entire transportation planning process and are essential to enable the Texas Department of Transportation (TxDOT) to effectively meet the mobility needs of the state. This guide provides an introduction to the transportation planning and travel demand forecasting requirements and establishes the policies, processes, and methodologies for developing traffic forecasts for the various stages of TxDOT project development.

APPLICATION OF THE TRAFFIC FORECASTING GUIDE

This guide is intended for use by TxDOT personnel, other public agencies, and/or consultants performing traffic forecasting for TxDOT projects. It explains the internal policies and procedures governing the development of traffic forecasts and describes the forecasting methodologies appropriate for each stage of project planning and development. The information provided by this guide is not intended to replace sound transportation planning judgment. However, deviation from the procedures or methodologies presented herein should be cleared with the TxDOT's Transportation Planning and Programming Division (TPP) prior to performing the traffic forecast.

The chapters in this guide are not designed merely to list traffic forecast requirements or to describe the forecasting methodology appropriate for TxDOT projects. They also provide background information relevant to each planning and/or forecasting stage and provide contextual guidelines for selecting among alternative methodologies. A general description of the information presented in each chapter is provided below.

Chapter 1, *Introduction and General Information*, discusses the purpose and application of the Traffic Forecasting Guide and describes the procedures for requesting a traffic forecast from TPP. The chapter concludes with a section describing the organization and functions of the five

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Chapter 16 summarizes the standardized methodology for intercity route studies in Texas. This chapter also illustrates the sensitivity of such studies to traffic characteristics, economic development, and system connectivity.

TRAFFIC FORECAST REQUEST PROCEDURES

The local District Project Manager is responsible for making the appropriate traffic forecast request. It is important that the type of forecast requested be appropriate for the type and stage of the project and that the request not be made too early in the study. Inappropriate forecast requests or changes to an initial request may result in delays in completing the project forecast. In order to ensure that the level of forecast detail requested is appropriate, the District Project Manager should include a copy of the Commission Minute Order or the Investigation and Planning Expense (IPE), Form 254 Rev., authorizing the work with the request for a traffic forecast form.

Requests for traffic forecasts for project planning should be sent directly to the Traffic Analysis Group Manager in TPP. The Group Manager will work with the individual forecasting group leader to schedule preparation of the traffic forecast and will notify the District Project Manager of the approximate date of completion. Scheduling conflicts will be resolved through consultation with affected District Project Managers and the Traffic Analysis Group Manager.

A standard form has been developed to assist District Project Managers in making the traffic forecast requests (Figure 1). This form requests general project information required for

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administration purposes as well as more specific information required to prepare the traffic forecast. Should the District Project Manager determine to change the forecast or the forecast data, a letter should be attached to the request form listing the changes and explaining the reason for those changes. The Traffic Analysis Group Manager will determine if the changes are reasonable, justifiable, and necessary to properly analyze the project. The Traffic Group Manager will notify the Project Manager in writing of the decision to approve or deny the requested variation in traffic forecast or related data. If the request is denied, an explanation of why it was denied will be provided.

By April of each year, District Offices and Divisions should forward a list of projects that will need traffic forecasts during the coming fiscal year. The project list should be grouped by project type (feasibility study, new location, project planning study, advanced planning, design, pavement, etc.) and should include an approximate deadline for submitting the data. A specific request for traffic data should be submitted approximately three months prior to that deadline, using the form in Figure 1. This information will enable TPP to organize, schedule, and manage requests for traffic forecasts more effectively. Preparation of forecasts will be scheduled according to individual project schedules, TxDOT priorities, and available resources. Additional traffic forecast requests or changes to existing requests may be made at anytime by notifying the Division. Such requests will be scheduled according to the same above criteria.

Type of project   _____   Feasibility Study
                                   _____   Advanced Planning
                                     If advanced planning, will there be more than 1 alternative?
                                              _____   Yes   _____   No   If yes, approximately how many alternatives?
                                     _____   Environmental
                                     If environmental, is the project EA or EIS? _____
                                     _____   PS&E
                                     _____   Final Design
                                     _____   Pavement Design
                                     _____   Other, please specify_____

Dist No.   _____   Project Manager_____ Date   _____

County _____   Highway No. or
Name_____

Control No.   _____   Section No._____ Length   _____   (metric/miles)

Scope of Project _____

End Product of Authorized I.P.E.   _____

Current State of Project Development_____

Has there been previous preliminary work on this project?   _____   Yes   _____   No

Provide a general description of the transportation improvement(s) being studied _____

Project Data (to be provided by Project Manager)

Base Year

_____

Design Year

_____

Facility Type (controlled access highway, divided highway, FM, major urban arterial, etc.)

_____

No. of existing lanes_____

No. of proposed lanes_____

Additional data:

1.   Current land use maps along the facility and the location of major traffic generators.

2.   Past and current traffic counts for the facility and major cross-streets.

3.   Map showing facility alignment; new location projects to include the length (meters/ft) for each link of the facility

Figure 1. Request for Traffic Forecast

FUNCTIONS OF THE TRANSPORTATION
PLANNING AND PROGRAMMING DIVISION

TPP is responsible for urban, rural, and statewide transportation planning; traffic forecasting; project development and programming; and traffic data collection and analysis. There are five groups within the Division: Administrative, Data Management, Intermodal Planning, Traffic Analysis, and Programming and Scheduling.

Administrative

The Administrative section is responsible for all personnel management and training activities for the Division, employee assistance, purchasing, and internal review. This section also provides oversight for the sale and distribution of maps, serves as the legislative liaison, coordinates the requirements under the Americans with Disabilities Act, and handles special state and national studies.

Data Management

Data Management includes those responsibilities associated with automation coordination, automation security, oversight of the Highway Performance Monitoring System (HPMS) and the Texas Reference Marker System and with maintenance of the Road Life System, the Roadway Data File, the Bridge Inspection File, and the Rail Crossing File. This section is also responsible for state and county highway maps.

Intermodal Planning

The Intermodal Planning section encompasses the statewide and urban transportation planning responsibilities of TxDOT. Specifically, this section oversees the development of the Statewide Intermodal Transportation Plan, coordinates the urban area and state transportation planning efforts, conducts route and feasibility studies, and manages the scenic byway program.

Traffic Analysis

Traffic Analysis is responsible for traffic data collection; traffic forecasting; mobile source air quality analysis; environmental assessments; and traffic analysis for project planning, pavement,

and geometric design. The collection and analysis of traffic data specifically includes vehicle classification, AADT adjustments, permanent recorder data analyses, maintenance of the traffic log data for existing and forecast traffic, truck weigh-in-motion counts, and speed monitoring. This section also prepares the urban transportation travel demand forecasts, traffic forecasts for project planning, design and environmental analysis, traffic data for the Transportation Commission Public Hearings and Project Development Plan and trains personnel in travel demand modeling and corridor analysis.

Programming and Scheduling

The Programming and Scheduling section programs and schedules all TxDOT projects. This section prepares the Project Development Plan, assigns control and job numbers for all projects, and manages federal funding. Additionally, it develops construction letting schedules, verifies monthly lettings, and manages allocation programs and project overruns and underruns for monthly lettings.

THE INTERMODAL SURFACE TRANSPORTATION
EFFICIENCY ACT (ISTEA)

Background

Provisions of ISTEA permit much greater state and local discretion in allocating funds between transit and highways and among levels of the highway system. This has intensified concern over how well models capture the long run effects of distinctly different infrastructural alternatives (travel time, cost, location, etc.). Comparisons between transit and highway options are likely to receive particular scrutiny.

History

With the completion of the interstate highway system, the debate on the reauthorization of the surface transportation legislation focused on the nature and size of the post-Interstate program. The shortage of financial resources remained a serious problem, as did the issues of an increase in the federal gas tax, the level of funding for the program, the amount of flexibility in using those funds for other than highway purposes, the federal matching share, and the degree of authority that local agencies would be given in programming the funds. Other related issues are the continuation of federal transit operating subsidies, developing criteria for new rail systems, and the earmarking of funds for specific highway projects.

The bill signed into law by President George Bush on December 18, 1991, opened a new era in surface transportation. ISTEA authorized $151 billion over six years for highways, mass transit, and safety programs. The Act created a surface transportation program with flexible funding that provided new opportunities to address statewide and urban transportation problems.

The purpose of the Act was set forth in its statement of policy: "It is the policy of the United States to develop a National Intermodal Transportation System that is economically efficient

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*Information in this chapter is based on *A Manual of Regional Transportation Modeling Practice for Air Quality Analysis*, by Greg Harvey and Elizabeth Deakin, National Association of Regional Councils, July 1993.

and environmentally sound, provides the foundation for the Nation to compete in the global economy, and will move people and goods in an energy efficient manner."

National Highway System

Title I, Surface Transportation, established a new National Highway System (NHS) consisting of 155,000 miles (plus or minus 15 percent) of interstate highways, urban and rural principal arterials, and other strategic highways. The final system was to be proposed by the Department of Transportation, after consultation with the states, and be designated by law by September 30, 1993. In the interim, the NHS was to consist of highways classified as principal highways. The NHS was funded at $21 billion over six years at an 80 percent federal matching share. States could transfer up to 50 percent of their funds to the Surface Transportation Program and, with approval of the Department of Transportation, up to 100 percent in states with nonattainment areas.

Funding was provided for the completion of the remaining links of the interstate system and for continuation of the interstate maintenance and interstate transfer programs.

Surface Transportation Program

ISTEA created a new block grant program, the Surface Transportation Program (STP), which made funds available for a broad range of highway, mass transit, safety, and environmental purposes. STP funds can be used for highway construction, bridge projects, transit capital projects, carpool, parking, bicycle and pedestrian facilities, highway and transit safety improvements, transportation control measures (TCMs), and wetland mitigation efforts.

The STP was authorized at $23.9 billion over six years at an 80 percent federal matching share. Additional funds could be transferred to the program from the so-called equity adjustments. Each state is required to set aside 10 percent of the funds for safety construction activities and another 10 percent for transportation enhancements which include bicycle and pedestrian facilities, acquisition of scenic easements, landscaping, preservation of abandoned rail corridors, archaeological research, and mitigation of water pollution from highway runoff. The remaining 80 percent must be allocated statewide.

Congestion Management and Air Quality Programs

A new Congestion Mitigation and Air Quality Improvement Program was established with an 80 percent federal matching rate for transportation projects in ozone and carbon monoxide nonattainment areas. Such projects are required to contribute to areas meeting National Ambient Air Quality Standards. If a state does not have any of these areas, it could use the funds as if they were STP funds. The funds are to be distributed based on each state's share of population in nonattainment areas weighted by the degree of air pollution. A minimum apportionment of 1/2 percent was guaranteed to each state.

Congestion Pricing Program

A Congestion Pricing Pilot Program was established for five congestion pricing pilot projects with up to three of them on interstate highways. The program was funded at $25 million annually with a 50 percent federal matching share.

Other Programs

Special projects and programs were created in several areas. The National Magnetic Levitation Prototype Development Program was authorized at $725 million to develop a prototype maglev system selected from applicants across the nation. A Maglev Project Office was to be established jointly between the Department of Transportation and the Corps of Engineers.

A separately funded $25 million High Speed Ground Technology Development Program was created to demonstrate and promote new high speed ground transportation technologies already under construction or in operation. Another provision of the Act allowed the use of federal-aid highway rights of way for commuter or high speed rail, maglev systems, and mass transit facilities where there was sufficient land or space and such use would not adversely affect automobile safety.

Tolls were permitted on federal-aid highway facilities to a much greater degree than in the past. Projects that would become eligible for federal funding were expanded to include initial construction of toll facilities, 4R (Resurface, Restore, Rehabilitation, Replace) work on toll facilities, and reconstruction or replacement of free highways (except interstate facilities), bridges and tunnels, and conversion of toll facilities. The federal matching share for highway projects was 50 percent (50 or 80 percent for bridges or tunnels, depending upon the nature of the work).

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The Bridge Replacement and Rehabilitation program was continued with minor changes. Up to 40 percent of a state's funds could be transferred to the NHS or STP. In addition, 539 special projects were Congressionally designated at a total cost of $6.2 billion.

ISTEA also created a program to fund state planning, design, and development activities of scenic byways.

The Planning Process

ISTEA's impact on the planning process is of particular interest to those who would develop and apply travel demand models and forecasts. ISTEA strengthened the metropolitan planning process and expanded the role of the Metropolitan Planning Organizations (MPO) in project selection and transportation decision making. Under ISTEA, MPOs continue to be required in all urbanized areas with populations of 50,000 or more. Existing MPOs remain unless revoked by the governor and local units of government representing 75 percent of the affected population in the metropolitan area (or as otherwise provided under state or local procedure). New MPO designations or redesignations can be made by agreement between the governor and local units of government with the same representation as required for revocation. More than one MPO can be designated for an urban area if the governor determines that the size and complexity of the area warrant it. In urban areas with more than one existing MPO, planning organizations are to coordinate plans and programs with each other and the state.

Metropolitan area boundaries were defined to carry out the metropolitan transportation planning process and for expenditure of STP funds suballocated to areas over 200,000 in population. The boundaries are to be established by agreement between the governor and the MPO and are to be urbanized during a 20-year forecast period, possibly extending to the MSA or CMSA boundary. In nonattainment areas, the boundary has to encompass the nonattainment area unless the MPO and governor decided to exclude a portion.

Large urbanized areas over 200,000 in population were designated as transportation management areas (TMAs). These areas have additional requirements related to congestion management, project selection, and certification. The governor and MPOs could request additional designations as TMAs.

Under ISTEA, each metropolitan area has to prepare a long range plan, updated

periodically, that identifies transportation facilities which function as an integrated transportation system. Such plans will include a financial strategy, assess capital investment and other measures to preserve the existing transportation system, make the most efficient use of existing transportation facilities to relieve congestion, and indicate appropriate enhancement activities.

ISTEA requires MPOs to include consideration of 15 interrelated factors in the development of their 20-year metropolitan transportation plan. One important factor is the effect of transportation decisions on land use and development and their consistency with land use and development plans. Abbreviated planning procedures can be used for areas not designated as TMAs based on the complexity of the transportation problems. Abbreviated procedures are not allowed in nonattainment areas for ozone and carbon monoxide (CO).

In TMAs, the transportation planning process has to include a congestion management system (CMS) for the effective management of new and existing transportation facilities through the use of travel demand reduction and operational strategies.

MPOs are required to develop a Transportation Improvement Program (TIP) in cooperation with the state and transit operators. The TIP must be updated at least every two years and approved by the MPO and governor, with a reasonable opportunity for public comment prior to approval. The TIP must include a priority list of projects and a financial plan consistent with the funding that can reasonably be expected to be available.

In TMAs, all projects, except those on the NHS and projects under the bridge and interstate maintenance programs, are to be selected by the MPO in consultation with the state from the approved TIP in accordance with the priorities established in the TIP. Other projects are to be selected by the state in cooperation with the MPO from the approved TIP. In all other metropolitan areas, all projects are to be selected by the state from the approved TIP, in cooperation with the MPO.

Federal certification of the transportation planning process is required for TMAs at least every three years. TMAs that are not certified are subject to funding sanctions. One percent of highway funds, except those for interstate construction and substitution, are authorized for metropolitan transportation planning. Additional funds can be spent from the NHS and STP programs. States are required to develop formulas for distributing planning funds based on population, status of planning, metropolitan transportation needs, attainment of air quality

standards, and other factors necessary to carry out applicable federal laws.

ISTEA also created a new requirement for states to undertake a continuous statewide transportation planning process modeled on the metropolitan planning process. States are required to develop a long range plan covering all modes of transportation. The Act also requires coordination with metropolitan transportation plans and opportunity for public input. The state plans and programs are to provide for the development of transportation facilities that function as an intermodal state transportation system. As in the metropolitan planning requirement, specific factors are mandated for inclusion.

Metropolitan Transportation Planning Process Elements

As noted above, ISTEA is very specific about what must be addressed in the metropolitan planning process. While methods and analytical procedures are generally not specified, ISTEA mandates that the following factors be explicitly considered, analyzed as appropriate, and reflected in the products of the planning process:

- Preservation of existing transportation facilities and (where practical) ways to meet transportation needs by using existing transportation facilities more efficiently.

- Consistency of transportation planning with federal, state and local energy conservation programs, goals, and objectives.

- The need to relieve existing congestion and to prevent future congestion. Such consideration includes congestion management strategies which improve the mobility of people and goods, as well as CMS based on travel demand reduction and operation management strategies. These elements are to be considered at all stages in the planning process.

- Impacts of transportation policies on land use and development, including the consistency of transportation plans and programs with land use and development plans.

- Programming of expenditures for transportation enhancement activities as required by the Surface Transportation Program (23 U.S.C. 133).

- Effects of all transportation projects to be undertaken within the metropolitan area, regardless of source of funding. This analysis must include project effectiveness, cost effectiveness, and financing vis-a-vis meeting transportation demand and transportation system performance, including impacts on community goals

regarding economic development, housing, and employment.

- International border crossings and access to ports, airports, intermodal transportation facilities, freight distribution routes, recreational areas, and military installations. Analysis should include goods and services problem areas, as well as intermodal facility access.

- Connectivity of roads within metropolitan planning areas with roads outside of those areas.

- Transportation needs identified through the use of the management systems required under 23 U.S.C. 303.

- Preservation of rights-of-way for construction of future transportation projects, including corridor projects.

- Freight movement enhancements.

- Use of life cycle costs in the design and engineering of bridges, tunnels, or pavement. Operating and maintenance costs must be explicitly considered in analyzing transportation alternatives.

- The overall social, economic, energy, and environmental effects of transportation decisions. The effects of the plan on housing, employment, and community development with the appropriate emphasis on transportation related air quality problems should also be included.

- Expansion, enhancement, and increased use of transit services.

- Capital investments that would result in increased security in transit systems.

ISTEA further requires certain additional aspects of the planning process itself which include:

- A proactive public involvement process in connection with the transportation plan, including timely public notice, full public access, and early and continuing public involvement in plan development.

- Consistency and compliance with the 1964 Civil Rights Act.

- Compliance with the Americans with Disabilities Act.

- Involvement of traffic, ridesharing, parking, safety, and enforcement agencies as well as other operators (public and private), toll authorities, and city officials.

- Involvement of local, state, and federal environmental, resource, and permit agencies.

Simplified procedures may be developed and proposed for attainment areas not designated as TMSs. Finally, appropriate reports and documentation of the planning process is required. Major investment studies may be conducted in addition to these requirements.

TRANSPORTATION-AIR QUALITY PLANNING REQUIREMENTS
Background

ISTEA requires models which can estimate the impacts of various transportation alternatives in a number of areas. One particularly challenging aspect of transportation planning and analysis is air quality. The data and models prepared in response to ISTEA will play a major role in meeting the various requirements of the Clean Air Act (CAA). These data and models will be the basis of mobile source inventory preparation and updates, as well as mobile source emissions monitoring and tracking. The data and models will also be critical to TCM analyses and to evaluations of the conformity of transportation plans to the State Implementation Plan (SIP) for attainment of the National Ambient Air Quality Standards (NAAQS) for ozone, CO, oxides of nitrogen (NO_x), and particulates.

Mobile Source Inventories

Emissions inventories will be key determinants of the emphasis on transportation activities in air quality planning since the updated inventories will be used to establish the relative contributions, current and projected, of mobile sources and stationary sources, as well as to help identify and evaluate potential control measures. Although emissions inventories can be prepared in various ways, most mobile source emissions inventories draw upon metropolitan area transportation models and data.

In order to assemble inventories of mobile source emissions, accurate information specific to each metropolitan area is needed about the nature and extent of vehicular travel. Mobile source inventories must be produced for 1990 (the base year), for the projected attainment year, and in some cases, for one or more years in between. Items on which inventory estimates are based include:

- Vehicle miles traveled (VMT) - the number of miles traveled by vehicles of various types, preferably for each link of the highway system (or at least for each grid cell in a metropolitan area photochemical dispersion model). In Texas, VMT is determined by time-of-day, day-of-week, vehicle type, roadway classification, and area type.

- Speed - the average speed for vehicles on each link in the highway system. For many analyses, this is needed by time-of-day.

- Vehicle fleet characteristics - the number of vehicles of each EPA type "garaged" in the metropolitan area. These data often include categories of light duty and heavy duty, as well as engine type, age, etc.

- Vehicle trips - the number of trips originating and ending in each geographic subarea, grid cell or zone.

While default estimates are available for many of these items (usually based on national or state averages), metropolitan area travel surveys and output from travel models are frequently used to help prepare the emissions inventory. The base year inventory may be estimated directly from traffic counts and other available data, but projections of future year inventories are difficult without the aid of a metropolitan area travel model. In practice, base year inventories are often developed in whole or in part from model runs as well, because of the limitations of centrally available traffic data in many urban areas.

More refined emission estimates could be prepared using data from travel models. For example, running emissions, comprising up to half of the volatile organic compound (VOC) and CO mobile source output, are proportional to miles traveled, with per-mile rates that vary significantly with speed. Start-up emissions (both cold start and hot start), comprising about one half of the CO inventory and one-third of the VOC inventory for mobile sources, occur in the first several minutes of vehicle operation. Hot soak emissions occur when the vehicle is turned off at the end of the trip. The count of garaged vehicles determines the localized output of diurnal VOC emissions. All of these elements of the mobile source emissions inventory can be estimated from data taken from travel surveys and models.

Recent research by the Environmental Protection Agency (EPA) and others suggests that two other factors may be a significant portion of VOC and CO running emissions and may need to be accounted for as well:

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- Occurrences of high acceleration - the average duration and number of instances of high acceleration (such as might occur at a freeway ramp, especially with a metering light) in each grid cell.

- Occurrences of extended idling and delay - such as might occur on congested highway segments or at toll booths, by link or by grid cell.

Most transportation models currently do not account for these occurrences explicitly (microscopic traffic operations simulation models are an exception), but in the future such details may need to be taken into account.

VMT Estimation and Tracking

In future years, the VMT estimates on which plans are based will be compared to "actual" VMT estimates derived from field studies or other sources. The CAAA provide much incentive for an area to develop the most reliable VMT (and other) data and forecasts it can. Over-predictions of VMT and other travel indicators will lead to overestimation of the need for emissions controls. Under-prediction could result in difficulties in making conformity findings and achieving air quality progress goals, which in turn could trigger a need to apply drastic mitigation measures when problems become apparent (possibly more extensive and expensive than additional controls would have been at the outset).

Current guidance from EPA calls for data from the Federal Highway Administration sponsored HPMS to be used in estimating current VMT even though in some areas there are too few sample counts for these data to be reliable. In these cases, alternative methods will be applied instead of or in addition to using HPMS data. In general, forecasts are based on growth rates derived from regional travel models.

A major concern is that past model-based projections of VMT, trips, and vehicle ownership have tended to be low. For example, trend data in some regions indicated VMT growth of 3 percent to 4 percent, while models predicted VMT growth of only 1 percent to 2 percent. In addition, errors often have been concentrated in fast growing parts of the region (typically the suburbs) and among certain categories of traveler (in particular, women). This has led air quality agencies to seek a better understanding of travel forecasting methods and their performance and to ask for assurances that the sources of past errors have been understood and corrected. Periodic

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comparisons of traffic counts and other measured data with forecasts are expected to provide a basis for model evaluation, problem diagnosis, and correction.

Instead of refining model-based estimates, an alternative would be to simply base VMT, trips, and vehicle ownership estimates on extrapolations from past trends. However, using extrapolations in air quality planning and model-based estimates in other aspects of the transportation planning process could lead to awkward divergences in estimates (unless transportation model results were adjusted to agree with trend projections). This could entail some risk for the modeling agency (typically the MPO). In addition, model-based projections of growth can take into account numerous details concerning changes in the composition, location, and magnitude of population and employment; whereas, most extrapolations are much simpler and, hence, much less rich in their reflection of factors underlying posited changes. Thus, model improvements designed to improve forecasts of VMT and other travel indicators seem the preferable route to most analysts, even though such improvements may be relatively costly and time consuming.

Conformity Analyses

The conformity provisions of the CAAA pose one of the biggest challenges most transportation organizations will face in transportation-air quality planning and analysis. Both federal actions and certain activities of the MPOs themselves are subject to the conformity provisions which basically require that plans, programs, and projects conform to the applicable SIP for achieving clean air and must be found not to lead to new violations of the National Ambient Air Quality Standards, exacerbate existing violations, or interfere with attainment of the standards or compliance with interim emission reduction requirements.

The conformity provisions focus attention on the model's credibility in estimating medium to long run plan and program impacts. For example, under the interim guidelines for determining the conformity of transportation plans and programs to SIP assumptions and commitments, the MPO is required (among other things) to compare the full TIP to the nonattainment area with a no-build scenario. After approval of a revised SIP, the comparison will be to motor vehicle emission estimates and necessary reductions contained in the SIP. Both types of analyses are likely to receive close scrutiny by environmental and other interest groups who will seek a demonstration

that all phenomena which plausibly could affect such a comparison have been taken into account.

Transportation Control Measure Analyses

The CAAA of 1990 require that only the more heavily polluted metropolitan areas include TCMs in their SIPs. However, other areas may be required to include TCMs under state law, or they will do so by choice after considering the available pollution control options. As noted above, ISTEA further encourages the consideration of TCMs and related strategies. As a result, estimates of TCMs' effectiveness will be needed by numerous regions.

The inclusion of TCMs in regional transportation modeling has often proven to be a complex matter. Capital investments, which also happen to be TCMs (such as transit extension or HOV lanes), generally can be adequately represented in regional model systems, but many other TCMs (rideshare incentives offered in only selected corridors, transit subsidies available only in some areas or to some users) are likely to place heavy demand on regional travel and data models. Moreover, typical regional models are unequipped to handle many TCMs, including signal timing, ramp metering, elements of employer-based demand management programs, many land use and urban design measures, and pricing strategies.

Evidence from a variety of TCM implementation experiences has been compiled as a basis for initial screening of TCMs, and simple sketch planning methods sometimes embody this evidence in spreadsheets. While these methods are useful if carefully applied and thoughtfully interpreted, the use of "transfer experience" approaches to justify TCMs has proven vulnerable to challenges. For example, business groups are unhappy about proposed employer-based requirements while environmental groups are distrustful of benefits claimed for added HOV lanes and traffic flow improvements. Hence, MPOs may find that they either will have to extend the behavioral reach of their models (add explanatory variables relevant to TCMs) or find ways of grafting credible off-model (or supplementary model) estimates of TCM impacts onto conventional model results.

CLEAN AIR ACT TRANSPORTATION REQUIREMENTS

As the overview of transportation-air quality analysis requirements has illustrated, the CAAA of 1990 affect transportation planning in a variety of ways. Because of the importance of

this legislation for many MPOs, a detailed review of key provisions is presented in this section.

General Provisions

The CAAA of 1990, like the Amendments of 1970 and 1977, rely on a combination of locally-developed SIPs and federally-mandated controls for attainment of national ambient air quality standards for ozone, CO, NO_x, and particulates (PM10) by statutory deadlines. However, the 1990 amendments greatly expand and add specificity to the requirements for ozone and CO nonattainment areas. They also establish, for the first time, deadlines which vary with the pollutant and the severity of the pollution problem and allow later deadlines with more extensive requirements for the more polluted areas.

Titles I and II of the CAA set forth air pollution prevention and control emissions standards for moving sources, respectively. Among other things, Title I establishes the process for designating and classifying nonattainment areas, authorizes the EPA to determine nonattainment area boundaries, defines nonattainment area classifications, establishes deadlines and requirements to match the severity of pollution, sets forth plan development procedures and review criteria, defines criteria and schedules for imposing sanctions (highway and emission offsets) and for promulgating Federal Implementation Plans (FIPs).

Title II directs the federal government to phase in a variety of mobile source controls, including tighter HC, CO, and NO_x tailpipe emission standards for cars and trucks beginning with 1994 models; reduced new-car evaporative emissions during refueling; more tightly controlled fuel quality (e.g., controlled for volatility and sulfur content); mandated re-formulated gasoline (beginning in 1995) for the most severely polluted ozone nonattainment areas; oxygenated fuels during winter months for areas designated as moderate or serious for nonattainment of CO standards; and a clean fuel pilot program for Los Angeles. To a large extent, transportation planners will depend on the emission reductions which should result from Title II programs and will follow the provisions of Title I to develop other measures, as needed, to meet the ambient air quality standards for the applicable deadlines.

Sections 110 (Implementation Plans) and 172 (Nonattainment Plan Provisions in General) of Title I cover requirements which apply to all nonattainment areas' SIPs. These sections of the amendments set forth objectives and procedures for SIP adoption and revision and require

enforceability and timely implementation of control measures.

Section 110(a)(2) states that each implementation plan shall:

- include enforceable control measures and schedules for compliance necessary to meet the Act's requirements;

- provide necessary assurances that the state (or general purpose local governments or regional agencies) will have adequate personnel, funding, and authority under state and local law to carry out the implementation plan (and is not prohibited by any provision of federal or state law from carrying out the implementation plan);

- provide necessary assurances that, where the state has relied on a local or regional government agency for the implementation of any plan provision, the state has responsibility for ensuring adequate implementation of such plan provision; and

- meet requirements for intergovernmental consultation and participation in plan development, and for enhanced public notification on pollution and health, public awareness of control measures, and public participation in regulatory actions.

Section 172(c) requires that nonattainment areas' SIP revisions must:

- provide for the implementation of all reasonably available control measures as expeditiously as practical;

- require reasonable further progress (RFP) (defined as "such annual incremental reductions in emissions as . . . may reasonably be required . . . for ensuring attainment of the . . . standard by the applicable date"); and

- include contingency measures to take effect without further action by the state or EPA if the plan fails to make RFP or to attain the standard by the applicable attainment date.

Other provisions of Title I establish due dates and deliverables. The time allowed for the first major submissions under the 1990 amendments is short. Updated emission inventories, including current and projected mobile source contributions to total emissions, were due in November 1992. Revised SIPs also were due in November 1992 in CO attainment areas (at the same time as the updated emissions inventories) and in November 1993 for ozone nonattainment areas. These plans must include control measures as needed to demonstrate attainment by the applicable deadline(s).

Beyond these tight initial deadlines, the amendments emphasize a continuous transportation-air quality planning and decision-making process. Updates of state and local planning procedures,

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renewals of assignments of responsibility, and provisions for involvement of elected officials are mandated. Nonattainment areas must periodically assess VMT, vehicle trip levels, congestion, and emissions, and, based on their findings, must prepare SIP revisions as needed to offset emission levels which exceed those assumed in the SIP. EPA's Transportation-Air Quality Planning Guidelines are to be updated as necessary to maintain a continuous planning process and must include methods for reviewing plans on a regular basis. Determinations of the conformity of transportation plans, programs, and projects to the SIP must be made no less frequently than every three years, with revisions to transportation proposals as needed. Finally, the U.S. Department of Transportation (DOT) and EPA must submit a report to Congress every three years beginning in 1993 assessing how well federal, state, and local air quality-related transportation programs are achieving the goals of, and compliance with, the CAA.

Emissions Inventories and Emission Budgets

One SIP revision activity of critical interest to transportation agencies is determining emission reduction targets for transportation. Based on the updated emissions inventories, the respective contribution of stationary and mobile sources to total emissions and pollution levels will be determined. This will result in an "emission reduction budget" being assigned to mobile sources, i.e., to the transportation sector.

Emission reduction budgets will indicate the clean-up burden that will be placed on transportation plans and programs, as well as the extent to which TCMs will be needed. Also, staying within this budget will be one of the tests of transportation plan and program conformity with the SIP. If unrealistically large emission reduction targets are assigned to transportation sources and placed in the SIP, conformity demonstrations will be difficult to make; without such demonstrations of conformity, projects could be delayed or stopped. Thus, it is in the best interest of transportation agencies, including state DOTs and MPOs and interested local agencies, to participate in the evaluation of relative emission contributions and the needed mix of stationary and mobile source controls.

Transportation Control Measures

TCMs are required only for some nonattainment areas and for some circumstances under the 1990 amendments. Otherwise, the choice of whether to use TCMs and what TCMs to use is discretionary with state and local officials, as long as the overall set of control measures can reduce emissions to show attainment by the applicable deadline(s). Nevertheless, many areas will need to analyze a range of TCMs, as many are likely to need to implement at least some of them in order to meet interim milestones as well as ultimate deadlines.

MPOs play a key role in analyzing TCMs and in recommending which ones to include in the SIP. MPO roles are further underscored by ISTEA which gives MPOs increased responsibility for and control over the programming of projects within their boundaries and in nonattainment areas provide special funds for TCM implementation (congestion management/air quality funds).

Once TCMs are adopted in an approved SIP, their timely implementation will be a key criterion in future conformity determinations. If TCM implementation does not proceed on schedule, conformity demonstrations could be difficult to make, with the result that projects requiring federal approval or assistance could be delayed or stopped.

EPA has issued several documents to assist in TCM planning, analysis, and implementation, including an update of its 1978 Transportation-Air Quality Planning Guidelines as well as information on the 16 TCMs listed in Section 108 (Cambridge Systematics, et al., March 1992). These documents can serve as valuable starting points for MPOs in deciding how to proceed with TCM evaluation.

The Transportation-Air Quality Planning Guidelines produced by EPA cover planning and programming activities necessary to respond to CAA transportation requirements. Developed with input from the U.S. DOT and state and local officials, this document's primary purpose is to provide guidance for planning and implementing transportation measures needed to achieve emission reductions in accordance with CAA requirements. The guidelines include information on how to:

- identify and evaluate alternative planning and control activities;

- review plans on a regular basis as conditions change or new information is presented;

- identify funds and other resources necessary to implement the plan and obtain interagency agreements on providing such funds and resources;

- assure participation by the public in all phases of the planning process; and

- carry out a continuous planning process.

The TCM information documents provide general guidance on the emission reduction potential of each type of TCM, discuss other benefits and costs of TCMs, and identify implementation issues. The information is intended to serve as a starting point for TCM evaluation. It is not, however, a substitute for locally-conducted analyses of TCMs nor for local consultation on various measures' acceptability. State and local transportation and air quality officials must determine what measures are "reasonably available" (i.e., are cost-effective and feasible) in their urban area based on the characteristics of the region's transportation systems, its population and employment characteristics, its institutional and financial capacities, and community responses to the various proposals.

Conformity

Section 176(c) of the CAA requires departments, agencies, and instrumentalities of the federal government to assure that activities they engage in, assist, approve, fund, license, or support in any way are in conformity with applicable SIPs. Similar requirements apply to MPOs in approving projects, programs, and plans. The EPA, with the DOT's concurrence, is responsible for promulgating criteria and procedures for demonstrating and assuring conformity.

The CAA states that conformity to a SIP means conformity to the plan's purpose of eliminating or reducing the severity and number of violations of the National Ambient Air Quality Standards and that activities will not cause or contribute to a new violation of any standard, increase the frequency or severity of an existing violation, or delay timely attainment of any standard or interim milestone. In addition, transportation plans and programs conform only if: (1) emissions from such plans and programs are consistent with emissions projections and reductions assigned to those transportation plans and programs with the SIP, i.e., are consistent with the emissions budgets or targets; and (2) the plans and programs provide for timely implementation

of SIP TCMs consistent with SIP schedules.

Sanctions

Sanctions for failure to comply with the CAA, including the withholding of funds for certain highway projects, were an option under the 1977 amendments; but the EPA imposed these sanctions in a very limited fashion. For example, since 1980, the EPA imposed highway sanctions in just seven states; and in five of these states they applied the sanctions to just one urban area. Moreover, in three of the seven states, the sanctions were in effect for less than two months; in two others they were in effect for less than two years. Overall, few highway projects were delayed and few federal highway dollars were withheld.

Highway sanctions may increase in importance under the 1990 amendments. First, because certain other sanctions were deleted, highway funding restrictions could become the primary sanction available. Second, highway sanctions can now be applied statewide under certain circumstances. Third, while sanctions formerly were applied only when an area failed to submit, or make reasonable efforts to submit, a SIP, sanctions may now be triggered when the EPA disapproves a SIP or a state fails to make any submission required by the Act or implement any provision in an approved SIP. Moreover, highway sanctions can be imposed for failures not related to transportation or mobile sources (e.g., for failures related to stationary source measures). Finally, EPA discretion in determining when to impose sanctions has been reduced, with the amendments making the criteria more explicit that could result in highway funding restrictions and prescribing a relatively limited list of projects that can be exempted from sanctions (high-occupancy vehicle [HOV] incentives, single-occupancy vehicle [SOV] disincentives, and congestion relief measures.)

Specific Requirements for Ozone Nonattainment Areas

Specific requirements apply to ozone nonattainment area SIPs in addition to the general SIP requirements described earlier. Deadlines and other requirements are based on the severity of ozone pollution. Requirements are cumulative and escalate in stringency by nonattainment area classifications as the severity of pollution increases. The six classifications, corresponding design values, and attainment dates are:

Table 1
Ozone Nonattainment Area Classifications

Classification	Design Value (PPM)	Attainment Date
Marginal	.121-.138	11/15/93
Moderate	.138-.160	11/15/96
Serious	.160-.180	11/15/99
Severe 1	.180-.190	11/15/05
Severe 2	.190-.280	11/15/07
Extreme	.280 and above	11/15/10

As of July 1993, 42 areas were classified as "marginal", 31 as "moderate", 14 as "serious", 9 as "severe", and 1 as "extreme" for ozone nonattainment.

Areas with the worst air quality must implement the most stringent and the greatest number of controls. For example, areas classified as "moderate" must require Reasonably Available Control Technology (RACT) for stationary source controls on new and existing 100-ton sources of VOC (not covered by EPA Control Technique Guidelines); "serious" areas must require RACT on 50-ton sources; "severe" areas must control 25-ton sources; etc. Emissions from new sources are subjected to increasingly more stringent offset requirements ranging from a 1.1 to 1 offset in "marginal" areas to a 1.5 to 1 offset in "extreme" areas. Vehicle inspection/maintenance programs similarly must be more rigorous in the more polluted areas.

An area's classification also determines the number and stringency of transportation requirements, covering both the planning and programming of TCMs imposed by the Act.

RFP requirements may be among the most difficult for MPOs to meet. Ozone areas classified "moderate" and above should have submitted SIP revisions by November 15, 1993, that demonstrate plans to achieve a percentage VOC emission reduction from a 1990 baseline by November 15, 1996, (defined as an area's total, actual VOC and NO_x emissions during 1990.) In addition, emissions due to growth must be offset. Reductions from several federal mobile source control programs promulgated before the 1990 amendments were adopted, including tailpipe standards, evaporative emission controls, and fuel volatility standards, may not be credited towards the 15 percent reduction.

Less than a 15 percent 1990-1996 reduction would be acceptable only if the 1993 SIP revisions:

1.   implement new source review requirements applicable to "extreme" areas;

2.   apply RACT to all existing major sources;

3.   implement all measures that can be feasibly implemented in the area in light of technological feasibility; and

4.   demonstrate that the plan contains control measures achieved in practice by similar sources in nonattainment areas of the next higher classification.

Additional RFP requirements apply for those areas classified as "serious" or worse. A SIP revision due November 15, 1994, for such areas must demonstrate an additional VOC reduction of 3 percent annually, averaged over each consecutive three-year period after 1996 until attainment. This RFP requirement also excludes major federal mobile source control measures promulgated prior to 1990. However, reductions from federal measures promulgated after 1990 could be credited toward the annual 3 percent reductions required after 1996. Reductions of less than a 3 percent annual average can be allowed only if conditions 3 and 4 listed above are met.

Neither the required reductions nor the alternative conditions are expected to be easy to meet, and many areas are likely to need to implement TCMs to meet RFP requirements.

The scheduled emission reduction requirements applying to "serious", "severe", and "extreme" ozone nonattainment areas are called milestones. The first milestone is the 15 percent reduction from 1990 VOC levels; to be accomplished by 1996; the next milestones are the 3 percent annual average reductions over each consecutive three-year period thereafter until attainment is demonstrated (subject to the options for lesser reductions if other conditions are met, as described earlier). Areas must demonstrate to the EPA that these milestones have been met. Areas failing to submit a compliance demonstration or to meet a milestone must choose one of the following: (1) re-classify to the next higher category and implement more stringent requirements, (2) implement additional control measures from the applicable contingency plan which could include TCMs, or (3) adopt an economic incentive and transportation control program.

The following TCMs are listed in Section 108(f) of the 1990 Amendments:

1.   Programs for improved public transit

2.   Restriction or construction of certain lanes or roads for use by buses or HOVs

3. Employer-based transportation management programs including incentives

4. Trip reduction ordinances

5. Traffic flow improvement programs that achieve emissions reductions

6. Fringe and corridor parking facilities serving HOV and transit

7. Programs to limit or restrict vehicle use downtown or in other areas of emission concentration, particularly during peaks

8. HOV/ridesharing service programs

9. Time or place restrictions of road surfaces or areas to bikes and pedestrians

10. Bike storage, lanes, and other facilities, public and private

11. Programs to control extended vehicle idling

12. Programs to reduce extreme cold start emissions

13. Employer-sponsored programs to permit flexible work schedules

14. Localities' SOV trip reduction planning and development programs for special events and major activity centers including shopping centers

15. Pedestrian and non-motorized transport facility construction and reconstruction

16. Programs for voluntary removal of pre-1980 vehicles

Section 182(g)(4), dealing with the consequence of missing VOC milestones, states that an economic incentive program may include state-established emission fees, a system of marketable permits, fees on the sale and manufacture of products, the use of which contributes to ozone formation, and incentives and requirements to reduce VMT in the area, including any of the TCMs identified in Section 108(f). Revenues from such a program are to be used to handle administrative costs (not more than 50 percent of total revenues) and/or to provide emission reduction incentives and assist in the development of lower-polluting control technologies and products.

Milestone requirements may trigger TCMs in areas classified as "serious" or worse. Section 182(c)(5) of the 1990 amendments states that, beginning in 1996 and every third year thereafter, such areas must submit a demonstration as to whether current aggregate vehicle mileage, aggregate vehicle emissions, congestion levels, and other relevant parameters are consistent with those used for the area's demonstration of attainment. If levels are found to exceed those projected in the attainment demonstration, a SIP revision must be submitted within 18 months to reduce projected emissions to levels consistent with those in the attainment demonstration. Such a SIP revision must

include TCMs including, but not limited to, measures selected from those listed in section 108(f).

Probably reflecting concerns about TCMs, the amendments indicate that in selecting TCMs, states should ensure adequate access to downtown and other commercial areas and avoid measures that increase or relocate emissions and congestion rather than reduce them. This language also appears in the section for "severe" areas.

TCM requirements apply earlier to areas classified as "severe" or worse. For these areas, the 1992 SIP revisions must identify and adopt transportation control strategies to offset emission increases due to growth in VMT and vehicle trips; to achieve in combination with other controls, the required periodic emission reductions; and to demonstrate attainment.

Employer Trip Reduction Programs also are required in "severe" areas and should have been included as part of the areas' November 15, 1992, SIP revisions. This is the only TCM whose implementation is specifically required in the 1990 amendments. At a minimum, employers with 100 or more employees must implement programs to reduce work-related employee VMT and vehicle trips and must increase the average vehicle occupancy of employee work trips by at least 25 percent above the area average. Employer plans, due by November 15, 1994, must "convincingly" demonstrate compliance by November 15, 1996.

Areas classified as "extreme" nonattainment for ozone must implement all the transportation requirements for "moderate", "serious", and "severe" areas. In addition, each SIP revision for "extreme" areas may contain provisions, applicable during heavy traffic hours, to reduce the use of high polluting or heavy duty vehicles, notwithstanding any other provision of law. Note that the language is permissive, i.e., the use of such measures is discretionary. Currently, only Los Angeles is classified as an "extreme" ozone nonattainment area.

Specific Requirements for CO Nonattainment Areas

The 1990 amendments define two classifications of CO nonattainment areas: "moderate" (design value 9.1 - 16.4 ppm; attainment date December 31, 1995); and "serious" (design value 16.5 ppm and up; attainment date December 31, 2000). Moderate areas are divided into two subclasses, with those having a design value greater than 12.7 ppm required to undertake more stringent measures.

Inventories of CO emissions from all sources were required at the same time as the VOC

and NO_x inventories, November 15, 1992. Updates are required every three years thereafter beginning September 30, 1995. By November 15, 1992, "moderate" CO attainment areas had to submit a SIP revision showing the specific annual emission reductions necessary for attainment of the CO standard by December 31, 1995. However, SIP revisions for all CO nonattainment areas with a design value over 12.7 ppm must contain forecasts of VMT for each year until attainment and must provide annual updates of forecasts and annual reports containing estimates of actual VMT and an assessment of VMT forecast accuracy. The November 15, 1992, SIP revision also had to provide for the automatic implementation of specific measures if "actual" VMT exceeds the VMT forecasted or if an area misses the attainment deadline. These contingency measures are to take effect without further action by the state or EPA and, thus, will require advance planning. (Note, however, that for most areas, EPA expects the RFP requirement to be more of a constraint than the offset requirement.)

Required mobile source controls for CO nonattainment areas are: (1) oxygenated fuels of at least 2.7 percent oxygen content during high CO season (design value of 9.5 ppm or above, SIP revision was due November 15, 1992); (2) enhanced I/M (design value above 12.7 ppm, SIP revision was due November 15, 1992); and (3) clean-fuel vehicle fleet programs (design value above 16 ppm, population greater than 250,000, SIP revision was due May 15, 1994). TCM requirements for "serious" CO areas are similar to those for "severe" ozone areas. By November 15, 1992, areas classified as "serious" for CO were to have submitted SIP revisions that identified and adopted transportation control strategies, with implementation of such measures as necessary to demonstrate attainment. These transportation strategies must offset growth in emissions due to growth in VMT and vehicle trips. Additional documentation, not required for "serious" ozone areas, is required for "serious" CO areas. Their November 1992 SIP revisions were also required to (1) explain a failure to adopt any section 108(f) measure, (2) contain alternative control measures providing comparable emission reductions, or (3) explain why such reduction is not necessary for attainment.

Areas classified as "serious" must also submit a demonstration by March 31, 1996, showing that the emission reduction specified in the 1992 SIP revision, and required by December 31, 1995, has been achieved. If the demonstration is not submitted or the milestone is missed, a SIP revision must be submitted within nine months which implements an economic incentive and transportation

control program and achieves annual emission reductions needed for attainment by 2000 or earlier. Note that the economic incentive and transportation control program is mandatory when the milestone is missed by a "serious" CO nonattainment area, whereas ozone areas that miss a milestone can choose one of three options.

The considerable emphasis put on reducing CO emissions via transportation actions reflects the fact that CO emissions come mostly from mobile sources. However, states and MPOs still will need to determine what mix of strategies will best match their specific CO problems. Since CO concentrations typically are localized rather than region-wide, TCMs which focus on "hot spots" may play a significant role.

CHAPTER 3: INPUT DATA AND ASSUMPTIONS[*]

OVERVIEW

Background

Input data requirements vary according to the goals and objectives of the model. Analyses designed for estimating transit patronage, or the effectiveness of TCMs, will require more input data than models designed for assessing local traffic patterns and flows.

Transportation analysts must also balance the desire for more refined data against budget and time limitations. A careful balancing of modeling objectives and resources is critical.

The input data requirements depend on whether the objective is base year model development (model calibration or validation) or future year forecasting, although there is overlap between the two. All modeling approaches require as a minimum the number of households and employment in each zone plus a highway network. The advanced approach augments these basic data requirements with additional information on income, population, auto ownership, travel costs, and a transit network.

Basic Approach

An acceptable basic modeling approach designed to forecast daily vehicle trips requires only residential (household) and non-residential (employment) data. The household data should be stratified by income or auto ownership and may also be stratified by other significant trip making variables, such as number of persons (household size), structure type, density (units per acre), or workers per household. Stratification of households can be estimated from mean values and existing distribution curves. The employment data need to be stratified into retail and non-retail categories or basic and non-basic employment. (Area may also be used for the non-residential trip end estimation.) All of the data must then be distributed geographically into zones for the model. Major special generators should also be included, such as colleges, airports, and military bases. These models may use land use-based information, such as acres of residential use, acres of

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[*]Information in this chapter is based upon *State of California Department of Transportation Travel Forecasting Guidelines*, California Department of Transportation, November 1992.

industrial use, building permits, or other readily available information rather than socioeconomic data derived from demographic and economic forecasts. Comparisons should be made to reflect the compatibility of the data.

Advanced Approach

An advanced modeling approach includes (in addition to the data required for the basic approach) a stratification of the employment into four or more categories, generally following the Standard Industrial Classification Codes (SIC) or Institute of Transportation Engineers (ITE) land use codes. Cost of travel data (tolls, parking, fares, auto operating costs, etc.) would be required for mode choice and other models. Agency management should determine which approach is most appropriate, although the advanced approach is generally applicable only to the largest metropolitan areas.

SOCIOECONOMIC DATA

Background

Socioeconomic data consist of housing and employment data. These data are supplemented with income and auto ownership data. There is often confusion about the difference between the terms "socioeconomic" and "land use" data. Generally, land use data involve areal units, such as acres or square footage. Socioeconomic data involve direct observations of social or economic characteristics, such as population, auto ownership, or employment. It is possible to go between the two types of data using conversion factors.

Household Income and Auto Ownership

Information on the number of dwelling units, households, population, workers, and household income are among the most straightforward data to obtain for modeling purposes. The decennial U.S. Census provides most of this information at the census tract and block group levels. Transportation analysts must further divide (or aggregate) the data into transportation analysis zones.

Data Use

The number of households or dwelling units in a zone are used to estimate productions by each zone. This is a critical piece of information, since trip attractions are normalized to trip production estimates. Household data are generally preferred to dwelling unit information, since dwelling units may be unoccupied. If dwelling units are used to estimate trips, it is important to specify the definition of dwelling unit to include or exclude vacant dwelling units.

Structure type (such as single family detached or multi family), population, income, and auto availability provide supplementary information that improves the accuracy and sensitivity of the trip generation forecasts. Income and/or auto availability are critical pieces of information for the trip generation and mode choice analysis.

The number of autos/vans/small trucks available for household use shows a considerable correlation with both person trips and vehicle trip generation for the household. It also influences mode choice, since zero-auto households are by definition transit or carpool dependent.

Household income or auto ownership must be included if models have a mode choice component, since low income and/or zero auto households are much more likely to use transit. Because income is highly correlated with the number of trips made, income or auto ownership is desirable even for highway models.

Non-household population is a variable infrequently included in models. This includes persons whose primary or permanent residence is outside traditional housing units: in barracks, dormitories, nursing homes, congregate care facilities, or institutions (hospitals, prisons, etc.). The single characteristic that probably best defines this group is that eating/kitchen facilities are in common (shared). Three unrelated adults sharing a rented single family home should be considered a household for purposes of trip generation analysis.

The importance of group quarters population will depend upon the number of such persons there are. They are classified in the census. In some cases, the non-household population may be treated as part of some larger special generator (like a military base or university).

Data Sources

The Census Bureau (U.S. Department of Commerce) decennial census is the best source of information on current population and housing (including population, age, dwelling unit number and type, etc.), and is available by census tract or block group.

The State of Texas (Texas Department of Commerce) also provides estimates of existing city and county population each year. TxDOT, Division of Vehicle Registration, can provide information on vehicle registration by type of vehicle and county. This is useful in establishing historical vehicle ownership trends. Aerial photos may be helpful, but since the use of a building is difficult to determine (except for single family dwelling units), they are useful mainly for dwelling unit counts in known homogeneous neighborhoods. Aggregation of the large number of photos needed to cover any reasonable size study area is also very labor intensive. Local utilities are a source of new water or electric connections by type of unit and can help determine growth since the last census.

Forecasting Procedures

Planners typically forecast population and household growth using one of two procedures, a "market-based" approach based on demographic and economic trends or a "build out" approach based on the local agency general plans. These procedures are sometimes distinguished as "top down" and "bottom up" approaches.

The "top down" approach is preferred because it is based on national, state, and regional economic and demographic trends which are known to control regional growth. Land use plans, by contrast, can only allocate the growth to specific geographic locations. The ideal forecasting approach combines both approaches, identifying and resolving differences between local general plans and economic reality.

The most important criteria in selecting any method is that it be consistent with the decennial census in terms of the variables produced. Various survey methods that can be used to update the census are discussed below.

Population Forecasts

The State of Texas forecasts the population of the state for five-year intervals for the next 20 years. Recent experience indicates that the greatest source of error in predicting Texas population is in predicting net migration and births, both of which were greater than predicted during the 1980s. Migration depends on state, national, and international conditions that are very difficult to forecast. Births depend on age-specific fertility rates which are also difficult to predict (and are impacted by migration). Population growth is allocated to the counties based on current and estimated share of state growth. Advanced practice often includes in-house cohort survival and migration analysis capability.

Household Forecasts

The current trends in persons per household are extrapolated and modified based on current expectations regarding household formation and family size. Local planning departments typically make forecasts of household size in their general plans. The forecasted number of households is calculated by dividing the population forecast by estimated household size.

Allocation to Jurisdictions and Zones

An acceptable method of doing population forecasts, particularly for shorter periods, is a "shift/share" type model. A shift/share model begins with the assumption that an area has typically "captured" a certain share of growth in the state/region/county. More advanced practice allocates land uses to the traffic analysis zones (TAZ) based on availability of land suitable (physically and legally) for particular uses. The details of this methodology are beyond the scope of this document.

Usually, there is little dispute regarding the total regional forecast. Some local agencies may dispute allocations at the jurisdictional level. Most of the problems are at the zonal level where a great deal of judgment is used to decide which zones get which kind of growth. At this microscopic level, a detailed review by local agency planners is extremely valuable.

Error Checks

Current practice for validating socioeconomic input data include the following:

- Check data against control totals - Sum existing and future zonal population,

household, employment, and other socioeconomic data by city and county for the whole region. Check these totals against control totals for these jurisdictions obtained from census data and independent forecasts for jurisdictions.

- Compare existing to forecasted data by district - Subtract existing data from forecast data at the zone or district level. This will show which zones grow (and which ones don't) in activity level, and may indicate inconsistencies in the forecasting techniques or other errors. Negative growth, in particular, should stand out. A GIS or graphic software color display of this data is especially useful for recognizing errors.

- Check densities - Calculate population, employed resident, and employment densities (persons per acre) for each zone and display it in a GAS format using colors or bar charts keyed to density. Aberrations will be immediately obvious. Look for zones that counter general trends in density.

More advanced practice considers the allocation of socioeconomic data to individual traffic zones. Forecasting this information is best performed with computer software that can automatically and accurately track the totals and the allocations.

Employment Information

Employment data are some of the more difficult pieces of input data to obtain for a model. They are prone to a greater level of uncertainty than household information. The best sources are at the state level. Some analysts have attempted to use commercial floor space instead of employment data; but their models have been difficult to calibrate, since not all floor space is occupied and occupancy densities can vary widely.

Data Sources

There is no single "best" source of employment data. The modeler must trade off accuracy and reliability against the difficulty of obtaining data from each respective source. A brief discussion of some representative sources for both basic and advanced practice follow.

The Texas Department of Commerce has data on the existing number of jobs and employed residents by industry sector and county. They also make short-term projections of future employment. More detailed data by zip code can be obtained on magnetic tape. These data are often subject to "non-disclosure" requirements that may prevent presentation of data to the public

at levels of detail that would allow identification of a specific employer. The 1990 Census Transportation Planning Package (CTPP) provides information on where resident workers are employed.

City or county building and finance departments may have information on building permits and local business employment, especially if the business license tax is based on number of employees. Data vary widely but usually include the workplace address and type of business and sometimes the number of employees on the premises. County assessors can provide information based on their parcel records. Unfortunately, such data require extensive aggregation. Past experience has shown that these records are sometimes inaccurate and that land use codes used for assessment purposes have limited value for transportation planning application.

Commercial business data providers, such as Dun & Bradstreet or DRI, can provide information on existing employment in an area. Information is typically provided at the zip code level, by firm size. It is also possible to obtain individual firm names and addresses which could be aggregated into TAZs using an address matching program. This information is proprietary and somewhat expensive, although it may be less costly than having to do the field surveys or using other primary data collection techniques.

The Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce makes projections of future employment, by sector, for all metropolitan statistical areas (MSA) in the United States. These forecasts project 50 years in some cases.

Forecasting Procedures and Error Checks

The forecasting procedures for employment are very similar to those described above for households. Similarly, the coding and error checking procedures for employment data are identical to those discussed above for household information.

Conformity for Subarea Models

While these models are created primarily to provide more detail within a specific jurisdiction and are designed to be used within that jurisdiction to address specific local concerns, they are also being asked to generate air quality and travel behavior information for use in decision making at the regional level.

The regional transportation planning agency should discuss and determine with local agencies the degree of conformity or consistency required in terms of input socioeconomic forecasts, forecasting assumptions, and forecasting results. Agencies using area-based land use data should also develop socioeconomic data forecasts using conversion factors that will allow for comparison to regional socioeconomic forecasts.

As noted above, the CAA also has specific conformity requirements which these models and analyses must meet.

SPECIAL TRIP GENERATORS

Special trip generation input data are used to estimate the trip making characteristics of specialized land uses (special generators) internal to the region. Special generators are major land uses for which the standard trip generation and distribution equations are not expected to produce reliable estimates of their travel patterns. They augment information from the trip generation portion of the forecasting process.

Special generators should be used wherever trip generation cannot be adequately represented by the standard equations in the trip generation model. At a minimum, special generators should represent airports, colleges, and military bases.

The best special trip generation input data sources include actual field counts and surveys. The best source of existing condition data for a special generator is a cordon count of the generator (to establish actual trip generation) plus socioeconomic data on the generator provided by the institution itself.

Where actual trip generation counts of the site are not feasible (either using manual techniques or automatic counters), published trip generation studies for similar facilities may be used (such as those published by ITE). Special generators may generate trip productions, trip attractions, or both.

The travel characteristics of special generators should be forecast based upon projections provided by the institutions themselves. In the absence of this information, trend line projections may be used, but with caution.

EXTERNAL STATIONS AND TRIPS

External stations are points on the boundary (or cordon line) of the region where significant amounts of travelers (usually highway traffic) enter and exit the region. Travel at an external station represents both through travel (X-X trips) and other external trips (I-X and X-I).

Basic practice estimates external trips by collecting traffic counts at the external stations. Advanced practice includes conducting origin-destination surveys at the stations.

Data Sources

A variety of techniques can be used to assess base year external station travel volumes. These include manual and machine counts, regional or statewide travel models, roadside interviews, and license plate surveys.

Forecasting Procedures

Future travel to external stations is determined by applying either growth factors or using a statewide travel demand model. The growth factor technique typically applies a growth factor to the existing count based on the population growth of the counties outside the model area served by that external station.

Error Checks

External stations are best coded as separate trip purposes. This allows the modeler to give these special treatment at the trip distribution stage. These data can be entered into a spreadsheet and imported into the transportation planning software. Sources of the count data and assumptions used in the forecasts should be fully documented to ensure replication and consistency of results for future models.

NETWORK DATA

Background

The best sources of highway network and transit network data are field surveys and local public works departments. Forecasting network improvements generally consists of compiling lists of proposed, approved, and funded projects from local agencies, the approved TIP, and TxDOT.

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Transportation Analysis Zones

Analysts are significantly constrained by resource availability in deciding how many zones to create in the region and what boundaries for these zones should be. Generally, more zones mean greater accuracy for the model; however, land use data are difficult to obtain for levels of detail smaller than census tract or block group. Zone boundaries should ideally be set to include only homogeneous land uses and to facilitate loading of traffic on the network. In practice, census tract boundaries pretty much dictate the feasible zone boundaries for the model.

Number of Zones

Typically, 200 to 800 zones are used in urban area and single county models. Large regions may exceed 1,000 zones. Rural area models might use as few as 100 zones. Regional models typically have zones that are aggregations of one or more census tracts. Some regions have one zone per census tract. Single county models may split the census tracts and have one to three zones within each census tract, or they may use block group data.

Whatever number of zones are used, the number of zones should be balanced to the level of detail in the coded network.

If the transportation model is used for facility planning, then the network should include at least one lower level facility type than the lowest level being analyzed. Most models will have eight to 12 highway network links for each zone. To estimate intersection turning movements, the model needs about three zones for every intersection. Thus, to model turning movements at 100 intersections, about 300 zones are needed. Even more zones are often needed because a less than ideal zone system must be used to conform to the census tract boundaries.

Too many zones can also cause rounding problems for most software packages. For models with more than 600 zones, modelers should consider using a trip generation multiplication factor of between 10 and 100 to minimize rounding problems during trip distribution and mode choice.

Zone Boundaries

To the extent possible, zones should contain a single homogeneous land use (thus minimizing intrazonal trips that are not assigned to the network). Zones should not be split by major topographical barriers to travel such as rivers, mountains, canyons, or freeways (since the

model assumes that 100 percent of the zone is accessible to each of the centroid connectors by which the zone is connected to the network). Walk access to transit service should also be considered.

Practical considerations (such as aggregation and disaggregation requirements) dictate that TAZs nest within census tract boundaries. Census tracts may be aggregated or disaggregated as necessary, but the census tract boundaries must be preserved to facilitate working with the census data. Rules for developing zone boundaries can be found in various publications, such as FHWA's "Calibration and Adjustment of Travel Forecasting Models" (1990).

Highway Networks

Basic Data and Mapping

Accurately scaled base mapping is a must for all models. The best mapping will depend upon the area covered and level of detail. U.S. Geological Survey (USGS) maps are often used and are now available in digitized form for many CAD and GAS packages. Proprietary maps are often used, but the modeler should be aware that such maps contain a surprising number of errors and may not always be up to date. It may be desirable to standardize node coordinates on the Texas Plane Coordinate System to make it easier to splice networks from different regions.

Centroid Connectors

Centroids are the "centers of activity" of a zone. They do not represent the geographic center of the zone, unless development is uniform within the zone. Strip commercial zones are a problem with centroid location. Usually, drawing the zone around the strip commercial area and locating the centroid in the center of activity solves this problem, although it may still result in the modeled trips being less than the actual counts along the street due to intrazonal trips. In large rural zones, the centroid connector should be coded in a location representing the logical center of possible future development.

As a minimum, one can code the same speed on all connectors (typically 15 mph). More desirable practice is to vary the speed according to the area type. The speeds on centroid connectors should represent the local street system.

In a Central Business District (CBD), auto trips may be attracted to a zone with a parking

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facility in it rather than the zone when the attraction end land use is located. This is particularly true if the zones are small, as suggested above, to reflect walk access to the transit system. In that case, it may be desirable to consider the vehicle trip end attractions in the zone where parking is available by re-assigning these trips after the mode choice step.

Link Data

Link data include the inventory of the existing and future highway and transit services supplied to the area. Minimum practice is to code these facilities as independent functional classes, for example, centroid connectors, freeways, expressways, arterials, collectors, etc. Some modelers include more detailed divisions, such as rural roads, local streets, freeway ramps (metered and unmetered), streets with two-way left-turn lanes, etc. The number of classes depends upon the limitation of the software, as well as what the modeler intends to do with the information (for example, if separate capacities or speeds will be assigned to each). The degree of access control should also be taken into account when assigning link capacities.

Time/speed on link (free versus congested) - Most transportation software requires the "free flow" speed which represents the uncongested travel time with traffic control devices in place. Some describe this as the travel speed at 3 A.M. In certain instances, the level of service (LOS) "C" speed should be used (for example, as input to the gravity model).

Directionality (one way or two) - Various error checking techniques are available to assure that a two-way link has not been coded one-way, or vise versa.

Number of travel lanes - The availability of special lanes (left-turn pockets, two-way left-turn lanes, auxiliary lanes on freeways, etc.) increase capacity but should generally be accounted for with either a different functional classification or assignment group code or a special user field code.

Link capacities - Link capacities are typically coded at LOS C (the point at which noticeable reduction in speed begins), but in some cases LOS E is used. Capacities may also be adjusted, either on individual links or network wide as part of the calibration process. For peak hour, it is common to use ideal Highway Capacity Manual saturation flows adjusted for percentage green time at signals. For average daily traffic, peak-hour capacity should be converted to daily capacity, assuming a set percentage of daily traffic occurring during the peak hour. Daily

capacities are typically ten times the peak hour but can be as high as 20 times peak hour on heavily congested facilities.

Node coordinate (XY) data - Some analysts have used a generic system of coordinates such as the state planar coordinate systems or the universal transverse mercator (UTM) system. USGS topographical quads usually have the former in black and the latter in blue. Typically, each coordinate requires five or six digits. The modeler should assure himself that his software can accommodate coordinates of this size before beginning the coding process.

User fields - Most software allows "user" fields to be coded for a link which can be used creatively for a number of purposes. These include specifying the city or county where the link is located, the air quality grid cell the link belongs to, whether the link is part of the urban county's congestion management program network, or the federal aid status of the link.

Intersection Turn Penalties and Prohibitors

Intersection turn penalties are not really necessary to get good assignments except in a fine grid network. Turn prohibitors (infinite penalties), however, may be needed to prevent impossible movements. Many software packages do not fully implement turn prohibitors. Some minimum path algorithms get confused by turn prohibitors. Coding one-way links at an intersection is an alternative to using turn prohibitors. As a minimum, turn prohibitors should be used in any model where particular movements are not possible due to physical characteristics of the road network or regulations. Time delay penalties are sometimes coded in more advanced models and models where the size of the area and importance of the turn movement's output make these delays important. Most software permits at least two approaches to coding turn penalties.

Special Links and Issues

Freeways and freeway to freeway interchanges - As a minimum, these facilities should be coded as one-way links with ramps as nodes. This practice tends to reduce the mistakes made in coding prohibited turns at interchanges and other locations, as well as making the freeways stand out better on plots. Expressways are also sometimes coded as a pair of one- way links.

Freeway interchanges with surface streets - Practice varies in this area with the minimum being to code a freeway interchange as a set of two nodes. If this is done, the movements to and

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from the freeway from the surface street should probably be penalized (delay). Desirable practice is to code all important features of the interchange, entrance and exit ramps, collector and distributor roads, etc. If ramps are explicitly coded, the modeler should be careful that the distance and time on the ramps is correctly specified. Use of automatic features within the model to calculate distance based on coordinates should not be used for these facilities. Interchanges are often exploded (enlarged) to make them more legible on plots and computer displays and will not be truly to scale. This is particularly true where loop ramps are used, although the loop configuration need not be explicitly coded.

HOV facilities - Most transportation planning software available today allows coding of HOV facilities as a special type of link usable only by HOV trips. (A trip O&D matrix of such trips is then required.) The modeler should refer to the specific coding requirements in the software documentation.

Ramp metering penalties - This is an area where practice is still evolving. As a minimum, some agencies have coded a fixed penalty associated with entrance ramps of one to three minutes to represent the average delay during the peak hour. (Ramp metering delays probably should not be included in ADT models.) However, it has been noted that this approach may create oscillations and instabilities in the model since the delay penalty is flow dependent. That is, increasing the ramp penalty will divert trips to other routes, thereby reducing demand and, thus, the ramp delay itself. This feed back effect may be difficult to equilibrate in practice. A desirable approach might be to code the metered ramp as a special facility with separate volume/delay curves. The capacity of the ramp would have to be adjusted to reflect the average ramp metering rate over the peak period. This assumes that the ramp metering rate is fixed, which is probably a reasonable assumption.

Error Checks

All networks contain errors. Given that even small networks include thousands of pieces of information, this is inevitable. Even well checked networks can contain a substantial number of errors. Modelers often do not make use of simple error checking features available to them. The modeler should spend as much time as possible in checking the networks and other input data prior to calibration of the model. If the results are not checked until after calibration, it is possible

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that multiple errors may cancel each other out and be missed. This could result in satisfactory calibration but unsatisfactory forecasts. Specifically, the modeler should check for valid ranges of input values, visually inspect the network, use color plots of network features, have more than one person review the input data, build trees or shortest paths from selected critical zones, and produce a table of minimum travel times between zones for inspection.

Advanced Practice: Transit Networks

Transfer Links

Transfer links are walking links between transit stops. These links have no capacity limitations, but distance and walking speed should be coded. These are typically a maximum of 0.25 miles long with average walk speed of 2 to 4 mph. Transfer time is usually weighted with a factor between 1.5 and 3, compared to in-vehicle time.

Walk Access Links

Walk access links are walking links between a zone centroid and a transit stop of a given distance and walking speed (no capacity). These should be no more than 0.5 miles long with a typical maximum speed of 2 to 4 mph. Transit passengers are normally not allowed to use walk access links to walk through a zone centroid from one transit stop to another. Walk access links represent the primary way transit trips get to or from the transit network. They are very important because they define the area that is transit accessible. Unlike the highway network, many areas within the region are not within a reasonable walk of a transit route. Most networks use a rule of connecting any centroids to the network when the walk distance to a stop or station is less than 0.50 miles. Desirable practice is to define what percentage of zone trips are transit accessible. This requires additional effort, but it may be possible to automate this process in the future with GAS technology. The key is to provide small zones around areas that are transit (walk) accessible. Walk time is usually coded with a weight between 2 and 3. The weights are usually determined as part of the calibration of the mode choice to survey data. Walking speed is typically coded at 3 mph, but the modeler should consider barriers (topography, drainage, etc.) and grade as inhibitors of pedestrian access.

Auto Access Links

Auto access links are auto links between a zone centroid and a transit stop of a given distance and speed (no capacity). Transit passengers are allowed to use this link in one direction (from zone to transit stop) but not in the reverse direction. For this reason, these auto access links cannot typically be used to represent the use of taxis at the destination end of the transit trip. Drive access to transit plays an important role, primarily to express transit services (bus and rail) going downtown. Auto access links should be coded only at the production end of the trip since few people keep a car at the attraction end of the trip which they cannot drive from the attraction end station. Some software allows this to be done in path building. In software without this feature, the directionality of the drive access link can be made one way, toward the transit route in the A.M. peak or away from transit in the P.M. peak.

Auto connectors are typically coded at 15 to 25 mph. Since trip makers may perceive this as out-of-vehicle time, it may be appropriate to weight this time by a factor of 1.5 to 3 compared to in-vehicle travel time. Usually, a stiff transfer penalty is added to avoid overestimation of trips. The penalty represents the physical time needed to transfer, as well as schedule padding that the trip maker adds to ensure being at the stop on time. Some models have had to use as much as 100 minutes of in-vehicle travel time to calibrate the model. More typical values are approximately 10 to 15 minutes.

The true catchment area for park and ride is difficult to determine. User surveys can determine this. Typical practice is to link only those areas outside the walk area that are no more than three to five miles away. End-of-the-line stations may have larger catchment areas. It is probably desirable to restrict drive access to express bus and rail services unless local surveys indicate otherwise. This can be done with mode-to-mode transfer inhibitors available in most software.

Basic Data

Good scaled base mapping is critical for developing transit networks, especially in downtown areas where the route density is very high. The modeler should also obtain transit schedules and route maps for all services to be included. Minor services (paratransit, dial-a-ride, subscription bus, and airport services) are generally not included.

Both daily and peak transit networks are used by different agencies. However, the preferred approach is to develop a peak network since transit services often vary considerably by time of day; and it is difficult to represent average daily transit supply conditions. The volumes obtained from the peak-hour network can be factored daily using relationships specific to the transit operator and type of service being provided (express, local, etc.). Future transit service plans are typically developed from the region's various transportation plans and the operator's own studies.

Headways

Typically, only transit services that have at least two trips during the peak period are included in the transit network. If headways are irregular, the most common practice is to use the mean headway. When headways exceed ten or 15 minutes, passengers usually consult schedules; so the true waiting time may be less than suggested by headways.

The cap should be determined by the calibration process. It is usually in the range of 15 to 20 minutes. The modeler should be forewarned, however, that any changes in headway outside the cap (for example, a reduction from 60 minutes to 30 minutes) will not show an increase in mode share. Some overcome this problem by discounting the wait time for headways in excess of 20 minutes. The theory is that for long headways, travelers will schedule their arrival at the station so that all of the waiting time will not be spent at the station.

Transfer Coding

Transfers should be prohibited for certain modal combinations, such as drive to local bus. A matrix of penalties can also be added for certain types of transfers, such as drive access.

Special walk access links may be coded between transit stations that are not proximate to each other but where transfers are known to occur. Transfer wait time is usually considered to be one-half of the headway of the transit route transferred to, but if timed transfers are present, the transfer wait time can probably be capped at five to ten minutes. A lesser amount of time should not be used since, in most cases, the physical change of vehicle, as well as scheduling requirements, require that timed transfers be this long.

Parking Costs

The appropriate zonal value for parking cost should also be a result of the mode choice model calibration process. Some travel demand models consider the parking cost only for those who pay for parking (the posted parking rates). A valid option is to consider average parking cost, including free parking. This way, reduction or elimination of free parking can be tested directly. Parking duration (typically eight hours for work trips and one or two hours for non-work trips) should be used to convert per hour costs into per person trip costs.

Forecasting future parking charges should be done in one of two basic ways. The minimum technique assumes that the real (inflation adjusted) cost remains the same in the future, or else a modest increase over inflation occurs. A better technique involves projecting parking cost as a function of employment density in the CBD or else considering the ratio of parking supply versus demand in a specific area. This technique is most applicable in areas that expect to grow significantly in the future.

Transit Fares

Future transit fares are probably best estimated in consultation with transit operators who often operate under legislative constraints of maintaining minimum fare box recovery ratios or other procedural limitations on fare increases. In the absence of compelling evidence to the contrary, it is probably best to assume that the existing (real) fares will remain constant in the future. This is equivalent to assuming that fares increase at the same rate as other prices (i.e., inflation).

Most models use the adult cash fare. It may be desirable to make exceptions where evidence suggests otherwise. For example, if a large number of commuters use heavily discounted monthly passes, it may be better to use that fare for home-based work trips. Similarly, areas or routes with large numbers of students who get discount fares may require adjustments. Appropriate transfer fares (from one route to another, from one operator to another, or between modes) should also be included. Transit agency staff should be consulted regarding their fare policies and plans.

Tolls and User Fees

Only the largest metropolitan areas have toll facilities, though many areas may be

considering them. As a minimum practice, the analyst should convert the toll cost into the cost and add this time to the delay on the link for inclusion in trip distribution, mode choice, and trip assignment models. Discounted tolls or carpool passes can be considered. The discounted value could be applied only to home-based work trips and based on the weighted average of the auto toll paid. Some software allows the addition of a cost variable to a link which can be used to create a user cost network.

CALIBRATION AND VALIDATION DATA

Calibration data are used to determine the parameters and constants of the model travel demand equations. Validation data are used to determine the accuracy of the model traffic and transit patronage estimates, that is, how well the model performs on a known set of data. Calibration and validation use different data sources. Calibration data are vital to ensure the accuracy of individual equations and parameters used in the model. Validation data are vital to test the overall validity of the model's forecasts.

The best source of model estimation and calibration data is a local household travel survey that is less than ten years old. The 1990 CTPP is the next best source of travel behavior data; however, it gives information only on commuter travel. Multi-purpose trips, such as home to day care to work, are not explicitly dealt with in the census. The greatest strength of the CTPP is the small scale geography to which information is coded. If a public agency provides the Census Bureau with a correspondence table between its TAZ system and census block groups or tracts, the Census Bureau will tabulate all of the transportation related question by TAZ. Furthermore, the Bureau can produce an origin-destination matrix of commuters (home and work locations). This O-D matrix must, of course, be factored to produce actual trips since not every person makes a trip to his or her work place every day.

Traffic Counts

Counts should be for the same year as the year for which the land use data have been compiled. Count locations should also be tied to the cordon line or screenlines used when calibrating the model. Published traffic volume counts should be used with caution since these counts often represent AADTs and are based on profiles of a route or link updated with control

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station counts. Screenlines should bisect the study area along major physical barriers so that all real world streets that cross a screenline are also in the model network. Avoid splitting zones with screenlines.

Multi-day counts are best and should be for the season in which the model is calibrated. When calibrating a peak model, counts should be from a consistent peak period. It is desirable to have directional volumes for peak calibration. The count locations should be distributed throughout the study area and used to create screenlines.

Highway Travel Speeds and Travel Times

Travel speeds are used in coding the model. Motorists typically will travel faster than the posted speed under freeflow conditions (LOS A). Pneumatic traffic counters can also provide speeds. Floating car methods can provide useful information on freeflow and congested speeds. Model output speeds can be used as a comparison with the loaded (post- assignment) speeds in the calibrated model. Thus, the use of posted speeds, while acceptable, does not always represent the freeflow speeds along a road. Advanced application should include floating car data to check free flow and congested speeds.

Origin-Destination and Trip Length Information

Primary sources of information include the census journey to work information and recent travel surveys. These sources should be supplemented with the agency's own household travel surveys at regular intervals and possibly with roadside interview or license plate surveys at selected locations.

The biggest problem with these travel survey data is that they are costly to collect and cannot be updated frequently. Small scale surveys (involving several hundred or a few thousand households) can be useful in calibrating the model coefficients in gravity and mode choice models. Larger surveys are needed to establish valid O-D patterns, particularly if the analyst wants to disaggregate this information by time of day, mode, income, or other travel- related characteristics.

Vehicle Occupancy

These data are usually collected for peak periods only at screenlines, although they can be

included in household travel surveys for all trip purposes and time periods. If direct observation of this information is made by surveyors, the key points in the highway network should be selected, such as external stations, cut line locations, cordons around business districts, and on freeways.

Local Trip Generation Surveys

Local trip generation studies can provide area-specific data on trip making characteristics. These studies are usually done only for special generators and in CBDs. Published rates (such as ITE) may vary in downtown areas from local data, since they impact suburban land uses and most downtown have a large number of trips made by parking and then walking from one activity to another. If demographic characteristics in an area are much different than the average (for example family size and composition), local trip generation studies may also be warranted.

Trip generation rates are sometimes adjusted as part of the calibration process. In most cases, however, the published trip generation rate for a given site type overestimates travel when used in a regional model. For example, the ITE rates tend to be from East coast, middle income suburban areas with relatively low levels of transit service.

CHAPTER 4: TRAVEL DEMAND MODELING OVERVIEW[*]

BACKGROUND

Travel demand modeling as it is most commonly practiced is often referred to as the "four-step process." The four steps are:

- Trip generation
- Trip distribution
- Mode choice
- Trip assignment

The differentiation between large regions and other regions is based on a combination of population and density of the region, complexity of the transportation system, number and location of activity centers, degree of congestion, and degree of air pollution. Whenever possible, it is also desirable for the models for small- and medium-sized regions to meet the guidelines for advanced models. However, time, staff, and budget often constrain the capabilities of small- and medium-sized regions; and use of advanced level modeling techniques is not always possible.

There is substantial experience with the four-step modeling process. It has been in use for over 25 years. Most of the significant development in the four-step process occurred during the first ten years of that period. Most existing models in use today are based on a model structure and specifications that are 15 to 20 years old. The most significant advancements in the past ten years have been in transferring regional models from mainframe computers to micro- and minicomputers. With this transition has come some simplification of the model systems and enhancements which have improved the models' sensitivity, flexibility, and accuracy.

CRITERIA
Overview

Each model should be based on sound behavioral theory of how individuals or households make travel choices. The structure of choice sequences and the variables used in each model of

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[*]The information in this chapter is based on *State of California Department of Transportation Travel Forecasting Guidelines*, California Department of Transportation, November 1992.

choices should reflect a logical process of decision making, and the behavioral theory analyzing that process should provide a basis for judging the reasonableness of model estimation results. The models, through their input variables, should be sensitive to relevant influences. This sensitivity is necessary to capture travel behavior and to evaluate alternatives based on changes in policy or exogenous variables. If the models are not sensitive to relevant influences, they are not useful for analyzing alternatives based on these influences, regardless of the precision with which they match base year ground counts

Put differently, models need to be unbiased. Models are often calibrated to reproduce observed traffic counts or travel behavior but without regard to behavioral theory or econometric principles. Bias in the model due to improper or incomplete model specification, inaccurately measured input data, or colinearity in input variables can result in grossly inaccurate forecasts for future years. The criteria specified for developing and applying travel demand forecasting models are specifically designed to address the predictive capabilities of the models. If they do not capture travel behavior and remain biased, they are not useful predictors of future travel demand.

Specification

Specification of the models is the process of defining the model structure and the econometric methods for estimating the model and selecting the variables for inclusion in the model. Model specification also involves defining the terms relevant to each step.

Calibration

Calibration is the process of estimating the parameters of the model from baseline travel data. For trip generation, the calibration process results in trip rates or equations for trip productions and attractions. For trip distribution, calibration is the estimation of the factors affecting the propensity to travel. For mode choice, calibration produces the coefficients and constants in the utility equation of each competing mode. In trip assignment, calibration results in the estimation of the parameters in the volume-delay equations.

Validation

Validation, in this context, is the process of determining the relative accuracy and sensitivity

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of the model as a forecasting tool. This usually involves applying the modeling process using aggregate data sources, representing a current or previous year, and the comparing the results to actual data collected in the field. Validation data sources should be different than those used in calibration, but validation can also include application of the model with the calibration data base stratified by socioeconomic characteristics or geographic subdivisions. This provides a test of the sensitivity of the model to input data variation.

Validation may also include checks on the reasonableness of model parameters. This can be done by comparing model results with results from other models in the state or to reported regional, state, or national trends. Validation using actual data sources is often limited to verifying the entire four-step process after trip assignment. However, each step in the four-step process incorporates the results from the previous steps and should be validated separately to reduce compounding errors.

CHAPTER 5: TRAVEL DEMAND MODELING TRIP GENERATION[*]

OBJECTIVE

Trip generation models provide the estimates of the number of trips (by purpose) produced by or attracted to a TAZ as a function of the demographic, socioeconomic, location, and land use characteristics of the zone. Trip generation models have three parts: trip production models, trip attraction models, and the normalizing or scaling process that converts the total trips generated into trip productions and attractions. Trip productions are defined as the number of trips produced in a TAZ; trip attractions are the number of trips attracted to a TAZ. Trip production models estimate trips produced in a zone; trip attraction models estimate the trips attracted to a zone; and the scaling process ensures that, for each trip purpose, the number of trips attracted within the total modeling domain equals the number of trips produced.

The distinction between trip productions and attractions and trip origins and destinations can be described with an example. If a traveler makes a round trip from home to work, the trip generation model will estimate two home based work trip productions from the home zone attracted to the work zone; and the trip balancing process (to convert trip productions/attractions to origins-destinations) will convert these two trips into one home based work trip from the origin (home zone) to the destination (work zone), and one home based work trip from the origin (work zone) to the destination (home zone).

Trip generation models divide trips into five types:
- home based trip productions,
- home based trip attractions,
- non-home based trip productions and attractions,
- internal/external and external/internal trip productions and attractions, and
- external (through) trips.

These trip types are distinguished by the measures, or variables, used to estimate trips. Non-home based trips are generated from residential variables and converted to trip productions

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through a reallocation process that shifts the production zone from the residential areas to the nonresidential areas, in keeping with the nature of the non-home based trips. External trips are often estimated outside of the trip generation model, based on trip-making characteristics outside the study area or region.

Trip generation models can be designed to produce estimates of either person trips or vehicle trips, depending on the derivation of the trip rates or equations. A model that produces estimates of vehicle trips in the trip generation step of the process precludes the application of a separate mode choice model in the third step of the process, because the mode has been pre-determined to be auto (or vehicle) for all the trips generated. Such models have no sensitivity to policies or programs that would influence mode choice or auto occupancy. This limits their usefulness for transportation planning in the current environment.

MODEL SPECIFICATIONS

Trip generation models determine the total number of trips or the demand for travel of each TAZ in the region. These models should be based on an econometric relationship that estimates person trip productions and attractions on the basis of trip-making behavior of the individual, land uses, and socioeconomic characteristics. The results of the trip generation models are used in conjunction with the other three modeling steps to estimate travel demand for each highway and transit route segment. The results of the trip generation model are also used to estimate trip-related emissions (starts and parks) for air quality analysis.

The econometric relationship of a trip generation model defines the frequency and distribution of travel as a function of the activities and land uses in a TAZ. This model assumes that trip making and activity can be related by trip purpose. Trip purposes are classified as home based or non-home based trips. The model also assumes that the intensity of travel can be estimated independent of the transportation system characteristics. Finally, the model assumes that the relationship between trip making and activity will remain stable over time.

Trip Purposes

Trip generation models include individual specifications for trip productions and attractions by trip purpose. The decision to include more trip purposes should be weighed against the

increased complexity and effort involved in estimating travel behavior for each purpose. Trips are defined as internal if both ends of the trip are within the study area. Trips are external if both ends of the trip are outside the study area. Trips with one end of the trip in the study area and one end outside the study area are internal-external or external-internal trips. Most models stratify trips by purpose only for internal trips.

The trip purposes divide travel behavior into activities such as work, school, or shopping. The model generates or attracts trips by purpose to a particular zone and provides sensitivity for each trip purpose to evaluate trip-making behavior. If a regional agency proposes to estimate trips for three internal trip purposes, these purposes are most often defined as:

- home based work
- home based nonwork
- non-home based

If a regional agency proposes to estimate trips for five or more internal trips, the trip purposes to consider include:

- home based work (or home-to-work)
- home based shop (or home-to-shop)
- home based social/recreational
- home based school
- home based other (home-to-other)
- non-home based (or other-to-other and/or other-to-work)
- visitor (total based trips)

Two types of trips introduce additional complexity into specifications of trip purpose: linked trips and chained trips. Linked trips are those trips that serve a passenger, such as taking a student to school, or that require multiple modes, such as driving to a transit station and completing the trip on transit. These trips should be included in the travel demand model as a single trip. Chained trips, on the other hand, are trips with more than one purpose, such as stopping at the dry cleaners on the way to work. These trips are represented in the model as two unrelated trips, each with a single destination and single purpose.

It is important to recognize the definition of chained trips in the survey data available for use in developing the model. The Census Journey-to-Work data define the single or multi-purpose

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trip to the workplace as one trip from home to work. This definition is not compatible with most surveys which define any multi-purpose trip as two (or more) individual trips.

Home Based Trip Production Models

Trip generation models are defined by the travel behavior associated with home based trips and estimated trips based on a measure of resident population. The most commonly used variable in these models is the number of households or occupied dwelling units in a TAZ, although residential population can be used in combination with the number of households or dwelling units. Home based trip production models should also include socioeconomic characteristics of the resident population to refine trip rates. The most common socioeconomic characteristics used in home based trip production models are income and auto ownership. Additional socioeconomic characteristics that may be used include household size, dwelling unit type (single family or multi-family), density (dwelling units per acre), or workers per household.

Home Based Trip Attraction Models

The trip generation models produce estimates of home based trip attractions based on the land use or socioeconomic data of a TAZ. The home based trip attractions should be based on an estimate of the intensity of the nonresidential uses (number of employees or floor area), the nature of the use (the type of industry), and possibly a measure of the population. The stratification of nonresidential land uses could easily be justified by the range of trip attraction rates developed for these land uses in ITE's *Trip Generation Manual* (ITE 1991) but needs to be weighed against the difficulty of estimating and projecting these data for application to the model. It should be noted that this ITE report should not be used to estimate trip rates for home based trip attraction models. It is used here as a tool for identifying appropriate stratifications of nonresidential land uses. It can, however, be used to estimate special generators.

For advanced models, four or more categories of nonresidential data are recommended to capture the variations in travel behavior affected by different types of land uses. Some typical categories for nonresidential land uses are agriculture, industry, commerce, office, public buildings, transportation and utilities, and/or education and health. It is important to recognize the difference between land use (or socioeconomic) categories and Standard Industrial Classifications (SIC).

Land use data describe the type of activity. SIC codes describe the type of industry. An example is the headquarters of a mining corporation which has an SIC code for mining and an office land use.

Non-Home Based Models

Non-home based trip productions and attractions are related to an estimate of the residential and nonresidential land uses in an analysis zone. These trips will include visitor trips, trips by workers from work to shop, non-work trips by residents for which neither end of the trip is home, and truck trips. The non-home based trip purpose often provides less accurate estimates of trips than the home based purposes because of higher uncertainty in the estimates of nonresidential land uses and the lack of data collected in most travel surveys for this purpose. Commercial (including truck or freight) travel is particularly difficult to explain in the absence of a survey directed at commercial travel. Non-home based travel should incorporate a measure of residential population as well as nonresidential land uses stratified by industry type. Non-home based trip productions and attractions should be based on a measure of residential and nonresidential land use or socioeconomic data stratified by the nature of use or the socioeconomic characteristics.

State-of-the-Practice Methods

Two commonly used techniques for estimating internal trip productions and attractions are cross-classification and linear regression. Cross-classification is simple to calibrate and apply and requires fewer assumptions about underlying distributions among the zones than regression. Cross-classification requires a reasonable number of observations in each of the cross-classification cells, and these data are generally more readily available for home based trip production models than for the other trip generation models. In regression analysis, highly correlated trip-making characteristics can cause problems. These correlated variables can produce illogical coefficients and biased constants that are inappropriate at the TAZ level. This has further repercussions when applying the regression analysis to a focused model with large variations in zone size or for transferring the model to an area with different zone sizes.

Examples: Cross-classification estimates home based work trip productions from trip rates by auto ownership and type of dwelling unit. Linear regression estimates home based work

attractions from total employment.

Linear regression or distribution curves can also be used to stratify the households or dwelling units into auto ownership or income categories. An example of a linear regression equation to stratify households into auto ownership categories is:

Households with no Vehicles =

Total Households * [0.24 - 0.22 * (Single Family Households/Total Households) - 0.13 *

ln (Population / Total Households) + 1.68 * (1000 / income)]

An example of a distribution curve for zones in the low income group is:

35 percent of households have low income

26 percent of households have low to medium income

22 percent of households have medium to high income

17 percent of households have high income

Internal-External and External-Internal Trips

Internal-external and external-internal trips are estimated using the same techniques as the internal trip purposes but only for the internal portion of the trip. The external portion of the trip is set equal to the traffic count at the external station, less any external (through) traffic. The trip generation model uses this estimate of traffic at the external station as a "control" for the number of trips entering and exiting the study area at this location.

External Trips

External trips, or through-trips, begin and end outside the study area but travel through the study area at some point. Through-trips are frequently estimated outside the trip generation model using available data sources or O-D survey data.

Special Generator Trips

Special generators are land uses that have significantly different trip rates than the general land use category trip rate associated with it. ITE's *Trip Generation Manual* (ITE 1991) provides trip rates for most specialized land uses. TAZs may have land uses other than the special generator which should estimate trips based on the trip production and attraction trip rates. One should be

careful not to double-count special generator trips. This type of trip should, at a minimum, be estimated for military bases, airports and colleges.

CALIBRATION AND VALIDATION

The calibration of the trip generation model generally occurs in three steps for each trip purpose: estimating trip productions, estimating trip attractions, and balancing the trip ends from each model. The calibration process will result in an identification of the significant variables and the trip rates or regression equations. The process may also include estimation of equations to stratify or distribute the variables by their socioeconomic characteristics.

The calibration process may result in the identification of significant variables that are difficult to forecast. For example, if crime rate becomes a significant factor, it may be useful in predicting the number of trips generated; but it may be difficult to forecast and could reduce the predictive abilities of the model if the forecast of the variable is inaccurate. In this case, one may consider alternative variables that would capture the travel behavior and provide more confidence in the forecasts. Forecast problems may also result in models that have developed submodels to distribute the residential population into socioeconomic groups, such as income stratifications, when the forecasts were only developed for average income. In this case, the forecast distribution into income groups may be assumed to be the same as the distribution that is estimated in the base year. Variables that are difficult to forecast accurately should be avoided.

A number of commonly available statistical software packages can be used to estimate trip rates or regression equations from survey data and produce the necessary statistics to evaluate the model. Linear regression models have statistical measures to evaluate the goodness-of-fit. Unfortunately, there are no readily available statistical measures to assess the goodness-of-fit or reliability of cross-classification. One should consider the variability of the data within each cell of the classification scheme because cross-classification is sensitive to the classification of each variable. The highest and lowest classifications are often less reliable because of the relatively low number of observations typically found there (see Stopher & Meyburg 1975.)

A reasonableness check of the model should determine if the trip rates or regression coefficients are consistent with behavioral theory. One example is whether trip rates increase with increasing income. Another example is the size of the constant in the regression equation. A final

check might be whether the overall number of trips per household (or per person) is consistent with regional or statewide estimates.

The final step in the trip generation calibration process is to "match" the production and attraction trip ends. The trip distribution model requires that total productions equal total attractions. Typically, the attraction trip ends are scaled, or normalized, to equal the total number of production trip ends based on the assumption that the trip production model is more reliable than the trip attraction model for home based trip purposes. The non-home based trip purpose should be scaled using an approach that accounts for the fact that the non-home- based trip is often produced in a different zone than it is generated. For example, if the non-home based trip production model is estimated from household based survey data, the model estimates non-home based trips from households when the trip is, by definition, "not home based." One approach to normalizing the non-home based trips is a "reallocation" of the trip productions from the zone of generation to the zone of attraction. The reallocation process would then reflect the production of trips from the source of the activity.

The results of trip generation models are the number of trips produced or attracted in each analysis zone by trip purpose. Trip generation models should be calibrated from survey data and recalibrated every ten years.

The validation process, on the other hand, is designed to ensure that the trip generation model adequately replicates travel behavior under the range of conditions for which the model is likely to be applied. Trip generation model results should be validated for total trips in each trip purpose, and total person trips per household (or total trips per person) should be compared to national or statewide sources or other regional models in Texas to ensure consistency. The time and cost involved in obtaining actual field data sources for the validation of the trip generation model may limit this type of validation. However, application of the trip generation model in a previous year for which survey data are available can provide a test of the temporal stability of the model.

CHAPTER 6: TRAVEL DEMAND MODELING TRIP DISTRIBUTION*

OBJECTIVE

The trip distribution step in the four-step process distributes all trips produced in a zone to all possible attraction zones. The model uses the number of trip productions and attractions estimated in the trip generation model and the transportation system characteristics to distribute the trips. The product of trip distribution is a set of zone-to-zone person trip tables stratified by trip purpose, that is, the model produces person trip tables for each trip purpose.

MODEL SPECIFICATIONS

A central assumption of the trip distribution model is that each traveler making a trip chooses a destination from all of the available destinations based on the characteristics of each competing destination and the relative impedance associated with traveling to each destination. The two most significant factors for destination choice are the relative attractiveness of a zone measured by the number of attraction trip ends, and the relative impedance between the production zone and the attraction zone measured as a function of time and cost. Socioeconomic factors, such as income or auto ownership, may also influence destination choice.

State-of-the-Practice Methods

There are two types of trip distribution models in widespread use: gravity models and growth factor models. One distinction between these methods is the data requirements. The gravity models require data relating to the attractiveness of a zone which is obtained from the trip generation model. The Fratar models, also known as growth factor models and named after Thomas J. Fratar who developed the technique for application of growth factors for trip distribution, require a base estimate of origin and destination trips and a growth factor. While the gravity model is most commonly used in trip distribution models, the growth factor model is often used for distributing external trips (through travel) or for producing incremental updates of trip

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*The information in this chapter is based on *State of California Department of Transportation Travel Forecasting Guidelines*, California Department of Transportation, November 1992.

tables when full application of the trip distribution model is not warranted.

The gravity model is based on Newton's law of gravity which describes the gravitational force between two bodies. In transportation models, the gravitational force is a function of the attractiveness of a zone (measured in the number of trip attractions) and the impedance (measured as a travel time or friction factor) to the zone. In its traditional form, this model assumes that the trip productions are fixed and iterates to estimate the trip attractions in each zone. This procedure assumes that people choose where to work or shop based upon where they live.

The friction factor is developed from the travel impedance distribution. Typically, application of the friction factor involves use of higher friction factors for shorter trips to demonstrate a realistic assessment of the propensity to travel. The use of travel demand models for air quality analysis has increased the need for accuracy of the friction factor curve for short trips. This is because the friction curve has often been assumed to be a steadily decreasing function, instead of the actual travel impedance distribution, which is zero for trips of walking distance. The best-fit friction factor curve should reflect the full travel impedance distribution. Friction factors are calculated from a comparison of the estimated and observed trip length frequency distributions, and research has shown that these distributions (or the average trip length) remain relatively stable over time (Voorhees 1968).

Growth factor models (Fratar models) represent a simple form of the trip distribution model based on an expansion of existing interzonal trips by using growth factors. Growth factor models are generally used because of the limited data requirements and should be used to forecast external travel, in general. External (or through) trips that are not generated in or attracted to the study area are also often distributed using this method.

Impedance

The gravity model requires a measure of impedance from each origin zone to each destination zone. Impedance generally represents the travel time and cost. Many distribution models in the past defined impedance as the free-flow or uncongested travel impedance for all trip purposes and used the v/c ratio on a route segment to measure it. A more accurate representation of impedance may be warranted for many applications. Impedance values are constructed to reflect:

- congested or uncongested time periods

- a composite of highway and transit travel impedances

- a composite of travel time and cost

Most regional models use congested travel time for the home based work trip purpose and uncongested travel time for all other trip purposes. Methods are available to use a volume-weighted combination of congested and uncongested travel impedance appropriate for each individual trip purpose, but this process is not widely used.

To sum, trip distribution models should use impedance values that reflect those used in the calibration process. These values should be based on realistic estimates of travel time and speed. Most trip distribution models have been developed with the assumption that the highway travel impedance is a sufficient representation of travel impedance for estimating destination choice and that the development of a composite highway and transit travel impedance is not sufficiently cost-effective to justify the extra effort required. The definition of travel impedance as a composite of travel time and cost commonly includes cost or toll facilities, but excludes operating costs.

Advanced models should incorporate a feedback loop from trip assignment to trip distribution when there is evidence that congestion significantly affects impedance. Uncongested travel impedances input to trip distribution are acceptable if the impact of congestion is not significant.

K-Factors

K-Factors are the zone-to-zone adjustment factors that account for social or economic linkages that impact travel patterns but are not reflected accurately by the gravity model. An example of an economic situation affecting travel patterns is the proximity of blue collar neighborhoods to the CBD. The gravity model assigns work trips from those neighborhoods to the CBD based on the short distance and associated low impedance. As a result, the model may overestimate these trips. The actual travel patterns may be quite different.

Unfortunately, the use of K-Factors reduces the credibility of the forecasts because they limit the response of the model to variables that are likely to vary over time (e.g., travel time and cost). A few K-Factors may be justified for specific social or economic linkages that impact travel patterns. In general, however, they should be used sparingly and cautiously in gravity model

applications.

Intrazonal Trips

Intrazonal trips represent trips that are made entirely within one zone. They are assumed to take place on local streets and are not allocated to the roadway network during trip assignment. VMT produced by such trips are essential. For example, when travel models are used for emissions inventories, intrazonal travel can have a significant impact on total regional emissions but little impact on major transportation facilities. Fortunately, it is easy to estimate intrazonal VMT.

Intrazonal impedances are typically estimated using the nearest neighbor method. This involves using half of the travel impedance to the nearest zone as the intrazonal impedance. These figures may be adjusted to reflect terminal impedances or the time spent outside the vehicle at the beginning or end of the trip. The number of intrazonal trips are generally determined by applying the gravity model, but other methods include assuming that a fixed percentage of the trips by purpose will be intrazonal regardless of zone size.

CALIBRATION AND VALIDATION

The calibration of the gravity model involves estimating friction factors (F_{ij}) and zone-to-zone adjustment factors (K_{ij}). In the first iteration of the gravity model calibration, the F_{ij} and K_{ij} are set equal to 1. The friction factor is then calculated by comparing observed versus the model-estimated trip length frequency distributions, using manual adjustment of the curves or variety of mathematical functions. Most calibration processes require an iterative procedure to estimate the friction factors.

K-Factors can be calculated from a comparison of observed trips to estimated trips for a zone-to-zone (or district-to-district) interchange but should represent only explanatory differences in socioeconomic data from one area to another, rather than zone-to-zone adjustment factors used to improve the model results. Trip distribution models should be recalibrated every ten years based on available survey data.

The validation procedure for the trip distribution model is similar to the validation of the trip generation model. Due to the time and cost limitations involved in data collection, the

validation process relies on the verification of reasonableness and consistency with available data sources. Trip distribution models should be validated by comparing the average trip length for each trip purpose to national or statewide averages and other regional models. Back-casts to a previous year for which survey data are available often provide a test of the temporal stability of the model.

CHAPTER 7: TRAVEL DEMAND MODELING MODE CHOICE[*]

OBJECTIVE

The mode choice model separates the person trip table into the various alternative modes by trip purpose. The available modes have expanded in recent years to include stratification of the auto mode by vehicle occupancy (drive alone, two occupants, three occupants, etc.), as well as the stratification of transit modes into transit technologies and types of operation (local bus, express bus, light rail, heavy rail, etc.) and the various types of access to transit (walk or drive). The mode choice model estimates person trip tables by mode and purpose.

MODEL SPECIFICATIONS

The mode choice model estimates a traveler's choice among modes based on characteristics of the traveler, the journey, and the transportation systems. The traveler characteristics affecting mode choice include auto ownership, income, workers per household, and trips for more than one purpose (chained trips). Journey characteristics are the origin and destination, the trip purpose, and the time of day the trip is made. Transportation characteristics include travel time (in and out of the vehicle), costs (fares and auto operating costs), and parking (availability and cost), as well as the comfort, convenience, reliability, and security of the mode.

The journey characteristics are a function of the trip purpose and the time of day the trip is made. For simplicity, many mode choice models assume that trip purpose defines when the trip is made. That is, all home based work trips occur in the peak period and all other trip purposes occur in the off-peak time period. This assumption allows the use of peak impedance tables for the home based work mode choice model and off-peak impedance tables to be used for other purposes.

The characteristics of the transportation system include travel times (in-vehicle and out-of-vehicle travel times) and travel costs (out-of-pocket, maintenance and operating costs), as well as performance-related variables that are difficult to quantify, such as comfort, reliability, and

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[*]The information in this chapter is based on *State of California Department of Transportation Travel Forecasting Guidelines*, California Department of Transportation, November 1992.

security. Transit travel times include time spent driving to transit, as well as time spent in transit vehicles. Out-of-vehicle travel time should be classified by function for transit (waiting time, walking time, time to transfer, etc.) and by terminal end for highway modes (origin terminal time and destination terminal time). Transit mode of access (walk or drive) can be included in mode choice models as well.

In small- and medium-sized regions, the transit modal share is often not significant enough to justify developing a behavioral model of mode choice. In such cases, an alternate (and simpler) approach is to estimate district-to-district factors representing the transit, carpool, and drive-alone modal shares and apply them to each trip table by purpose. This method is acceptable if the regional agency is not involved in testing the sensitivity of carpool or transit policies.

Overall, the mode choice model should be consistent with good econometric practice and should remain an unbiased estimator of trips by mode and purpose. The method should include significant variables and provide sensitivity to policy variables.

Discrete choice models, where the choice among modes is limited to the number of available modes, have been well researched (see Ben-Akiva and Lerman 1985 or Stopher and Meyburg 1975) and may be the most common modeling methodology used in mode choice models. Discrete choice modeling allows the incorporation of all significant variables which reduces the bias from influences not included in the model.

Discrete Choice Models

The predominant mode choice model in use today is a logit model, a form of discrete choice model based on the behavior of travelers within a particular market. Logit models predict the choice that a traveler will make based upon travel times and costs, socioeconomic characteristics of the traveler, and other unique attributes of the trip. Work mode choice models differ from non-work mode choice models based on the peak and off-peak transportation services available for these trip purposes.

The logit model is based on the assumption that an individual associates a utility with each alternative in a choice set. The individual then will select the alternative which provides the highest utility. The utility, U_{in}, which individual n associates with alternative i has two components: a systematic component, V_{in}, and a random component e_{in}. The systematic component

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can be represented analytically as a function of observable characteristics of the individual and the alternative. The random component results from unobserved attributes of the alternative, such as taste variations among individuals and inaccuracies in the specification of the systematic component of the utility. The assumption of the logit model is that the random components of the utilities are independent and identically distributed. An additional assumption that distinguishes logit from other probabilistic discrete choice models is that the random components also have a Gumbel distribution (Ben-Akiva and Lerman 1985).

The characteristics of the logistic curve for mode choice models are derived by relating the systematic utilities that a given individual associates with each mode to the probabilities of choosing a particular mode. The utility function allows any number and specification of the explanatory variables; whereas, the generalized cost function is generally limited and has several fixed parameters. This allows a more flexible representation of the policy variables that may be relevant to the analysis. The coefficients of the variables reflect the relative importance of each attribute (Ortuzar and Willmusen 1990).

The logit form further assumes the independence from irrelevant alternatives (IIA) property. Violation of this assumption is caused by incorrect or incomplete specification of the utility function. A common result of such specification errors is that two or more alternatives are correlated because they are perceived by the decisionmaker as being similar in some unobservable attribute.

A high correlation in the unobserved attributes of two or more alternatives in a choice set causes bias in the parameter estimates. There are two techniques that are designed to reduce or eliminate such bias. One approach is to "nest" the choice model by first modeling the choice among the alternatives with high correlation in unobserved attributes and then modeling the choice of primary alternatives (grouped alternatives). The second method involves the use of a probit, rather than a logit, formulation. This type of formulation explicitly incorporates the correlation between alternatives in the model. The use of the probit structure is analytically more complex and can be prohibitively expensive to estimate when the number of alternatives is large.

The logit model assumes that the error terms are independent across alternatives. When this assumption holds, the multinomial logit structure can be used in lieu of the nested logit structure. If, on the other hand, unobserved attributes are shared by two or more alternatives in a choice set,

components of the error term will be correlated, thus, violating a key assumption of the logit model. The direction of the nesting structure will depend on which choice has correlated unobserved attributes. Ben-Akiva and Lerman (1985) and McFadden (1973) have demonstrated that when a nested logit structure is appropriate, the models can be estimated sequentially.

Incremental Mode Choice Models

The incremental mode choice model provides a method to analyze the impact of changes in fares, levels of service, or other mode attributes on mode split when baseline mode share and baseline values of the attribute are known. There are two types of incremental mode choice models: incremental elasticity and pivot-point. Incremental elasticity analysis uses a sensitivity factor (percentage change in mode share resulting from a 1 percent change in an attribute) that can be based on a logit model or on observed response to changes in an attribute. Pivot-point mode choice models use the multinomial logit model and the changes in the LOS variables (only for those variables that are expected to change). Further information on incremental models can be found in Ortuzar and Willmusen (1990).

The incremental approach has the advantage of forecasting mode shares directly from the actual (existing) mode shares, as opposed to full discrete-choice models that forecast mode shares based on relative travel times and costs for each mode. In contrast, the discrete-choice models can provide more insight for new modes that are not adequately represented in existing mode shares, such as HOV trips where there are no available HOV facilities.

CALIBRATION AND VALIDATION

Calibration

The calibration of the mode choice model should produce estimates of the coefficients and the bias constant in the modal utilities in the logit equation. One example of a typical utility equation for the transit impedance can be found in the *Procedures and Technical Methods for Transit Project Planning* (UMTA 1990):

Transit utility =
       -0.5   (bias constant)

-0.02   * transit in-vehicle travel time

-0.04   * transit out-of-vehicle travel time

-0.008   * transit fare/household income

-1.5   * autos owned

-1.0   (0 if walk access, 1 if drive access)

After specifying the available set of alternatives and other variables, the calibration of the mode choice model should produce the utility function for each mode alternative. Software packages are available for multinomial and nested logit models.

Goodness-of-fit measures test the performance of the model in predicting mode choice by comparing predicted volumes to observed data. The t-test will determine the significance of any variable in the modal utility equation. The coefficient of the variable is significantly different than zero at the 95 percent confidence level if the absolute value of the t-score is greater than 1.96.

The sign of the coefficient is also a test of the expected impact of the variable on the utility equation as well as an indication of potential specification error. An incorrect sign suggests the latter and implies the variable should be dropped from the equation. On the other hand, a variable with a correct sign and a statistically significant coefficient should be included in the utility equation. Policy variables are an exception to this rule. Although their lack of variability can produce an insignificant coefficient, they can still be included if their sign is correct.

An additional model performance test is the log-likelihood ratio. This test provides an indication of the explanatory power of variables. A variable improves the overall performance of the model if the log-likelihood ratio decreases.

If a nested logit model structure is being evaluated, various combinations of nested structures should be tested and compared to the original multinomial structure. These tests will ensure that the chosen model structure is appropriate for the area being modeled. If the nested structure fails to improve the performance of the multinomial model structure, the additional effort involved is usually not warranted.

Mode choice models should be calibrated at least once every ten years. Nested model structures should be evaluated in advanced models used to evaluate carpool alternatives or multi-modal transit systems.

Validation

       The validation process for the mode choice model involves identifying a validation data source other than the calibration data source and comparing observed modal splits with model-estimated modal shares by districts. Again, the cost of collecting data for validation limits the ability to validate using actual data. However, application to a prior year or to a segment of the calibration dataset can provide a test of the sensitivity of the model. Similar to the validation procedure for trip generation and distribution, validation for mode choice models should rely on the consistency and reasonableness of the results compared to available data sources. Mode choice models should be validated using available estimates from national, statewide, or regional sources of transit or carpool mode shares by purpose. Assignments of the transit or carpool mode shares may be used to compare the results to on-board surveys or actual traffic counts.

CHAPTER 8: TRAVEL DEMAND MODELING TRAFFIC ASSIGNMENT*

OBJECTIVE

The objective of the trip assignment model is to allocate the various modal trip tables to the alternative paths or routes available. Typically, transit trips are assigned to the transit network where path choice includes all transit modes; and vehicle trips are assigned to the highway network where path choice is affected by various use restrictions for HOV or truck trips. The trip assignment model should produce estimates of vehicular traffic assignments on the roadway network and person trip assignments on the transit network.

MODEL SPECIFICATIONS

The trip assignment models use impedance to determine path choice for each mode. The methods for trip assignment vary by mode: highway and carpool (HOV) assignments and transit assignments. The assignment methodologies for each are determined by the structure of the network, available path-building algorithms, and capacity resistant capabilities.

Impedance

The highway network characteristics contain data to determine the travel impedance for each path, or route, where travel impedance is defined by some combination of travel time and cost. The travel impedance is defined in Chapter 6 for the trip distribution model.

The value of speed used in calculating travel impedance should represent average observed uncongested speeds identified as free-flow speeds. The application of the trip assignment results in an estimate of congested speeds. Travel impedance values in the trip assignment model should represent the travel time (and cost for areas with toll facilities), along a link calculated from the average observed uncongested speed along a facility, including intersections and other average delays. The average observed uncongested speed should not include any delays due to congestion.

In the past, models would input free-flow link speeds and adjust this value during validation

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*The information in this chapter is based on *State of California Department of Transportation Travel Forecasting Guidelines*, California Department of Transportation, November 1992.

of the model. The performance of the trip assignment model has historically been based on accurate link volumes, and the adjustment of speeds was used to assist in this goal. The objective of travel demand forecasting models has shifted to include producing data for emissions inventories which are dependent upon accurate estimates of speeds. This additional purpose of estimating accurate speeds in the trip assignment model may change the requirements for the input travel impedance.

Capacity

The capacity of a roadway link is affected by the LOS on the link. The capacity of a freeway link at LOS E may be 2,000 vehicles per lane per hour when the capacity of the same freeway link at LOS C might be 1,750 vehicles per lane per hour. Typically, travel demand forecasting models use link capacity defined by LOS C or D. The capacity will impact the congestion on a link, defined by the v/c ratio, as well as the delay on the link caused by the congestion.

Highway Assignment

Highway assignment models load the vehicle trips onto the highway network using a range of path-building algorithms and typically iterate each assignment to account for congestion on the system. There are two path-building algorithms in wide use: all-or-nothing and stochastic (or multi-path). The all-or-nothing algorithm assigns all of the trips to the minimum path and should be used only in combination with iterative, incremental, averaging, or equilibrium methods to further adjust the assignments. The stochastic algorithm estimates a probability that a trip will take the minimum path or some other "efficient" path and assigns proportions of the total trips to various paths based upon the estimated probabilities. This technique was popular for some time because of its ability to capture travel behavior more effectively than the all-or-nothing algorithm. However, the stochastic assignment cannot produce turning movements for intersection capacity analysis or selected-link assignments. These limitations significantly restrict the use of this model.

The iterative process used in highway assignment models provides a variety of methods to combine the result of each iteration; equilibrium, incremental and averaging. The equilibrium method first developed by the Urban Mass Transportation Administration (UMTA) in the Urban

Transportation Planning System (UTPS) programs is an optimization procedure that searches for the best combination of the current and previous iterations. Equilibrium is said to be achieved when no trip can reduce travel impedance by changing paths. The incremental approach combines the previous iteration with a fixed percentage of the current iteration. Certain applications of the incremental method update speeds for capacity restraint based upon a full assignment of the trips but keep only the fixed percentage identified in the increment. The averaging method combines the results from one iteration with the results of other iterations to produce a volume-weighted average assignment across all iterations.

The most common highway assignment models include adjustments to the travel time or speed estimated for each path based on congestion and defined by the v/c ratio. This is generally termed a capacity restrained assignment. These adjustments are made through volume-delay equations which estimate the delay associated with traffic volumes for each segment in the system.

Various assignment highway path building algorithms, iterative techniques, and volume-delay equations should be tested to determine the trip assignment model that produces the closest match to actual traffic counts while remaining behaviorally consistent and producing useful output reports.

HOV Assignments

High-occupancy-vehicle (HOV) trips are estimated with the mode-choice model and can be assigned to the highway network simultaneously with low-occupancy-vehicle (LOV) trips or sequentially before or after the LOV trips. HOV trips are defined as any vehicle trip for which the occupancy level is sufficiently high to satisfy restrictions on HOV links in the system. In some regions, this may vary by facility. LOV trips may be drive-alone only or may include two-person carpools, depending on the facility-specific definition of HOV. Another frequently used term, single-occupant vehicle (SOV), refers only to the drive-alone mode.

The preferred method loads the HOV trips simultaneously with the LOV trips. This method provides equal opportunity for HOV trips to use LOV facilities and causes LOV trips to consider HOV volumes in selecting the best paths which can be critical on arterial approaches to HOV facilities. The sequential approach gives preference to the trip table assigned first but may be useful if software packages do not support the simultaneous method.

Transit Assignment

The transit assignment procedures predict the route choices for the transit trips. The choice of a transit route is influenced by different attributes of the transit network, all of which affect the overall travel impedance. The perception that time spent outside a vehicle or time spent transferring from one vehicle to another is more onerous than time spent riding in a vehicle affects the weight of these variables in the impedance function, but both types of travel time should be included.

Three issues warrant discussion concerning transit assignment: the supply of transit services, the estimated cost of transit service to the passenger, and the definition of generalized impedance. The supply of transit services is defined by the capacity of a transit vehicle and its corresponding frequency. The transit network consists of route segments (links) and transit stops (nodes) that form transit routes (lines). The estimated cost of using a transit service is the average fare paid to take the trip, including transfer fares. If discounted fares are significant, the average fare should reflect these discounts.

The generalized impedance is a function of the in-vehicle travel time (IVTT), the time spent waiting for a vehicle (WAIT), the time spent walking to the transit stop (WALK), the time spent transferring from one route to another (XFER), a penalty to represent distance to transferring (XPEN), and the fare (FARE):

IMPEDANCE = a*IVTT + b*WAIT + c*WALK + d*XFER + e*XPEN + f*FARE

Where a,b,c,d,e,f are coefficients associated with the impedance.

The coefficients on the out-of-vehicle travel times (WAIT, WALK, XFER) can be two to three times the value of the coefficient on the in-vehicle travel time.

Transit assignment techniques may vary from one software package to another, but the most common path-building algorithm is the all-or-nothing method. This method chooses the minimum impedance path based on the generalized impedance function. The all-or-nothing method can overestimate routes with a high frequency of service or underestimate routes that are highly competitive, but not the minimum path. Modeling the path choice or using a multi-path transit path-building algorithm are possible solutions to the weakness of the all-or-nothing algorithm. Another issue in transit assignment is the assumption that capacity does not limit transit route choice or assignment. Prashker (1990) investigated the possibility of restraining transit assignments

to available capacities and incorporating a multi-path building algorithm.

Further guidance on transit assignment techniques may be found in the "Procedures for Transit Project Planning," (UMTA 1990) and Modeling Transport (Ortuzar and Willumsen 1990). Although the objective of the transit trip assignment model is to reflect the importance of transit vehicles on congestion and air quality, the transit assignments process assigns transit person trips rather than transit vehicles. The assignment of transit vehicles is determined by a combination of operational policies and travel demand. For the purposes of air quality, the transit travel demand model is relatively insensitive to the assignment of transit vehicles and the resulting air quality.

CALIBRATION AND VALIDATION

Technically, separating calibration and validation of the trip assignment model is difficult because there is generally only one data source available for both exercises. In practice, calibration of the highway assignment model includes identifying the model specifications and adjusting the volume-delay equations to adequately represent the region. Validation of the model includes checking the accuracy of any link data assumptions and evaluating the reasonableness of the input data (network- or zone-based) by comparing the model-estimated assignments to traffic counts. It is important to recognize that traffic counts are themselves only estimates of traffic volume and should be tested for reasonableness during validation along with the other input data. Counts could have errors caused by variation in the mix of vehicles or may not have been adjusted for seasonal or day-of-the-week variations. Errors could also be due to mechanical counter failure, field personnel mistakes, or improper count location.

Traditionally, highway assignment models have been calibrated and validated based primarily on the comparison of estimated model volumes to traffic counts. The calibration results can be summarized from the model-estimated volumes on link segments and compared to traffic counts for various facility types and for facilities experiencing congestion. Adjustments to the volume-delay equation or the trip assignment method can impact general and over- or underestimation of link volumes. The validation effort involves more link-specific summaries of model-estimated volumes compared to traffic counts, either by screenline, by district, or by individual link. Errors found at this step in the modeling process can lead to adjustments which may compensate for assignment/ground count differences. Inaccurate screenline estimates may

imply incorrect trip distributions; inaccurate district estimates can imply incorrect trip generation rates or equations; and inaccurate link estimates can imply incorrect network characteristics. Incorrect mode-choice estimates may also affect any or all of the above.

The regional agency should strive to obtain traffic counts on 10 percent or more of the regionwide highway systems being analyzed. This 10 percent goal also applies to the distribution of counts in each functional class (freeways and principal arterials, at a minimum). Validation for groups of links in a screenline should include all highway segments crossing the screenline.

Calibration and validation of the transit assignment model follows the same procedure as the highway assignment model, replacing traffic counts with transit ridership. Again, inaccurate estimates can imply incorrect assumptions used in path-building or mode-choice.

Many statistics can be helpful in calibrating or validating trip assignment models: absolute difference, percentage difference, average error, average percentage error, standard deviation, R squared, root mean square error, and the correlation coefficient. The statistics are helpful in determining the overall performance of the trip assignment model and the four-step travel demand forecasting process.

A test of the percentage error by functional class provides a measure of how well the assignment model is loading trips onto the functionally classified systems. The percentage error by functional class is the total assigned traffic volumes divided by the total counted traffic volumes (ground counts) for all links that have counted volumes, by functional class. Suggested error limits are listed in Table 2.

Table 2
Suggested Regionwide Validation Criteria

Functional Class	Percentage Error
Freeways	Less than 7 percent
Principal Arterial	Less than 10 percent
Minor Arterial	Less than 15 percent
Collectors	Less than 25 percent
Frontage Roads	Less than 25 percent

Source: FHWA Calibration & Adjustment of System Planning Models; December 1990.

The correlation coefficient estimates the percentage of actual ground counts that are explained by the estimated traffic volumes and is produced by most software packages. The suggested regionwide correlation coefficient should be greater than 0.88.

The VMT is a significant factor for emissions inventories and should be compared to available data sources (e.g., the Highway Performance Management System or HPMS). The HPMS and other regional estimates of VMT are also subject to estimation error and are reasonable only as verification of consistency. They do not provide a useful measure of the accuracy of the model system.

The validation process should also include the comparison of ground counts to estimated volumes on individual freeway and principal arterial links, as well as screenlines defined to capture the travel demand from one area to another. The suggested link-specific validation criteria is that 75 percent of freeways and principal arterials and all screenlines meet a certain maximum desirable deviation.

CHAPTER 9: TRAVEL DEMAND MODELING "ADVANCED TOPICS"[*]

TIME-OF-DAY DISTRIBUTION

The allocation of travel to specific time periods can occur at various stages within the four-step modeling process, but the most common application is to develop time period specific trip tables after mode choice. Time-period-specific trip tables should be developed for severely congested time periods in the day and should be identified by the nature of the difference between impedances from one time period to another as peak-period or peak-hour tables.

Peak-period trip tables represent all trips within a one- to four-hour period of peak travel. Peak-hour trip tables represent the highest hour of travel within the morning or afternoon time periods. Peak spreading occurs when the capacity of the transportation system is severely constrained in the highest demand portion of the peak period. To avoid severe congestion, travelers choose to make trips earlier or later; and a spreading of the peak occurs. The result is usually a longer peak (congested) period and a more even distribution within the peak period. If peak spreading has occurred, a separation of the peak-periods into individual peak-hours is often not warranted. If the level of congestion in the peak hour is significantly different than the average conditions in the peak period, then the peak hour should be estimated separately.

The stratification of link volumes by hour of the day as a post-process to trip assignment is commonly used to estimate emissions. Time-of-day distributions can be estimated at various stages in the four-step travel demand process. If distributions are estimated prior to trip generation, trip rates are stratified by time period and purpose. If they are estimated following mode choice, peaking factors are applied by purpose and mode for each time period. Finally, if distributions are estimated following trip assignment, link volumes are stratified by hour of the day.

The most common method to estimate the time-of-day distribution in regional travel models is to estimate a set of peaking factors from actual data and apply these to the trips by purpose and mode. The peaking factors indicate the proportion of trips in a particular time period

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[*]The information in this chapter is based on *State of California Department of Transportation Travel Forecasting Guidelines*, California Department of Transportation, November 1992.

that are destined to (or away from) the trip attractors. Peaking factors are often developed for the A.M. and P.M. peak periods (or peak hours), while the remainder of the daily trip table is allocated to the off-peak period.

Some models assume that the home based work (HBW) purpose represents the peak-period trips and all other trip purposes represent the off-peak period. This assumption may be reasonable for the mode choice model but may not be reasonable for trip assignment. Regional travel demand models have in the past emphasized the peak-period for planning purposes, but further accuracy in time-of-day forecasts is required for emissions inventories.

FORECASTS

The complexity of travel demand models is often limited by the ability to accurately forecast the data and assumptions defined in the models. Although the basic structure of the four-step modeling process has changed little in the past 20 years, there have been some developments over time to incorporate more complex traveler behavior and system performance characteristics to capture the causal relationship behind shifts in travel. Both the calibration and validation efforts involved in each of the four models can verify the ability to estimate travel demand from travel behavior and system characteristics. Typically, each of the four models in the travel demand forecasting process assumes that the parameters and coefficients estimated through model calibration do not change over time. The input socioeconomic and network characteristics tested during model validation will change over time and are developed for each model application year.

Forecasts for the trip generation model require estimates of future year socioeconomic data (households and employment, stratified by those categories identified in the trip generation model). If special generators were used in the base model, estimates of future special generator trips should be incorporated into the forecast year model. Internal-external and external-internal trips based on estimates of traffic at the external station also need to be estimated for the future year. Typically, special generator and external travel are estimated by growth factors for the forecast year.

The gravity model application of the trip distribution model assumes that the friction factors and K-Factors do not change over time. This assumption is based on the use of these factors to capture the travel behavior not otherwise accounted for in the model. Because the

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behavior producing these factors is not well defined, the assumption that the factors are constant is suspect. The production and attraction trip ends are forecast from the trip generation model, and the zone-to-zone impedances are estimated from the system characteristics for the forecast year.

The mode choice model contains coefficients that explain the relationships between travel behavior and mode choice. The model-calibrated coefficients remain constant over time. The travel time, or impedance, values are derived from forecast changes to the highway and transit systems. Costs are input in base year dollars and only change over time if the forecasts differ from the increase due to inflation.

Assessments of the performance of travel demand forecasting models indicate that the errors occurring are dominated by poor forecasting of the input variables (Bates and Dasgupta 1990). An additional difficulty with forecasting performance is that the assumptions in trip distribution and trip assignment that are not directly related to travel behavior (i.e., K-Factors and path-building algorithms) are difficult to forecast themselves.

FEEDBACK MECHANISMS

Many assumptions in the four-step travel demand forecasting process concern the impedance of a trip. The impedance of a trip is a function of the travel time and cost from the origin to the destination. The impedance is derived from the transportation system characteristics. Feedback mechanisms represent the equilibration of impedance at one or more steps in the modeling process. Much of the discussion on feedback mechanisms of impedance leads to a need for further research regarding the benefits of incorporating feedback mechanisms versus the cost associated with the equilibrium required in the modeling process. A significant portion of the costs involved will result from the need to recalibrate each model after incorporating feedback loops.

The first assumption occurs in the development of land use data. Land use forecasts are frequently developed with the assumption that transportation system characteristics will not impact land use. Thus, land use is normally developed for a forecast year and assumed to be constant across various transportation system alternatives. Although low, medium, and high growth scenarios are sometimes developed, they are rarely impacted by the transportation system

alternatives. This assumption is based upon the need to produce objective forecasts of land use data and the few practical applications into the behavioral theory of how land use is impacted by transportation system characteristics.

Most trip generation models assume that the decision to make a trip is made independently of transportation system characteristics. This assumption has been identified as further research for the trip generation model but has not been incorporated into state-of-the-practice models.

The trip distribution model is the first of the four-step process to incorporate impedance values as a variable. The current state-of-the-practice models use uncongested impedances to determine the destination choice of a trip. Some models estimate congested impedances as a function of facility type and area type as a shortcut to using modeled congested impedances. Current state-of-the-art models complete the four-step process and feed back the congested impedances to trip distribution. Some models equilibrate this feedback loop until the congested impedances used in trip distribution match the congested impedances output from trip assignment.

Congestion has been identified as having a significant impact on mode choice. Therefore, mode choice models have incorporated feedback loops of the congested impedances as well as the estimate of transit impedance where it is affected by highway congestion. State-of-the-art models have equilibrated this feedback loop.

Trip assignment is the only step in the modeling process where feedback loops and the equilibration of congested impedances are incorporated into state-of-the-practice models. The capacity restraint function is the technique used to estimate delay from congestion and iterate to affect path choice on the basis of this delay.

MODEL DOCUMENTATION

Model documentation is intended to improve the understanding and usefulness of travel demand forecasting models. Documentation that is too brief or is not updated to reflect changes in the model will be of limited use to modelers. Since model documentation usually contains a variety of information, it is essential that it be thorough in order to facilitate comparisons among models. The following is a list of suggested topics for model documentation:

- Description of model area and network coverage

- Tabulation of land use or socioeconomic data for all years modeled

- Description and summaries of all variables in the networks

- Source and coverage of traffic counts used in modeling

- Description of the trip generation model by trip purpose

- Identification of special generator and external trips input to trip generation

- Summary of trip generation results (productions and attractions by purpose by year

- Description of the trip distribution model by trip purpose

- Description of the source and form of friction factors used by trip purpose

- Description of the impedance measures used in trip distribution, including intrazonal and terminal time

- Identification of K-Factors and their derivation

- Summary of trip distribution results (total intrazonal trips and average trip length by trip purpose)

- Description of the mode choice model by trip purpose

- Description of the variables (and units) used in the mode choice model

- Summary of the mode choice results (district-to-district trips by purpose by mode)

- Identification of the source and value of interregional trips

- Description, if applicable, of the peak-hour models

- Description of the trip assignment model

- Description of the trip impedance measures used in trip assignment

- Identification of the volume-delay and path-building algorithms applied in trip assignment

- Summary of the trip assignment results (VMT, VHT [vehicle hours traveled], delay, and average speed)

- Identification of model variation tests and results for each model stage

MODEL APPLICATIONS

Analysis of Transportation Control Measures

The increasing concern about air quality has resulted in increasing use of travel demand forecasting models in the evaluation of the potential impact of TCMs. TCMs include a wide variety of measures designed to reduce vehicular travel, including rideshare promotion, parking pricing, increased transit service, alternative work schedules, and bicycle and pedestrian facilities. The impact of TCMs is normally assessed on the basis of changes in VMT, trips, or changes in pollutant emissions. Travel demand models would readily produce the impacts on the desired form, but most travel demand models are relatively insensitive to the variables that are affected by the TCMs (e.g., trip cost by alternative mode, travel comfort, awareness of alternatives). An analysis of TCMs can often use the data contained in the travel demand model, even when the travel demand model itself is not capable of forecasting TCM impacts. In such applications, the travel demand model supplies baseline travel characteristics; but the actual TCM impact is predicted in a post-process model that is sensitive to the relevant influences.

TCM analysis should predict TCM impact on the basis of either relevant econometric relationships based on travel behavior theory or on empirical evidence of effectiveness where methods have been tried before. It should be made clear whether empirical evidence represents average effectiveness or maximum feasible effectiveness. The TCM analysis should take explicit account of the cumulative impact of multiple TCM measures and how that may differ from the sum of the individual impacts. When TCMs are analyzed as post-process, care should be taken to ensure that TCM measures already incorporated in the travel demand model are not double counted.

Congestion Management

The Congestion Management Program (CMP) has become a driving force for many regional transportation agencies to develop or update their transportation model. While the CMP legislation does not specifically require a travel demand model, certain requirements imply the

need for a model. The land use analysis program, for instance, requires a "program to analyze the impacts of land use decisions made by local jurisdictions on regional transportation systems . . .". The legislation further states that "the agency . . . shall develop a uniform database on traffic impacts for use in a countywide transportation computer model and shall approve transportation computer models of specific areas within the county that will be used by local jurisdictions to determine the quantitative impacts of development on the circulation system that are based on the countywide model and standardized modeling assumptions and conventions" (Section 65089, Government Code).

This legislation, in combination with the 1990 Federal CAAA, prompted a critical look at travel demand forecasting models. Many people apply travel demand forecasting models without a clear understanding of the strengths and weaknesses. This often results in a lack of understanding of the appropriate applications of the model. For instance, transportation modelers do not believe that regional transportation models are accurate enough for intersection capacity analysis but can be used in an incremental analysis to forecast LOS for intersections. Subregional models are often used for intersection capacity analysis and are required by legislation to be consistent with the regional model. This requirement will serve to determine an equivalence between one forecast and another and should improve the decision-making process by providing results based upon similar assumptions. In theory, this is a strength of the legislation; in practice, it will take some time to provide consistency among travel demand forecasting models.

The intent of the CMP is to reduce congestion on the highway network by coordinating land use, air quality, and transportation planning. The travel demand model is the link between these areas and will provide the necessary connection among them. The models are currently being applied to analyze congestion on highway and transit networks and as input data to emissions inventories.

Regional and Subregional Modeling Relationship

The CMP legislation requires consistency between regional and subregional (or local) models. Consistency should be determined by comparing the input data, model assumptions, and results. The most effective way to achieve consistency among these models is to directly connect the input data sources and the parameters and assumptions. Some regional models are developed

to incorporate existing local area models. Subregional models can be developed directly from regional model databases and follow similar modeling assumptions or apply regional modeling results where appropriate (e.g., to capture major mode split impacts of large transportation projects). Subregional models have the advantage of closer attention to detail and more accurate input data, while regional models have the advantage of capturing regional travel behaviors that might be difficult to model in smaller areas. Both models stand to gain from incorporating parts of other models or using the other models as a reasonableness check where validation data are scarce.

CHAPTER 10: URBAN AREA TRANSPORTATION FORECASTING IN TEXAS[*]

TRAVEL MODELING IN TEXAS
The Texas Travel Demand Package

The Texas Travel Demand Package (Texas Package) is a set of mainframe computer programs used to forecast travel in urbanized areas in Texas. The Texas Package is operated by the Planning and Programming Division (formerly Division 10) of TxDOT and has been developed and updated since the 1960s by TxDOT and the Texas Transportation Institute (TTI) of The Texas A&M University System. The models used in the Texas Package follow the widely accepted four-step urban transportation modeling process. The Texas Package contains three of the models: trip generation, trip distribution, and traffic assignment. Many of the urbanized areas in Texas have only modest public transportation systems; therefore, the Texas Package does not contain a mode choice model. However, some urbanized areas in Texas, such as Houston, have developed mode choice and HOV models to complement the Texas Package.

This chapter provides an overview of travel modeling in Texas based on a summary of the Texas Package. More detailed descriptions of model development, surveys, and computer program user manuals are available for each of the specific models.

Texas Forecasting Organization

There are currently 25 MPO areas in Texas, four of which are classified as nonattainment areas under the CAAA of 1990. The Texas Package is used for travel forecasting in all areas with the exception of Dallas-Fort Worth. The Dallas-Fort Worth area is covered by the Dallas-Fort Worth Travel Model, a four-step travel model developed and maintained by the North Central Texas Council of Governments (NCTCOG) in cooperation with TxDOT.

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[*]The material in this chapter is an excerpt from Tom A. Williams and George B. Dresser, *Summary Documentation for the Texas Travel Demand Package*, Research Report 1375-1, Texas Transportation Institute, College Station, TX, December 1992.

THE TRAVEL MODELING PROCESS

Travel Surveys

Typical travel surveys in Texas may contain several elements: a home interview survey to gather data on household travel patterns, a workplace survey to collect both employee and non-employee trip data at the workplace, and occasionally an on-board transit Origin-Destination (O-D) survey to provide information on transit users. Also, other aspects of urban area travel may be surveyed, such as truck and commercial vehicle travel and "special generators." Special generators are urban activities which are unusual in their traffic generating characteristics, such as theme parks, stadiums, and large shopping malls. In addition to travel surveys, the Journey-to-Work section of the Decennial Census is used to collect information on work trip characteristics.

The travel surveys and the journey-to-work surveys provide information used to develop trip production and attraction rates (vehicle and person) by purpose, household characteristic disaggregation curves, trip length frequency distributions (TLFD) by purpose, mean trip lengths by trip purpose, and temporal travel distributions. Trips per employee, auto occupancy, autos per household, mode of travel, and special generator trip rates are also calculated from the surveys.

The survey information is used as input to the trip generation models. Trip rates are compared to other urbanized areas to check for reasonableness. Other measures, such as person (or vehicle) trips per household are compared, and trip production/attraction balancing factors are checked. The TLFD is used as input to trip distribution, or a synthetic trip length frequency is derived from the survey data.

Roadway Inventories and Traffic Counts

Roadway inventories are performed periodically in urban areas in Texas. Inventories are performed by driving the network, and are, therefore, sometimes referred to as "windshield" surveys. Typical data of greatest importance to planning models collected by windshield surveys include:

- Roadway speed - estimated speed on each class of roadway

- Capacity - number of lanes, whether the road is divided or undivided, and parking prohibitions

Texas maintains an extensive system of observed traffic counts. TxDOT has a large system of permanent traffic recording stations in urbanized areas which continuously collect traffic counts. TxDOT also collects traffic counts at other permanent sites and for specific studies. An additional system of traffic counts is maintained by other agencies within urban areas.

Calibration

Calibration refers to the process of estimating model variables such as trip rates, friction factors, mean trip lengths, and TLFDs. All variables are based on surveyed or observed data. A model is calibrated for the year in which the field data are collected. A calibrated model needs to be tested and validated for a year other than the calibration year to verify the predictive ability of the model.

Validation

Validation is the process of using a previously calibrated model to predict traffic volumes and comparing the predicted volumes with observed volumes for a year other than the calibration year. Extensive traffic counts must be made in order to validate a model. If trip rates, friction factors, and mean trip lengths are borrowed from another urban area or if default values are used, the model can still be validated for its predictive ability to replicate observed traffic counts.

Calibration Methodology

Several steps are used in the calibration process. Adjustments are made to each model run, and new parameters are estimated. The first step in the process is to run the model regionwide using default variables from previously calibrated models or another similar urban area. Based on the initial results, regionwide values are developed for trips per person, VMT per person, and the labor force participation ratio (population to employment ratio).

These values can be compared with surveyed values or typical values for urban areas. The model is then used to predict traffic volumes on links. The links can be aggregated to form screenlines and cut lines, imaginary lines partially or wholly crossing the urban area. Totals of

observed traffic volume and predicted traffic volume are compared across screenlines and cut lines.

Depending on the magnitude of the error in the model's predictive ability, model parameters are adjusted. Values which may be changed include:

- Socioeconomic data

- Trip rates by trip purpose and auto occupancy

- Centroid connectors

- Intrazonal travel times

- Network speeds and capacities (assumed LOS threshold)

- Trip distribution bias factors six

Validation Methodology

After the model is calibrated to within a specified margin of error, a validation is performed for a year other than the calibration year. This process is performed periodically as demographic estimates and comprehensive traffic counts become available for a given validation year.

In the validation process, the calibrated model parameters are assumed to be correct because they were used to "validate" against the calibration year traffic. Traffic assignment results for the validation year are compared to traffic counts collected during the same year. A percentage error is calculated and aggregated according to the following categories:

- Regionwide

- Functional class

- Area type

- District or subarea

Screenlines are developed and a comparison of total counted volume versus total assigned volume crossing the screenline is made. Where deficiencies occur, the trip table is adjusted with bias factors to account for the difference in assigned volume.

In urban areas where estimates of VMT are prepared using statistical methods, the total VMT from a traffic assignment can be compared. VMT can be estimated using traffic counts and a roadway inventory. Annual increase in VMT for a given urban area is generally at a steady rate. The predictive ability of the model can be used to estimate VMT for a given year and then compared to the expected VMT regionwide, by functional class and area type.

Once a calibrated and validated model is developed for an urban area, the model can be used to forecast the impacts of future activity on the planned transportation system for a given forecast year. Also, the models can be used to test alternatives in planned transportation systems and the effectiveness of the modified plans.

DEMOGRAPHICS

Households

Census data are used for developing initial estimates of the number of households, population, and household sizes for an urban area. This information is aggregated to census tracts or traffic serial zones (TSZs) within an urban area. When the base year does not fall on a census year, the current census data are updated with building permits, subdivision plats, and other local data or locally acceptable judgment processes. Aerial photography is used in some areas to update zonal land use information. Projections of population and number of households for census tracts and/or zones within the urban area are usually accomplished through a step-down procedure, allocating regional control totals to specific census tracts or zones.

Forecast households are developed locally or may be obtained from another source (e.g., Texas Natural Resource Conservation Commission) for the urban area. The forecast control totals are developed cooperatively but are driven by the county forecasts from the Texas State Data Center. TxDOT is currently required to work within the high and low range population forecasts set by the Texas State Data Center.

Population forecasts are usually developed at large aggregations (sometimes the whole region) and are used as control totals for distribution to smaller zones. The distribution to subareas within the region is accomplished through the use of a heuristic model, a simulation model, an activity distribution model, professional judgment tempered with knowledge of local development patterns (Delphi), or other methods which are considered credible by local decision

makers. This distribution may be done in one or several steps (e.g., population distributed to districts and then to zones within each district).

Population forecasts at the census tract or zone level are usually the basis for estimating the number of households. This may be accomplished through the use of an average household size for the urban area or the census tract (from census data) or by other procedures developed locally. The forecasts at the tract or zone level are constrained to agree with regional totals.

The number of households of different sizes at the tract or zone level are usually obtained by applying disaggregation curves. These curves are developed from census data at the census tract level. The percentage of households of each size (within the census tract) is plotted versus the average household size for the census tract. The curves are plotted in such a way that the percentages of each household size will add up to 100 percent. For example, a tract is determined to have an average household size of 1.4. Using the disaggregation curves, the percentage of households falling in each household size (one person, two persons, etc.) can be looked up. These values are applied to the total number of households in the tract to determine the number of households falling into each household size category.

Income

Several techniques are used to estimate and forecast household income. In some cases, income is assumed to remain constant over time implying that no real growth in income or purchasing power will occur. The basic data requirement of the Texas Package trip generation model is an estimate of the number of households within each income range. The method normally employed is a disaggregation method similar to the household size disaggregation process.

Methods for estimating median or mean income at the zone or tract level vary among urban areas. Some of the methods employed are:

- No growth

- A constant rate of growth or compounded rate

- Income growth applied to new development only

- Historical trends

- Regional growth forecasts from outside agencies, such as the Bureau of Economic Analysis

- Other mathematical techniques

Auto Ownership

Auto ownership is used in some areas in lieu of income for trip generation models. The methods of estimating auto ownership usually involve income as an independent variable. The Texas Package method uses a zonal median income as input to disaggregation curves showing the number of households with 0, 1, 2, and 3+ autos.

Employment

Employment forecasts are integral to the analysis of future roadway needs. Usually, employment is forecast on a regional basis, which is disaggregated later in the process (control total). Several sources for control total employment forecasts are often used in an urban area and are selected based on local judgment and political processes. A common source for base year regional employment estimates is the Texas Employment Commission. Forecast employment is derived from various locally accepted sources and methodologies.

Employment is generally separated into three categories: Basic Employment, comprising industries which are part of an economy larger than the region, such as manufacturing; Retail Employment, reflecting jobs generated by local shopping; and Service Employment, which is made up of office and institutional type jobs.

Allocation of employment is performed by local judgment and heuristic models. Forecast CBD employment is most often estimated from various sources at the local level. Several urban areas use allocation models which distribute employment on the basis of the location of other activities in TSZs and the effect of distances between zones. Examples of these types of models include the Lowry Model and the Dram/Empal Model.

NETWORKS AND ZONES

Networks

TxDOT develops computerized representations of regional roadway systems with assistance from MPOs, municipalities, and other agencies. Networks are built around TSZs, detailed analysis zone structures. Special connector links referred to as centroid connectors represent access to the regional roadway network from zone centroids. Centroid connectors represent local roadway access between the centroid of zonal activity and the regional network. The operational characteristics of centroid connectors reflect zone size, proximity of land development to the regional roadway network, and local street speeds and capacities.

The physical and operational attributes of roadways, such as number of lanes, speed limit, one-way or two-way facility, divided or undivided facility, and 24-hour nondirectional weekday count are obtained from roadway inventories. Additional traffic count data are obtained from saturation counts performed by TxDOT. These traffic counts are coded into the base year roadway network and are utilized in the validation of the process.

Area Types

Areas of differing density levels, called "area types," are developed to represent the fact that the duration and amount of traffic congestion, which influence roadway capacity, vary throughout a region. Area type categories help to quantify differences in traffic signal spacing, maximum permissible speeds, and other factors which ultimately relate to differences in population and employment densities. The area types normally used are CBD, urban, suburban, fringe suburban, and rural.

Area types are used to assign network speeds and capacities to individual links. Coded network speeds and capacities within a given roadway functional class vary by area type.

The methodology used for calculating the area type is a classification of each TSZ based on a function of population and employment density. The equation is:

$$\text{TSZ factor} = \text{TSZ population density} + B * (\text{TSZ employment density})$$

where:

$$B \quad = \quad \text{study area population/employment ratio}$$

TSZ population density   =   TSZ population/acres

TSZ employment density   =   TSZ employment/acres

The constant "B" in this equation is the employment/population ratio for the entire study area. Density values are in persons per acre. The results are placed into five or six ranges of values which define the area types. Thus, each TSZ receives an area type classification. When using six area type classifications, the typical classes are CBD, CBD fringe, urban, suburban, suburban fringe, and rural.

Functional Class

The second predominant characteristic used to determine capacity and speed of a facility is the functional class. Functional class is used to assign speeds and capacities to the network. Functional class is subdivided into facility types to further identify the characteristic of the specific segment. For instance, divided principal arterials may be subdivided into facility types reflecting continuous left-turn lanes or left-turn bays. Toll facilities are separately identified to reflect the operational policies of these facilities.

Capacity

Link capacity is used during the assignment process for capacity restraint assignments. Capacity restraint assignment techniques are based on the finding that as traffic congestion increases, the speed of traffic decreases. The assignment process assigns trips according to impedances coded for each network link, usually travel time. There is a direct relationship between travel time (or speed) and the volume on a transportation facility. Capacity restraint attempts to bring the assigned volume, the capacity of a facility, and the related speed into balance. Capacities are cross-classified by functional class (or facility type) and area type. The capacities typically used are based on a service volume at LOS C and are derived from the Transportation Research Board Highway Capacity Manual. However, in some instances other levels of service may be used depending on the characteristics of the urban area.

Several factors influence the determination of capacity. The characteristics of a facility which must be taken into account include the percent of daily traffic occurring during the peak hour (K-Factor), the maximum flow rate factor (peak hour factor), the directional split, the percentage of trucks, and the ratio of green time to total traffic light cycle length. The threshold for capacity determination in rural, less congested urban areas is LOS A or B. In contrast, the threshold for determining capacity in more congested urban areas is LOS C or D.

Speed

Link distance divided by the link speed produces an estimate of link travel time. Link travel times, or network impedances, are the basis for the development of minimum path routes from each zone to every other zone in the network. The speeds assigned to each link in the Texas Package are derived from two sources: speed surveys, where actual observed traveling speeds are measured and coded to each link, and more commonly, the *Highway Capacity Manual* produced by the Transportation Research Board. The *Highway Capacity Manual* identifies a range of speeds suitable to meet an LOS C for each functional classification.

Distance

Link lengths, or distances, are critical in determining link travel times. Distances are calculated during the process of digitizing the network. The base maps typically used for digitizing the network are county roadway maps originally drawn from a USGS survey map base. Networks are digitized using the Intergraph computer design system. Roads are drawn as curvilinear features; and the distance on each link, including curves, is calculated by the computer system, which is later transferred to the Texas Package.

Zones

Detailed zones used in the Texas Package, TSZs, are developed as the basis for estimating travel. The area covered by a given TSZ is determined by aggregating homogeneous land uses. Serial zones are bounded by the roadway network or other physical characteristics, such as a railroad line or stream.

Zones in the Texas Package vary in size. Serial zones are generally sized by the detail of the network. TSZs are aggregated into larger geographic areas called districts and sectors. Districts and sectors are used for summary information and some aggregate modeling statistics. Aggregated zones are also used for mode choice modeling in urban areas where this step is performed. Traffic assignments and trip distribution are performed at the TSZ level.

TRIP GENERATION

The Trip Generation Process

Trip generation is the process used to estimate trip-making activity. Measuring travel demand in terms of trip productions and attractions is normal practice. The units for which these estimates are derived are subareas within an urban area referred to as zones. Trip generation is defined as the procedure by which estimates of the number of trips produced and attracted by the zone within an urban area are developed. Thus, it plays an important role in the overall process of urban traffic forecasting. The Texas Package trip generation models include TRIPCAL3, TRIPCAL4, and more recently, TRIPCAL5.

TRIPCAL3 and TRIPCAL4

Current trip generation practice involves two programs: TRIPCAL3 and TRIPCAL4. TRIPCAL3 computes the number of attractions for each TSZ. Trip attractions are estimated for four different trip purposes: HBW, home based non-work, non-home based (NHB), and truck-taxi trips. The program allows the user the flexibility to input land use in terms of acres or employment or a combination of both, i.e., acres for some zones and employment for others. The ability to input trip productions and attractions for special generators is also provided. Trip rates are input for each trip purpose and cross-classified by area type and households, employment, or acres of land. It is not a true cross-classification model because the trip rates are applied in an aggregate manner which is similar to the way a regression model operates. The output from TRIPCAL3 is input to TRIPCAL4.

TRIPCAL4 computes the trip productions for each serial zone. Trip productions are estimated for each zone using a cross-classification model. Trip rates (either person trips per household or auto-driver trips per household) are input to the program and cross-classified by

income and auto ownership. Five income categories are normally used with the percentage of households with 0, 1, 2 and 3+ autos being input to the program for each income category. The percentage of trips by trip purpose for each income category is also input for HBW, home based non-work, and NHB trips. Truck-taxi productions are set equal to the truck-taxi attractions after the attractions have been scaled to sum to the control total truck-taxi trips input to the program.

Truck and taxi trips are estimated prior to running TRIPCAL3 and TRIPCAL4. Generally, truck and taxi trips are estimated to be about 10 percent of the total trips in a given urban area. For forecast years, a lesser percentage is used to reflect a slower growth rate than other trip purposes. Information relating to the percentage of truck and taxi trips is derived from observed counts.

Trips originating external to the urban area are estimated from traffic counting at external stations around the periphery of the region. Using a manual process, the external trips are divided into external-through trips and external-local trips. Typically, the trip purposes used with TRIPCAL3 and TRIPCAL4 include:

- HBW

- Home based non-work

- NHB

- Truck-taxi

- External-local

- External-through

TRIPCAL5

A recently developed trip generation package used with the Texas Package is TRIPCAL5. TRIPCAL5 is designed to be flexible and allow the user different options in developing estimates of travel demand. This allows the trip generation process to be designed to use available data and improve the overall travel demand estimates. The different options include trip production models, trip attraction models, disaggregation models, multiple trip purposes, and user-selected data inputs.

Trip Purposes

Up to ten trip purposes may be used in TRIPCAL5 with specific trip rates or models for each. The only limitation is that the same type of cross-classification model must be used for each run where those trip purposes are being estimated using a cross-classification model. Typical trip purposes which might be used are:

- HBW

- Home based school (non-college)

- Home based school (college/post-high school)

- Home based shopping

- Home based other (HBO)

- Non-home based work

- Non-home based other

- Truck-taxi

- External-local

Estimation of Trip Productions

Three trip production models are included in TRIPCAL5:

- A two-way cross-classification model which allows trip rates to be stratified for up to six categories for each independent variable

- A three-way cross-classification model which allows trip rates to be stratified for up to six categories for two of the independent variables and up to four categories for the third independent variable

- A linear regression model with up to six independent variables

The recommended trip production model is a two-way cross-classification model with person trips (or auto-driver trips) per household cross-classified by up to six row categories and up to six column categories. While the program was developed to allow the user to input any

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independent variables for the cross-classification model, the recommended independent variables are median household income and household size.

Estimation of Trip Attractions

Five trip attraction models may be used to estimate trip attractions:

- A two-way cross-classification model and attraction trip rates stratified for up to six categories for each independent variable

- A three-way cross-classification model with trip rates stratified for up to six categories for two of the independent variables and up to four categories for the third independent variable

- A cross-classification/regression model with trip rates stratified for up to 24 generation areas by households and employment type

- A linear regression model with up to six independent variables

- A two-tier regression model with six independent variables

The recommended trip attraction model is a regression type cross-classification model for each trip purpose stratified for up to 24 generation areas. While referred to as a regression type model, it would be developed in a similar manner as a cross-classification model using trip rates per employee and per household stratified by area type for up to 24 generation areas. It is referred to as a regression type model because the trip rates are applied to the independent variables (employment and households) in the same manner as the coefficients in a linear regression equation. The trip rates are normally developed from data from a workplace survey and not developed using statistical regression techniques.

Since many areas do not have data available to develop cross-classification attraction models, regression type models are widely used. Many areas, due to data limitations, must develop regression relationships using zones aggregated to district levels with additional models used to allocate district level attractions to the zones within the district. For this reason, an option is included which allows these "two-tier" regression models to be input.

Disaggregation Models

The disaggregation models provided in TRIPCAL5 are for three production model variables: households by household size, households by household income, and households by auto ownership. For any one of these three variables, the user may choose to input the marginal distribution for each zone, input a disaggregation curve for the urban area which is used to develop a marginal distribution for each zone, let the default model in the program compute the marginal distribution for each zone, or use a combination of those three methods. While TRIPCAL5 is oriented to those three variables, the user may select and use any other variable desired as long as the marginal distribution is input for each zone.

Special Generators

The trip production and attraction models are developed for average conditions and land development types in an urban area. Land use activities considered unique within an urban area are handled as a special generator. Trip productions and attractions are estimated on an individual basis independent from TRIPCAL5, and the resulting productions and attractions are directly added to the zone.

Trip Balancing

It is intuitive that all trips produced in an urban area must be satisfied with a complimentary trip attraction, because all externally related trips are accounted for in the process. Since they are developed independently, trip productions and attractions may not equal each other at the regional level after estimation is performed across all zones.

An option is included in TRIPCAL5 which allows regional control of total trip productions and/or trip attractions to be input directly for each trip purpose. The trips are then scaled to the control total by proportionally weighting the number of trips in each zone.

Another option is to balance productions to attractions, or attractions to productions, depending on the methodology used in estimation and whether the productions or the attractions are considered more reliable. Generally, HBW trips are balanced to attractions when a workplace survey is used as a basis for calculating the attraction rates. Since production models are generally more reliable than the attraction models, other trip purposes use productions as control

totals. The model will be structured to set the zonal productions equal to the zonal attractions for NHB trips and truck-taxi trips after all scaling and balancing has been done.

TRIP DISTRIBUTION

The Texas Trip Distribution Package

Trip distribution is the process by which the trip interchange volumes between zones are estimated. Thus, the expected urban travel pattern is described. Over time, a number of methods have been employed ranging from the uniform factor method and the Fratar method of successive approximations (both of which used observed data to project into the future) to a variety of mathematical models. These latter models are often referred to as synthetic distribution techniques. The model used in the Texas Package is the gravity model.

The Texas Package provides the analyst with the option to select either of two synthetic, mathematical distribution techniques. The alternatives are MODEL and ATOM. TLFD is an input to both MODEL and ATOM.

The Trip Length Frequency Distribution (TLFD) Model

During the era of O-D surveys, TLFD was determined manually by the analyst. Points were plotted on a graph with trips on the vertical axis and separations on the horizontal axis. From these points, a "smoothed" curve was drawn. This curve was input to MODEL and ATOM. With the discontinuation of O-D surveys, the need for an alternative method of determining the TLFD curve became apparent. A TLFD model was developed and put into use in 1974. Theoretical revisions were made and an improved TLFD model was made available in late 1979. These revisions overcame the tendency of the original model to underestimate trips at the very short separations.

To use the TLFD model, the analyst must estimate the mean desired trip length for each trip purpose. Next, the maximum separation at which trips can occur is either estimated by the analyst using a network program or the default set of estimation models in the TLFD model calculate the values. To control the underestimation of trips at the longer separations, the analyst may impose a limit to control the minimum percentage of trips at the maximum separations.

The principal benefit of an accurate trip length frequency estimation procedure is that it has allowed a reduction in the amount of data required from urban travel surveys. Previous research has shown that a home interview survey of approximately 600 dwelling units will provide a reliable estimate of the mean trip length but a poor estimate of the frequency distribution. Given the mean trip length, the procedure can be used to estimate the frequency distribution. The TLFD is, of course, of great importance since it is used as an objective function in the trip distribution process for both MODEL and ATOM.

The Texas Package method uses two inputs to estimate a synthetic TLFD: the mean trip length and the maximum trip length. Since a TLFD is generally presented as the percentage of trips occurring at each separation, the distribution may be thought of as a probability distribution. The gamma distribution approximates a TLFD in form. The statistical method of Maximum Likelihood is used to estimate the shape and scale parameters of the gamma distribution using the mean trip length and the maximum trip length. The form of the model is:

$$f_t = \frac{\beta^{\alpha}}{\Gamma_{\alpha}} \, t^{\alpha-1} \, e^{-\beta t}$$

where:

t	=	time
f_t	=	relative density of occurrence of trips
α	=	shape parameter
β	=	scale parameter
e	=	2.71828...
Γ_{α}	=	$(\alpha-1)!$

The two-parameter gamma model was found to decay excessively at the right-hand tail of the estimate of the TLFD; i.e., longer trips were underestimated. As a result, an option has been provided for the analyst to impose a constraint which specifies the minimum value which the right-hand tail should asymptomatically approach.

Gravity Model

Trip distribution is the conversion of trip ends (the product of trip generation) to interacting "trips." In other words, trip ends are joined to produce completed trips. To date, the most widely used trip distribution model is the "gravity model" which essentially describes trip interchange between zones as directly proportional to the relative attraction of each of the zones and inversely proportional to some function of the spatial separation between zones, usually time or distance. Because experience demonstrates that the exponent of travel time is not constant for all intervals of time, the basic gravity model is revised to express the effect of spatial separation on zonal trip interchange rather than the traditional inverse exponential function of time.

The Texas Package trip distribution model is a modified gravity model. It is self-calibrating (described later) and normally runs five iterations. It constrains the resulting trip matrix directly to desired productions and indirectly to desired attractions and desired trip length frequency. The model also accepts directional bias factors between sectors. All bias factors which are not entered will be set to 1.0. The Texas Package gravity model is as follows:

$$
T_{i,j} = \frac{P_i\, A_j\, F_{t_{i,j}}\, K_{s_i s_j}\, E_{i,j}}{\displaystyle\sum_{x=1}^{n} A_x\, F_{t_{i,x}}\, K_{s_i s_x}\, E_{i,x}}
$$

where:

$T_{i,j}$ = the trips produced in zone i and attracted to zone j (analogous to gravitational force)

P_i = the trips produced in zone i (analogous to mass of body i)

A_j = the trips attracted to zone j (analogous to mass of body j)

t(i,j) = the travel time in minutes between zone i and zone j (analogous to separation between bodies i and j)

$F_{t(i,j)}$ = empirically derived travel time factor that expresses the average areawide effect of spatial separation on trip interchange between zones that are t(i,j) apart

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$K_{s(i),s(j)}$ = specific zone-to-zone adjustment factor bias to allow for the incorporation of the effect on travel patterns of defined social and economic linkages not otherwise accounted for in the gravity model formulation

$E_{i,j}$ = the interaction eliminator function which has a value of 1 if the interaction from zone i to zone j is used or a value of 0 if the interaction from zone i to zone j is eliminated

External Trip Distribution

External-through trips are assigned a distribution pattern based on individual judgment or on a cordon survey, if available. Forecast external-through trips are distributed with the use of a Fratar Model. External to local trip patterns are obtained by assuming that external trips will pattern the NHB trips. NHB trip attractions are used to rank the external to local trips; and an external-local trip distribution model is run, including zonal adjustment factors, if needed.

MODEL and ATOM

MODEL and ATOM perform the same task: generating trip distributions. Although they vary in fundamental methodology, the inputs and outputs are similar. A brief discussion of the two processes will follow.

MODEL is the original synthetic mathematical distribution model in the Texas Package. This trip distribution model, sometimes referred to as a constrained interactance model, loosely parallels the gravitational law introduced by Isaac Newton in 1686. MODEL includes an interaction constraint option which limits the number of attraction zones eligible to receive productions from a given zone. This will provide a more rational mix of interactions for the smaller production zones. The interaction constraint applies to all zones in the study area, and its use is optional at the discretion of the analyst. If there appears to be a sector-to-sector distribution problem, adjustments can be used to modify interactions between specified sectors. An important feature of MODEL is the direct use of the desired TLFD as an objective in the iterative process. Under this approach, the traditional friction factors of the gravity model (the relative measures of the impedance to travel due to spatial separation) are treated as simple

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iteration variables. Probably the most significant feature of this model is its ability to balance attractions and trip lengths.

Interaction Constraint

The model also accepts a production interaction curve and selects eligible interactions based on the larger values of the desired attraction values divided by the separation between the zone pairs. This limits the number of attraction zones eligible to receive productions from a given zone. The interaction constraint is applied due to problems often encountered in dealing with a large number of small zones. A pre-processor routine is employed to preselect the eligible interactions based on a user-defined production-interaction curve which describes the maximum likely interactions for a given zonal production volume.

ATOM

For simplicity, the term ATOM is used for the Texas Package trip distribution model when, in fact, it is more proper to refer to it as the "atomistic model." It is also known as a spatially disaggregate trip distribution modeling technique.

The following terms and their definitions from Webster's dictionary form the basis for the nomenclature adopted to describe the ATOM model:

atomism, n.   -   doctrine that the universe is composed of simple, indivisible,
                      and minute particles (atoms)

atomize, v.t. -   to view or treat as made up of discrete or atomistic units

atom, n.   -   one of the minute particles postulated in atomism

Using this nomenclature, the disaggregate (or atomistic) approach can be described as follows: The basic premise of the atomistic approach is that travel occurs between small parcels of land (i.e., atoms) rather than between zones. In other words, the traditional zones may be viewed as aggregations of atoms between which travel occurs. A gravity model analogy can be applied to atom pairs that form a zone pair to estimate the expected atom interchange volumes. These atom interchange volumes are essentially accumulated to form the zonal interchange volumes needed for traffic assignment.

ATOM had its genesis in the need to overcome the differences which result from the use of a common trip length frequency objective when modeling at two significantly different levels of detail. An example would be the 515-zone sketch planning structure for Houston as compared to 2,600-zone structure for the traditional detailed planning study. Research has shown that where sketch planning zones are from two to ten times the size of small zones used in the detail study, the difference in the results when the small zone results are aggregated to large zone equivalents are of sufficient magnitude to dictate the use of different TLFDs for calibrating trip distribution models at the two levels of detail. It is apparent that there is a strong basis for a credibility gap if differing TLFD's are used. Similar problems are observed in the estimation of intrazonal trips at two levels of planning detail.

Having established the problem of using a trip distribution tool such as MODEL at two levels of detail, a solution, ATOM, was developed. ATOM uses, as does MODEL, a gravity analogy in its basic formulation. ATOM is unique, however, in that it provides for the assignment of spatial attributes to zonal activities. In other words, a range of separation intervals is accepted by the models. This is a significant departure from the logic of MODEL where all zonal activity is concentrated at the zonal centroid, an assumed point in the zone which represents the center of gravity of trip ends.

In the logic of ATOM, a square space consisting of 400 equal-sized "atoms" is centered on the zonal centroid. This space encompasses the activity within the zone and is called the centroid area. The only additional datum required to use ATOM is a zonal parameter, called RADIUS, which describes the desired size of the centroid area for each zone. In effect, this parameter measures the distance in minutes of travel time from the center point of the zonal centroid to the nearest point on the perimeter of the zone. This nearest point must be on a segment of the street and highway network. Care must be exercised to avoid mistaking a geographical barrier (e.g., river) or a man-made barrier (e.g., railroad, canal) for a segment of the network. There are situations where a river or a railroad form a part of the zone boundary. With the spatial dimension of each zone established, ATOM then functions essentially as MODEL in the distribution of trips, not only between zone pairs but within the zones, thus producing calculated intrazonal trips.

Zone-to-Zone Bias Factors (K-Factors)

There may be factors specific to an urban area, other than those related to travel time, which affect patterns of travel. Various social and economic conditions may also affect travel patterns.

The Decennial Census transportation package includes data for each census tract of residence and employment; i.e., the trip ends for the HBW trip purpose. These data represent the actual surveyed origins of the HBW trip. The coverage of the Census is generally every one out of six households and, therefore, provides a good basis for calibrating the modeled HBW trip matrix.

Generally, the amount of adjustment that is required would be dependent on the ratio of the O-D survey results to the unadjusted gravity model results for a particular movement. However, it is also dependent to a more limited extent on the proportion of trips produced in any zone which are to be adjusted. The following formula has been used to express the relationship between the adjustment factor for any zone movement and these two factors:

$$K_{i,j} = \frac{R_{i,j}\ (1 - X_i)}{1 - (X_i\ R_{i,j})}$$

where:

$K_{i,j}$ = adjustment factor to be applied to movements between zone i and zone j

$R_{i,j}$ = ratio of O-D survey results to the gravity model results for the movement between zone i and zone j

X_i = ratio of O-D trips from zone i to zone j to total O-D trips leaving zone i

The trip distribution model applications require the zonal trip productions and attractions by purpose produced in the trip generation process and the zone-to-zone travel times for the minimum time paths estimated using the highway network with 24-hour speeds. In addition, the

models require estimates of the zonal radii values, estimates of the TLFDs by purpose, and any needed bias factors (also referred to as K-Factors) by trip purpose.

MODE CHOICE AND HOV MODELING

The Texas Package does not contain a mode choice model. The Texas Package trip generation model estimates vehicle-driver trips or person trips. Houston, San Antonio, and Austin have developed separate mode choice models to complement the Texas Package for transit forecasting. The Texas Package does contain, however, a model for predicting vehicle usage of HOV lanes.

This section summarizes the models used by the Metropolitan Transit Authority to perform mode choice modeling (Source: "Metropolitan Authority of Harris County, Texas - Priority Corridor Alternatives Analysis - Methods Report No. 3: Travel Demand Forecasting," September 1990).

Mode choice modeling in Houston is accomplished through the use of multinomial logic equations for each trip purpose. The Houston trip generation model estimates person trips which are separated into transit and auto vehicle trips in the mode choice model. The models used by METRO to perform mode choice modeling are multinomial mode choice models originally developed and calibrated for the Houston-Galveston region by TTI and Barton-Aschman Associates. Three separate models are used, one each for HBW, HBO, and NHB. The HBO model sums the home based school, home based shopping, and HBO trips purposes used by the Houston-Galveston Area Council of Governments (HGAC) in the other modeling phases.

Each model is a six-dimension multinomial logic model. The modes used for the HBW mode split are transit, drive alone, two person auto, three person auto, four plus person auto, and van. "Van" represents vanpooling and assumes an 8.9 person average van occupancy. The modes used for HBO and NHB mode split are transit, drive alone, two person auto, three person auto, four person auto, and five plus person auto. In all three models, transit is separated into walk-access and auto-access opportunities, and mode split is conducted for each.

Preparing Vehicle Trip Tables for Assignment

The trip generation and trip distribution models are applied at the detailed TSZ level. In Houston, the person trip tables are then collapsed to 784 transit analysis zones for application of the mode choice models. The subsequent post-mode choice highway analyses are performed at the TSZ level. The Texas Mezzo-level HOV Carpool Model in Houston provides an important "bridge" between the 784 transit zones and the 2,598 highway zones. Since the mode choice model does not have an HOV carpool component, the Texas Mezzo-level HOV Carpool model is also used as the model for forecasting HBW HOV carpool vehicle trips.

HOV Carpool Model

The Texas HOV model is essentially a "mezzo-level" adaptation and extension of the Atlanta HOV carpool model developed by Barton-Aschman Associates, Inc., for the Atlanta Regional Commission. One of the salient features of the model is its use and adaptations of three models originally developed for use in the Washington D.C., region. (These are the travel time ratio model developed by JHK and Associates for use in estimating HOV carpools in the Shirley Highway and IH-66 corridor inside the beltway; the logic model developed by Barton-Aschman Associates, Inc., for use in estimating HOV carpools in the Bolling/Anacostia corridor; and the travel time savings model developed by the Metropolitan Washington Council of Governments for estimating HOV carpools for long-range planning.) The three models are used as "shift" models, with the region's travel demand model data used as the basis for the shift. The final model results are obtained by computing a weighted average of the results from the three individual models.

A key difference between the Texas model and the Atlanta model is the level of detail at which the mode choice and auto occupancy data are input. The Texas model provides for the input of the expected percentage transit and the average auto occupancy at the sector interchange level rather than the zonal interchange level; provides an option for inputting the auto occupancy estimates by separation; and provides an option for inputting the expected percentage trips by school bus (since these school bus trips are not carried by the public transit system, this is an important option for converting home based school person trips to vehicle trips). This mezzo-level approach for inputting the percentage transit and expected auto occupancy provides the

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needed bridge between the two different levels of zonal detail used in the transit and highway modeling (Source: "Implementation of a Mezzo-level HOV Carpool Model for Texas," Texas Transportation Institute Research Report 1103-2F, November 1989).

TRAFFIC ASSIGNMENT

The Traffic Assignment Process

Following the creation of production/attraction trip tables during trip distribution, the vehicle trip tables are summed and converted to O-D format and assigned to the appropriate network (base year for base year trip table and forecast year for forecast year trip table). This 24-hour capacity restraint assignment is usually performed at the detailed TSZ level using the ASSIGN SELF-BALANCING program in the Texas Large Network Package. Several iterations of the capacity restraint model are used before the computation of the final assignment results. Between each iteration, the capacity restraint model adjusts the link impedances based on the link's volume/capacity (v/c) ratio (regardless of whether or not the link volume is over or under capacity). The v/c ratio is calculated using a weighted average of the assigned volumes from the preceding iterations.

Impedance Adjustment Function

The impedance adjustment function used in the capacity restraint model is based on the Federal Highway Administration (FHWA) impedance adjustment function. The impedances used in the Texas Package are usually travel times, although a composite cost based on a combination of distance and travel time (or other variables) is possible. The FHWA function assumes the impedance is based on a "zero volume" link speed. Since Texas highway networks have been traditionally coded using a 24-hour speed rather than a zero volume speed, a modified version of the FHWA impedance adjustment function was implemented. The formula for the Texas impedance adjustment function is:

$$I_{n+1} = [\ 0.92\ +\ 0.15\ (\frac{V_n}{C})^4\ ]\ I_1$$

Subject to: I_{n+1} $<=$ $(n+1)I_1$

where:

V_n	=	a weighted average of the volumes assigned on all preceding iterations
C	=	LOS link capacity
I_1	=	LOS link impedance
I_{n+1}	=	adjusted link impedance

The Texas impedance adjustment function increases impedance when the v/c ratio exceeds 0.85 for all links on every iteration. Again, the FHWA function (sometimes called the BPR function) from which the Texas function was derived is based on input free-flow travel times. The input speeds for the Texas model are observed speeds. Therefore, the assumed beginning v/c ratio is 0.85. For links exhibiting a v/c ratio less than 0.85 after a single iteration, the impedance is lowered.

The constraint is imposed in order to limit the magnitude of the impedance adjustment. The maximum impedance adjustment varies by iteration. Following the initial assignment, the maximum impedance adjustment factor is 2 (reducing the 24-hour speed by one-half). The maximum impedance adjustment factor is increased by 1 for each of the succeeding iterations.

Following the iterations (usually five), the model computes the final assignment results by using a weighted average of the link volumes from each of the preceding iterations. The weighting of the iterations is a user-specified input, although a multiple regression technique is possible but not recommended. The iteration weights used in the 1985 base year assignment for the Houston-Galveston region are 10, 10, 20, 20, 20, 20 percent. Satisfactory results have been obtained in other areas using the following weighting percentages: 15, 15, 20, 20, 30.

The Texas Large Network Package

The assignment tool of the Texas Package is the Texas Large Network Package (LARGENET). The LARGENET can accommodate a study area consisting of up to 4,800 zones, 16,000 nodes, and 20,000 link data cards, and a maximum link impedance of 10.23 minutes. The package provides the user with several choices as to the procedure by which trips between zones are assigned to the network.

The ASSIGN model is a straightforward, single iteration, all-or-nothing process. In the LARGENET, this is accomplished using the routines BUILD TREES and LOAD NETWORK. Where unacceptable anomalies appear, the analyst must make adjustments and run ASSIGN again.

To overcome this handicap, ASSIGN SELF-BALANCING was developed. This model provides an iterative or repetitive cycle of assignments with internal capability to adjust link impedances between iterations. The adjustment of link impedances is accomplished by comparing the number of trips assigned to a link in the preceding iteration with the capacity of the link. Where the link is over- or underassigned, an algorithm is used by which the original link impedance is adjusted so as to discourage so many trips or so as to attract more trips. Thus, over the usual three to six iterations, the model "self-balances" each link assignment.

The LARGENET needs a network in the form of link data and a trip matrix which is a product of the Texas Trip Distribution Package. If ASSIGN is to run, there is little else necessary, because this is a single iteration of the classic all-or-nothing assignment. If, however, the analyst chooses ASSIGN SELF-BALANCING with the capacity restraint option, some choices exist; and some possible added inputs must be considered.

There are two options in capacity restraint. This has to do with how the results of the several (three to five) iterations are combined. One option allows the program to exercise a default option by which a multiple regression is performed. When the multiple regression option is selected, it is quite possible that the results of the first and/or the second iterations will not be used in the final calculation. Intuitively, this situation cannot be justified. The other option allows the analyst to specify a percentage weight for each iteration. Then the specified portion of each iteration is summed, and the result is shown as the last iteration. If five iterations are specified, the composite of these five iterations is shown as iteration six. Either process provides

a degree of multiple routing which is not possible with a single all-or-nothing assignment. Both options use the same capacity restraint algorithm or formula. The second option was developed to ensure that a part of each iteration went into the final results.

Where limited access, high-capacity facilities play an important part in the study area network, it may be necessary to take steps to prevent the tree builder from assigning relatively short trips on and off the freeway. This can be accomplished by introducing a turn penalty at all, or specified, on and off ramps. Turn penalty values ranging from .25 minutes to .75 minutes have been used, but a penalty of 0.5 appears to be most reasonable.

CHAPTER 11: FORECASTING INPUT DATA[*]

BACKGROUND

Estimating travel demand is a critical part of transportation planning. It is typically accomplished through a process which involves four major steps: trip generation, trip distribution, mode split, and trip assignment. Trip generation involves estimating the number of trips being produced and attracted by discrete subareas within the urban area referred to as zones. Trip distribution is the process by which the number of trips that are interchanged between zone pairs is estimated. Mode split is the process of estimating the number of those trips that will use each mode that is available for transportation. Trip assignment is the process of predicting the route or line (e.g., transit) that the trips will take in going from one zone to another. The results of these steps are estimates of the travel demand on the facilities being analyzed. Additional refinement is typically necessary before final estimates of the travel demand are developed.

This chapter reviews and analyzes two important aspects of estimating and predicting urban travel demand. The first aspect is that of obtaining and developing the data and information used in developing and calibrating urban travel demand models. More specifically, this chapter deals with the design and conduction of urban travel surveys in the state of Texas.

The second aspect of urban travel demand deals with the development and projection of the input data which is used in urban travel demand modeling. The importance of this information is readily apparent since it determines the output from the trip generation process.

URBAN TRAVEL DEMAND MODELING DATA

Urban travel demand modeling data consist of that data necessary for the development of travel demand estimates using travel demand models which have been developed typically from travel surveys or borrowed from similar urban areas. The importance of these data lie in the fact that they are the basis for the resulting estimates of travel demand. Their accuracy and spatial

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[*]The information in this chapter is excerpted from David Pearson, *Urban Travel Demand Modeling Data*, Texas Transportation Institute (forthcoming).

distribution determine the eventual outcome of the travel demand forecasts and subsequent project recommendations.

The trip generation models developed for an urban area define the type and level of detail of the input data. For example, if the trip generation model requires estimates of the number of households by household size, income, and auto ownership to estimate the number of trips being produced, the input data at the zone level will consist of the number of households stratified by those three categories. There are a number of different travel demand models in use in urban areas with different input data requirements. This section will focus on the input data requirements of the trip generation models. It will be noted, however, that those input data items are typical for the most part for the trip generation models used in other urban areas.

The purpose of this section is to present a discussion of the different techniques and methods used in the development of the input data required for travel demand estimation. The first section discusses the data requirements. The second section discusses the general data development process. Following that is a description of the methods and techniques typically available for developing forecast of different variables at the regional level. The fourth section discusses the different allocation methods and techniques for developing estimates of the input data at the level required for travel demand modeling, i.e., the zone level. The last section presents a description of the practice used in different urban areas, both within and outside Texas.

Data Requirements

The trip generation models, as recommended for use by TxDOT, require estimates of the number of households stratified by household size, household income, and auto ownership at the zone level for the estimation of trip productions. The trip attraction models require estimates of the employment in each zone stratified by employment type and area type. These data requirements represent the most detailed level anticipated for use in travel demand modeling under the recommended trip generation model, TRIPCAL5. There are other options available which would typically require less detail since TRIPCAL5 provides considerable flexibility in the trip generation model used for travel demand estimation. For purposes of this report, the specific data elements that will be discussed are population, households, auto ownership, household income, employment, and area type.

Population and households are discussed jointly, since they are typically estimated together; e.g., households are generally estimated based on population using an average household size. Area type estimation is discussed separately relative to methods and techniques and is not discussed in the section on allocation methods and techniques, because this variable is estimated from other forecast variables. Employment is another variable which has three categories which must be estimated. These categories, as per the recommendations previously mentioned, are basic employment, retail employment, and service employment. The definition of each of these categories is by SIC code. Basic employment includes employment in the SIC categories from 1000 to 1799 and 2000 to 5199. Retail employment includes employment in the SIC categories 5200 to 5999, and service employment includes the SIC categories 6000 to 6799 and 7000 to 9799.

Data Development Process

The development of the input data required for travel demand modeling typically follows a fairly standard process. The steps, methodologies, and techniques used may vary significantly but the overall process is fairly consistent and generally consists of the following steps:

1. Development of estimates at the regional, subregional (sometimes referred to as district), and zonal level for the base year (i.e., existing conditions).

2. Development of projections of each variable for some future year for the region under study.

3. Allocation of the regional projections to each subarea within the region. Typically, this first allocation is to either districts or sectors which represent aggregations of zones (a zone is considered to be the finest level at which data projections will be made for purposes of travel demand modeling).

4. Allocation of the subregional estimates to the zones which comprise each subregion.

It should be noted that while this process is considered to be typical, it is not the process followed in all cases.

DATA DEVELOPMENT

Travel demand models are those models which are used in trip generation for the purpose of developing estimates of trip productions and attractions for each zone. These models are developed using research findings in combination with available data. Typically, the data which are available for model development and calibration will strongly influence the type of trip generation model developed.

Theory

Trip generation is the process of estimating the number of trips that are produced and attracted by discrete subareas (referred to as zones) within an urban area. These trips are classified into two principal categories, home based and NHB. A home based trip is a trip for which either the origin or the destination of the trip is the home. NHB trips are all other trips. The zone where a home based trip is produced is the zone in which the home is located regardless of whether the zone is the origin or destination. The zone where a NHB trip is produced is the origin zone for the trip. The zone where a home based trip is being attracted is the non-home zone. The zone where a NHB trip is attracted is the destination zone. These definitions are significant because they form the basis on which the trip generation models are subsequently developed. Trip productions are estimated using models which are based on the characteristics of the household. Trip attractions are estimated using models which are based on the characteristics of the land use activities attracting the trips. The development of trip generation models are therefore predicated and dependent on the data available for model development and calibration.

Trip generation models generally fall into two categories, linear regression models and cross-classification models. The type of model used is, in many cases, dependent on the data available for the development and calibration of the model. Other considerations are the trip purposes being estimated and whether specific models are being employed for each trip purpose.

Linear regression has been and continues to be used in trip generation modeling. The models used relate the number of trips (either productions or attractions) to various independent variables at the zone level. Trip productions are usually related to socioeconomic characteristics of the households at the zone level such as household size, number of autos owned, household

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income, age of head of household, number of licensed drivers, etc. Trip attractions are usually related to the characteristics of the land use activity or intensity measures such as employment, acres of development, amount of parking, square feet of leasable area, etc. The variables used typically depend on the trip purpose and whether productions or attractions are being estimated.

Cross-classification, also referred to as category analysis, is considered a disaggregate approach to estimating trips. Trip rates (e.g., trips per household or trips per employee) are stratified (i.e., cross-classified) by certain socioeconomic characteristics which have been found to influence the type and number of trips produced or attracted. The estimation of the trips produced by a zone involves estimating the number of households in the zone which had the characteristics of the categories by which the trip rates were stratified. For example, the number of households with two persons in them and having an average household income between $7,500 and $9,999 would be multiplied by the trip rate of 0.92 to estimate the number of trips produced by those households. The households within each zone would be disaggregated into each cross-classification category and multiplied by the appropriate trip rate to estimate the number of trips produced. Trip rates can be developed for estimating trip attractions in a similar manner. Each trip purpose may also have separate trip rates.

The basic key in the trip generation model is the data used to develop and calibrate the model. These data generally come from travel surveys. Up until the mid-1980's, the trip rates and models used in Texas were based on O-D travel surveys conducted in the 1960s and early 1970s. Beginning in the 1980s, TxDOT began an effort to update the base information for their trip generation models and procedures. This effort was intensified to correspond with the conduction of the 1990 census and consisted of having a number of travel surveys conducted in urban areas within the state.

Travel Surveys

Travel surveys are the basis for the information by which trip generation models are developed and, in some instances, may be used to study and/or analyze travel patterns within an urban area. In the sixties and early seventies, travel surveys were done by having surveyors conduct home interviews in randomly selected homes throughout the urban area. This method provided the most reliable and accurate information; but it required a great deal of time,

manpower, and money. These first surveys were designed to gather information on the characteristics of the household and the number, purpose, and mode of travel for each trip made by persons five years and older in the household during a 24-hour period, typically during the middle of the week. The information gathered from the surveys and from secondary sources (e.g., employment) was used to develop trip production models and trip attraction models. The models were used to predict the number of trip productions and attractions in the future by assuming that the trip-making characteristics would remain stable over time with any increase/decrease in travel being caused by changes in either households and/or land use activities.

While trip generation models have changed somewhat over time (i.e., since the sixties), the information necessary to develop and calibrate those models has remained basically the same. What has changed has been the amount of information and the techniques for obtaining the information. It became apparent in the seventies that funding was not sufficient to update the earlier travel surveys in the same manner as they were originally accomplished.

Consequently, new techniques (or in some cases modified old techniques) were developed in the late seventies and eighties and applied in obtaining the travel information necessary for updating or validating trip models being used in major urban areas. While the techniques may have changed, the information being gathered has remained fairly consistent with a few exceptions. One of the major changes (over the first travel surveys) has been the reduction in the sample size (i.e., the number of individual surveys being conducted). This was a result of increasing costs and insufficient funds to conduct similar massive surveys as done in the sixties.

In Texas, the Dallas-Fort Worth and Houston areas were the first to update their regional travel surveys in the mid-eighties. The Dallas-Fort Worth survey was actually several distinct, independent surveys. It included a household travel survey, a workplace survey (of both employees and individuals traveling to the workplace for reasons other than work), and a special generator survey. The Houston travel survey was primarily a household travel survey. In 1989, a travel survey was also conducted in Texarkana, Texas. These surveys and the experience gained in their implementation subsequently led to a fairly consistent survey methodology for use in conducting similar travel surveys in Texas.

As a result of the surveys conducted in the Dallas-Fort Worth, Houston, and Texarkana areas and the recognition that the basis for the travel demand models was questionable due to the

age of much of the data, an effort was successfully initiated by TxDOT to fund and supervise extensive travel surveys in several different sized urban areas throughout the state. The intent was to compile a comprehensive data base on travel by which travel demand models used for transportation planning could be updated using the latest techniques and data available. The San Antonio urban area was selected for the first of these surveys. Surveys were subsequently conducted in Tyler, Amarillo, Brownsville, and Sherman-Denison, Texas.

As the first of several areas where travel surveys would be done, the travel survey in San Antonio became the preliminary design tool for the travel surveys that would follow. The surveys conducted in Dallas-Fort Worth, Houston-Galveston, and Texarkana all provided a base of information relative to the techniques to be used, information to be gathered, and methodologies. This was especially appropriate since each of those surveys were different in one way or another. Using the information and knowledge gained in the previous three travel surveys, the San Antonio travel survey was structured to consist of the following five distinct travel surveys:

1. Household survey
2. Workplace survey
3. Special generator survey
4. External travel survey
5. Truck travel survey

The following sections contain descriptions of the procedures established in the San Antonio travel survey for each of the individual surveys above. Some of the procedures were modified based on the results of the San Antonio survey, and these modified descriptions are included in lieu of the original procedures.

Household Survey

The household survey was designed to obtain information on the number, length, purpose, mode, and time of day trips were made by persons five years of age and older in sample households over a 24-hour period. The survey had four major areas of determination: sample size, identification of the information to be obtained, methodology, and quality control.

The sample size for the household travel survey posed one of the most difficult areas of consideration. The necessary sample size for obtaining certain levels of accuracy may be estimated using standard statistical methods based on an estimate of the coefficient of variation for each trip rate (i.e., trips per household) within each cell of the household stratification being used in the survey. The estimates of the coefficient of variation were not readily available, and they were subsequently estimated using information from the survey done in the Dallas-Fort Worth area. The primary household stratification selected for use in the household travel surveys was household size (four categories: 1, 2, 3, and 4 plus) by auto ownership (four categories: 0, 1, 2, and 3 or more). The overall level of accuracy desired for estimating the mean trip rates for each of three trip purposes (i.e., HBW, home based non-work, and NHB) was set at ± 5 percent with a level of confidence of 90 percent. The desired level of accuracy for the average trip rates (for each trip purpose) within each cell of the primary cross-classification stratification was set at ± 10 percent with a level of confidence of 90 percent without exceeding a sample size of 2,500 households.

It was recognized that to maintain the desired level of accuracy within the most significant cells, the criteria would have to be relaxed in the least significant cells to stay within the specified overall sample size of 2,500 households. The least significant cells were identified as those with zero auto ownership and those where the number of autos exceeded the persons in the household. The sample size of 2,500 households was based primarily on limiting the overall cost of the survey and ensuring that the resulting data would be sufficient to provide reasonable results. No specific sample size is indicated for the zero auto households by household size, but a total number of 390 is specified for the zero auto ownership category. The sample size requirements could also be relaxed for those cells where the autos owned exceed the persons per household. Trip rates were also to be reported for two other stratifications of households, household size versus household income and household income versus autos owned.

Household size in this secondary stratification ranged from 1 to 5 or more while household income was stratified by quintiles of households. A minimum number of samples in each cell of the secondary stratifications was required to ensure some degree of statistical reliability. The actual sample sizes per cell would vary depending upon the area being surveyed and the proposal justification for the survey (i.e., consultants could propose and justify specific sample sizes per

cell). The principal criteria was the stratification categories, the minimum of 2,500 households to be surveyed and the levels of accuracy. Since the San Antonio survey was completed, the sample size has been relaxed to require a minimum sample of 1,500 households and a maximum sample size of 2,500 households. This was based on an analysis of the survey results in San Antonio which indicated, using the variance of the trip rates, that a total sample of 1,500 households would yield results within the level of accuracy required. This also gives more flexibility to proposers to document and justify smaller sample sizes and possibly reduce the cost of the survey.

The determination of the information desired from the survey was fairly straightforward. This was due to the fact that substantial experience in household surveys was available from Dallas-Fort Worth, Houston, and Texarkana. Experience in travel demand modeling also guided the delineation of the information that would be needed in developing new or updated models. The household survey instrument consisted of two major components, a household information component and a travel diary information component. The household survey instrument requested the following information:

1. Confirmation of mailing address, type of residence, number of people living at that address, the number of persons five years of age or older, the number of persons in the household that were employed, and the number of vehicles available for use by members of the household.

2. For each person in the household five years of age and older, their sex and age, an indication as to whether they were or were not a licensed driver, their relation to the head of the household, whether they were employed, and whether or not they traveled on their travel day.

3. The combined total annual income of all members of the household. Ten ranges of income (in $5,000 increments) were on the survey form and the responders were requested to indicate into which range their total household income fell.

In the second component of the household travel survey, each person five years of age and older was requested to complete a travel diary on their travel day. The travel diary obtained the following information:

1. The day the travel was recorded.

2. The location/address (i.e., origin) and departure time for the first trip.

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3. The name and address (or nearest intersection) of each destination (beginning with the first trip); the first trip including the time of arrival; the purpose of the trip; the mode of travel, the number of persons in the vehicle; if it was a car, truck, or van and the cost for parking (if any). If the trip was made by bus, they were asked how much the fare was and how they got to the first bus stop. They were also asked to record the time they departed each destination.

The methodology for implementing the household survey included several steps. The selection of the households to be included in the survey was done using a stratified random sampling technique. These households were then contacted by phone and asked to participate in the survey. If contact with a household selected in the sample was not made on the initial attempt, the household was called back at different times. As many as three to five attempts were made to contact the households. The characteristics of each household that agreed to participate was monitored during the initial contact to ensure that the number of desired households in each stratification cell was not exceeded. It was recommended that professional telemarketing firms be utilized in the initial contact of households, in the follow-up calls, and in the collection of the survey information.

Following the initial contact, those households agreeing to participate would be sent a household survey and travel diary with instructions to complete the survey forms and travel diary for a specific day. The household would be contacted prior to their travel day to remind them to complete the survey on their travel day and to determine if they had any questions concerning the survey information sent them.

Two procedures have been used for collecting the travel survey information from the household. In the first procedure, the household was contacted by phone the day after their travel day; and the household and travel information was obtained directly over the phone. The household was asked to return the survey forms so that the agency would have a hard copy of the results for future reference. In the second procedure, the households were requested to mail back the survey forms after their travel day. The surveys were checked; and if any inconsistencies or missing information was noted, the households were called back to obtain the missing information and/or clarify any inconsistencies.

Use of the first procedure with well trained interviewers has the potential of obtaining more accurate numbers of trips, because the interviewer would be able to note and question any

inconsistencies during the interview as well as clarify any questions and/or confusion the household may have had in completing the forms. The interviewer, in many cases, can obtain information on trips that may not have been recorded by the household. The disadvantage of the procedure is that households may not be motivated or inclined to return the survey forms which are necessary for purposes of project management and documentation. The second procedure has the advantage of ensuring the survey forms will be obtained in their original form, but the disadvantage is that missing trips will not be discovered unless there are obvious errors or inconsistencies on the survey forms.

Quality control was recognized as one of the most important issues to be addressed during the survey. It ensured that the ultimate survey results would be as usable and unbiased as possible. Quality control and checking was done at each step of the implementation of the household survey. Records were kept on the number of calls made to each household and the household response concerning the survey. If the response was positive, the characteristics of the household were obtained to determine what stratification the household belonged and to ensure that the number of households in that stratification were not being disproportionately included in the survey (i.e., the quota for each cell was not exceeded).

The telephone contact records were recorded and monitored each day. This provided up-to-date information as to where the survey was in terms of obtaining the necessary number of households (by cell) to participate in the survey. As the travel data were collected by phone, they were edited by the interviewer; and any missing information was obtained from the household at that time. The interviewer's supervisor edited the completed surveys and returned them to the interviewer for a call back if there were any errors or inconsistencies. An additional edit check was made by computer relative to answers which could be compared logically.

Workplace Survey

The workplace survey was intended to collect data by which person, auto driver, and truck-taxi trip attraction rates could be estimated. Detailed data would be provided on non-residential trip generation characteristics which would not be available from the household travel survey. Two categories of workplaces were identified, freestanding workplaces where the business could be isolated for survey purposes and non-freestanding workplaces where the

business might be located in a building or area with other businesses and could not be isolated completely for survey purposes. The workplace survey was composed of three individual surveys: a survey of the employees travel characteristics, a survey of the non-employees traveling to the workplace, and a survey of the commercial truck and taxi trip characteristics relative to the workplace. As in the household survey, there were four major areas of determination: sample size, identification of information to be obtained, methodology, and quality control.

Sample size for the workplace survey was a difficult issue to resolve. This was principally due to the lack of prior experience in surveying workplaces, the fact that the sample drawn would be a cluster sample (i.e., relative to the employees), and the variability of number and type of workplaces between urban areas. Data from the workplace survey done in Dallas and Fort Worth were used to develop an estimate of 282 establishments which needed to be surveyed in San Antonio to achieve results with ±12 percent accuracy at a 90 percent confidence level. This number however, would not be applicable to other urban areas. These establishments were to be stratified by area type and type of industry (similar to the stratification used in Dallas-Fort Worth). The total number of workplaces to be surveyed should be established based on a specified level of accuracy, the amount of funding available, and the variability in the trip attraction rates. Consequently, the determination of the number of workplaces to be surveyed within each stratification is left to the proposer, subject to the criteria that the number should be based on the attraction rate variability and the distribution of the establishments among the cross-classification categories of area type and type of industry.

There are five categories of area type: CBD, CBD fringe, urban residential, suburban residential, and rural. The determination of the area type for each zone is based on the population and employment density within the zone as computed from the following equation:

$$Factor = Population\ Density\ +\ B * Employment\ Density$$

where:

Population Density	=	Persons per square mile
Employment Density	=	Employment per square mile
B	=	Area population/area employment

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The constant B is calculated using the population and employment for the entire area and weights the population and employment variables. Work establishments were to be grouped by three types of industry: basic, retail, and service. The definition of these categories was by SIC code numbers. Basic industries include SIC codes from 1000 to 1799 and 2000 to 5199. Retail industries included SIC codes 5200 to 5999, and service industries included those codes 6000 to 6799, 7000 to 9799. Business establishments were to be grouped according to those stratifications. The number within each cell of the cross-classification to be sampled was to be determined based on the attraction rate variability (based on data from other surveys) and the areawide distribution of business establishments by area type and type of employment. It was also noted that area types could be combined for the purpose of selecting the samples but not in the reporting of the survey results. This resulted in three categories for San Antonio and is considered to be reasonable for most areas. The survey was to include all of the employees at the business establishment.

The survey of non-employees was dependent upon the establishment. Where possible, all non-employees were given a survey, requested to complete it, and return it prior to leaving. Where there were large numbers of non-employees, every "nth" non-employee would be surveyed. The survey of the trucks and taxis consisted of an actual count of the vehicles at those establishments that are freestanding. At non-freestanding workplaces, truck and taxi arrivals were determined from the survey instrument, inquiries by survey staff, and deliveries to the business establishment (i.e., they would be counted as a truck arrival). Truck delivery information for the survey day was also requested from establishments. To determine the base for expansion of survey results, all persons and vehicles traveling to the business establishment were counted.

The information considered necessary in the workplace surveys characterizes the travel patterns of employees at the workplace, the characteristics of trips to the workplace by non-employees, and the truck and taxi trips generated by the workplace. The following information was requested in the employee survey:

1. The beginning location and departure time for the employee, first trip that day.

2. Beginning with the end of the first trip and continuing for each trip thereafter, the address of each destination, the arrival time at each destination, and departure time from each destination.

3. The purpose of each trip, i.e., to return home, go to work or for work related travel, school, social/recreation/shop/eat, pick up or drop off a passenger, to change mode, or other (blank space provided).

4. The mode of transportation for each trip, i.e., driver of a car/truck/van/motorcycle, passenger in a car/truck/van/motorcycle, walk, bicycle, taxi, commercial vehicle (over one ton), bus, school bus, and other (blank space provided).

5. If the mode was by car, truck, or van, the total number of people (including the employee) in the vehicle was requested.

6. The parking cost, if parking was paid.

7. If the mode was by bus, the fare paid for the bus ride and the mode of travel to the bus stop, i.e., drove auto and parked, was dropped off, walked, carpooled with bus riders, or other (blank space provided).

The employee survey provided space for information for nineteen trips. The last question asked how many more trips the employee would make that day.

The workplace non-employee survey was designed as a questionnaire where an interviewer would ask specific questions and record the answer. The following information was obtained in the non-employee survey:

1. The persons being interviewed was first asked if they worked at the establishment. If they did, the interview was terminated to avoid duplication with the employee survey.

2. The next question was whether they had traveled straight from the home to the establishment or from another location.

3. The third question was the approximate time they arrived at the establishment.

4. The fourth question was how they made the trip to the establishment, i.e., mode of travel: driver of car, truck, van, or motorcycle; passenger of car, truck, van, or motorcycle, walk, bicycle, bus, taxi, school, commercial vehicle (over one ton), or other (blank space provided).

5. If the trip was by car, truck, or van, they were asked how many persons, including themselves, were in the vehicle. If the trip was by bus, they were asked how much bus fare they paid.

6.   The sixth question was the purpose of the trip to the establishment. The purposes considered were work related, school, social/recreational/shop/meal, delivery, and other (blank space provided).

7.   The last question asked was whether or not they were going home immediately after they left the establishment.

The third survey involving the workplace was the truck and taxi survey. For those freestanding workplaces, actual counts of the trucks and taxis to the business were made. For those businesses that were not freestanding, the number of deliveries were counted and considered to be truck trips. The other truck and taxi trips were obtained from the survey forms and questions during the survey.

The methodology used in implementing the survey differed for each of the three workplace surveys, as would be expected from the previous descriptions. The employee surveys were self-administered. Survey forms were provided to the employer who was requested to distribute them to all of the employees on the survey day. In addition, the employer was requested to furnish the number of employees in attendance on the day of the survey as well as the number absent. The completed surveys were collected by the employer and picked up by the firm doing the survey.

The methodology used in the non-employee survey was the interview technique. Persons arriving at the establishment were stopped by the interviewer who asked the questions and recorded the answers. In addition, counts were made of all arrivals regardless of whether they were interviewed or not. Where possible, interviews were attempted with all arrivals. In those locations where this was not possible, interviews were done with every "nth" person arriving at the establishment.

The truck and taxi survey consisted of actually counting the number of truck and taxi trips to the establishment. In those locations where this was not possible (e.g., non-freestanding establishment), the number of deliveries were counted and considered to be truck trips. Other truck and taxi trips were obtained from the survey forms and questions during the interviews.

Quality control in each of the surveys was accomplished by ensuring each interviewer had adequate training prior to implementing the survey. As surveys were collected, they were edited and checked, both visually and with computer programs. Surveyors were also prepared to answer

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questions relative to use of the data being collected. Since many employers were reluctant to allow the survey because of the potential sensitive nature of some of the data, it was agreed that none of the data, once collected and analyzed, would be reported for individual employers.

Special Generator Survey

Special generators are those establishments with unique characteristics that preclude the estimation or projection of travel demand using normal or typical trip generation models. For these establishments, surveys are done to establish travel characteristics typical for each class of special generator. The special generator categories established in San Antonio were regional shopping centers, hospitals, colleges/universities, airports, regional recreational facilities, and military bases. These categories may or may not be the same between urban areas. They are generally defined at the beginning of the survey and specific establishments identified for inclusion in the survey. Provision has to be made for possible refusal to participate; and, when feasible, more than one facility may be identified. The survey of the special generators was very similar to the workplace but allowed the unique characteristics of the generators to be considered. The information gathered was to enable the development of trip attraction rates, both person and vehicular, for internal person, auto-driver, and truck-taxi trips. As in the workplace surveys, the special generator surveys consisted of three parts, an employee survey, a non-employee survey, and a truck-taxi survey or count. Since only one special generator is typically surveyed in each category, sample size was not a major determinate. The major considerations were the information to be collected, the methodology, and the quality control. These, for the most part, were the same as in the workplace survey. The major areas of difference are discussed in the following sections.

The identification of the additional information to be obtained for the special generators is based on the anticipated use of the data in the development of specific models for estimating travel demands generated by the special generators. Much of the information was obtained during the initial contact and negotiation with the establishment concerning the conduction of the survey. The additional information typically obtained for airports is the number of flights per day, number of deplaning passengers per day, and amount of parking. The additional information for colleges or universities typically includes student enrollment and the number of students living

on and off campus. Information on regional malls will typically include the number and name of the anchor stores, gross leasable square footage, and amount of parking. Additional information for hospitals will normally include the number of beds and amount of parking.

Other special generators may require different information. The basis for identifying this information will depend on the type of special generator and the attributes of the generator which may be explanatory relative to the number of trip productions and/or attractions of the generator. The data mentioned in this section are typical but are not meant to be the only information which may be collected. In addition, the surveys may be modified depending on the special generator. For example, in San Antonio, the question on the reason for the trip in the non-employee survey at the hospitals had to be eliminated due to the potentially sensitive nature of why people would be making the trip to the hospital. As in the workplace surveys, vehicle and person counts were made to determine the total number of trips being made to each special generator. The survey forms used in the special generator survey were the same as those used in the workplace survey for employees and non-employees.

Quality control was maintained in the same manner as in the workplace surveys. Surveyors were trained and supervised during the conduction of the survey. The surveys were checked both visually and by computer for errors. As the surveys were processed, certain statistical tests were also performed to determine the adequacy of the sample being obtained. A minimum response of 20 percent or a minimum of 100 completed surveys was identified as desirable in the case of the employee surveys. For the non-employee survey, at least 30 trips for each trip purpose and mode and 100 auto-driver and auto-passenger were to be obtained if possible. For the truck-taxi survey, a representative sample would be attempted with surveys, if feasible, and as a minimum, truck counts would be done.

Truck Survey

The truck survey was actually a combination of a commercial truck and taxi survey. The purpose of the survey was to obtain information by which truck-taxi trip rates could be developed and to develop trip lengths and TLFDs for truck and taxi trips.

In the San Antonio survey, industrial firms were selected at random from the phone book, contacted by phone, and asked if they would participate in the survey. The survey was designed

to gather trip information for trucks weighing one ton or more. In certain cases, the firm allowed surveyors access to the travel logs for their trucks and the survey data was collected directly from the logs. The following information was collected in the truck survey:

1. The date the trips were made and the type of vehicle, i.e., payload weight, number of axles, description, etc.

2. The location or address where the first trip of the day began and the departure time for the first trip.

3. The destination (i.e., address) of each trip as well as the arrival and departure time.

Provision was made on each survey for information on up to 18 trips. The last question asked was how many more trips the person would make in that truck that day. While taxis were not surveyed directly in San Antonio, later travel surveys included tasks designed to obtain information on the number of taxi trips and trip length of those trips. In the San Antonio survey, 400 usable truck surveys were obtained which included a representative mix of different types of trucks with payload capacities of one ton or more. This number has varied in some later surveys.

Prior to the survey, surveyors underwent training for both the solicitation of firms' participation as well as the actual collection of the data. Training also included how the data would be used, and kept confidential and how to deal with individuals reluctant to participate in the survey. The surveys were checked, edited, and computer checked for inconsistencies.

External Travel Survey

The purpose of the external travel survey was to obtain information on the characteristics of person and vehicular trips moving through the study area and to/from the study area to areas outside the study area. The survey was conducted at those points where streets/highways cross the cordon line which defines the boundary of the study area. An important assumption was made in San Antonio and in subsequent surveys that the outbound trips would mirror the inbound trips, and it was not necessary to survey vehicles traveling in both directions. The survey was subsequently done only on outbound vehicles. In addition to the survey, 24-hour directional

traffic counts were done at each location, and vehicle classification counts were done during the hours that the survey was conducted.

While the general location at each facility for the survey was determined initially, the actual location was identified through a joint effort of the consultant and TxDOT by field observation. This was necessary to ensure that the final traffic control plan (one was required for each location) could be developed and to ensure safety for the interviewers and supervisors during the survey. Generally, traffic was narrowed into one through lane in the outbound direction. One to three vehicles were moved out of the travel lane to the shoulder where the surveyors conducted their interviews, and the rest of the traffic was allowed to continue through the survey site. After the survey was completed, the vehicles resumed their travel; and another one to three vehicles moved to the shoulder for the survey. If traffic congestion created a queue of vehicles greater than 0.75 miles in length (approximately), the interviewers stopped interviewing; and the traffic was flagged through the site to reduce the congestion and time delay. The survey was conducted during a 12-hour daylight period except for those locations where it was determined that the survey could obtain acceptable results and meet the minimum required number of surveys (e.g., in San Antonio this number was 400 and in Amarillo the number proposed was 300) within a shorter time period.

Surveyors and supervisors were trained prior to conducting the survey. The most critical aspect of the external survey was the development of the traffic control plan and the monitoring of the traffic conditions during the survey to ensure that delays and congestion did not reach levels that increased the likelihood of an accident.

Model Requirements

As discussed earlier, the purpose of conducting the travel surveys is to obtain the information necessary to develop and calibrate a model for estimating travel demand within an urban area. As may be noted, the design of the travel surveys was more or less predicated on the use of a particular model, that being a cross-classification model for both trip productions and attractions for trips other than special generators, truck-taxi, and external-local. This design was based on professional judgment in combination with the knowledge of the general types of models in use in most urban areas today.

While the collection of the data was designed around particular types of models, there still remains a great deal of flexibility in the use of the data for developing modified or new models. This possibility will not be realized until the data being collected have been thoroughly analyzed to ascertain the relationship between travel demand and the specific information obtained. The initial intent of the travel surveys was to obtain that information for updating the current travel demand models, and the information obtained will accomplish that objective. Further research may reveal, however, that some adjustments and/or modifications improve the current models in terms of accuracy and reliability.

FORECASTING METHODS AND TECHNIQUES

A considerable number of different methods and techniques are used in forecasting different variables for travel demand models. The discussion in this report does not include every method and/or technique nor does it include every possible variation of the methods and techniques presented. It should be noted that urban areas have adapted variations to certain models and techniques to fit their own needs and circumstances. The descriptions and discussions within this section are somewhat general and are intended to present the more commonly used methods and techniques in a format that allows consideration of the method or technique in terms of its theoretical basis, complexity, assumptions, and understanding generally how it works. The following discussions are presented for each of the main input data variables; and, in some cases, there will be overlap where certain models are used for estimating more than one variable.

Population and Households

These two data elements are grouped together because the estimate of one is typically derived from the other. For example, if the population for an area has been estimated by some method, the number of households might be estimated by multiplying the population by an average household size based on the census. The reverse could also be done. This section will discuss methods and techniques for estimating population for an urban area. A discussion at the end will address the estimation of households based on the estimated population.

Generally, projection of population may be accomplished using the following techniques:

1.   Ratio or share methods

2.   Extrapolation methods

3.   Component analysis methods

4.   Joint economic-population methods

5.   Carrying capacity methods

Ratio or share methods are predicated on the assumption (which may be based on historical observations) that an area will grow or decline in relation to the growth or decline of a larger area for which a projection already exists. It is generally recognized that projections are easier to develop for larger areas than smaller areas, and data are normally more readily available for larger areas than small areas. For population, the assumption could be made that the ratio or share of the larger area's population will remain constant or it could be adjusted based on observed historical trends and projected into the future. The projected (or constant) ratio would be applied to the projected population for the larger area to obtain the projected population for the area under study. This technique is considered very suitable for those areas where historical trends have established a dependency of the study area on the larger area and indicate a stable ratio or changing ratio that can be projected into the future.

Extrapolation methods are felt to be more applicable to shorter range forecasts (i.e., less than ten years). For this reason, these methods are not considered well suited for use in transportation planning. They are, however, considered suitable for five- to ten-year forecasts, especially in slow growing areas and in those areas where the only data available may be from historical censuses. The simplest extrapolation method is to plot population versus time (i.e., year) and, using judgment, draw a line through the historical points on the plot. That line can then be continued through the year for which a forecast population is desired to obtain an estimate of the forecast population. The analyst may also draw the plot on semi-logarithmic paper. A straight line on regular graph paper indicates that population would be growing in equal increments for equal increments of time. A straight line on semi-logarithmic paper (with population on the logarithmic scale) would indicate a constant rate of change with respect to time.

Other extrapolation methods include the fitting of a mathematical relationship to the plot of population versus time. Some of the mathematical relationships which may be used include a linear model, exponential model, Gompertz model (an "S" shaped relationship), a logistic model, a modified exponential model, and a polynomial model. Each of these produce a different

relationship with population over time and may be mathematically or manually "fitted" to the plot of the historical data.

Component analysis methods base the projection of population on the analysis of the changes in the basic components of population, i.e., births, deaths, and migration. These projections are considered most appropriate where the urban area under study is characterized as being independent of any larger area; and, thus, changes in population will be unrelated to changes in the larger area. These methods are the most widely used in preparing regional population forecasts. These techniques are also referred to as cohort component methods because the components of population change, i.e., births, deaths, and migration, are analyzed and projected separately in disaggregate fashion with each component disaggregated by age, sex, and sometimes race. The total population projection is the sum of the projection for each component. This method is more complicated and sophisticated than the extrapolation trend methods, but its underlying theory is relatively simple and straightforward. It equates the population in an area at a point in the future as being equal to the base year population plus the projected births in the area minus the projected deaths in the area plus the in-migration of population to the area minus the out-migration of population to the area. Some subtle variations in the components are used in the method, depending upon the area and the analyst.

Different techniques may be used to project each component of population change. Each requires assumptions; and, in many cases, the techniques of ratios and extrapolation are used to project the rates of change in the different components based on historical observations. The advantage of this method is its soundness in theoretical basis. If the assumptions made relative to the projections in the rates of change for the different components are correct, the resulting estimates of population must be correct since the method accounts for each possible change in population.

The method requires the projection of mortality, fertility, and migration rates that are age specific and sex specific (usually). Typically, five year age cohorts are used beginning with the 0 to 4-year-old group and ending with the 85 and over group. The survival (based on the mortality rate) rate and net migration rate is applied to each cohort to estimate the population in each cohort to arrive at the estimated population in that cohort at the end of five years (e.g., from 1980 to 1985). Birth rates are applied to the women of child bearing age (by five year age

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cohort) to estimate the births during that five-year period which then becomes the population in the 0 to 4-year-old cohort at the end of the five years. These birth rates may be sex specific or percentages may be applied (developed from historical, national, and/or local sources) to estimate the births by sex. The births are also adjusted for mortality and migration. Population by age cohort is projected in five-year increments from the base year to the forecast year for each sex.

Economic-population projection techniques vary considerably in regard to whether the technique truly integrates the projection of both or whether the output of the economic model is used as input to another demographic (e.g., population) projection model. For example, estimates of employment could be used to adjust migration estimates for the population model. These techniques are generally driven by the economic side of the model. The models are built in most cases, around the concept of two types of economic activity: one serving a larger area outside the boundaries of the study area and one serving the needs of the study area itself. The activities serving the area outside the study area are referred to as "basic," while the activities serving the study area may be called "non-basic," local, or secondary. Growth of population within the study area is considered to be related to the growth in basic activities. Population is estimated as a function of this growth in basic activities and the related growth in non-basic activities. This estimate may be computed by using of a constant ratio or a projected changing ratio. The underlying theory is that the basic industries provide goods which are exported to areas outside the study area. The employment in those industries is supported by the employment in non-basic industries. The changes in employment are related to the changes in population and form the basis for the estimates of population in the future.

Carrying capacity methods are based on the capacity of natural systems to carry a certain size and spatial organization of activities. These require certain assumptions dealing with community goals, economic structure, land use distribution, pace of development, etc., and are used most frequently as checks on the reasonableness of results from other models.

Once the population for an area has been forecast, it is necessary to relate that population into the number of households for trip generation purposes. This may be done by assuming an average household size and multiplying the total population by the average persons per household. The key is the average household size for the urban area. Typically, this is based on census data, and two options are available. One, it may be assumed that the average household size will

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remain constant over time. In this case, it would simply be a matter of multiplying the projected population by the average household size observed in the latest census.

The second option is to analyze the historical pattern of household size for an area using census data from several censuses. Extrapolation methods could be used to manually fit a curve to the historical data or fit a mathematical relationship to the data. The resulting relationship would be extrapolated to produce an estimate of the average household size in the future. Care must be exercised in the extrapolation to ensure that the future estimate is reasonable, since strict application of a mathematical formula could result in a negative household size (this is especially true since average household size has been declining in many urban areas).

Household Income

Projecting household income is one of the more difficult tasks in the development of data for estimating travel demand. It is difficult because of the variability of income, the impact of inflation on income, the lack of definitive relationships which explain the causality of changes in income, and the need for estimates of the number of households by household income by different ranges at the zone level as well as at the regional level. While difficult to project, its importance in the estimation of travel demand has been firmly established. There are several techniques and methods by which household income may be estimated at the regional level. In most cases, estimates of the distribution of households by household income will be developed for the region initially and then used to project the change in income at the zonal level. In the discussion of these, it is assumed that any projection will be done in terms of constant dollars with the base year (i.e., the year the dollar represents) being the same year as was used in the calibration of the trip generation models. Some of the methods used to project income are as follows:

1.   Judgmental assumptions methods
2.   Extrapolative methods
3.   Step-down methods
4.   Mathematical techniques

Judgmental assumption methods refer to those methods involving a high degree of local judgment with little or minor use of other techniques. One such method is the assumption of no

change between the base year and the forecast year. This assumes that there would be no growth in terms of real income for the forecast year, and incomes would be held constant. It would be necessary for the local analyst to assume an income for those areas not developed in the base year but projected to be partially or fully developed in the forecast year. On a regional basis, it would be assumed that the distribution of households by household income would remain the same as observed in the latest census.

Another judgmental assumption method is based on the premise that any change in income will be due to new development only. Household income for existing development would remain constant through the forecast year. The income for new development would be assumed based on local knowledge. The resulting estimates would then be a weighted average for the entire urban area. The key in this method would be the estimate of the new development and the household income for that development which would be added to the existing distribution of households by household income.

Extrapolative methods, as implied by their name, are those methods that involve some sort of trend analysis based on historical observations. The trend in income (in terms of constant dollars) is assumed to continue into the future for the purpose of estimating the future distribution of households by household income. For example, the respective distributions of households (or families) by household (or family) income for two different censuses are first put on a comparable dollar basis. The two distributions are compared to determine the relative change (growth or decline) in each income range to develop a factor which may be applied to the base year income range to estimate the percentage of households in that range in the forecast year. There are several variations to this method. For example, an estimate of the average annual growth in real income may be developed locally and used with assumptions on the growth rates for various income groups (e.g., quintiles of population) to develop a forecast distribution. Either of these examples will produce a projected distribution of households (or families) by income. Once projected, the analyst for the local area may adjust the resulting distribution to reflect local conditions.

Step-down methods are referred to as such because they generally involve the use of a forecast developed by an outside agency for different areas, for example, the Bureau of Economic Analysis produces projections of income for the United States, for states, for economic areas,

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MSAs, and water resource regions. Forecasts for the larger areas are stepped down to the smaller areas while maintaining the integrity of the forecast for the larger area. The forecast of income for a local area could be borrowed directly or used to generate adjustment and growth factors for the base year distribution to estimate the forecast year distribution. Ratios could also be established between the local area distribution (using census data) and the larger area distribution. These ratios could be applied directly to the projected income for the larger area to forecast the income for the local area.

Mathematical techniques are a combination of historical trend forecasting and use of a mathematical formulation to estimate the distribution of households by household income. Historical trends are used to project the mean household income for the area. That projection is used in combination with a calibrated income distribution model to develop an estimate of the distribution of households by household income. This method requires the calibration of an existing distribution of households by household income to a mathematical relationship. The gamma distribution is one mathematical distribution which has been used for this purpose. There are some variations in this method. One is where the gamma distribution is normalized and fit to an existing distribution from the census. The forecast mean is used to reverse the normalization process, and this results in a forecast distribution with the forecast mean. Another recently developed variation is to estimate the shape parameter for the gamma distribution based on the forecast mean income. The resulting distribution is adjusted in an iterative manner until the distribution has the forecast mean household income within a certain error (e.g., plus or minus 1 percent). Both variations produce distributions of households by household income with the projected mean household income.

Auto Ownership

Auto ownership is used in some areas in lieu of income for trip generation models. In some cases, it is used in combination with income and other variables for estimating travel demand. The projection of auto ownership for a region may be done in the following ways:

1. Continuation of existing trends
2. Mathematical models
3. Combination of one and two

The continuation of existing trends usually involves the use of census data or vehicle registration data with the assumption that the observed relationships will continue into the future. Census data may be used to establish a relationship between auto ownership and another variable, typically income. Using a plot of the percentage of households by auto ownership versus household income for the MSA, and given an estimate of the average household income, the percentage of households with zero, one, two, and three or more autos may be estimated. This method assumes that the relationship will hold true for the future.

Mathematical models may include linear regression, extrapolation of historical trends (using different type curves), and/or use of disaggregate models. These models may be developed for each category of auto ownership or for estimating another variable (e.g., autos per household) which is used to generate an estimate of the number (or percentage) of households in each auto ownership category. The complexity of the models vary from linear regression with one independent variable to a combination of a linear regression with multiple independent variables and a binary logit model. Some of the variables used as independent variables for estimating auto ownership include household size, household income, population density, number of workers in the household, age of head of household, etc. It is important to note that to develop estimates of auto ownership for a future year, each of the variables used in a particular model must also be projected for the future year.

A combination of the two methods is also used to develop estimates of the number of households by auto ownership. For example, one model uses per capita income and household size to estimate the average number of autos per household. Average household income is used with observed relationships of auto ownership to develop an initial estimate of the percentage of households by auto ownership. These percentages are then adjusted to maintain the relative shape of the distribution and produce the initial estimate of average autos per household.

Employment

Estimates of employment are typically necessary in determining trip attractions in the travel demand modeling portion of trip generation. Most models will also use several categories of employment in estimating travel demand. Estimates of employment at the regional level may be developed using one or a combination of the following methods:

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1. Ratio techniques
2. Trend extrapolation techniques
3. Economic base techniques
4. Input-output techniques
5. Econometric models

Ratio techniques (sometimes referred to as step-down techniques) are frequently used in projecting employment directly or economic activity which is used to estimate employment. An analysis of the share of employment (or activity) that is located within the study area relative to the total employment (or activity) of a larger area (referred to as the parent area) is done to determine the proportion or ratio of the employment that is within the study area. The analyst may then assume that this proportion or ratio will remain constant and apply it to the forecast for the larger area to estimate the employment (or activity) expected in the study area. The analyst may, based on historical data or local considerations, project a change in the proportion or ratio. One method of examining changes is through the use of shift-share analysis. That analysis basically looks at the shifts in employment (or activity) in the study area relative to the shifts in the larger area over the same time period. This provides a basis for adjusting the proportion or ratio of employment in the study area relative to the employment in the larger area over the forecast period. The drawback to this technique is its lack of ability to explain the cause for changes. It only identifies and quantifies the relative and absolute changes that have occurred over a certain time period. The advantage to this method is it utilizes a projection for a larger area which is typically based on more rigorous models and data which may not be available at the local area. It is also straightforward and relatively easy to apply.

Trend extrapolation techniques may be applied to employment in much the same manner as population. It consists of applying linear and/or non-linear relationships to historical employment data. These applications may be manual, graphical, and/or statistical curve fits. These techniques are also applicable to surrogate variables which may be used to estimate employment (total or subcategories). These techniques are also used in many instances with other techniques such as ratio methods (e.g., relationships used to project changes in proportion or ratios) and economic base analyses.

The economic base technique involves a thorough analysis of the economic base of an area. It is similar to other techniques in that it is based on the concept of two types of economic activity, one being basic or primary and the other being local, secondary, or service. Changes in population, employment, and other demographic variables are assumed to be related to the change in the basic employment. The reason lies in the concept that the existence of a region (or any area) is dependent on the goods and services (produced by basic activities) that it produces internally but sells to areas outside the region. The income for these goods and services provides the means for obtaining materials, food, and services which the region cannot produce itself.

In addition, the economic activities which are local in nature and market and support the basic activities are also supported and funded through the income achieved from the basic activities. The analysis of the economic base principally attempts to define the ratio between basic and service employment (or activities). This ratio can be defined in two ways. One is the proportion between the total basic employment in the study area to the total employment in the service activities. The other is the proportion of the increase in the total study area's basic employment to the increase in the total employment in the service activities. Using this ratio, a multiplier may be computed that is equal to the total (or increase) basic and service employment to the total (or increase) basic employment. By projecting the basic employment in the study area, the multiplier may be applied to yield an estimate of the total employment in the region. Similar logic and application could be applied to population as it relates to employment to yield an estimate of population in the study area. The difficulty may be in the development of the estimate of future basic employment. This could be done using one of the other techniques described in this section. One of the drawbacks to this methodology is that it tends to ignore the function of the circulation of income within the economy of a region, and the general model may be an over simplification of the economy of a region.

Input-output techniques are a continuation of the economic base and multiplier techniques. The difference lies in the complexity and detail involved in the development and application of the techniques. The premise for the technique is that the output for a particular industry is related to the amount of products produced by the industry that is absorbed by other industries and the amount of products produced by the industry which goes to the final demand. Knowing final

demand and the amount of goods required from each industry to produce goods from other industries, a system of linear equations may be identified and solved for the total goods produced by each industry. The model also has the capability for the inclusion of a spatial element relating industries between regions. The model establishes a mathematical relationship between industries. Presumably, a change in one industry may then be used to estimate the changes in other industries and produce a net result for the entire economy for the study area. The production of each industry would be related to the employment in each for purposes of projecting employment. For projection purposes, the change in the industries would have to be projected in order to estimate the overall changes in the other industries. This would probably require a iterative technique.

Econometric models attempt to model the complex relationships between industries and other variables (e.g., labor, personal income, government policies, etc.) on either a regional, multi-regional, or national scale. Considerable variation exists between the types of models within this general group. For example, some are considered "bottom-up," others "top-down," and others are a mixture of the two. Top-down models generally start with national projections and allocate them to regions while maintaining the control totals. Bottom-up models begin at the regional level, and the end result is projections or estimates at the national level. The models attempt to define the various relationships between industries, output, demand, prices, transportation, interest rates, policies, etc., in order to develop a means for estimating changes in regional, multi-regional, and national economies. A comprehensive review of the technical details of these models is not possible in this report. These types of models are the most technically and theoretically sophisticated and the most demanding in terms of data requirements and development.

ALLOCATION METHODS AND TECHNIQUES

As discussed in an earlier section, the typical process for developing forecasts of the data required for travel demand modeling involves developing regional forecasts of each variable, allocating the variables to subregion areas, and allocating the variables within each subregion to the zone level. The previous section presented some of the methods and techniques used for projecting population, households, household income, auto ownership, and employment at the

regional level. The purpose of this section is to present some of the methods and techniques used for allocating regional forecasts to the subregional and zone levels.

Six general categories of methods were identified as being the most popular methods used for allocating land use demographic projections. These methods deal primarily with the allocation of population/households and employment. In some instances, household income is also allocated. A discussion will be presented on methods for estimating household income and auto ownership following the discussion of the following six categories of allocation methods:

1. Land-use-based socioeconomic models

2. Spatial interaction models

3. Optimization models

4. Delphi techniques

5. Analytical methods

6. Non-modeling approaches

Land-use-based socioeconomic models are typically regression analysis-based models which use population, employment, or households as dependent variables with a set of independent variables that determine the number within each zone. Employment may be estimated with a different regression equation for each category of employment used, and households may be estimated with a different equation for each income category of households. One of the more widely used models in this category was the EMPIRIC model. The EMPIRIC model was actually a family of models designed to allocate projected regional population, employment, and lane use growth between a set of smaller subregions or districts. It consisted of a set of simultaneous linear equations which related changes over time in the distribution of population, employment, and land use. Population was generally broken down by age, household size, and household income. Employment was broken down by SIC code and land use acreage by type of use. This type of model can be developed and implemented quite easily, but questions have been raised as to its applicability for forecasting due to the assumption of constancy relative to the regression coefficients. The number of independent variables can be quite large, and each of those also has to be forecast for input to the model(s).

Spatial interaction models typically refer to models developed along the principles of the Lowry model, the Model of Metropolis. The input to this model is the projected basic

employment by zone of work. The model uses a gravity model to allocate these workers to their zone of residence. Dependent families of the workers are estimated using a ratio of total population to total employment. The nonbasic (or service) workers needed to serve the basic employment and their dependent families are located by means of another gravity model. These workers are then located to their zone of residence using a similar model as used for the basic employees and their dependent families estimated in the same manner. This leads to further generation of nonbasic employees and so on, until the increments of change become insignificant. Several versions of the Lowry model have been developed and are widely used. These include the Time Oriented Metropolis Model (TOMM), the Projective Land Use Model (PLUM), and the Integrated Transport and Land Use Package (ITLUP). Two submodels within the ITLUP program, the Disaggregated Residential Allocation Model (DRAM) and the Employment Allocation Model (EMPAL), are discussed in more detail in the following paragraphs.

Regional forecasts of population and employment (by type) serve as control totals which are allocated to subregional areas referred to as districts. While DRAM and EMPAL could be used to allocate directly to the zone level, another allocation process is used to allocate the district-level forecasts to the zones within the districts due to the lack of data for calibration at the zone level. The data requirements are somewhat extensive for the calibration and use of these models for allocating the forecast control totals.

The data required at the district level for the base year calibration of the models consist of the population by district of residence, employment by district of work for two different historical time periods (usually five to ten years apart), households by income quartile and group quarters population, land use by district (total land area and unusable land), land area occupied by commercial land uses, land area occupied by industrial land uses, land area occupied by residential land uses, forecast total usable land (developed plus developable), land area used for streets, vacant and developable land, and zone-to-zone travel time or costs for the base year.

The regional data required for the forecast year in addition to the forecast population and employment (by type) include the percentage unemployment by sector, number of employees per household by income quartile, jobs per employee, and a conversion matrix relating employment type to income group.

Using the base year data, behavioral parameters, and adjustment factors (referred to as K-Factors) are calibrated for both DRAM and EMPAL. The behavioral parameters reflect the local conditions and the K-Factors make adjustments at the district level to reflect unusual or unexplained patterns of development. Once these are calibrated, the models may be run for the forecast year. EMPAL is first used to distribute each category of employment among the districts. DRAM then uses the EMPAL results to forecast the residential location of the workers by income quartile. EMPAL is a modified version of the singly constrained spatial interaction model with three primary modifications: use of a multi-variate index of zone attractiveness; use of a separate, weighted lagged variable outside the spatial interaction formulation; and use of a constraint procedure which can be applied at either the zone or sector level. DRAM is also a modified version of the standard singly constrained spatial interaction model with two primary modifications: the use of a multi-variate, multi-parametric attractiveness function which represents the attractiveness of an area for residential location and the inclusion of a procedure that permits district and sector-related constraints. The attractiveness function in DRAM has two components; one represents the size or capacity of the zone for residential development, and the other reflects the socioeconomic composition of an area.

Optimization models attempt to produce an optimum allocation of a particular quantity, subject to a set of constraints. This quantity could be allocated by households, by type of housing, and/or by employment by sector. An optimized objective function is subject to the constraints which ensure that the entire quantity being optimized is allocated, that no supply-side constraints are violated, and that all allocations are non-negative. Some of the models which fall under this category are the Technique for the Optimal Placement of Activities in Zones (TOPAZ) and Project Optimization Land Information System (POLIS). POLIS is a non-linear programming-based land use allocation model. Activity patterns are influenced by location decisions of individuals selecting a job and a house to live in and by firms choosing a site to locate new employment. The model simulates the changes between two states of development. Only the new increase in employment opportunities and households are allocated for each time period with the relocation of base year employment accomplished by increasing the number of jobs to be distributed. Examples of constraints applied during the allocation include:

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- Origin destination constraints on work trips where work trips are related to households and to employment by appropriate trip rates

- Origin destination constraints on shopping trips where shopping trips are related to households and to retail employment within a zone by appropriate trip rates

- Land use density constraints for employment and housing

- All employment and housing allocated

- Spatial-sectoral constraints for county employment

- Specification of a certain number of jobs and housing units in certain zones

These examples are from the POLIS model as developed and applied by the Association of Bay Area Governments in the San Francisco Bay Area Region.

The Delphi method for allocating regional forecasts uses the combined opinions of a group of individuals to perform the allocation. Those individuals are typically well informed individuals and/or experts. A two-stage allocation process may be used which involves two different groups of individuals, one to allocate to a district level and one to allocate to the zones within the districts. The technique is designed to be a structured form of consensus building.

The first step in developing this technique is establishing the group of individuals to serve on the Delphi panel. This step is crucial and provides the basis for the ultimate success of the method. Since the purpose of the panel is to allocate land use and demographic forecasts within the study area, it follows that the members of the group should be knowledgeable about development issues and the history of development within the study area. An ideal composition would be local government officials, land use and transportation planners, representatives of utility companies, neighborhood associations and citizen groups, private consultants, academics, business representatives, and school district officials. The total number of panel members should be kept to 20 or less in order to facilitate the summarization of voting results.

One of the first tasks of the panel will be the review and approval of the regional forecast and the methodology used to produce that forecast. A package should be prepared for each member on the panel which describes the forecasts and the methodology used, describes the Delphi process including the questionnaires to be used, defines the measures used in the process, and lists criteria that will be used to end the cycle of response seeking. This preliminary package

should also include any policy alternatives, a description of the external factors and future events which may influence allocation, and any other information which would prove useful to the panel members in addressing their task.

The second major step in this process is the development of the most probable scenario. This will detail the general content of the urban form assumptions relative to the major components, land use distribution and density, demographic characteristics, travel characteristics, potential sites for special activity centers, etc. This step could involve the evaluation of several alternative development scenarios or even the evaluation of components of different alternatives. Panelists may be asked to respond by ranking each alternative (or component) as to the likelihood, or even relative to the desirability, of it occurring. Ranking could be from 1 to 10, 1 to 20, or 1 to 5 depending on the items being evaluated and the local analysts' judgment. After each response, the results would be summarized and given to the panelists for review and discussion.

Following this, another survey (same as the first) would be completed by the panelists. The process would be repeated until a point is reached that the differences between the responses (from prior survey) is insignificant. Typically, the process should converge with the panelists reaching some consensus relative to the issues being addressed.

The third major step would be the development of the forecasts for the subregional areas (i.e., districts). Prior to beginning the actual forecasting process, the staff should prepare the input data for use by the panelists. That data would typically consist of the control totals of projected population (and possibly households), employment, and income. Fact sheets would also be prepared for each district with information on the development trends, existing conditions, development capacity, special characteristics (e.g., constraints to development), and zoning considerations in the district. Any site-specific allocations which were developed in the second step would need to be removed from the control totals prior to allocating the forecasts in this step.

The panelists review the input information and evaluate the development probability for each district, and each member develops a forecast variable for each district based on judgment. One method which might be used is that of having each panelist rate the development probability of each district for each variable based on the different factors influencing development. The

combined ranking of all the panelists could then be used to apportion the forecasts for each variable to the districts. The final forecasts would be obtained through a questionnaire being completed by each panelist concerning the forecast of each variable for each district. The questionnaire would be resubmitted to the panelists (several rounds might be required) until the responses converged and stabilized.

The fourth and final step is the allocation of the district forecasts to the zones within the district. This process is similar to that used in step three. Additional detail may be considered in the development of the attractiveness (or probability) measure for the zones, e.g., proximity to transportation and/or major employment centers.

Analytical methods are generally those methods which may be (in a broad sense) considered models but lack the mathematical complexity of the urban development models such as PLUM, POLIS, DRAM, EMPAL, etc. These types of models generally involve the use of some rule of apportionment to distribute the regional projections to smaller areas within the study area. In some instances, an initial apportionment may be made using these methods; and a follow-up application of the Delphi technique may be used to adjust the apportionment or to take the apportionment down to the zone level. These models generally fall into two categories, ratio methods and carrying capacity methods. Both have been previously discussed.

Non-modeling approaches is a broad category which is used to describe the methods and techniques used in areas that are, to a large extent, judgmental. These methods may involve some analytical calculation and possibly computer manipulation, but they are usually very simple and have none of the theoretical complexity of the models previously described. There is no one description (even general) which may be used to describe the techniques which may be involved in these methods. An example of a method used in one area involved the development of two projections at a subregional level. One estimate was based on the future distribution being the same as observed in an earlier census; the other was based on the distribution being the same as an earlier forecast (forecast year prior to the year being forecast at that time). An average population was computed for each subregional area from the two distributions. The population growth forecast for the region was then distributed to the subregional areas based on the same percentage forecast for the earlier forecast and added to the current population for each area. This resulted in two separate forecasts for each subregional area. These two forecasts were

averaged to develop the final estimate for the forecast year. Forecasts by this type of method frequently require modification to reflect local judgment concerning future growth. Virtually an unlimited number of different techniques may be developed and applied under this category. The advantage is generally in the simplicity of the method and the ease of understanding for both the local staff and local elected officials.

SUMMARY AND CONCLUSIONS

The estimation and prediction of urban travel demand is dependent on the travel demand model being used and the data that are input to the model. Both issues relate to the trip generation phase of travel demand modeling and produce the cornerstone for the phases which follow trip generation.

The urban travel demand model is dependent on the information used to develop and calibrate the model. These models are typically developed using results of extensive travel surveys. These surveys and the information obtained are critical in terms of ensuring that the models which result will produce reasonable estimates of both existing and future travel demand.

The data that are input to the urban travel demand model are as important as the model itself. If bad or incorrect information is input to a good model, the results will be questionable. The development of reasonable forecasts of urban travel requires both a solid travel demand model and reasonable projections of the input data needed for input to the demand model.

CHAPTER 12: RURAL AREA TRANSPORTATION PLANNING[*]

BACKGROUND

Estimates of future traffic on rural highways can be obtained by two fundamentally different approaches: trend projections and forecasts. With trend projections, only traffic data are considered. Forecasting techniques, however, are based on relationships between traffic and certain explanatory variables.

The method most commonly used to estimate future traffic volumes on rural highways is trend analysis. This type of analysis uses historical traffic trends to develop an estimate of annual growth which is likely to occur in the future. The annual growth rates used in trend projections are determined by examining a plot of the historical traffic data by using simple linear regression techniques to fit a line through the historical data or by simply choosing two data points which define the most appropriate trend and calculating an average growth rate from these points. Traffic growth rates derived from historical data inherently capture the combined effects that population changes, economic activity, and other factors have had on traffic growth. The use of these trend-based methods to estimate future traffic assumes that past trends, including the relationships between traffic growth and various sociodemographic factors, will continue unchanged into the future.

The use of this simplistic trend-based approach is frequently attacked on the grounds that it does not explicitly account for the fact that the various economic and demographic factors which can affect traffic demand could exhibit future growth rates which differ substantially from historical trends. While this argument is fundamentally sound, it could also be argued that given the relatively slow, uniform traffic growth rates experienced on most rural highways, these trend-based procedures generally provide results which are sufficiently accurate for most rural highway planning applications where traffic volumes are generally low enough that modest errors in estimates of future traffic are not likely to alter basic design decisions. However, in those situations which require the capability to assess the effects that alternative economic and

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[*]The information in this chapter is excerpted from Robert W. Stokes and George B. Dresser, *Elasticity-Based Traffic Forecasting Models for Rural Highways in Texas*, Texas Transportation Institute, September 1991.

demographic growth scenarios might have on future traffic volumes, forecasting techniques based on relationships between traffic volumes and the underlying variables which generate that traffic are more appropriate than simple, trend-based projection techniques.

This chapter presents a brief discussion of trend forecasts but focuses mostly on rural traffic forecasting models which are sensitive to certain county and state economic and demographic factors. The models are based on the concept of "elasticity" where elasticity of demand (e.g., average daily traffic [ADT]) with respect to a certain variable (e.g., population, employment, income) is defined as the rate of change of demand with respect to that variable.

The discussion of elasticity-based models is limited in that it does not represent all functional classes or ADT volume groups of rural highways in Texas. It should also be noted that elasticity-based models are most successful with high volume (ADT > 15,100) interstate and minor arterial classes of rural highways (based on R^2 of at least 0.75). The "next best" models were for the minor collector class of rural highways (R^2 values of approximately 0.50).

TREND PROJECTION FORECASTING MODELS
Forecast Requirements

The data required to complete a forecast for the planning or design of a rural area project include the base and design years to be used, current land use maps and the location and type of major traffic generators, future land use maps and/or major traffic generators, historic and current traffic and/or turning movement counts along the facility. If the facility is a new location project, historic and current count information for the closest parallel facilities and for major cross-facilities should be provided. A description of the facility type, the number of existing and proposed lanes, and a general schematic or straightline map are also needed.

The type of forecast data required will depend on whether the project is in the planning or design stage of project development. For projects in the planning stage, the forecast data needed include:

- Estimates of base or current year nondirectional ADT.
- Forecast of design year nondirectional ADT.
- Forecast of the traffic parameters D, K, and T.
- Design year turning movements at major cross facilities.

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The forecast data needed for the design of rural facilities include:

- Design year nondirectional ADT.

- Detailed turning movements at major intersections.

- Design year traffic parameters D, K, and T.

Forecast Methodology

Most trend-based traffic projections for rural areas involve three steps. This process is best used for projects in counties where the population and employment growth rates are anticipated to be stable relative to past growth.

Step 1. Existing Traffic on the Existing Network.

A straightline network map of the existing roadway system is prepared and the existing ADT with turning movements is posted on the straightline project network.

a. Prepare a straightline network map. The straightline map is a line drawing representing the roadway system within the project area. This map usually includes the major roads (freeways, arterials, and major collectors) but may be drawn in more detail to include lesser roads when required for the project. Straightline networks may be prepared using standard intersection and interchange drawings from Intergraph files compiled to represent the project system. For some projects, however, the typical drawings do not apply; and the straightline network map must be prepared manually.

b. Compile existing traffic data from current and historical counts for the facilities included in the straightline network. These count data may be obtained from a variety of sources. The usual sources of existing counts include:

- Division files, such as the RI2T, log of previously completed projects in the same corridor or in an adjacent corridor.

- Traffic maps or freeway ramp maps.

- Previous studies or counts of the facility made by the district office or other local agency.

Generally, existing traffic count data are considered out-of-date if they was not collected within the last five years. Even when count data are less than five years old, other information

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that may suggest recent traffic volume changes, such as major changes in the development of the road system within the project area, is carefully reviewed to assist the analyst in estimating changes in traffic patterns or volumes that may have occurred since the counts were made. This information, along with historical traffic data, is used to determine a reasonable average annual growth rate to estimate current year volumes from traffic counts made during a previous year.

When suitable counts for a project are not available, 24-hour counts are made. Usually, automatic count equipment is used to count through movements. Turning movement counts generally are estimated through visual observation of an intersection.

c. Post the link volumes on the straightline network and estimate turning movements. The count data compiled in step b above are refined and posted on the straightline map. If turning movement counts are not available, turning movements are estimated. The methodology used to estimate nondirectional turning movements is described in Chapter 14.

Step 2. Existing Traffic on the Proposed Network.

Existing base year ADT with turning movements is put onto the proposed network.

a. Prepare a straightline drawing of the proposed network. This straightline drawing will include any proposed improvements expected to be completed within the project area by the design year.

b. Divert existing traffic on the existing network (as prepared in Step 1) to the proposed network. There is no set procedure used by analysts to estimate traffic diversion from the existing to the proposed network. This step is based entirely on professional judgment. The type and characteristics of the proposed facility/improvement (such as access control, capacity, and speed) and the adjacent land use serve as a basis for assigning existing traffic to the improved network.

Although diversion is the source of most traffic assigned to the improved network, most analysts assume that if the proposed facility or improvement currently existed, some additional traffic could be expected to be generated by the presence of additional capacity. Thus, traffic beyond what would be considered to occur due to normal diversion may be assigned to the new or improved facility.

c. Adjust volumes on existing facilities to reflect the estimated diversion of traffic to the proposed facility.

d. Estimate turning movements for the existing traffic on the proposed network.

Step 3. Future Year Traffic on the Proposed Network.

An average annual growth rate for each facility on the proposed network is developed and applied to the existing traffic to produce a forecast using a simple growth rate factor.

a. Calculate the average annual growth rate for existing and proposed facilities. A linear regression equation is used to compute a growth rate for facilities that exhibit linear growth. Growth rates for facilities that do not exhibit linear growth are estimated using professional judgment with regard to current and historic traffic counts, existing and anticipated land use, and expected population and employment trends. The growth rates for new facilities are based on growth rates for similar, existing facilities. Generally, lower growth rates are used in developed areas, intermediate growth rates are used in partially developed areas; and higher growth rates are used in largely undeveloped areas.

b. Apply the growth rates developed in the previous step to the existing traffic on the proposed network. Traffic is forecast to the specified design year by multiplying the existing volumes by the average growth rate. Link and turning movement volumes are refined.

c. Post the refined traffic volumes and turning movements on the project schematic.

ELASTICITY-BASED FORECASTING MODELS

The remaining section of this chapter is designed as an introduction to the concept of using elasticities in traffic forecasting. The example in this section is used for illustration purposes and is based on preliminary analyses performed by Stokes and Dresser (1991). It should be noted that elasticity-based forecasting models showed promising results only for rural minor arterials with ADT > 15,100 vehicles (Equation 12-6). Their use should be considered supplemental to current forecasting procedures in cases where evidence suggests that future county-level population and employment growth rates may be substantially different from past growth rates.

Background

The elasticity of demand with respect to a certain variable is defined as the rate of change of demand with respect to that variable, normalized by the current levels of demand and the variable in question. Demand is said to be elastic with respect to variable x if the absolute value of the elasticity is greater than 1 (i.e., a 1 percent change in x results in a greater than 1 percent change in demand). Demand is inelastic with respect to x if a 1 percent change in x results in less than a 1 percent change in demand. In the case where the absolute value of elasticity is exactly 1, demand is said to possess unit elasticity with respect to variable x.

Demand elasticity models can be estimated in three ways:

1.   Quasi-experimental approaches, which include demonstration projects in which factors affecting travel demand are altered and the resulting changes in demand are monitored.

2.   Time-series analysis of demand levels that are not related to changes in specific factors which might affect travel demand, usually involving some form of regression analysis.

3.   Derivation of elasticities from cross-sectional demand models.

The time-series approach assumes that the demand function is approximately linear over the range of interest. Analysis based on this approach is often referred to in the literature as pivot-point analysis and is the most common approach to the use of elasticities in travel demand analysis. The general form of these simple (i.e., single-variable) elasticity-based models is as follows:

(Eq. 12-1)

$$D_2 = D_0 \left[1 + e_{Dx}(x_2 - x_0)/x_0\right]$$

where:

D_0 =   initial level of demand

D_2 =   new level of demand

e_{Dx} =   arc elasticity of demand with respect to x

x_0 =   initial value of variable x

x_2 =   new value of variable x

The basic model stated by Eqaution 12-1 can be modified by expressing demand in terms of ADT, extended to make allowance for more than one explanatory variable, and rearranged to yield the following more general form. This is a more useful expression because the elasticity portion (i.e., the right-hand side) of the equation allows the analyst to calculate a traffic growth factor directly.

<div align="right">(Eq. 12-2)</div>

$$(ADT_f - ADT_p)/ADT_p = {}_{j=1}\Sigma^n e_j[(x_{j,f} - x_{j,p})/x_{j,p}]$$

where:

ADT_f = future (design year) ADT

ADT_p = present (base year) ADT

$x_{j,f}$ = future value of variable x_j

$x_{j,p}$ = present value of variable x_j

e_j = arc elasticity of ADT with respect to x_j

n = number of variables.

It can be shown that, given an equation of the following form:

<div align="right">(Eq. 12-3)</div>

$$Y_i = \beta_0 + {}_{j=1}\Sigma^n \beta_j X_{ij}$$

where:

Y_i = value of dependent variable at the ith observation

i = $1, \ldots, n_l$

X_{ij} = value of jth independent variable at ith observation

j = $1, \ldots, n$

β_0 = constant term

β_j = regression coefficient for jth independent variable

n_l = observation number

n = number of independent variable

Elasticities can be estimated by:

(Eq. 12-4)

$$e_j = \beta_j(\hat{u}_{Xij}/\hat{u}_{Yi})$$

where:

e_j	=	elasticity of ADT with respect to independent variable x_j
$\hat{u}_{Xij}$	=	overall mean of the jth independent variable
$\hat{u}_{Yi}$	=	overall mean of the dependent variable

Thus, the explanatory variables that best estimate ADT and their respective elasticities can be derived using multiple linear regression techniques.

Advantages and Limitations

An elasticity-based forecasting model has a number of potential advantages over other, more simplistic traffic projection methods. First, the range of volumes over which elasticity-based models can be applied is much greater than that used in developing the model. The reasoning behind this premise is that elasticity-based forecasts rely on a discovered relationship of underlying variables which generate traffic rather than on a simplistic review of past traffic growth trends. Second, the use of present ADT to estimate future ADT reduces the problem of underestimating nonresident travel. Nonresident travel grows at a rate similar to resident travel in elasticity-based models. A final, practical advantage is that the elasticity portion of the model (see right-hand side of Eq. 12-2) calculates a growth factor directly. As a result, the model can be easily transformed into a set of nomographs, thereby simplifying and expanding the use of the model as a forecasting tool.

While elasticity-based models offer a number of practical and theoretical improvements over simplistic trend-based procedures, a number of subtle pitfalls are commonly overlooked in applying these models. Meyer and Miller note the following issues which the analyst should keep in mind in applying elasticity-based traffic forecasting models:

1. Elasticities are often computed from fairly aggregate statistics with little or no market segmentation. Thus, considerable potential for "aggregation bias" exists in most elasticity calculations.

2.   Since elasticities assume that all factors other than the one in question are being held constant, *they are useful only for short-run predictions* [italics added], since in the long run many of these factors are apt to change.

3.   Most elasticity analyses implicitly or explicitly assume either the constant elasticity case or the [nonconstant] linear demand case as the basis for their calculations. Either assumption is most tenable for small changes in the system. The larger the projected system change, the more likely it will be that the demand response will be nonlinear, nonconstant-elasticity response, which is poorly predicted by the elasticity analysis.

4.   Considerable confusion exists over the correct use of pivot-point techniques. Pivot-point analysis assumes a linear demand function that permits a new demand to be estimated based on an elasticity which has been computed at a particular pivot point. Correct usage of this technique requires consistency in the definition of the pivot point. That is, the same point must be used to estimate the elasticity and to predict new demand levels.

Since elasticities are not constant along a linear demand curve, the value of the arc elasticity will vary depending on whether it is computed using the point (D_0, x_0) or the point (D_1, x_1) as its base. Either point can be used in the calculation as the base point, providing that all subsequent calculations retain this point as the base.

Another problem encountered in developing and implementing elasticity-based traffic forecasting models (and forecasting models in general) is that the accuracy of the models is determined to a large extent by the accuracy of the forecasts of the sociodemographic data which are used in the models. Care should be exercised in selecting logical input variables which are regularly forecast at the state, county, and local levels.

Forecast Requirements

Traffic volume data can be obtained from the Roadway Inventory and Traffic Log (TLOG) maintained by the TxDOT. The TLOG computer file contains current ADT, historical ADT for the previous nine years, design year (20 year) trend-based forecasts of ADT, and general design-related data for the highways on the State and Federal-Aid Highway Systems. The traffic volume data in the TLOG were obtained from permanent automatic traffic record (ATR) count stations, manual volume and vehicle classification counts, and truck weight studies. The data are recorded by highway control-section and highway functional classification.

The traffic volume data base used in this example consists of ADTs for the years 1986 through 1988 for the following functional classes of rural highways: (1) rural inter-states, (2) rural principal arterials, (3) rural minor arterials, (4) rural major collectors, and (5) rural minor collectors. The three most recent years of data were used to ensure an adequate sample size and to permit the establishment of a reasonably current pivot point from which to forecast future traffic volumes. The traffic data base consisted of over 6,500 observations of ADT for each of the three years from 1986 to 1988.

The coefficients of variation for the average show that the standard deviations of the traffic volume data for all functional classes except the interstate highways are in excess of 100 percent of their respective means. The extreme degree of variability exhibited by the traffic data, both within and between functional classifications, suggest that in order to reduce the degree of randomness in the traffic data, the initial phases of the analyses would need to focus on stratifying the data within each highway functional classification into more uniform groupings. Stokes and Dresser stratified the data into uniform, distinct, ranges of ADT values by using Duncan's Multiple Range Test. This test identified the four statistically different ($\alpha = 0.01$) groups of average ADT shown in Table 3.

Table 3
Results of Duncan's Multiple Range Test

ADT Group	Range[a] (ADT)
Group 1	> 15,100
Group 2	8,460 - 15,100
Group 3	1,030 - 8,459
Group 4	< 1,029

[a]Mean ADTs within each group (range) are not significantly different ($\alpha = 0.01$).

The economic and demographic data and forecasts used in this example were obtained from a private consulting firm (1). These data were chosen because the data from various local sources (state agencies, universities, etc.) were not consistent in terms of the contents of the data

sets and/or the levels of geographic or temporal disaggregation of the data. The data set selected for use in this study contains historical data and forecasts for each year for the period 1970-2010 for all counties and MSAs in Texas.

A general validation of the "reasonableness" of demographic data can be performed at the aggregate (i.e., state) level by comparing the alternative data base sources. In this case, the consultant's data and locally developed data were compared with the middle-range forecasts developed by the State Data Center (SDC). In this case, the consultant's forecasts were comparable to the SDC forecasts.

The explanatory (predictor) variables considered in the preliminary study by Stokes and Dresser are listed in Table 4. These variables were chosen because previous studies have shown that these variables reflect conditions at the county and state levels that can affect traffic demands and because their values are fairly easy to obtain through sources available to TxDOT. The historical and forecast values of all of the variables in Table 4 except vehicle registrations were obtained from the data prepared by the private consultant. The historical vehicle registration data were obtained from TxDOT, Motor Vehicle Division.

Table 4
Summary of Explanatory Variables

Variable Label	Variable Description
COREG	Vehicle Registrations (County)
STREG	Vehicle Registrations (State)
COEMP	Total Employment (County)
STEMP	Total Employment (State)
COPOP	Total Population (County)
STPOP	Total Population (State)
COHH	Number of Households (County)
STHH	Number of Households (State)
COHIN	Average Household Income[a] (County)
STHIN	Average Household Income[a] (State)
COHHS	Persons/Household (County)
STHHS	Persons/Household (State)
COPIN	Personal Income[a] (County)
STPIN	Personal Income[a] (State)

[a] 1982 dollars.

Results

The best results were obtained from two-variable models consisting of combinations of county population (COPOP), county employment (COEMP), and/or county households (COHH). However, in assessing alternative regional growth scenarios, the analyst is often more concerned with population and employment than with households. Therefore, the two-variable models which relate ADT to changes in population and employment have a broader appeal than any of the other two-variable models.

Tables 5 and 6 present summaries of the regression models and the corresponding elasticities of ADT with respect to county population and county employment for the interstate and minor arterial classes of high-volume rural highways, respectively. Equations 12-5 and 12-6 represent the elasticity-based models for these two classes of rural highways.

Rural Interstate Highways

$$ADT_f = ADT_{86} [1 + 2.4065 (\Delta COEMP) - 3.3160 (\Delta COPOP)] \qquad \text{(Eq. 12-5)}$$

Rural Minor Arterial Highways

$$ADT_f = ADT_{86} [1 - 2.5749 (\Delta COEMP) + 3.5481 (\Delta COPOP)] \qquad \text{(Eq. 12-6)}$$

where:

ADT_f = future ADT

ADT_{86} = 1986 ADT

Δ = change in predictor variable with respect to its 1986 value (e.g., $\Delta x = (x_f - x_{86})/x_{86}$, where x_{86} and x_f denote 1986 and future values of x)

As shown in Tables 5 and 6, the interstate and minor arterial models and their individual parameters are highly significant. However, the signs of the COPOP and COEMP coefficients exhibit several inconsistencies. In the case of the model for rural interstate highways, where the ADT values decreased and the economic and demographic variables increased for the period of analysis for the four counties in the base data, increases in the values of the predictor variables should result in a decrease in ADT (i.e., the COPOP and COEMP coefficients should be negative). As shown in Table 5, however, only the COPOP coefficient is negative. The

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seemingly anomalous sign for the COEMP coefficient may be due to correlations between the county population and employment variables and/or to the effects of missing variables. In any case, the interstate model is based on data where the ADT values decreased for the period of analysis and, as a result, is of limited value as a forecasting tool.

Table 5
Summary of Regression Model and Elasticities
for High Volume (ADT > 15,100) Rural Interstate Highways

Variable	Mean	Parameter Estimate	t for H_0: Parameter = 0	Prob > t
Intercept	1.0000	58745.8867	28.220	0.0001
COEMP	405853.3333	0.1824	8.954	0.0001
COPOP	741311.6667	-0.1376	-12.176	0.0001
ADT	30761.6667	--	--	--

$R^2 = 0.97$ Elasticity[a] of ADT with respect to COEMP = 2.4065
F-Value = 163.957 (p-value = 0.0001)   Elasticity[a] of ADT with respect to COPOP = -3.3160

[a]Calculated from Eq. 12-4.

The sign of the coefficient for the population variable in the model for rural minor arterial highways (Table 6) also appears to be contrary to the observed data. As noted in the previous discussion of the results of the preliminary statistical analyses, both the ADT values and the predictor variables for this class of highways experienced increases for the four counties in the high volume ADT data group.

Table 6
Summary of Regression Model and Elasticities
for High Volume (ADT > 15,100) Rural Minor Arterial Highways

Variable	Mean	Parameter Estimate	t for H_0: Parameter = 0	Prob > t
Intercept	1.0000	476.8886	0.127	0.9004
COEMP	480006.6111	-0.0920	-3.810	0.0017
COPOP	741185.9444	0.0821	4.398	0.0005
ADT	17150.4444	--	--	--

$R^2 = 0.65$ Elasticity[a] of ADT with respect to COEMP = -2.5749
F-Value = 13.917 (p-value = 0.0004)   Elasticity[a] of ADT with respect to COPOP = 3.5481

[a]Calculated from Eq. 12-4.

Thus, it is expected that both the employment and population coefficients would have positive signs (i.e., ADT should increase with population and employment). As in the case of the interstate highway model, this anomalous behavior may be due to correlations between the population and employment variables and/or to the effects of missing variables.

CHAPTER 13: TRAFFIC FORECASTING FOR PROJECT PLANNING*

GENERAL INFORMATION

Once the need for a project has been identified in the transportation system planning process, project planning is performed to evaluate possible alternative improvements and their associated impacts for a specific transportation corridor or facility. The goals of these planning studies are to establish the project feasibility; identify the preferred alternative; and to define the improvements to the extent that the facility size, the probable social, economic, and environmental impacts and the cost versus benefits can be assessed as accurately as possible.

It is important to note that each step shown in the chart may not be performed for every project and that there are no standard project planning study processes that have been defined by TxDOT for the different types of studies identified. A feasibility study, for example, may not be prepared for a specific project because the work has been accomplished by another agency (local city or county government, MPO, etc.). For other projects, extensive analysis of alternatives may not be required because there may be a limited range of solutions with which to improve travel. The type of planning study required should be determined by the local District Office.

This chapter presents a discussion of traffic forecasting requirements, the methodology for feasibility studies, and the advanced planning stage of project development. The advanced planning section includes a discussion of forecasting for three stages of alternatives analysis and environmental documentation that may be conducted during the advanced planning stage. A brief description of the forecast methodology used to develop traffic for each stage of alternatives analysis and for environmental documentation is included in this section. Information on using the referenced DOS-executable programs is found in Chapter 14, Traffic Forecasting for Project Design.

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*Information in this chapter is excerpted from Texas Transportation Institute publications *Traffic Forecasting Requirements by Project Type* and TRANPLAN *Corridor Analysis Procedures* by Patti Bass.

TRAFFIC FORECASTING FOR FEASIBILITY STUDIES

Purpose

Feasibility studies are performed to determine the engineering and economic feasibility of a proposed project. These planning studies are more detailed than the areawide system planning analyses in that they focus on improvements for a particular transportation facility or corridor. Such studies, however, do not require the level of detail and accuracy needed in traffic forecasting for the advanced planning phase of project development. Feasibility studies are often limited to the analysis of a certain type of improvement such as the construction of a new highway route instead of adding capacity to an existing facility or the addition of a HOV facility or express lanes to an existing roadway rather than the addition of mainlanes.

Feasibility studies involve preliminary engineering to establish the design feasibility, the general right-of-way requirements, and associated project impacts. This information is then used to develop cost estimates to determine the financial feasibility of the project in terms of a cost-benefit analysis. This type of study is not intended to result in detailed design, environmental analysis, or cost estimates but to determine if a project warrants further consideration and development.

Traffic forecasts are used in highway feasibility studies to analyze a preliminary facility alignment, cross-section, and access scheme to determine the effectiveness of the project to serve the projected demand and to estimate the financial feasibility of the project through some type of cost-benefit analysis of the project. Studies performed for projects in air quality nonattainment areas will need to broadly assess the probable impacts and/or benefits to air quality as part of the feasibility study as well.

Regional traffic forecasts are usually appropriate for feasibility studies. Subarea forecasts, however, may be developed for these studies when the system effects of the project have been analyzed previously during the transportation system planning process.

Forecast Requirements

Forecast data required to conduct feasibility studies usually include:

- Design year nondirectional ADT assignments with estimates of the directional distribution, and peak hour and truck percentages.

- Base year nondirectional ADT assignment with estimates of the directional distribution and peak hour and truck percentages.

- Base year and design year daily VMT for the system and the corridor.

- Base year and design year daily vehicle hours of travel for the system and the corridor.

- Base year and design year daily vehicle hours of delay for the system and the corridor.

- Base year and design year average vehicle speed for the system and the corridor.

The forecast data needed for the cost-benefit analysis (listed as the daily vehicle hours of delay above) will vary depending on the procedure used. Generally, however, cost-benefit analyses for feasibility studies use an estimate of user benefits based on estimates of reduction in travel delay or savings in travel time for the design year. These user benefits may be estimated for a specific facility, added capacity projects, the corridor, or the entire transportation system for new location projects.

The submission of a forecast request for a feasibility study should include the base and design years to be used in the study, current land use maps along the facility, the location and type of major traffic generators, past and current traffic counts for the facility, major cross-streets, and a map showing the general facility alignment. Also, the type of facility, type of operation (one-way vs. two-way), the number of existing lanes, the number of proposed lanes, and a general preliminary schematic or straightline map should be provided for each alternative to be studied. For new location projects, the length (in feet) of each link of the proposed facility should be included on the schematic or straightline map.

If the forecast is being performed in the District or by a consultant, other information that will be needed to perform the forecast includes the TRANPLAN files, *.ANT, *.NET, *.RAD, *.PNA, and *.EXT for the base year, the intermediate year, and the long-range forecast year for the specific metropolitan area in which the project is located. Copies of the DOS- executable programs NEWYR, BALANCE, and ALLOCATE, and the capacity/speed look-up table, functional classification table, and trip production and attraction rates for the urban area are required as well.

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Forecast Methodology

There are two major steps in the procedure for developing a traffic forecast for a feasibility study in urban areas. Each of these steps is briefly described below. Instructions for the use of TRANPLAN, the DOS NEWYR, BALANCE, AND ALLOCATE programs and the screenline refinement procedure are detailed in Chapter 14.

Step 1. Prepare Base Year and Existing Year Traffic

In this first step, the base year (the year used for validation of the most recent transportation system forecast) and the existing year traffic information (current year or the year immediately preceding the current year) are developed. This information will be used for comparison in subsequent steps of the process. For some projects, only the base year information will be needed. Projects located in areas that have experienced significant changes in population and/or employment or major changes in the transportation system that have resulted in changes to the general travel patterns may require updating the base year to the current year for use in the subsequent analyses. The decision to use the base year or the current year should be based on the specific changes that have occurred relative to the project. Prior to actually preparing the base year or current year traffic, however, several steps should be performed which will provide data required in subsequent steps.

a. Define the project study area and boundaries. The study area should be defined so that the major facilities which influence travel patterns within the area of the project are included. The size of the study area for each project will depend on the type of facility and the type of proposed improvements. A major freeway project will usually require a larger study area than a project on a minor arterial roadway. As a general rule, the study area should extend 2 to 3 miles either side of the project and 0.5 to 1 mile beyond the project termini. It should be remembered, however, that the study area boundaries may extend farther. It is important to include the major facilities, particularly parallel facilities.

b. Prepare a plot of the base year traffic counts, base year capacities and base year traffic assignment for the study area. Use TRANPLAN to plot the base year traffic counts, base year capacities, and base year validated assignment for the defined study area. The base year is the year used for the most recent transportation system forecast for the particular urbanized area.

c. Prepare a plot of the existing roadway network within the study area. The network file used in this step will be either the base year network or the intermediate forecast year network, depending on which year is closest to the current year. The intermediate forecast year is the year for which the 10-year system forecast was prepared. Use HNIS in TRANPLAN to revise the selected network within the study area to accurately represent the existing network. Changes or improvements that have been made to the roadways within the study area should be reflected in the base year network. If the intermediate forecast year network is used, changes to the network might involve deleting planned improvements that have not actually been implemented or adding improvements that have been implemented but were not included in the last system forecast.

At this time, the coded capacity and speeds of the facilities in the study area network should be reviewed and revised as needed to reflect changed conditions. Typical capacities and speeds for the various types of roadways for each urban area can be obtained from the capacity/speed look-up table for that area. If no network changes have occurred and the network file being used is the base year, this step is not required. A copy of one of the base year plots prepared above can be used. If the intermediate forecast year network is used and accurately represents the existing network, then a plot of that network file is all that is needed.

d. Make preliminary determination of screenlines. Screenlines may be required in subsequent steps to check the assignment produced by TRANPLAN within the study area. The base year or current year plot of the study area prepared in one of the previous steps can be used to select the appropriate screenlines. Screenlines should be selected to include roadways that represent likely alternatives for directional traffic within the study area. Several general rules should be followed in the selection of screenlines:

- Avoid meandering or diagonal roadways.

- Do not include zone connectors that are crossed by the screenline in the analysis.

- Screenlines should cross a minimum of three roadways and preferably no more than seven roadways.

- Screenlines should be no longer than necessary.

• Screenlines should be placed midway between major roadway crossings or every 2 miles, whichever is less.

e. Prepare a traffic assignment for the current year traffic on the existing network. This step is performed for those projects where the current year will be the base year of the study.

1. Use the DOS NEWYR program to develop a new production and attraction file for the current year. This program compares the base year or beginning year productions and attractions to the productions and attractions for the closest forecast year and interpolates the two production and attraction files to create a third production and attraction file for the current year in TRANPLAN format. This new production and attraction file will be based on the interpolation of productions and attractions at the zonal level by trip purpose from the base year and future year production and attraction files. NEWYR will also balance the attractions proportionally by zone and trip purpose to productions for the input files so that the new production and attraction file is balanced.

2. Run the long method of the TRANPLAN model.

3. Prepare a plot of the current year traffic assignment.

4. Check the assignment for reasonableness by comparing the assigned traffic to the base year traffic counts and base year assignment (as plotted in Step 1b) for each link. A useful check is to use the baseline assignment deviation analysis results in the screenline analysis spreadsheet. The rationale behind this check is that the maximum allowable deviation of a screenline traffic estimate should be such that a roadway design would not vary by more than one roadway lane.

   If the percentage deviation between the assigned volumes and current counts is unacceptable, correct the problem(s) in the modeling process. It may be that the level of growth anticipated during the system forecast was too little or too great compared to what actually occurred. Thus, the current year production and attraction file interpolated from the base year and intermediate forecast year may be reflecting too few or too many trips. There may also be coding errors in the network. If the productions and/or attractions in certain zones need to be changed to reflect more or less growth than previously forecast, use the ALLOCATE program to make the necessary revisions.

5. Make the appropriate revisions in the TRANPLAN process and rerun the assignment. Recheck the assignment. If the baseline deviation check is acceptable continue with the next step.

<u>Step 2. Develop and/or Refine Design Year Traffic on the Proposed Network.</u>

a. <u>Revise the design year network.</u> Compare the project schematic to the 20-year network used in the system forecast. If the network does not include the proposed project schematic or if more detail is needed in the network, update the network using HNIS in TRANPLAN. Coded capacities and speeds should be revised as needed to reflect known changes.

b. <u>Revise the design year network to include the proposed improvement.</u> Use TRANPLAN to revise the network to include the proposed improvement. This may include revising the coded capacity and speed for the facility to reflect changes made by the improvement. If the project is a new location project, the functional classification code will be needed. This code can be obtained from the functional classification table for the specific urban area in which the project is located. This step will be performed for each separate forecast made for a feasibility study.

c. <u>Determine adjustments to the design year production and attraction file.</u> If the project design year is the same as the 20-year system forecast year, the production and attraction file used for the system forecast will be used. This file may need to be adjusted, however, to reflect existing land uses and other anticipated growth if conditions have changed since the system forecast. Adjustments to the productions and attractions can be made to reflect changed conditions using the DOS-executable ALLOCATE program. The production/attraction rates for each trip purpose can be obtained for each specific urban area.

For projects where the design year is different from the system forecast year, the 20-year trip table will need to be adjusted to reflect estimates of productions and attractions for the design year. To make these adjustments, the DOS NEWYR program is used to either extrapolate the future trip table (system 20-year forecast trip table) to a year further in the future, or to interpolate to a design year between the intermediate and long-range forecast years if the design year was prior to the 20-year forecast year. If the project design year was prior to the 20-year forecast year, the DOS NEWYR program would be used to determine the factors.

d. <u>Assign design year traffic to the design year network.</u> Use TRANPLAN to assign the design year trip table (as determined in Step 2b) to the design year network developed in Steps 2a and 2b.

e. Refine design year traffic assignment. Use the percentage deviation results in the screenline refinement procedure to check the assigned volumes. For the refinement, use the current year traffic counts and assignment (for projects where counts are available) or base year traffic counts and assignment as the base year volumes.

It is not necessary to perform extensive adjustment of the assigned traffic in a feasibility study. A check for reasonableness of the forecast data produced and the assigned traffic, however, should be made. Areas where unusual data or assigned volumes that are considered to be unreasonably high or low should be analyzed in order to identify any coding errors or miscalculations in input data. If errors are found, they should be corrected and a new forecast and assignment completed.

Several forecasts may need to be developed during the study if major changes to the facility size and or alignment are required due to unforeseen conditions or impacts. The forecast data required and the level of detail and accuracy needed should remain the same for any forecast made. And, in all cases, the same production and attraction files should be used.

TRAFFIC FORECASTING FOR ADVANCED PLANNING STUDIES
Purpose

This phase of project development involves the environmental and public involvement process of project planning on reasonable alternatives, the preparation of the schematic design for the preferred alternative, and the determination of right-of-way requirements. Forecast data are required in this phase to evaluate alternative improvements, to determine the environmental impacts of reasonable alternatives, and to prepare and analyze the preliminary schematic design of the project. Although each successive analysis within this stage of project development depends on and builds on previous analyses, the forecast requirements for each major process in this phase (planning, design, and environmental documentation) are discussed separately to facilitate understanding of the different forecasting requirements. This section presents only a discussion on traffic forecasting for advanced planning. Traffic forecasting for environmental analyses is presented in the next section of this chapter. Traffic forecasting for roadway design is presented in Chapter 14. Additionally, those planning studies which include the analysis of transit options should refer to Chapter 7 regarding the mode choice modeling.

The goal of the advanced planning stage of project development is to identify the improvement that best addresses the design year travel demand, is cost-effective, and is publicly and environmentally acceptable. Due to the differences among specific TxDOT projects, the number type, and level of detail of traffic forecasts required during advanced planning will vary. Ultimately, however, the directional design-hour volumes (DDHV) used to develop and analyze the preliminary schematic plan will be produced from a forecast made during this process.

The level of planning performed for a project during this stage of project development will depend on the project size, the area in which the project is located, the type of improvement(s) to be studied, and the number and range of alternatives to be evaluated. For some large scale urban projects an alternatives analysis will be needed in order to identify the reasonable alternatives to be analyzed in the environmental and public involvement process. For other projects, the options available for improving travel along a facility or corridor may be limited to one type of improvement, such as adding mainlanes to an existing freeway. For these projects the evaluation of numerous alternatives is not required and the environmental and public involvement processes can be used to determine the preferred action, build or no-build.

Forecast Requirements

Generally three series of forecasts may be needed during this stage of project development:

1.   Forecasts for the initial evaluation of alternatives.
2.   Forecasts for the evaluation of selected alternatives.
3.   A forecast for the preferred alternative.

Each successive stage requires an increasing level of detail and accuracy; although, as mentioned, not all levels of forecasting will be needed for every project.

Initial Evaluation of Alternatives

Purpose. This phase of advanced planning should be performed where the number of build alternatives to be evaluated is greater than four. Travel forecasts should be prepared for each distinct alternative in order to develop information needed in the evaluation. Preliminary engineering during the alternatives analysis generally involves sufficient information to prepare

the horizontal alignment of various alternatives on aerial photography of the project area. The goal of conducting this initial evaluation is to narrow the number of alternatives by identifying those that will best satisfy the travel demand and are cost-effective. The analyses conducted in this evaluation also will provide information valuable to refining the alternatives selected for further study. Traffic forecasts are used to provide information used in the evaluation of alternatives.

Forecast Requirements. Refined traffic assignments are not required at this stage. Unadjusted directional or nondirectional ADT assignments (checked for reasonableness) may be used during this initial evaluation and actually are desirable, since using informed judgment to make adjustments to one assignment and not another may unintentionally bias the evaluation process. What is most important is the need to prepare alternative forecasts using the same design year socioeconomic forecast and design year base network. The only difference between alternative forecasts should be the specific network improvements being analyzed.

The forecast data needed will vary for each project depending on the range of improvements considered and the specific evaluation criteria set for the project. Generally, a base year assignment and travel forecasts of directional or nondirectional ADT for the design year, usually a 20-year horizon from the base year, are used. The exact forecast year(s) will be determined for each project. Other forecast data that are commonly used to highlight key differences between alternatives include:

- Estimates of the peak-hour percentage and the percentage of trucks for the build and/or design year.

- Average speed, travel time, and/or delay for the build and/or design year.

- Daily VMT for the build and/or design year.

- Daily vehicle hours of travel for the build and/or design year.

The submission of a request for forecasts for an initial evaluation of alternatives should include the build and design years to be used in the study, current land use maps along the facility and the location and type of major traffic generators, past and current traffic counts for the facility and major cross-streets, and a map showing the general facility alignment. Also, the type of facility, type of operation (one-way vs. two-way), the number of existing lanes, the

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number of proposed lanes, and a general preliminary schematic or straightline map should be provided for each alternative to be studied. If the project is a new location, project length (in feet) of each link in the facility should be provided for each alternative.

If the forecast is being made by the District or a consultant the TRANPLAN files *.ANT, *.NET, *.RAD, *.PNA, and *.EXT for the base year, the intermediate year, and the long-range forecast year for the specific metropolitan area in which the project is located are needed. Copies of the DOS-executable programs NEWYR, BALANCE, and ALLOCATE, and the capacity/speed look-up table, functional classification table, and trip production and attraction rates for the urban area and are required as well.

Forecast Methodology

The methodology that should be used to prepare forecasts for the initial evaluation of alternatives is similar to that used for feasibility studies. There are two major steps in the process used to develop the forecast and related information for the initial evaluation of alternatives in urban areas. These steps are briefly described below. Instructions for the use of TRANPLAN, the DOS NEWYR, BALANCE, and ALLOCATE programs and the screenline refinement procedure are detailed in Chapter 14.

Step 1. Prepare Base Year and Existing Year Traffic

In this first step, the base year (the year used for validation of the most recent transportation system forecast) and the existing year traffic information (current year or the year immediately preceding the current year) are developed. This information will be used for comparison in subsequent steps of the process. For some projects, only the base year information will be needed. Projects located in areas that have experienced significant changes in population and/or employment or major changes in the transportation system that have resulted in changes to the general travel patterns may require updating the base year to the current year for use in the subsequent analyses. The decision to use the base year or the current year should be based on the specific changes that have occurred relative to the project. Prior to actually preparing the base year or current year traffic, however, several steps should be performed which will provide data required in subsequent steps.

a. Define the project study area and boundaries. The study area should be defined so that the major facilities which influence travel patterns within the area of the project are included. The size of the study area for each project will depend on the type of facility and the type of proposed improvements. A major freeway project will usually require a larger study area than a project on a minor arterial roadway. As a general rule, the study area should extend 2 to 3 miles either side of the project and 0.5 to 1 mile beyond the project termini. It should be remembered, however, that the study area boundaries may extend farther. What is important is to include the major facilities, particularly parallel facilities.

b. Prepare a plot of the base year traffic counts, base year capacities, and base year traffic assignment for the study area. Use TRANPLAN to plot the base year traffic counts, base year capacities, and base year validated assignment for the defined study area. The base year is the base year used for the most recent transportation system forecast for the particular urbanized area.

c. Prepare a plot of the existing roadway network within the study area. The network file used in this step will be either the base year network or the intermediate forecast year network, depending on which year is closest to the current year. The intermediate forecast year is the year for which the 10-year system forecast was prepared. Use HNIS in TRANPLAN to revise the selected network within the study area to accurately represent the existing network. If the base year network is used, changes or improvements that have been made to the roadways within the study area should be made. If the intermediate forecast year network is used, changes to the network might involve deleting planned improvements that have not actually been implemented or adding improvements that have been implemented but were not included in the last system forecast.

At this time, the coded capacity and speeds of the facilities in the study area network should be reviewed and revised as needed to reflect changed conditions. Typical capacities and speeds for the various types of roadways for each urban area can be obtained from the capacity/speed look-up table for that area. If no network changes have occurred and the network file being used is the base year, this step is not required. A copy of one of the base year plots prepared above can be used. If the intermediate forecast year network is used and accurately represents the existing network, then a plot of that network file is all that is needed.

d. Make preliminary determination of screenlines. Screenlines may be required in subsequent steps to check the assignment produced by TRANPLAN within the study area. The base year or current year plot of the study area prepared in one of the previous steps can be used to select the appropriate screenlines. Screenlines should be selected to include roadways that represent likely alternatives for directional traffic within the study area. Several general rules should be followed in the selection of screenlines:

- Avoid meandering or diagonal roadways.

- Do not include zone connectors that are crossed by the screenline in the analysis.

- Screenlines should cross a minimum of three roadways and preferably no more than seven roadways.

- Screenlines should be no longer than necessary.

- Screenlines should be placed midway between major roadway crossings or every 2 miles, whichever is less.

e. Prepare a traffic assignment for the current year traffic on the existing network. This step is performed for those projects where the current year will be the base year of the study.

1. Use the DOS NEWYR program to develop a new production and attraction file for the current year. This program compares the base year or beginning year productions and attractions to the productions and attractions for the closest forecast year and interpolates the two production and attraction files to create a third production and attraction file for the current year in TRANPLAN format. This new production and attraction file will be based on the interpolation of productions and attractions at the zonal level by trip purpose from the base year and future year production and attraction files. NEWYR will also balance the attractions proportionally by zone and trip purpose to productions for the input files so that the new production and attraction file is balanced.

2. Run the long method of the TRANPLAN model.

3. Prepare a plot of the current year traffic assignment.

4. Check the assignment for reasonableness by comparing the assigned traffic to the base year traffic counts and base year assignment (as plotted in Step 1b) for each link. A useful check is to use the baseline assignment deviation analysis results in the screenline analysis spreadsheet. The rationale behind this check is that the maximum allowable deviation of a screenline traffic estimate should be such that a roadway design would not vary by more than one roadway lane. If the

percentage deviation between the assigned volumes and current counts is unacceptable, correct the problem(s) in the modeling process. It may be that the level of growth anticipated during the system forecast was too little or too great compared to what actually occurred. Thus, the current year production and attraction file interpolated from the base year and intermediate forecast year may be reflecting too few or too many trips. Or, there may be coding errors in the network. If the productions and/or attractions in certain zones need to be changed to reflect more or less growth than previously forecast, use the ALLOCATE program to make the necessary revisions.

5.   Make the appropriate revisions in the TRANPLAN process and rerun the assignment. Recheck the assignment. If the baseline deviation check is acceptable, continue with the next step.

Step 2. Develop and/or Refine Design Year Traffic on the Proposed Network.

a. Revise the design year network. Compare the project schematic to the 20-year network used in the system forecast. If the network does not include the proposed project schematic or if more detail is needed in the network, update the network using HNIS in TRANPLAN. Coded capacities and speeds should be revised as needed to reflect known changes. The same base network should be used for each alternative forecast made. The only network difference between each alternative forecast should be those related to the network differences among the alternative improvements.

b. Revise the design year network to include the proposed improvement. Use TRANPLAN to revise the design year network to include the proposed improvement. This may include revising the coded capacity and speed for the facility to reflect changes made by the improvement. If the project is a new location project, the functional classification code will be needed. This code can be obtained from the functional classification table for the specific urban area in which the project is located. This step will be performed for each separate alternative to be evaluated.

c. Determine adjustments to the design year production and attraction file. If the project design year is the same as the 20-year system forecast year, the production and attraction file used for the system forecast will be used. This file may need to be adjusted, however, to reflect existing land uses and other anticipated growth if conditions have changed since the system forecast. Adjustments to the productions and attractions can be made to reflect changed

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conditions using the DOS-executable ALLOCATE program. The production/attraction rates for each trip purpose can be obtained for each specific urban area.

For projects where the design year is different from the system forecast year, the 20-year trip table will need to be adjusted to reflect estimates of productions and attractions for the design year. To make these adjustments, the DOS NEWYR program is used to either extrapolate the future trip table (system 20-year forecast trip table) to a year further in the future, or to interpolate to a design year between the intermediate and long-range forecast years if the design year was prior to the 20-year forecast year. If the project design year was prior to the 20- year forecast year, the DOS NEWYR program would be used to determine the factors.

d. Assign design year traffic to the design year network. Use TRANPLAN to assign the design year trip table (as determined in Step 2c) to the design year network developed in Step 2b.

e. Refine design year traffic assignment. Use the percentage deviation results in the screenline refinement procedure to check the assigned volumes. For the refinement, use the current year traffic counts and assignment or base year traffic counts and assignment as the base year volumes.

Evaluation of Selected Alternatives

Purpose. The goal of evaluating a few alternatives is to select and accurately define the cross-section of the preferred alternative and any reasonable variations for comparison and evaluation with a no-build option in the environmental and public involvement process. Preliminary engineering is at the same level as during the initial evaluation, although more detail with regard to interchanges and ramp access is known. At this point in the process sufficient knowledge of the travel demand for the corridor or facility should be available such that a detailed representation of the improvements being studied can be coded into the network. The location and configuration of ramps; diamond, split-diamond, and directional interchanges; and major cross-streets should be included in the network. Additionally, if HOV lanes or other transit options are an alternative, the mode choice model will need to be used (See Chapter 7).

intersection approach may be used. For new location projects or projects in rapidly developing areas, local district staff should estimate the percentage of turning movements for each approach based on anticipated development and travel patterns. Chapter 14 includes a description of several methods for developing turning movement forecasts. The method selected should be appropriate for the type of improvement and level of detail required.

For projects where several alternatives are to be included in the environmental and public involvement processes of project development, the forecasts developed during the evaluation of selected alternatives may be used to develop the preliminary schematic design for each alternative for use in determining and analyzing the impacts associated with each alternative. The level of engineering design performed should be the same for each alternative and should include only what is necessary to identify any impacts and reasonable measures of mitigation in order to determine if an environmental impact statement will be required. The forecast data needed for the environmental documentation are presented and discussed in the section immediately following planning.

The traffic forecasts developed for selected alternatives are not intended to produce design-hour volumes. Forecast detail is important, however, because the data developed from these forecasts will be used to select the best improvement(s); to accurately define the facility cross-section; and, for some projects, may be used in the future for environmental analyses and as the basis to prepare design-hour volumes.

Traffic forecast requests for the study of selected alternatives should include the data requested on the appropriate forecast request form. This includes the build and design years to be used in the study, current land use maps along the facility, the location and type of major traffic generators, and past and current traffic counts for the facility and major cross-streets. For each alternative improvement, the type of facility, type of operation (one-way vs. two-way), the number of existing lanes and the number of proposed lanes, and a map showing the general facility alignment should be provided. For new location projects, the length (in feet) of each link of the facility should be provided for each separate alternative.

For forecasts being performed by persons or entities outside of the Transportation Planning and Programming Division, the TRANPLAN files *.ANT, *.NET, *.RAD, *.PNA, and *.EXT for the base year, the intermediate year, and the long-range forecast year for the specific

- Base year and design year daily VMT.

- Base year and design year daily vehicle hours of travel.

- Base year and design year daily vehicle hours of delay and/or travel time.

- Design year estimates of the percentages for peak-hour traffic and trucks.

The final forecast prepared for the selected alternative should be used as the basis for preparing the design-hour volumes for use in design and preparing the environmental analysis. The travel forecast and assignment produced for the preferred alternative should be accurate and detailed enough to allow a reasonably accurate preliminary schematic design to be prepared once turning movements have been adjusted to reflect reasonable estimates. This means that the number of mainlanes required and the location and type of access for the facility should be identified. It may be argued that no design should be prepared from any unadjusted forecast. Too often, however, extensive time and effort are expended preparing DDHVs only to have the design of the facility change, thus, requiring the DDHVs to be revised. The use of models calibrated for each urban area in conjunction with detailed directional networks should result in relatively accurate volumes (except for turning movements) in sufficient detail to prepare a preliminary schematic. Once the schematic has been prepared and checked for LOS, the final design-hour volumes can be prepared from the directional assignment. Use of a process such as this should result in a substantial savings of time and money in the preparation of DDHVs for design and environmental documentation. If it is not desirable to develop a preliminary design prior to development of the DDHVs, sufficient preliminary engineering should be performed prior to making the final forecast for the preferred alternative to ensure that the facility network being modeled will meet basic geometric design standards.

The submission of a request to the Transportation Planning and Programming Division for traffic forecasts for the selected or only alternative should include the base and design years to be used in the study, the type of facility, type of operation (one-way vs. two-way), the number of existing lanes and the number of proposed lanes, current land use maps along the facility, the location and type of major traffic generators, past and current traffic counts for the facility and major cross-streets, and a map showing the general facility alignment. If the project is a new location project, the length (in feet) of each link on the facility should be provided as well.

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If the forecast is being conducted by the District or a consultant, the TRANPLAN files *.ANT, *.NET, *.RAD, *.PNA, and *.EXT for the base year, the intermediate year, and the long-range forecast year for the specific metropolitan area in which the project is located are needed. Copies of the DOS-executable programs NEWYR, BALANCE, and ALLOCATE and the capacity/speed look-up table, functional classification table, and trip production and attraction rates for the urban area are required as well.

Forecast Methodology. The methodology that should be used to prepare forecasts for the selected alternative or a forecast where there is only one alternative being analyzed is the same as that used for the evaluation of initial alternatives; the steps outlined in that section may be followed. The only difference would occur for projects in which it has been determined that detailed networks will be used. For those projects, the existing and design year networks will need to be revised to include the level of detail desired. HNIS in TRANPLAN should be used to make the needed revisions. Instructions for the use of TRANPLAN, the DOS NEWYR, BALANCE, and ALLOCATE programs, and the screenline refinement procedure are detailed in Chapter 14.

FORECAST FOR DIRECTIONAL DISTRIBUTION, K-FACTORS, AND TRUCKS
Purpose

The accurate definition of the facility cross-section requires an estimate of the amount of traffic using the facility during the peak hour. For some projects, this may be prepared by making a 24-hour forecast (ADT) for the facility for the build and design years and applying certain planning factors, the directional distribution of traffic during the design hour (D), the percentage of traffic occurring in the design hour (K-Factor), and the design-hour percentage of trucks (T) to determine the design-hour volume. The following formula is applied to determine the number of lanes:

$$\text{Number of Lanes} = AWDT*[K*D*(1+T)]/\text{Service Flow Volume}$$

The selection of different planning parameters (K, D, T, and service flow volumes) can result in the over- or underestimation of the facility size by more than 50 percent. The usual range for

each of these planning parameters in large urban areas, the variation from the mean, and the possible effect on estimates of facility size are shown in Table 7. Because the values for K, D, and T usually decrease and the service volumes usually increase as an area becomes more urbanized, the errors compound rather than offset one another when the urbanization trend is underestimated. Thus, the size of the error in design could be more than 50 percent.

Table 7
Planning Parameter Effect on Design

Planning Factors	Range of Values	% Variation from Mean	% Effect on Facility Size
K	.08 - .12	±20	±20
D	.50 - .70	±17	±17
T	.02 - .10	±67	±4
Service Volume	1700 - 2000 pcphpl	±8	±8

The current method used to determine the K and D percentages for use in developing design-hour volumes for planning does not take into account the need for:

- Site-specific values: Peaking patterns may differ on various mainlane segments of the same freeway, between mainlane segments and their adjacent ramps, and even between ramp pairs. These patterns are relative to the time of the peak (A.M. or P.M.), the percentage of 24-hour volumes, and the directional distribution.

- Evaluation of system effects: When capacity is added on one facility, the K-Factor may increase. However, this increase in peak-hour volumes may be constrained by upstream or downstream congestion on facilities that cannot accommodate the increased peak flow. Thus, a lower K will occur on the improved facility.

- K-Factors representing average weekday traffic (AWDT): K values are currently developed using ADT which is usually less than AWDT. Yet, the design year ADT developed through modeling simulates typical weekday travel. Thus, use of K-Factors based on ADT can result in the overestimation of facility size.

- Evaluation of the effects of time: Both K and D tend to decline over time as an area becomes more urbanized and where different land uses exist. Use of current K and D to develop future design volumes must account for the expected trend toward urbanization as well as the development of multiple, different land uses.

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All of these factors can impact the estimation of design-hour volumes from 24-hour forecasts and, thus, affect the accurate determination of the freeway size.

Forecast Methodology

Despite the margin of error associated with using average K, D, and T factors to develop peak-hour volumes for an entire project length, this method is appropriate for use in many urban areas where rapid growth is not anticipated and the existing levels of congestion are not severe. The use of facility-specific K, D, and T factors based on current traffic data and forecast changes in land uses and densities, however, is recommended for project planning for existing highways. New location planning studies should use estimates of K, D, and T factors based on K, D, and T factors for similar facilities in the area and forecast changes in land uses and densities.

Peak-hour assignment models have been developed for forecasting traffic for use in planning in the two large urban areas, Houston and Dallas-Fort Worth. Research that focused on developing a peak-period assignment process for TxDOT has shown a relationship between peak-period volumes and the highest hourly volume within the peak period and that this relationship is much more consistent than that between the peak-hour volumes and the 24-hour volumes. This is largely because peak-period volumes include a directional split that is close to the peak-hour directional split. The use of a peak-period assignment process would eliminate the need to estimate the directional distribution of 24-hour assignments and, thus, may reduce the error associated with estimating the directional distribution for design-hour volumes. Use of a peak-hour computer assignment process can save substantial time associated with the manual factoring of assignments for several alternatives during the project planning process. Thus, use of a peak-hour model would be advantageous in large and/or rapidly growing urban areas.

TRAFFIC FORECASTING FOR ENVIRONMENTAL DOCUMENTATION
Purpose

Assessment of the social, economic, and environmental impacts of a transportation project is performed in varying stages of detail during the project planning and design process. A broad assessment of potential social, economic, and environmental impacts may be made during feasibility studies; and evaluation criteria set for the analysis of alternatives may include various

environmental impacts. Detailed environmental documentation, however, is usually not performed until the later phase of the advanced planning/schematic design stage after directional design-hour volumes and a preliminary schematic design have been prepared for the project under consideration. Traffic data are needed for environmental documentation to describe the project need and to assess the impacts regarding noise and air quality.

Forecast Requirements

Description of Project Need

Base year traffic data and a forecast of the design year average weekday traffic are required as part of the description of the project need. The need for a new freeway or additional capacity on an existing freeway is usually based on forecast travel within the corridor or along the facility. Traffic data are used to show that the existing capacity of the facility is not sufficient to handle the forecast traffic or that a new facility is needed to relieve congestion within a corridor. When the need for the project is something other than capacity, other forecast data may be required.

Noise Impact Analysis

The general procedures required in the analysis of noise impacts include a measurement and description of the existing noise levels for sensitive receptors along the facility, calculation of the design year sound levels for sensitive receptors, a comparison of the FHWA Noise Abatement Criteria (NAC) with the existing and predicted sound levels, and an evaluation of alternative noise abatement procedures for those impacted receptors. Comparison of the existing and predicted sound levels with the NAC is what determines whether a project will have an impact on the identified receivers and whether that impact is considered to be significant.

The FHWA traffic noise prediction computer program, STAMINA 2.0/OPTIMA, is used by TxDOT to model expected noise levels along transportation facilities. The noise levels predicted by this model are a function of:

- The distance of the receiver from the roadway.

- The relative elevations of the roadway and receptors.

- Traffic volume.

- The vehicle mix (percentage of medium and heavy duty trucks).

- Vehicle speed.

- Roadway grade.

- Topographic features.

- Noise source height of the vehicles.

Noise impact analysis using STAMINA 2.0/OPTIMA requires the following traffic data for each link on the facility and major cross-streets of the alternative(s) under consideration, including the no-build:

- Existing average weekday traffic with K and D factors, OR existing directional peak-hour traffic.

- Design year average weekday traffic with K and D factors, OR directional design-hour volumes.

- Existing and design year average travel speeds.

- Vehicle mix volumes or percentages for the peak hour for autos, medium duty trucks (two-axle, six-tire), and heavy duty trucks (three axle and above).

Air Quality Analysis

A project air quality analysis includes modeled estimates of CO concentrations for the present year conditions, the project build year and design year conditions, and the no-build design year conditions. All projects are modeled using worst-case meteorological conditions. Depending on the project, CO concentrations may be modeled at identified receptors along the project or at the right-of-way line.

Two models, MOBILE5.1 and CALINE3, are used to estimate CO concentrations for a project. MOBILE5.1 is an EPA model developed to calculate the basic emission rates for an area based on characteristics of the vehicle fleet, such as vehicle age and type, the percentage of cold starts, vehicle speeds, and ambient temperatures. These emission rates can be calculated for a designated year using estimated changes in fleet characteristics, speeds, cold starts, and other

parameters. The CO emission rates produced under MOBILE5.1 will decrease as speeds are increased up to approximately 48 mph. Once the speed of 48 mph has been exceeded, the emission rates begin to increase. This is important in the preparation of traffic forecasts for project air quality analyses, because if the proposed improvements result in projected traffic volumes indicating average speeds of 48 mph or better, the emission rates will increase and may cause an adverse effect on estimated CO concentrations, particularly where the traffic volumes have increased significantly as a result of the project.

CALINE3 is a California line source model that calculates the estimates of CO concentrations along transportation facilities based on source strength (emission rates X traffic volume), meteorology, site geometry, and site characteristics. The model can reliably predict CO concentrations for receptors within 492 feet of the roadway.

The traffic data required for air quality analyses include the following for each link of all alternatives (including the existing and no-build) and for major crossroads:

- Average weekday traffic with the K and D percentages or directional peak-hour volumes for the estimated time of project completion (ETC), ETC + 10 Years, and ETC + 20 Years.

- Average speeds (existing, ETC, ETC+10 years, and ETC+20 years).

- Vehicle mix volumes or percentages for ETC, ETC+10 years, and ETC+20 years:

  - light duty gas vehicles
  - light duty gas truck 1
  - light duty gas truck 2
  - heavy duty gas vehicle
  - light duty diesel vehicle
  - light duty diesel truck
  - heavy duty diesel vehicle
  - motorcycle

Forecast Methodology

The forecast methodology to produce information required to complete the environmental documentation is the same as that used in project planning. The methodology and level of detail selected is dependent on the stage of the project. That is, if environmental information is needed

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during the initial evaluation of alternatives, the methodology used to prepare the forecasts for the initial evaluation will produce the forecast information needed for the environmental analysis of project need and noise. When air quality analysis is needed, the preparation of forecasts for the estimated year of project completion (ETC), ETC plus 10 years, and ETC plus 20 years will be needed.

CHAPTER 14: TRAFFIC FORECASTING FOR PROJECT DESIGN[*]

Traffic forecasts for use in geometric and pavement design are developed by TPP through a process called corridor analysis. The type of traffic information provided for design depends on the project needs and is discussed below.

GEOMETRIC DESIGN

Purpose

During this stage of project development, the preliminary design of a facility (mainlanes, ramps, interchanges, intersections, driveway access, etc.) is prepared to a sufficient level of detail that the right-of-way requirements can be established and the environmental analyses prepared. For most facility types (controlled access highways, multi-lane noncontrolled access highways, two-lane rural highways, and urban arterials), certain aspects of the design are controlled by traffic volumes. Those design features controlled by volume are specific to each project type and are usually determined through a process called design analysis. Design analysis procedures for specific facility types and sections are generally the same as those used in an operations analysis. Design analysis is used to select the appropriate laneage and lane configurations to ensure that the facility will accommodate the forecast traffic volume at the desired LOS.

Forecast Requirements

A forecast using detailed networks is recommended for development of the design year AWDT volumes. The type of traffic data needed to prepare a design analysis includes:

- Design year DDHVs for each link on the facility, including ramps and cross-streets.

- Turning movement volumes for each intersection for the design year.

- Design year facility K-Factor.

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[*]Information in this chapter is excerpted from Texas Transportation Institute publications *Traffic Forecasting for Pavements Design* and *TRANPLAN Corridor Analysis Procedures* by Patti Bass.

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- Percentage of trucks, recreational vehicles and/or buses for the 24-hour period or for the peak hour.

The corridor analysis forecasting process does not produce DDHVs. Rather, a forecast of the AWDT, the estimate of the directional distribution (D), the percentage of traffic in the design hour, and the percentage of trucks are provided. The conversion of the 24-hour traffic forecast volumes to DDHV is performed by the project engineer using the traffic parameters provided.

A traffic forecast request should include the design year, current land use maps along the facility, and the location and type of major traffic generators, past and current traffic counts for the facility and major cross-streets, and a map showing the general facility alignment. Also, the type of facility, type of operation (one-way vs. two-way) number of existing lanes, number of proposed lanes, and a general preliminary schematic of the project should be provided. If the project is a new location project, the length of the proposed facility between cross-streets should also be given.

Other information that will be needed if the traffic is not being prepared by TPP includes:

- The TRANPLAN files *.ANT, *.NET, *.RAD, *.PNA, and *.EXT for the base year, the intermediate year, and the long-range forecast year for the specific metropolitan area in which the project is located.

- Copies of the DOS-executable programs NEWYR, BALANCE, and ALLOCATE.

- The capacity/speed look-up table, functional classification table, and trip production and attraction rates for the urban area.

Data that are required for forecasting the traffic parameters include:

- Current facility specific K, D, and T factors for projects on existing facilities.

- Current K, D, and T factors for similar facilities in the project area for new location projects.

- Forecasted changes in development and densities in the project area for all projects.

- The location and capacity of major facilities feeding into the project facility or into which the project feeds.

Forecast Methodology

There are three major steps in the corridor analysis procedure for developing detailed traffic and turning movements for project design in urban areas. Each of these steps is briefly described

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below. Instructions for the use of TRANPLAN, the DOS NEWYR, BALANCE, ALLOCATE programs, and the screenline refinement procedure methods to develop turning movements are detailed in the sections following the general procedures.

Step 1. Existing Traffic on the Existing Network

In this first step, the existing traffic (current year or the year immediately preceding the current year) and turning movements are developed for the existing roadway system. This existing traffic will be used for comparison in subsequent steps of the process. The decision to define the current year or previous year as the existing year should be based on the specific project needs and the year for which traffic counts are available. Prior to actually preparing the current traffic, however, several steps should be performed which will assist in identifying the links for which counts are needed and will provide data required in subsequent steps.

a. Define the project study area and boundaries. The study area should be defined to include the major facilities which influence travel patterns within the area of the project. The size of the study area for each project will depend on the type of facility and the type of proposed improvements. A major freeway project will usually require a larger study area than a project on a minor arterial roadway. As a general rule, the study area should extend 2 to 3 miles either side of the project and 0.5 to 1 mile beyond the project termini. It should be remembered, however, that the study area boundaries may extend farther. What is important is to include the major facilities, particularly parallel facilities.

b. Prepare a plot of the base year traffic counts, base year capacities, and base year traffic assignment for the study area. Use TRANPLAN to plot the base year traffic counts, base year capacities and base year validated assignment for the defined study area. The base year is the base year used for the most recent transportation system forecast for the particular urbanized area.

c. Prepare a plot of the existing roadway network within the study area. The network file used in this step will be either the base year network or the intermediate forecast year network, depending on which year is closest to the current year. The intermediate forecast year is the year for which the 10-year system forecast was prepared. Use HNIS in TRANPLAN to revise the selected network within the study area to accurately represent the existing network. If the base year network is used, changes or improvements that have been made to the roadways within the

study area should be made. If the intermediate forecast year network is used, changes to the network might involve deleting planned improvements that have not actually been implemented or adding improvements that have been implemented but were not included in the last system forecast.

At this time, the coded capacity and speeds of the facilities in the study area network should be reviewed and revised as needed to reflect changed conditions. Typical capacities and speeds for the various types of roadways for each urban area can be obtained from the capacity/speed look-up table for that area. If no network changes have occurred and the network file being used is the base year, this step is not required. A copy of one of the base year plots prepared above can be used. If the intermediate forecast year network is used and accurately represents the existing network, then a plot of that network file is all that is needed.

d. Make preliminary determination of screenlines. Screenlines may be required in subsequent steps of corridor analysis to refine or "smooth" traffic produced by TRANPLAN within the study area. The early selection of screenlines will assist in identifying the specific links within the study area for which current traffic counts are required. The base year or current year plot of the study area prepared in one of the previous steps can be used to select the appropriate screenlines. Screenlines should be selected to include roadways that represent likely alternatives for directional traffic within the study area. Several general rules should be followed in the selection of screenlines:

- Avoid meandering or diagonal roadways.

- Do not include zone connectors that are crossed by the screenline in the analysis.

- Screenlines should cross a minimum of three roadways and preferably no more than seven roadways.

- Screenlines should be no longer than necessary.

- Screenlines should be placed midway between major roadway crossings or every 2 miles, whichever is less.

e. Make traffic counts as needed. Current traffic counts should be made for each link crossed by a screenline, for other links as deemed necessary by the analyst, and for major turning movements.

f. Post the current traffic counts on the plot of the existing network. The existing traffic counts should be posted on the plot of the existing network. Based on these counts and other available count data, estimates of current traffic should be made and posted for those roadway links on which specific counts were not made. This information will be used in subsequent steps.

g. Prepare a straightline network map of the existing facility. A straightline map representing the existing facility should be prepared. A straightline map is a simple line drawing representing the facility and all cross facilities, ramps and/or interchanges. The level of detail included in this straightline representation of the existing facility will vary by project. If the project is a new location project, a straight-line map does not need to be prepared.

h. Post the current traffic volumes on the straightline map and develop turning movements. The traffic count data compiled in Steps 1e and 1f above are posted on the straightline map. If the straightline map includes more detail than the network plot developed in 1f, additional estimates of traffic counts for certain links may be required.

Once the current traffic volumes have been posted on each link, turning movements should be developed and posted on the straightline map. If turning movement counts or percentages are not available, one of the methods discussed in the section on "Turning Movements" can be used to estimate these movements.

i. Prepare a traffic assignment for the current year traffic on the existing network.

1. Use the DOS NEWYR program to develop a new production and attraction file for the current year. This program compares the base year or beginning year productions and attractions to the productions and attractions for the closest forecast year and interpolates the two production and attraction files to create a third production and attraction file for the current year in TRANPLAN format. This new production and attraction file will be based on the interpolation of productions and attractions at the zonal level by trip purpose from the base year and future year production and attraction files. NEWYR will also balance the attractions proportionally by zone and trip purpose to productions for the input files so that the new production and attraction file is balanced.

2. Run the long method of the TRANPLAN model.

3. Prepare a plot of the current year traffic assignment.

4. Check the assignment for reasonableness by comparing the assigned traffic to the traffic counts (as prepared in Steps 1e and 1f) for each link. A useful check is to use

the baseline assignment deviation analysis results in the screenline analysis spreadsheet. The rationale behind this check is that the maximum allowable deviation of a screenline traffic estimate should be such that a highway design would not vary by more than one roadway lane. If the percentage deviation between the assigned volumes and current counts is unacceptable, correct the problem(s) in the modeling process. It may be that the level of growth anticipated during the system forecast was too little or too great compared to what actually occurred. Thus, the current year production and attraction file interpolated from the base year and intermediate forecast year may be reflecting too few or too many trips. Or, there may be coding errors in the network. If the productions and/or attractions in certain zones need to be changed to reflect more or less growth than previously forecast, use the ALLOCATE program to make the necessary revisions.

5. Make the appropriate revisions in the TRANPLAN process and rerun the assignment. Recheck the assignment. If the baseline deviation is acceptable, use the screenline refinement to smooth the volumes.

Step 2. Existing Traffic on Proposed Network

a. Prepare a straightline map of the proposed facility/network.

b. Revise the existing network to include the proposed improvement. Use TRANPLAN to revise the existing network prepared in Step 1f to include the proposed improvement. This may include revising the coded capacity and speed for the facility to reflect changes made by the improvement. If the project is a new location project, the functional classification code will be needed. This code can be obtained from the functional classification table for the specific urban area in which the project is located.

c. Assign existing traffic to the improved network. Use TRANPLAN to assign the current year traffic developed in Step 1i to the improved network developed in Step 2b. Use the screenline traffic refinement procedure to check the assignment for reasonableness and refine the assignment. First, use the screenline procedure to check the percentage deviation between the current year counts and this assignment. Because this assignment will include network changes from the current network on which the counts were made, some professional judgment will be needed in interpreting the results of this check. If this check indicates a reasonable variation between the counts and the assignment, use the screenline procedure to refine the assignment. When using the procedure to refine the assignment, use the base year counts and assignment as the base year input and allow the current year assignment to be the forecast year input.

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d. Develop turning movements and post the traffic and turning movements on the straightline network map. Prepare turning movements using the most appropriate method. The section on turning movements details various methods that can be used depending on the data available and the type of intersection. Refine turning movements and traffic as needed to balance and post on the straightline map.

Step 3. Develop and/or Refine Design Year Traffic on the Proposed Network.

a. Revise the design year network. Compare the project schematic to the 20-year network used in the system forecast. If the network does not include the proposed project schematic or if more detail is needed in the network, update the network using HNIS in TRANPLAN. Coded capacities and speeds should be revised as needed to reflect known changes.

b. Determine adjustments to the design year production and attraction file. If the project design year is the same as the 20-year system forecast year, the production and attraction file used for the system forecast will be used. This file may need to be adjusted, however, to reflect existing land uses and other anticipated growth if conditions have changed since the system forecast. Adjustments to the productions and attractions can be made to reflect changed conditions using the DOS-executable ALLOCATE program. The production/attraction rates for each trip purpose can be obtained for each specific urban area.

For projects where the design year is different from the system forecast year, the 20-year trip table will need to be adjusted to reflect estimates of productions and attractions for the design year. To make these adjustments, the DOS NEWYR program is used to either extrapolate the future trip table (system 20-year forecast trip table) to a year further in the future or to interpolate to a design year between the intermediate- and long-range forecast years if the design year was prior to the 20-year forecast year. If the project design year was prior to the 20-year forecast year, the DOS NEWYR program would be used to determine the factors.

c. Assign design year traffic to the design year network. Use TRANPLAN to assign the design year trip table, as determined in Step 3b, to the design year network developed in Step 3a.

d. Refine design year traffic assignment. Use the screenline refinement procedure to smooth and check the assigned volumes. For the refinement, use the current year traffic counts and assignment or base year traffic counts and assignment as the base year volumes.

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e. Develop turning movements and post traffic on the straightline network map. Use the TPP's turning movement software or one of the other techniques discussed in the section on turning movements. Refine the link volumes and turning movements as needed to balance inflows and outflows. Post traffic on the straightline project map developed in Step 2.

Forecasting Turning Movements

Turning movements are required for planning and designing roadway intersections and interchanges. However, computerized travel demand models do not usually provide reliable turning movement volumes. As a result, future turning movements must be developed using other techniques.

This section describes how turning movements from TRANPLAN may be used and provides guidance on the use of several methods for estimating future turning movements detailed in NCHRP Report 255, *Highway Traffic Data for Urbanized Area Project Planning and Design.*

Selecting the Appropriate Procedure

Selecting the specific turning movement estimation procedure will depend on several factors. In some cases, more than one procedure should be used. Consider the following in determining the appropriate procedure:

- Type of project (project planning or design) for which the volumes are being developed.

- Availability of base year turning movement counts or percentages.

- Availability and suitability of future year turning movement assigned volumes.

- Type of assignment available: directional or nondirectional link volumes.

- Number of intersection approaches.

Regardless of which procedure is selected, professional judgment should be used throughout the process of developing estimates of future turning movements to ensure reasonable results.

Turning Movements from TRANPLAN

Although the turning movements from TRANPLAN assignments should not be used directly for planning or design, the turning movement results can be used as input to other methods described in this section or for comparing results obtained through other turning movement estimation procedures. To develop turning movements in TRANPLAN, the $PARAMETER "SAVE TURNS" should be entered in the $LOAD HIGHWAY NETWORK function file with the node numbers of the intersections where turning movements are desired. (The node numbers can be viewed in HNIS with the "POST SETUP" and "POST LINK" selections.) Subsequent to the assignment process, HNIS can be used to view the TRANPLAN turning movements on screen by selecting the "TURN MOVES" option. The turning movements developed by TRANPLAN cannot be plotted to paper. Thus, they must be copied manually while viewed in HNIS.

Factoring Method

The factoring method for developing turning movements for a future year is based on the principle that the discrepancy between a base year turning movement count and a base year assignment of turning movements is likely to be of the same magnitude in the future year turning movement assignment. Thus, the future year turning movement assignment can be modified using the relative ratios and/or differences between base year turning movement counts and the base year assignment of turning movements. This procedure uses the average of both a ratio and a difference factoring process. The data required to estimate future turning movements using the factoring method include:

- Future year TRANPLAN turning movement forecast.

- Base year TRANPLAN turning movement assignment.

- Base year turning movement counts.

One of the key features of this procedure is its simplicity. However, this simplicity means that some important factors are not considered in the estimation process. When used alone, the factoring procedure is appropriate for developing future turning movement estimates for feasibility studies, project planning studies, and preliminary design studies.

a. Ratio Factoring Method. In this part of the factoring procedure, each turning movement in the future assignment is factored by the ratio of the base year actual traffic count to the base year assignment using the following calculation:

$$V_{ri} = F_i * (B_{ci}/B_{ai})$$

where:

V_{ri} = ratio adjusted future year volume turning movement i

F_i = future year forecast volume for turning movement i

B_{ci} = base year traffic count for turning movement i

B_{ai} = base year assigned volume for turning movement i

Each turning movement and through volume is adjusted separately for each approach and then summed to produce the adjusted total approach volumes.

b. Difference Factoring Method. For the difference method, each turning movement in the future year assignment is factored by the difference between the base year actual turning movement count and the base year assigned turning movements. The following calculation is used:

$$V_{di} = F_i + (B_{ci} - B_{ai})$$

where:

V_{di} = difference adjusted future year volume for turning movement i

F_i = future year forecast volume for turning movement i

B_{ci} = base year traffic count for turning movement i

B_{ai} = base year assigned volume to turning movement i

Each turning movement and through volume on each approach is adjusted separately and then summed to produce an adjusted total approach volume.

c. Combined Method. The combined method combines the results of the ratio and difference factoring procedures. This averaged method tends to reduce the extremes experienced by the individual methods.

$$V_{fi} = (V_{ri} + V_{di}) / 2$$

where:

V_{ri} = ratio adjusted future year volume for turning movement i

V_{di} = difference adjusted future year volume for turning movement i

V_{fi} = final averaged future year volume for turning movement i

Special Consideration - Lack of Base Year Turning Volumes. If base year turning volumes are not available, total approach link volumes may be substituted for B_{ci} and B_{ai} in the ratio method only. This technique will not produce an adjustment that is as specific as that produced through the comparison of individual base year turning movements. Note that the difference method and, thus, the combined method, cannot be used if base year turning movement counts are not available.

$$V_{ri} = F_i * (B_{ci} / B_{ai})$$

where:

V_{ri} = ratio adjusted future year volume for turning movement i

F_i = future year forecast volume for turning movement i

B_{ci} = base year actual approach volume (link volume) for turning movement i

B_{ai} = base year assigned approach volume (link volume) for turning movement i

Iterative Procedure

Two variations of the iterative procedure for estimating turning movements are presented. One procedure provides turning movement estimates from directional approach link volumes and one provides estimates from nondirectional approach link volumes. Both procedures develop turning movements using a specified approach link volume and an initial estimate of turning

percentages. The number of iterations necessary to produce an acceptable set of turning volumes is dependent on the ability to make reasonable a priori estimates of turning movements. These procedures are most useful when a specified future year link volume must be retained for each intersection approach. For example, if the future year link volumes have been refined and are considered acceptable, this procedure would estimate turning movements without changing the approach link volumes.

Directional Volume Iterative Procedure. This procedure uses an iterative computational technique in which the rows (approach link inflows) and columns (link outflows) of a turning movement matrix are alternately balanced until an acceptable convergence is obtained. Normally, a maximum of six to ten iterations requiring one or two person-hours per intersection are required.

This procedure requires the following input data:

- Future year TRANPLAN directional link volumes (developed through the corridor analysis and refinement process).

- Either base year actual or base year assigned directional turning movements or an initial estimate of future year directional turning movements.

Base year traffic count data are preferred, but turning data from a base year assignment may be used. If base year data are not available, initial estimate of future year turning percentages based on an examination of adjacent land uses (current and future) and/or the turning movements at similar intersections should be made.

The directional volume method consists of five steps in which the following notations are used in the calculations:

n = number of links emanating from the intersection.

O_{ib} = base year (b) inflow to the intersection on link i.

O_{if} = future year (f) inflow to the intersection on link i.

D_{jb} = base year (b) outflow from the intersection on link j.

D_{jf} = future year (f) outflow from the intersection on link j.

T_{ijb} = base year (b) traffic flow entering through link i and leaving through link j.

T_{ijt} = future year (f) traffic flow entering through link i and leaving through link j.

P_{ijf} = future year (f) estimated percentage of traffic flow from link i to link j.

* = adjusted values in each iteration.

Step 1. Construct Initial Turning Movement Matrix. An initial matrix of turning movements to be used in the iterations must be constructed. If base year data are known (either counts or assigned volumes), construct a turning movement matrix of base year turning volumes (T_{ijb}) as shown below (Table 8).

Table 8
Turning Movement Matrix of Base Year Turning Volumes

		Columns (Outflows) D_{ib}				Total Link Inflows O_{ib} (O_{if})
		To Link 1	To Link 2	To Link 3	To Link 4	
Rows (Inflows) T_{ijb}	From Link 1					
	From Link 2					
	From Link 3					
	From Link 4					
Total Outflows D_{ib} (D_{if})						

Insert the row and column totals next. The row totals should represent inflows (O_{ib}) and column totals. The row totals should represent outflows (D_{jb}).

The sum of the volumes across each row and down each column should equal the O_{ib} and O_{jb}, respectively. The sum of the diagonal totals should equal zero. Once the base year volumes have been placed in the matrix, note in parentheses the future year total link inflow volume (O_{if}) and future year total link outflow volume (D_{if}).

If base year volumes are not known, construct an initial matrix of future year turning volumes (T_{ijf}) using estimated turning percentages. The T is developed by the following calculation: $T_{ijf} = O_{if} * P_{ijf}$. The matrix will appear as above, although no future volumes will be

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noted in parentheses. In this matrix, the row totals will be equal to the approach link inflow volume. The column totals may not, however, equal the outflow volumes for each link. The adjusted column totals (D_{jf}*) should be compared with the future year link outflows (D_{if}). If these adjusted outflows are acceptable (usually within $\pm$10 percent of the D_{if}), the procedure is complete. If they are not acceptable, further iterations will be necessary and the procedure should continue beginning with Step 3.

Step 2. Perform the First Row Iteration. This step is second in the procedure using base year volumes. If the initial matrix is constructed using future year volumes, omit this step. Make a copy of the matrix developed in Step 1 and replace the base year inflows (O_{ib}) with the future year inflows (O_{if}). Then adjust each individual turning movement according to the following:

$$T_{ijf}^{*} = (O_{if} / O_{ib}) * T_{ijb}$$

where:

T_{ijf}^{*} = adjusted future volume for this iteration

Construct a new matrix consisting of T_{ijf}^{*} and O_{if}, and calculate the new D_{ji}^{*} by summing the T_{ijf}^{*} in each column. The matrix at this stage is shown below in Table 9. The D_{jf}^{*} should be compared with the desired D_{jf} from Step 1. If the difference between these values is acceptable, the procedure is complete. Typically, a difference of $\pm$10 percent is considered to be acceptable. If a large discrepancy is apparent, continue with further iteration(s).

Table 9
Adjusted (1st Row Iteration) Turning Movement Matrix

		Columns (Outflows) D_{jf}*				Total Link Inflows O_{if}*
		To Link 1	To Link 2	To Link 3	To Link 4	
Rows (Inflows) T_{ijf}*	From Link 1					
	From Link 2					
	From Link 3					
	From Link 4					
Total Outflows D_{jf}*						

Step 3. Perform the First Column Iteration. This step is performed on the adjusted turning movement matrix developed in Step 2 or on the initial matrix developed in Step 1 when base year data are not available. Make a copy of the last matrix developed in the procedure. Replace the adjusted outflows (D_{jf}*) with the original D_{jf} in this matrix. Then adjust each individual movement according to the following:

$$T_{ijf}*^{new} = (D_{jf} / D_{jf}*) T_{ijf}*^{old}$$

where:

$T_{ijf}*^{old}$ = T_{ijf}* value in the matrix developed in Step 2.

$T_{ijf}*^{new}$ =   adjusted T_{ijf} after column iteration.

(The $T_{ijf}*^{new}$ becomes the $T_{ijf}*^{old}$ in subsequent iterations).

Next construct a new matrix consisting of the $T_{ijf}*^{new}$ and D_{jf} as shown in Table 10. Then calculate the adjusted O_{if}* by summing the $T_{ijt}*^{new}$ in each row.

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Table 10
Adjusted (2nd Row Iteration) Turning Movement Matrix

		Columns (Outflows) D_{jf}*				Total Link Inflows O_{if}*
		To Link 1	To Link 2	To Link 3	To Link 4	
Rows (Inflows) T_{ijf}*new	From Link 1					
	From Link 2					
	From Link 3					
	From Link 4					
Total Outflows D_{jf}*						

The O_{if}* should be compared with the O_{if} in the first matrix to check the acceptability of the value differences. Typically, a value of ± 10 percent is considered acceptable. If a large discrepancy is apparent, continue with further iteration(s).

Step 4. Repeat Row Iteration. If needed, repeat Step 2 for row iterations. Calculate new values for T_{ijf}*new and D_{jf}*, then compare D_{jf}* with D_{jf}.

Step 5. Repeat Column Iteration. If needed after Step 4, repeat the Step 3 column iteration procedure. Calculate new values for T_{ijt}*new and O_{if}*; then compare O_{if}* with O_{jf}.

The T_{ijt}* values in the final iteration matrix represent the final adjusted directional turning and through movements.

Nondirectional Iterative Procedure. This method has no theoretical basis or unique solution. Rather, the method produces a reasonable turning movement scenario based on the assumption that the volume of traffic on a given approach of an intersection is a function of the land use attractions and productions downstream of the intersection. This procedure relies heavily on professional judgment to select reasonable turning movement percentages and make final adjustments to the volumes after completing the calculations. Therefore, this procedure should be used for project-level planning purposes.

The procedure produces two-way turning volumes and an estimate of the total vehicle turning percentage. The method provides a five-step sequence and may have to be performed

iteratively to achieve a balanced distribution of turning and through movements. The number of iterations will vary, but three to four iterations requiring one to three person-hours will be sufficient.

The data required to estimate turns using this procedure include nondirectional link volumes (i.e., total both directions) on each approach.

Step 1. Estimate Total Turning Percentage. The first step is to determine the percentage of total inflowing traffic which turns (either right or left). The turning percentage value is estimated based on the unique characteristics of the intersection and comparable intersections from other parts of the urban area. If it is an existing signalized intersection and the actual green times given to individual turning movements are known at the subject intersection, these values can be used instead of the estimated percentage for the entire intersection.

The turning movement percentage is estimated relative to the sum of only inflowing (i.e., one direction) volume. The inflowing volume equals one-half the total nondirectional volume. Thus, sum the nondirectional link volumes for each intersection approach and divide by 2 to estimate the total inflowing volume.

$$V_1 + V_2 + V_3 + V_4 = V_T$$
$$V_T / 2 = V_I$$
$$V_{Turns} + V_{Thru} = V_I$$
$$V_I * V_{TP} = V_{Turns}$$
$$V_I - V_{Turns} = V_{Thru}$$

where:

$V_1...V_4$	=	nondirectional volume on each intersection approach
V_T	=	total nondirectional volume on all intersection approaches
V_I	=	total inflowing volume on all intersection approaches
V_{Turns}	=	volume of inflowing traffic making right and left turns
V_{Thru}	=	volume of nonturning inflowing intersection traffic
V_{TP}	=	estimated percentage of turning volume

Step 2 Calculate the Relative Weight of Each Intersection Approach. To calculate the relative weight of each approach, sum all nondirectional volumes on all intersection approaches. Express the volume on a particular approach as a proportion of total volume. The proportions (or relative weights) on all approaches must sum to 1.00.

$$V_1 / V_T = RW_1$$
$$RW_1 + RW_2 + RW_3 + RW_4 = 1.00$$

where:

$V_1...V_4$	=	nondirectional volume on each intersection approach
$RW_1...RW_4$	=	relative weight (or proportion) of each intersection volume to total intersection volume

Step 3. Perform Initial Allocation of Turns. In this step, the volume in each approach is allocated to the other intersection approaches. Multiply the total volume on an approach by the relative weights (as computed in Step 2) for the remaining approaches which involve turns. Do not perform this calculation for the through movements. Thus, for a 4-legged intersection, each approach volume would be multiplied by the relative weight of the approach to the right and the relative weight of the approach to the left. This calculation should be performed for each intersection approach to produce turns to other approaches. The following applies for the intersection shown:

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$$V_1 * RW_2 = V_{12}$$

$$V_1 * RW_4 = V_{14}$$

$$V_2 * RW_3 = V_{23}$$

$$V_2 * RW_1 = V_{21}$$

$$V_3 * RW_2 = V_{32}$$

$$V_3 * RW_4 = V_{34}$$

$$V_4 * RW_3 = V_{43}$$

$$V_4 * RW_1 = V_{41}$$
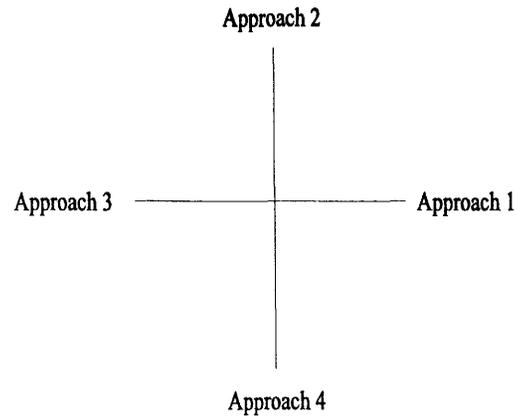
where:

V_1 = total nondirectional volume on Intersection Approach 1

RW_1 = relative weight of Intersection Approach 1

V_{12} = volume of nondirectional traffic on Approach 1 turning to Approach 2

The above calculation produces two sets of turning volumes between each turning opportunity (i.e., Approach 1 to Approach 2 and Approach 2 to Approach 1). To avoid doubling the turning volume, the volumes calculated above for each turning opportunity should be averaged to produce one nondirectional turning volume for each turning movement.

Step 4. Adjust Turning Volumes Based on Turning Percentage. The total volume of turns generated in Step 3 will typically exceed the likely volume of turns at the intersection. To adjust the Step 3 estimates, a turning adjustment must be imposed. The adjustment involves the following computations:

(a) Write down the total inflowing volume (Step 1).

(b) Write down the total turn percentage (Step 1).

(c) Compute total expected volume of turns as (a) * (b).

(d) Sum the turning volumes calculated during Step 3.

(e) Adjust the individual turns from Step 3 using either a difference method or ratio method.

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Difference method: subtract (d) from (c) and divide by the number of intersection turning movements. (A 4-legged intersection involves four turning movements, so divide by 4). Then add or subtract this from each turning volume developed in Step 3. This method may result in a negative turning volume if the initial intersection turning percentage was too low.

Ratio method: divide (c) by (d) and multiply each turning volume from Step 3 by this number.

At the end of this step, the sum of the individual turning volumes will equal the expected turning volume from Step 1.

Step 5. Balance the Approach Volumes and Adjusted Turning Volumes. The preceding steps will yield a turning movement estimate that conforms to the estimated turning percentage established in Step 1. In many situations, however, the method will not result in an intersection scenario that accounts for all the traffic traversing the intersection. To test for this situation, take each approach of the intersection and do the following:

(a)   Write down the total approach volume.

(b)   Subtract the turns made to/from that approach from cross streets.

(c)   Add the turns made to/from the approach on the opposite side of the intersection.

If the intersection clears all traffic, the total volume on the opposing approach of the intersection should equal the volume estimated from the above test. If these volumes do not correspond, an adjustment must be made to out-of-balance numbers to bring the analysis into equilibrium. Two situations are normally encountered in this analysis:

1.   The opposite intersection approaches show a greater difference in adjusted volume (Step 5) than was evident in the original volumes (Step 2).

2.   The two opposing intersection approaches have adjusted volumes (Step 5) that are closer to each other than was evident in the original volume (Step 2).

In the first situation, iterating the entire procedure from Step 2 using new approach volumes will narrow the volume difference between two opposing intersection approaches.

The second situation is more complicated: the difference in volume on opposing approaches must be increased. The following computations will provide an adjustment to increase the difference between the opposing volumes.

(a) Sum volumes on the two opposing approaches using original volumes input at the outset of the analysis (Step 2).

(b) Determine the proportion of this volume (a) represented by each of the two opposing approaches. This must sum to 1.00.

(c) Determine the approach volume difference between the adjusted and the original estimates.

(d) Multiply the proportions (b) by the volume difference (c). Add/subtract this number to/from the calculated volumes as appropriate.

The above adjustments should be applied to each intersection approach to ensure that the approach volumes are in scale relative to the completed turning volumes.

Directional Turning Movements For a "T" Intersection. Turning movement volumes at "T" intersections can be determined from the intersection directional link volumes and one turning movement count. Because a "T" intersection involves only six directional movements, simple mathematics are used to derive equations to aid in the solution. The data required for this procedure include the six directional link volumes for each approach (i.e., the inflow and outflow volume of each approach), and one of the six turning volumes must be known or estimated.

Based on the intersection configuration below, a typical solution for unknown volumes A, B, C, D, and E, where the volumes for F and links 1 through 6 are known, can be calculated as follows:

4 | 3

E F

A

5 ← ← B 2

6

C

1
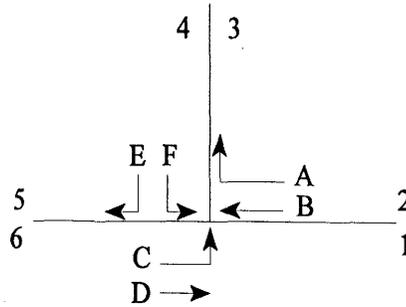
D →

Volume E = Volume 4 - F

Volume A = Volume 5 - E

Volume B = Volume 2 - A

Volume C = Volume 3 - B

Volume D = Volume 6 - C

To solve for the turning movements, use the known link volumes and volume for Movement F. Calculate the remaining volumes sequentially.

Nondirectional Turning Movement for a "T" Intersection. Nondirectional turn volumes can be easily computed if nondirectional link volumes on the three approaches are known. The nondirectional method is mathematically based on algebraic relationships. The two unknown turning volumes can be directly obtained from two independent equations. Input data required for this method are nondirectional link volumes for each of the three approaches.

Referring to the intersection shown for notations, the following equations are used:

X = (A - B + C)/2

Y = (C - A + B)/2

Where A, B, and C are link volumes, and X and Y are desired turning movements.

A

C ——————————————— B
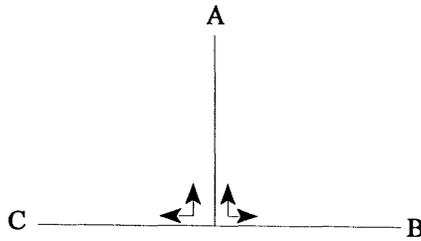
PAVEMENT DESIGN

Purpose

The forecast of the traffic loading expected to be applied to the pavement structure during its design life (usually 20 years) is an important consideration in pavement structural design. Traffic loading for pavement design is determined by converting the forecast traffic volume into a load equivalence factor. This load equivalence factor is defined as the ratio of the number of repetitions of an 18,000 pound single axle required to cause a given level of pavement damage to the number of repetitions of an axle of some other weight and/or configuration which are required to cause the same given amount of damage. The load equivalency factor is a function of variables such as axle weight, axle configuration, pavement type, pavement thickness, tire contact area, tire contact pressure, environmental conditions, and soil support. In traffic forecasting, however, the load equivalence factor for each specific axle weight and configuration, pavement type and thickness, tire contact area and other factors is taken as a set value.

Forecast Requirements

The load equivalence factor for each axle configuration and weight category is used to convert the axle weights to equivalent single axle loads (ESALs). The ESALs for each axle configuration and weight category are then added together to determine a total ESAL forecast for use in pavement design.

The forecast data needed for pavement design include:

- Base year ADT.

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- ADT traffic growth rate for the design year.

- Percentage trucks, including dual-rear-tire pickups and buses, for each classification category.

- Directional distribution for the design period.

- Lane distribution factor for the design period.

The traffic component having the greatest effect on pavement design is the truck vehicle type and weight classification data. Numerous studies have shown that there can be a large variation in the total volume of trucks and the volume of trucks by type and weight on a given facility between seasons, days and time of day, and that there can also be major variations between sites on the same facility. The truck classification and weight data used in most projects, however, is not project specific. Typically, these data are collected on similar highways in the same general geographic area. The assumption is that truck classification and weights are similar for like highways, and areas can introduce errors in magnitude of 3 or 4 into the ESAL estimates. Additionally, the variation in the traffic factors of pavement design is largely due to variation in the equivalency factors which are taken as given. Current site- specific truck classification and weight data should be collected for each project. Traffic load forecast accuracy can be improved by 30 percent from current levels by conducting 24-hour manual vehicle classification counts at specific pavement project types and improved by more than 85 percent conducting week-long weigh-in-motion (WIM) sessions at specific project sites.

The data required for forecasting for pavement design include:

- For projects in which the estimated cost is anticipated to be worth more than $248,000, a site specific 24-hour manual vehicle classification session should be conducted.

- For projects in which the estimated cost is anticipated to be worth more than $543,000, a site-specific week-long WIM session should be conducted.

Forecast Methodology

The methodology used to forecast ESALs for pavement design is presented below. The procedures used to forecast the individual components used in the ESAL calculation (ADT Growth

Rate, Percent Trucks, etc.) are discussed in the sections following the explanation of the ESAL calculation.

Total ESAL Calculation

The Total ESAL calculation is performed using the RDTEST68 computer program. The steps are as follows:

<u>Step 1</u>. The Base Year ADT, ADT Growth Rate, and Percent Trucks components are used to calculate Total Vehicles, Total Trucks, and Total Other Vehicles. Total Vehicles is the total number of vehicles expected to use the pavement facility during the design period. Total Trucks and Total Other Vehicles are, respectively, the total number of trucks and total number of non-trucks expected to use the pavement facility during the design period.
Total Vehicles is calculated using the following equation:

$$\text{Total Vehicles} = T * 365 * ADT_0 * (2 + GF_{ADT} * T)/2$$

where:

T = the length of the design period (years)

ADT_0 = Base Year ADT (vpd)

GF_{ADT} = ADT Growth Rate (percentage volume growth per year)

Given ADT_0 = 1000 vpd, GFADr = S percent per year, and T = 20 years:

Total Vehicles = 365 * 20 * 1000 * (2 + 0.05 * 20)/2 = 10,950,000

Total Trucks is found by multiplying Percent Trucks times Total Vehicles:

Total Trucks = Total Vehicles * Percent Trucks

Given 10,950,000 Total Vehicles and Percent Trucks = 10%:

Total Trucks = 10,950,000* 0.10 = 1,095,000

Total Other Vehicles is found by subtracting Total Trucks from Total Vehicles:

Total Other Vehicles = Total Vehicles - Total Trucks

Given Total Vehicles = 10,950,000and Total Trucks = 1,095,000:

Total Other Vehicles = 9,855,000

Step 2. Total Trucks and Total Other Vehicles are used in combination with an Average Load Equivalency Factor per Truck and an Average Load Equivalency Factor per Other Vehicle, respectively, to calculate the Total ESAL. An Average Load Equivalency Factor per Other Vehicle, AVG ESAL$_{ov}$, of 0.000626 is built into the RDTEST68 program. The total number of ESALs attributable to Total Other Vehicles, Total ESAL$_{OVs}$, is given by:

Total ESAL$_{Ovs}$ = Total Other Vehicles * AVG ESAL$_{OV}$

Given Total Other Vehicles = 9,855,000and AVG ESAL$_{OV}$ = 0.000626:

Total ESAL$_{Ovs}$ = 9,855,000 * 0.000626 = 6,169 ESALs

The Average Load Equivalency Factor per Truck is calculated by RDTEST68 for each ESAL forecast using the Axle Weight Distribution Table, Percent Single Axles, and Axle Factor. Table 11, the condensed Axle Weight Distribution Table, indicates that 35 percent of the axles passing the hypothetical WIM site are single axles which weigh between 0 and 10,000 pounds. In addition, each of these 0 to 10,000-pound single axles imparts an average of 0.01 ESALs to the pavement. In all, these 0 to 10,000 pound single axles contribute 0.0035 ESALs (i.e., 0.35 * 0.01 ESALs) to the Average Load Equivalency Factor per Truck Axle (AVG ESAL$_{axle}$). AVG ESAL$_{axle}$ is found by summing the contribution of all single and tandem axle weight groups. In this case, AVG ESAL$_{axle}$ is 0.4577 ESALs per axle. Note the relationship between AVG ESAL$_{axle}$ and the percent single axles in Table 11: Percent single axles effectively weights the contributions of single axles to the AVG ESAL$_{axle}$ while (1 - percent single axles), that is, percent tandems, weights the contribution of tandem axles to AVG ESAL$_{axle}$. As a result, given the same relative proportions of single axles among single axle weight groups (i.e., (35/45)*100% or 77.8 percent of single axles weigh between 0 and 10,000 pounds, and (9/45)*100 percent or 20 percent of single axles weight between 10,000 and 20,000 pounds, etc.) and tandem axles among tandem axle weight groups, a higher percent single axles will lead to a higher weighting of single axles and a lower weighting

of tandem axles in AVG ESAL$_{axle}$. Because the average load equivalency factor per tandem axle at a site is generally much larger than the average load equivalency factor per single axle at the site, a higher weighting of single axles will lead to a lower AVG ESAL$_{axle}$ for the site and vice versa.

The Average Load Equivalency Factor per Truck, AVG ESAL$_{Truck}$, is found by multiplying AVG ESAL$_{axle}$ by the Axle Factor:

AVG ESAL$_{Truck}$ = AVG ESAL$_{axle}$ * Axle Factor

Given an Axle Factor of 2.75 axles/truck:

AVG ESAL$_{Truck}$ = 0.4577 ESALs/axle * 2.75 axles/truck = 1.26 ESALs

This Average Load Equivalency Factor per Truck is then multiplied by Total Trucks to determine the total number of ESALs attributable to Trucks, Total ESAL$_{Trucks}$:

Total ESAL$_{Trucks}$ = Total Trucks * AVG ESAL$_{Truck}$

Given Total Trucks = 1,095,000and Average ESAL Per Truck = 1.26:

Total ESAL$_{Trucks}$ = 1,095,000* 1.26 = 1,379,700 ESALs

Step 3. The Total ESAL is the sum of Total ESAL$_{Trucks}$ and Total ESAL$_{Ovs}$:

Total ESAL = Total ESAL$_{Trucks}$ + Total ESAL$_{OVs}$

Given Total ESAL$_{Trucks}$ = 1,379,700ESALs and Total ESAL$_{OVs}$ = 6,169 ESALs:

Total ESAL = 1,379,700+ 6,169 = 1,385,869ESALs

Design Lane ESAL Calculation.

Step 1. The Total ESAL is used in combination with the directional distribution factor (D) to generate a One-Directional ESAL:

One-Directional ESAL = Total ESAL * D

Given Total ESAL = 1,385,869ESALs and D = 50%:

One-Directional ESAL = 1,385,869 * 0.50 = 692,935 ESALs

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<u>Step 2</u>. The One-Directional ESAL and the lane distribution factor, LF, are used to generate the Design Lane ESAL:

Design Lane ESAL = One-Directional ESAL * LF

Given One-Directional ESAL = 692,935 ESALs and LF = 0.80:

Design Lane ESAL = 692,935 ESALs * 0.80 = 554,348 ESALs

Forecasting Components of the ESAL Calculation

<u>Average Daily Traffic Growth Rate</u>. The ADT growth rate is the expected annual percentage growth in ADT over the design period. The design period is the block of time (generally 20 to 30 years) following pavement reconstruction during which the pavement facility is designed to provide adequate service. TPP determines an ADT growth rate for each ESAL forecast based on historical traffic volume data collected at or near the pavement project site. The growth rate is determined by performing a linear regression on the historical volume data. The output of the linear regression is an equation of the form:

$$ADT(t) \quad = \quad GR * t + ADT(0)$$

where:

ADT(t)	=	ADT at a point in time, t
GR	=	ADT growth rate, measured in vehicles per year (vpy)
t	=	time, measured in years (t = 0 corresponds to the first year of historical volume data used in the analysis)
ADT(0)	=	"t = 0" ADT identified by the regression, measured in vehicles per day (vpd)

An annual percentage ADT growth rate, GF_{ADT}, is found by dividing GR by ADT(0). For example, if the regression equation yields:

$$ADT(t) \quad = \quad 50 \text{ vpy} * t + 1000 \text{ vpd}$$

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A percentage growth is obtained by dividing 50 vpy by 1000 vpd; this results in a 5 percent per year ADT growth rate for the example equation. This procedure assumes that traffic growth follows a linear model.

Base Year ADT. The base year is the first year of the design period. Base year ADT is the two-directional ADT volume expected at the pavement facility during the base year. Base year ADT is determined by projecting one to two years ahead of the current year ADT at the project site. The ADT growth rate is used to make the projection.

TPP determines a current year ADT for each ESAL forecast based on traffic count(s) taken at or near the pavement project site. The traffic counts used in the analysis may have come from an ATR or a 24-hour coverage count. If the project encompasses two or more existing count locations, the current year ADT used in the analysis is a weighted average of the different locations' ADTs. The weights are determined by the length of road for which each ADT is applicable.

The following equation shows the relationship between base year ADT, current year ADT, and the ADT growth rate:

$$ADT_o = ADT_{current} * (1 + GF_{ADT} * T)$$

where:

ADT_o = base year ADT

$ADT_{current}$ = current year ADT

GF_{ADT} = ADT growth rate.

T = the number of years from the current year to the base year.

Percent Trucks. Percent trucks is the percentage of heavy trucks in the traffic stream. Percent trucks includes dual-rear-tire pickup trucks and buses. TPP determines the percent trucks for each ESAL forecast based on vehicle classification data.

If a manual vehicle classification site is located within the pavement project limits, classification data from the manual classification site are used to determine percent trucks. If a manual classification site is located on the same highway as the project site but outside the project limits, vehicle classification data from the manual classification site are used to determine percent

trucks at the project site; the determination is based on the ADTs at the two sites. If the ADT at the project site is higher than the ADT at the manual classification site, the percent trucks at the project site is assumed to be lower than at the classification site and vice versa. This adjustment of percent trucks from the manual classification site to the project site is accomplished using a "1/2-growth model" (i.e., a model in which truck volume grows [declines] between the two sites at 1/2 the rate total volume grows [declines] between the two sites). For example, given 10,000 ADT and 10 percent trucks at the data collection site and 12,500/ADT at the project site, percent trucks at the project site is found as follows:

1) subtract $ADT_{data\ collection\ site}$ from $ADT_{project\ site}$: 12,500 - 10,000 = 2,500(additional vehicles);

2) multiply the additional vehicles by $PCT_{data\ collection\ site}$: 2,500 * 0.10 = 250 trucks;

3) multiply this number of trucks by 1/2: 250*(1/2) = 125 additional trucks;

4) add the number of additional trucks at the project site to the number of trucks at the data collection site: 125 trucks + (10,000 vehicles * 10% trucks) = 1,125 trucks at the project site;

5) divide the number of trucks at the project site by total vehicles at the project site: 1,125 trucks/12,500 vehicles = 9.0% trucks at the project site.

The number of trucks has increased from 1,000 at the data collection site to 1,125 at the project site; but the percent trucks has decreased from 10 percent at the data collection site to 9 percent at the project site.

If there is no manual classification site on the same highway as the project site, classification data from another highway in the same geographic region as the project site are used in the analysis. Effort is made to identify a classification site on the same highway system (i.e., Interstate, U.S./State, FM) as the project site for this purpose. The percent trucks will be adjusted based on the ADTs at the two sites using the 1/2-growth model described above.

Percent trucks is assumed to remain constant throughout the design period. This implies an assumption that truck traffic grows at the same rate as overall traffic.

Percent Single Axles. Percent single axles is the percentage of total truck axles passing the project site that are single axles. A tandem axle is treated as one axle to calculate percent single axles. To illustrate, a 3-S2 (e.g., a typical 18-wheeler), which has one single axle and two tandem

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axles, has a percent single axles of 33.33 percent. TPP determines the percent single axles for each pavement project based on classification data obtained as described for percent trucks above.

Note, however, that when classification data from another site on the same highway or from another highway in the same geographic region as the project site are used in the analysis, percent single axles is not adjusted based on ADT. Percent single axles is determined by the truck traffic stream makeup (i.e., the proportions of individual truck types in the truck traffic stream), not the overall number of trucks. The truck traffic stream makeup is assumed to be approximately the same at the data collection and project sites.

Percent single axles is assumed to remain constant throughout the design period. This implies an assumption that the truck traffic stream makeup remains constant during the design period.

Axle Factor. The axle factor is the average number of axles per truck passing the site. A tandem axle is treated as one axle for axle factor calculation purposes. TPP determines an axle factor for each pavement project based on classification data obtained as described for percent trucks above.

When classification data from another site on the same highway or from another highway in the same geographic region as the project site are used in the analysis, the axle factor is not adjusted based on ADT. Like percent single axles, the axle factor is determined by the truck traffic stream makeup. The truck traffic stream makeup is assumed to be approximately the same at the data collection and project sites.

The axle factor is also assumed to remain constant throughout the design period. This implies an assumption that the makeup of the truck traffic stream remains constant during the design period.

Axle Weight Distribution Table. An axle weight distribution table gives the percentage of single and tandem axles weighed in different weight categories. An axle weight distribution table is shown in Table 11. Table 11 reads, for example, that 0.213 percent of all axles weighed at WIM station 501 were single axles between 0 and 2,000 pounds; no tandem axles weighed between 0 and 2,000 pounds.

A separate axle weight distribution table is produced for each of the state's permanent WIM stations each year. Six of these stations weigh trucks continuously throughout the year; trucks are

weighed during three 48-hour sessions per year at each of the remaining seven sites. In addition to the individual WIM station axle weight distribution tables, a statewide average axle weight distribution table is calculated by combining data from all permanent WIM sites.

If a pavement project is located on the same highway as a WIM site, the most recent year's axle weight distribution from that WIM site is used in the analysis. If there is no WIM site on the same highway as the project site, the statewide average axle weight distribution is used.

The axle weight distribution is assumed to remain constant throughout the design period.

This completes the list of ESAL forecast components supplied by TPP. TPP uses the RDTEST68 computer program to generate a Total ESAL forecast based on these components. The Total ESAL covers all lanes and both directions of travel at the project site. TPP provides the Total ESAL to the Design Division.

Design Lane ESAL. Pavements in Texas are designed based on the traffic loadings expected in the highway's design lane. A highway's design lane is the lane expected to experience the greatest number of ESALs over the design period. The design lane for many highways is the right-hand lane; but on some highways (e.g., urban freeways) the design lane is the second lane from the right. To identify the Design Lane ESAL it is necessary to distribute the Total ESAL between the two directions of travel and among the lanes in each direction. This is accomplished using a directional distribution factor and a lane distribution factor.

Directional Distribution Factor. The directional distribution factor applied by the Design Division is an expected average directional distribution for the entire design period. Fifty percent of the total ESAL forecast is assigned to each direction of travel on the highway. If there is strong reason to believe that trucks at the site travel loaded in one direction and unloaded in the other, a greater percentage of ESALs may be assigned to the "loaded" direction.

Lane Distribution Factor. The lane distribution factor is an expected average lane distribution for the entire design period. Currently 100 percent of the One-Directional ESAL is assigned to the design lane for highways with four or less lanes, 80 percent to the design lane for highways with six lanes, and 70 percent to the design lane for highways with eight lanes. D-8 describes these lane distribution factors as "conservative" indicating that the factors may tend to overestimate the design lane ESAL percentage.

Table 11
Example of an Axle Weight Distribution Table

WIM STATION 501, 1981-1983

Upper Weight Limit (pounds)	Single Axles		Tandem Axles (Percent)	Upper Weight Limit (pounds)	Single Axles		Tandem Axles (Percent)
	Percent	Cumula-tive Percent			Percent	Cumula-tive Percent	
2,000	0.213	0.213	0.000	31,000	0.017	49.912	1.206
3,000	0.419	0.632	0.017	32,000	0.000	49.912	1.522
4,000	1.625	2.257	0.000	33,000	0.000	49.912	1.377
5,000	2.344	4.601	0.000	34,000	0.000	49.912	1.736
6,000	2.729	7.330	0.068	35,000	0.000	49.912	1.488
7,000	3.268	10.598	0.119	36,000	0.000	49.912	1.454
8,000	4.978	15.577	0.231	37,000	0.000	49.912	1.437
9,000	7.460	23.037	0.727	38,000	0.000	49.912	1.377
10,000	9.291	32.328	1.411	39,000	0.000	49.912	1.274
11,000	7.161	39.489	2.369	40,000	0.000	49.912	1.112
12,000	3.413	42.902	2.669	41,000	0.000	49.912	0.812
13,000	1.890	44.792	2.190	42,000	0.000	49.912	0.658
14,000	1.069	45.861	2.318	43,000	0.000	49.912	0.462
15,000	0.710	46.571	2.173	44,000	0.000	49.912	0.427
16,000	0.761	47.332	1.942	45,000	0.000	49.912	0.316
17,000	0.496	47.828	1.719	46,000	0.000	49.912	0.145
18,000	0.248	48.076	1.557	47,000	0.000	49.912	0.1?9
19,000	0.419	48.495	1.488	48,000	0.000	49.912	0.102
20,000	0.308	48.803	1.488	49,000	0.000	49.912	0.145
21,000	0.325	49.128	1.206	50,000	0.000	49.912	0.085
22,000	0.136	49.264	1.009	51,000	0.000	49.912	0.000
23,000	0.231	49.495	0.958	52,000	0.000	49.912	0.017
24,000	0.136	49.631	0.761	53,000	0.000	49.912	0.017
25,000	0.077	49.108	1.060	54,000	0.000	49.912	0.000
26,000	0.059	49.767	0.744	55,000	0.000	49.912	0.000
27,000	0.017	49.784	0.941	56,000	0.000	49.912	0.000
28,000	0.077	49.861	1.060				
29,000	0.017	49.878	1.240				

BRIDGE PROJECT FORECASTING REQUIREMENTS

General Information

TxDOT provides guidance and assistance to the local District offices in the preliminary planning and design of all types of structures. Elements of assistance provided may include preliminary studies of structure types, estimates and economic comparisons, preliminary field inspections and location studies, and structure layout and presentation of preliminary data. Guidance on bridge design is based on the current Bridge Division Operation and Planning Manual and on current standards and interim specifications for highway bridges published by the American Association of State Highway and Transportation Officials (AASHTO).

Generally, project planning and design for bridges is performed in conjunction with the project planning and design of the approach roadway. Thus, the traffic forecast requirements for bridge project planning and design are generally the same as those for the different types of roadways previously discussed.

Except for the lowest volume roads, bridge widths conform to the roadway widths as determined by traffic volumes in the Highway Design Division Operations and Procedures Manual. The specific roadway and structure widths for the different types of roadways for the forecast design year ADT (and/or current ADT) are listed in Table 12. As indicated, the standard roadway and structure widths for controlled access freeway mainlane sections are not varied according to current or design year volumes. That is, if design year volumes for a controlled access freeway require six lanes to be built, the 6-lane cross-section shown for the desired median type will be used and will not be varied according to the current or forecasted traffic volumes. In all cases, the structure width for controlled access facility mainlanes matches that of the approach roadway. This is also true of ramps and direct connections except that at-grade roadway ramps without traffic barriers require a 2-foot inside shoulder and ramps and direct connections on structures require a 4-foot minimum inside shoulder.

The minimum roadway and bridge design width of the various types of multi-lane non-controlled access facilities, rural frontage roads, two-lane rural roads, and FM and RM roads is, however, determined by the design year and/or current year ADT. Depending on the road type, the design year volume, and in some cases the current volume, determines the number of lanes, the lane widths, the shoulder widths, and the type of cross-section (undivided or divided).

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- For multi-lane noncontrolled access facilities, bridge widths match the approach roadway including the usable shoulder. The roadway widths are determined by design year ADT volumes and the type of cross-section.

- For rural frontage roads, the lane width and shoulder width are determined by design year ADT volumes. Bridges match the roadway width.

- Bridge widths match the approach roadway widths on FM and RM roads. The design year ADT determines these widths.

- For two-lane rural roads other than FM and RM roads the roadway and bridge widths are based on design year and current ADT. Bridge widths match the approach roadway except on low volume roads where the design speed is over 50 mph. In this case, the bridge width is 4 feet wider than the roadway.

- Bridges on urban arterial streets will match the curb and gutter dimensions with a 4- to 6-foot sidewalk provided on each side.

- Off-system bridge rehabilitation or replacement should conform to state design standards and the Secondary Road Plan when applicable.

Traffic volumes and truck volumes are no longer considered in determining the design load of structures. Currently, TxDOT designs all on-system structures and the majority of off-system structures for an HS20 load. Some low volume off-system structures, however, may be designed at H20 loads. As a result, traffic forecasts do not affect the design of bridges except with regard to geometrics as discussed above.

Table 12
Roadway and Bridge Widths Based on Traffic Volumes

Facility Type	Design Year ADT	Roadway Width	Structure Width
Multi-lane Controlled Access Freeway	N/A		
Main Lanes			
4-Lane Divided	N/A	4+24+10 = 38	38
6-Lane Divided (depressed median)		4+36+10 = 50	50
6-Lane Divided (flush median)		10+36+10 =56	56
8-Lane Divided		10+48+10 = 68	68
1-Lane Direct Connection		2*+14+8 = 24	4+14+8 = 26
2-Lane Direct Connection		2*+24+8 = 34	4+24+8 = 36
Ramps other than Dir. Conn.		2*+14+6 = 22	4+14+6 = 24
		(*4 ft. min. to traffic barrier)	
Rural Frontage Roads	Less than 400	4+20+4 = 28	28
	400 To 750	6+22+6 = 34	34
	More than 750	8+24+8 = 40	40
Multi-lane Noncontrolled Access			
Undivided	7500 or Less	10+48+10 = 68 des.	68
		8+48+8 = 64 min.	64
Narrow Median (4 ft.)	5000 to 20,000	10+24+4+24+10 = 72 des.	72
		8+24+4+24+8 = 68 min.	68
Narrow Median (16 ft.)	5000 to 20,000	10+24+16+24+10 = 84 des.	84
		8+24+16+24+8 = 80 min.	80
Depressed Median	5000 to 20,000	4+24+10 = 38 des.	38
		4+24+8 = 36 min.	36
Narrow Median (4 ft.)	20,000 or More	10+36+4+36+10 = 96 des.	96
		8+36+4+36+8 = 92 min.	92
Marrow Median (16 ft.)	20,000 or More	10+36+16+36+10 = 108 des.	108
		8+36+16+36+8 = 104 min.	104
Depressed Median	20,000 or More	4+36+10 = 50 des.	50
		4+36+8 = 48 min.	48
Two-Lane Rural			
Low Volume	Current ADT 400 or Less	4+20+4 =28	28[1]
Less than 2200 Design		4+22+4 = 30	34[2]
Year ADT and:	Current ADT 400 to 750	6+22+6 = 34	34
	Current ADT 750 or More	8+24+8 = 40	40
	Current ADT More than 750	10+24+10 = 44 des.	44
		8+24+8 = 40 min.	40
High/Moderate Volume	2200 to 7500	10+24+10 = 44 des.	44
		8+24+8 = 40 min.	40
FM or RM Roads			
	0 to 50[3]	3+18+3 = 24	24
	400 or Less	4+20+4 = 28	28
	400 to 750	6+22+6 = 34	34
	750 or More	8+24+8 = 40	40

Notes:

[1]Applicable when design speed is 50 mph or less.

[2]Applicable when design speed is over 50 mph.

[3]Applicable only for projects involving 100 percent state funds.

Forecast Methodology

If a bridge project is being designed separately from the design of the approach roadway, the forecast methodology used in geometric design should be followed to determine the design year traffic for the bridge.

SIGNALIZED INTERSECTION DESIGN

Purpose

The design of signalized intersections involves consideration of traffic, roadway, and signalization conditions. TxDOT utilizes the critical lane analysis technique to determine if a proposed intersection design will provide an acceptable LOS in the design year. Thus, the design of signalized intersections is a trial-and-error process in that an initial design and signal plan must be assumed in order to determine if the intersection will provide satisfactory service.

Forecast Requirements

The traffic forecast data required for testing the design of signalized intersections include:

- DDHVs for each movement (through traffic, right and left turns) on each approach. The DDHVs should be in passenger car equivalents; thus the adjustments for trucks and/or other heavy vehicles should be made to the volumes.

- Design year peaking factor. The peaking factor is similar to the peak-hour factor used in the design analysis procedures previously described in that it is used to adjust the design-hour volume to the peak 15-minute flow rate within the hour.

The submission of a request for a traffic forecast for design should include the design year, current land use maps along the facility and the location, type of major traffic generators, past and current traffic counts for the facility and major cross-streets, and a map showing the general facility alignment. Also, the type of facility, type of operation (one-way vs. two-way), the number of existing lanes, the number of proposed lanes, and a general preliminary schematic of the project should be provided. Additionally, if the project is a new location project, the length of the proposed facility between cross-streets should be given.

Other information that will be needed if the traffic is not being prepared by TPP includes:

- The TRANPLAN files *.ANT, *.NET, *.RAD, *.PNA, and *.EXT for the base year, the intermediate year and the long-range forecast year for the specific metropolitan area in which the project is located.

- Copies of the DOS-executable programs NEWYR, BALANCE, and ALLOCATE.

- The capacity/speed look-up table, functional classification table, and trip production and attraction rates for the urban area.

Data that are required for forecasting the traffic parameters include:

- Current facility-specific K, D, and T factors for projects on existing facilities.

- Current K, D, and T factors for similar facilities in the project area for new location projects.

- Forecast changes in development and densities in the project area for all projects.

- Location and capacity of major facilities feeding into the project facility or into which the project feeds.

Forecast Methodology

The methodology used to prepare traffic forecasts for the design of a signalized intersection is the same as that used to prepare forecasts for the geometric design of roadways.

USING TRANPLAN AND THE DOS-EXECUTABLE PROGRAMS

This section describes the following corridor analysis procedures:

1. Using the DOS NEWYR program for interpolating a set of production/attraction files to develop a production/attraction file for an intermediate year for which there is no current traffic assignment.

2. Using the DOS NEWYR program for extrapolating a forecasted production/attraction file to get a design year production /attraction file for which there is no current assignment.

3. Running the DOS BALANCE program to balance production/attraction files.

4. Running the DOS ALLOCATE program to revise productions and/or attractions and reallocate productions and/or attractions to equal the designated urban area control totals.

5.	Helpful network editing procedures.

6.	TRANPLAN modeling flowchart.

7.	Helpful plotting procedures and example parameters.

Running the NEWYR Program

Interpolating a Production/Attraction File

NEWYR is a DOS-executable program (NEWYR.EXE) that takes a base year or beginning year set of productions and attractions and compares them to a future year set of productions and attractions to produce a new production/attraction file. The program can be run to produce a new production/attraction file ("PNA" file) for an interpolated year between the base year and the forecast year, or it can be run for an extrapolation year beyond the forecast year.

For instance, assume that an urban area has been modeled with the Texas Package and the validation year is 1987. Two forecasts have been done, one for 1995 and the other for 2005. But you need a current year, 1994, set of traffic data to test a proposed facility. The best method to get the data would be to update the network to 1994 and rerun the model with 1994 demographics. This, however, is too time-consuming. Instead, use NEWYR to produce a 1994 PNA file for input into TRANPLAN.

First, the study area model needs to be converted to TRANPLAN. Once this is done for all years, all the files you need are ready. Type "NEWYR" from the subdirectory where the TRANPLAN model files reside, and the program will ask you for the following information:

Input the base year PNA file -
(Enter the filename of the 1987 production/attraction file.)
Input boundary year TRANPLAN PNA file -
(Enter the filename of the 1995 production/attraction file.)
Output adjusted PNA filename -
(Enter the name of the new output adjusted PNA file.)
What is the base year?
(Enter "1987".)
What is the boundary year?
(Enter "1995".)
What is the future/intermediate year?
(Enter "1994".)
Will this be (I)nterpolation or (E)xtrapolation?
(Enter "I".)

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The program will then begin running and will interpolate the two production/attraction files to create a third PNA file in TRANPLAN format. The new PNA file will be based on interpolation of productions and attractions at the zonal level, by trip purpose, from the two input PNA files (base year and boundary year).

The program also ensures that both input PNA files are balanced. NEWYR will balance both input files internally so that the output adjusted PNA file is balanced as well. NEWYR balances all attractions proportionally by zone and trip purpose to productions so that the sum of all attractions in the urban area equals the sum of all productions in the urban area.

Figure 2 shows the overall procedure to develop traffic for a new year using the NEWYR interpolation program and the TRANPLAN model. Figure 3 provides examples for selecting the appropriate base, boundary and future years for use in the NEWYR program.
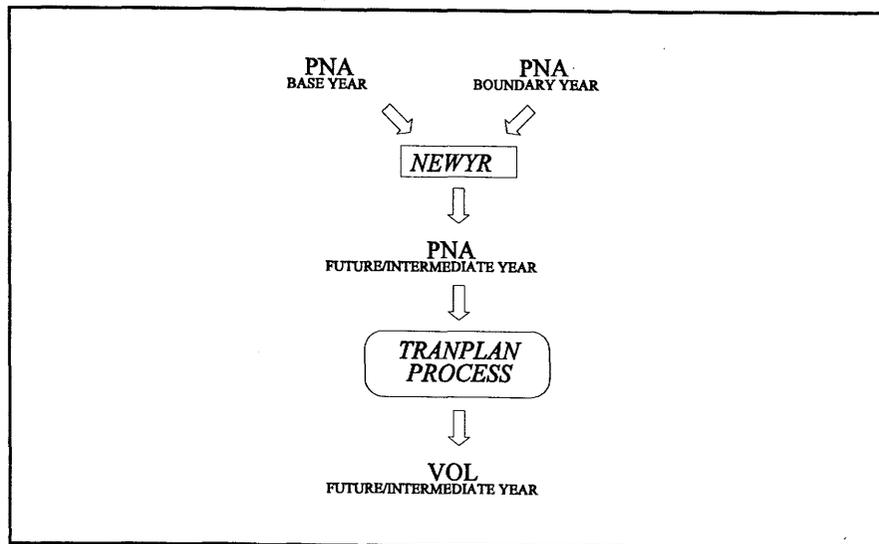
Figure 2. The NEWYR program PNA file interpolation/extrapolation.

Definition of Base, Boundary, & Future Years

BASE   FORECAST   FORECAST

1987   1994   1997   2000   2005   2010

BASE YEAR = 1987   BASE YEAR = 1997   BASE YEAR = 1987 OR 1997

BOUNDARY YEAR = 1997   BOUNDARY YEAR = 2005   BOUNDARY YEAR = 2005

INTERMEDIATE YEAR = 1994   INTERMEDIATE YEAR = 1999   EXTRAPOLATION YEAR = 2010
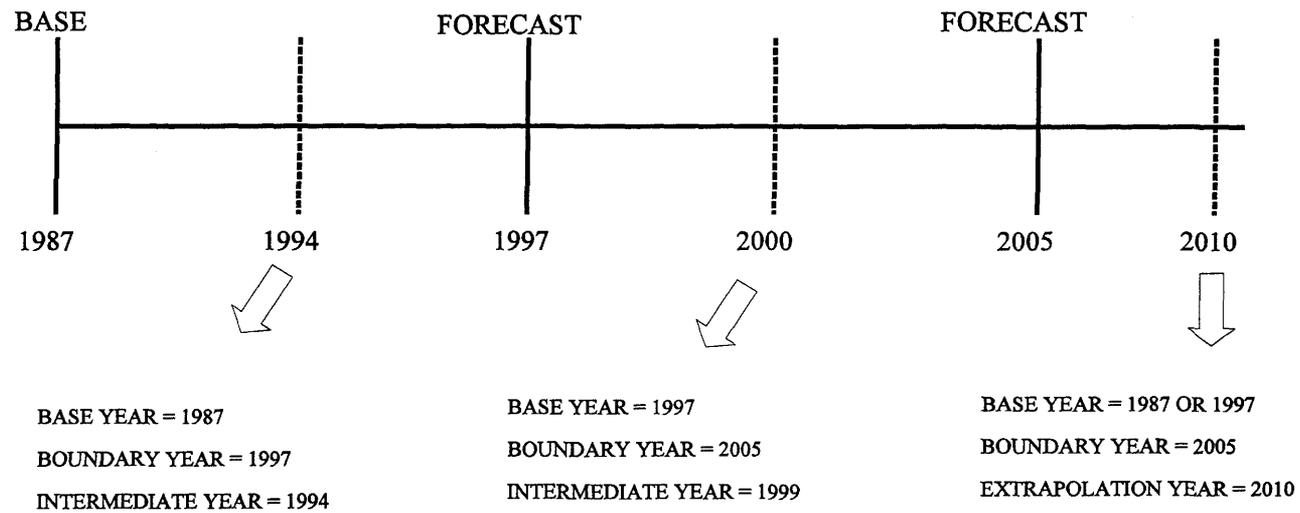
Figure 3.   A conceptual timeline of possible corridor analysis forecasts.

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The year that you want to interpolate (in our example 1994) should fall between the closest base year and boundary year for which there is a full model run, or production/attraction files. In our example, the base year was 1987, and the boundary year was 1995. The base year could have been 1995 and the boundary year 2005 if our intermediate (or interpolate) year was 1999 and there was a 1995 forecast model based on demographic forecasting.

After running the NEWYR program to interpolate two files to an intermediate year, the "new" PNA file is ready to be used in running TRANPLAN. Refer to the document, *Texas TRANPLAN Application Guide* for instructions on how to run the TRANPLAN model.

Extrapolating a Production/Attraction File

When the design year is beyond the 20-year forecast year, the PNA files for the forecast year are extrapolated to develop the new PNA file. Extrapolation of PNA files is done with the same program, NEWYR. The only difference between running NEWYR for interpolation versus extrapolation is that when extrapolation is done, the resulting PNA file must be balanced. That is to say, the file needs to be modified so that total attractions for the urban area are equal to total productions for the urban area. The DOS BALANCE program described below is used to perform this task.

To run an extrapolation using NEWYR, follow the steps below. In this case, assume an urban area has been modeled, and the base year (validation year) is 1990. Two forecasts were performed, one for 2000 and one for 2010. The design year of the project is 2012. Type "NEWYR" from the subdirectory where the TRANPLAN model files reside, and the program will ask you for the following information:

Input the base year PNA file -
(Enter the filename of the 1990 production/attraction file.)
Input boundary year TRANPLAN PNA file -
(Enter the filename of the 2010 production/attraction file.)
Output adjusted PNA filename -
(Enter the name of the new output adjusted PNA file.)
What is the base year?
(Enter "1990".)
What is the boundary year?
(Enter "2010".)
What is the future/intermediate year?

```
(Enter "2012".)
        Will this be (I)nterpolation or (E)xtrapolation?
(Enter "E".)
        Use (B)ase year or (F)uture year friction factors?
(Enter "F".)
```

The program will then begin running and will extrapolate the 2010 PNA file to create a new PNA file for the desired year in TRANPLAN format. The new PNA file will be based on extrapolation of productions and attractions at the zonal level, by trip purpose, from the input PNA files. As noted above, however, the PNA file created through the NEWYR extrapolation process will need to be balanced before it is used in TRANPLAN. This can be accomplished using the DOS BALANCE program described below. After the new PNA file has been balanced, it may be used in running TRANPLAN. Refer to the *Texas TRANPLAN Application Guide* for instructions on how to run the TRANPLAN model.

Running the BALANCE Program

The BALANCE program is a DOS-executable program that uses the same process that the TRANPLAN $Gravity Model uses to balance total attractions to total productions and writes out a new, balanced PNA file. The BALANCE program should be run on the PNA file created through the NEWYR extrapolation process. It is not necessary to use BALANCE after creating a file through the NEWYR interpolation.

BALANCE can also be used to ensure that the PNA file being used is, in fact, balanced. If the total productions equal the total attractions for the urban area, BALANCE will not affect the PNA file. If the total attractions are greater than the total productions for all zones in the model PNA file, BALANCE will decrease the number of attractions in each zone in proportion with the zone's contribution to the total. In other words, if one zone has 20 attractions while another has 200 attractions, the zone with 200 attractions will be decreased greater than the zone with 20 attractions because it contributes to the total to a greater degree.

To run the BALANCE program type "BALANCE" from the subdirectory where the TRANPLAN files reside, and the program will ask you the following information:

Input TRANPLAN PNA File -

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(Enter the filename of the unbalanced production/attraction file)
    Output Adjusted PNA Filename -
(Enter the file name of the new adjusted production/attraction file)

Running the Allocate Program

    During corridor analysis, it is occasionally necessary to change the number of productions and/or attractions for a particular zone because the conditions originally anticipated when the forecasts were made have changed. For instance, a visit to the project area may indicate that the traffic levels are greater than what was originally anticipated. This may be the result of a new shopping center, office complex, or subdivision. When this occurs, the number of attractions or productions for each affected zone should be revised to reflect the current conditions.

    One way to make these changes is to edit the TRANPLAN PNA file. However, a problem occurs when the edited PNA file is used in TRANPLAN. On a regional level, the total productions in an urban area must equal the total attractions in that area (except for external trips). If the level of attractions or productions in a zone is changed, the TRANPLAN $Gravity Model will automatically balance all attractions or productions proportionally by zone to match the production or attraction total for the region. Thus, what was thought to be updated was revised by TRANPLAN.

    One solution to this problem is to manually change the level of attractions (or productions) in other zones so that the control total productions (or attractions) are not violated. If, for example, at the time the forecast was made it was expected that a regional shopping mall was going to be developed in a certain zone, but instead it was developed in another zone, the TRANPLAN PNA file can be manually edited to increase the number of attractions in the zone where the development occurred and decrease by the same number the attractions in the zone where it did not occur as expected. If, however, a number of zones are involved and the "trade-off" of productions and/or attractions between zones is not clear, manually editing the PNA file can be time consuming and very subjective.

    The DOS-executable ALLOCATE program was written to reallocate the productions or attractions proportionally to or from all zones where changes were not made. ALLOCATE will not change the control total productions or attractions for the urban area. The ALLOCATE program reads a PNA file in which changes to the productions and attractions have been made for

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up to ten zones. Only attractions or productions, but not both, can be changed for any one run of the ALLOCATE program. Other subsequent runs can be performed if both attractions and productions are to be changed or if the attractions or productions for more than ten zones need to be revised.

When modifying a zone's productions or attractions, it is imperative to begin with a balanced production/attraction file, one where total productions equals total attractions. If you are unsure whether the PNA file being revised is balanced, run the BALANCE program before making changes to either the productions or attractions. If the file is balanced, the program will not make any changes to the file. To run the program, type "ALLOCATE" from the subdirectory where the TRANPLAN files reside; and the program will ask you the following information:

Have (P)roductions or (A)ttractions been changed?
Warning: **Input PNA File Total Productions Must Equal Total Attractions!**
               Use BALANCE program Before Altering Attractions!
(Enter P for productions or A for attractions.)
               Input TRANPLAN PNA File -
(Enter the filename of the balanced and revised production/attraction file.)
               Output Adjusted PNA Filename -
(Enter the filename for the new adjusted PNA file.)
               Enter zone(s) To Keep Attractions (Productions) Constant -
               Press Enter when finished...
(These are the zone numbers of the zones in which the attractions (productions) were revised to reflect current conditions.)
               Enter Zone Number or Press Enter
(Enter first zone number in which attractions (productions) are to be kept constant, i.e., "21," and hit Enter.)
               Enter Zone Number or Press Enter
(Enter next zone number in which attractions (productions) are to be kept constant, i.e., "133." If only one zone was changed continue to hit enter through the remaining "Enter Zone Number" inquiries. Remember, up to ten zones may be changed for one run of ALLOCATE.)
               Reading and Reallocating PNA File Attractions (Productions)...

After running ALLOCATE, the next step is to run the "long method" of the TRANPLAN model on the appropriate, edited network. Refer to the *Texas TRANPLAN Application Guide* for instructions on running the TRANPLAN model.

Figures 4 and 5 provide information on the procedures for using the DOS-executable programs and TRANPLAN to obtain a current year forecast traffic assignment are a design year forecast assignment and for changing attractions or productions.

TRANPLAN Corridor Analysis

Texas Package Model Years: 1987, 1997, 2005
Current Year: 1994
Design Year: 2014

OBJECTIVE: GET CURRENT YEAR ASSIGNMENT

1987.PNA   1997.PNA

NEWYR

1994.PNA

Adjust a Zone's
Attractions or Productions?

Yes

Change
P's or A's

No

1987.NET

ALLOCATE

1994.PNA

HNIS

New94.PNA   ⟹   TRANPLAN RUN   ⟸   1994.NET

1994.VOL

Plot
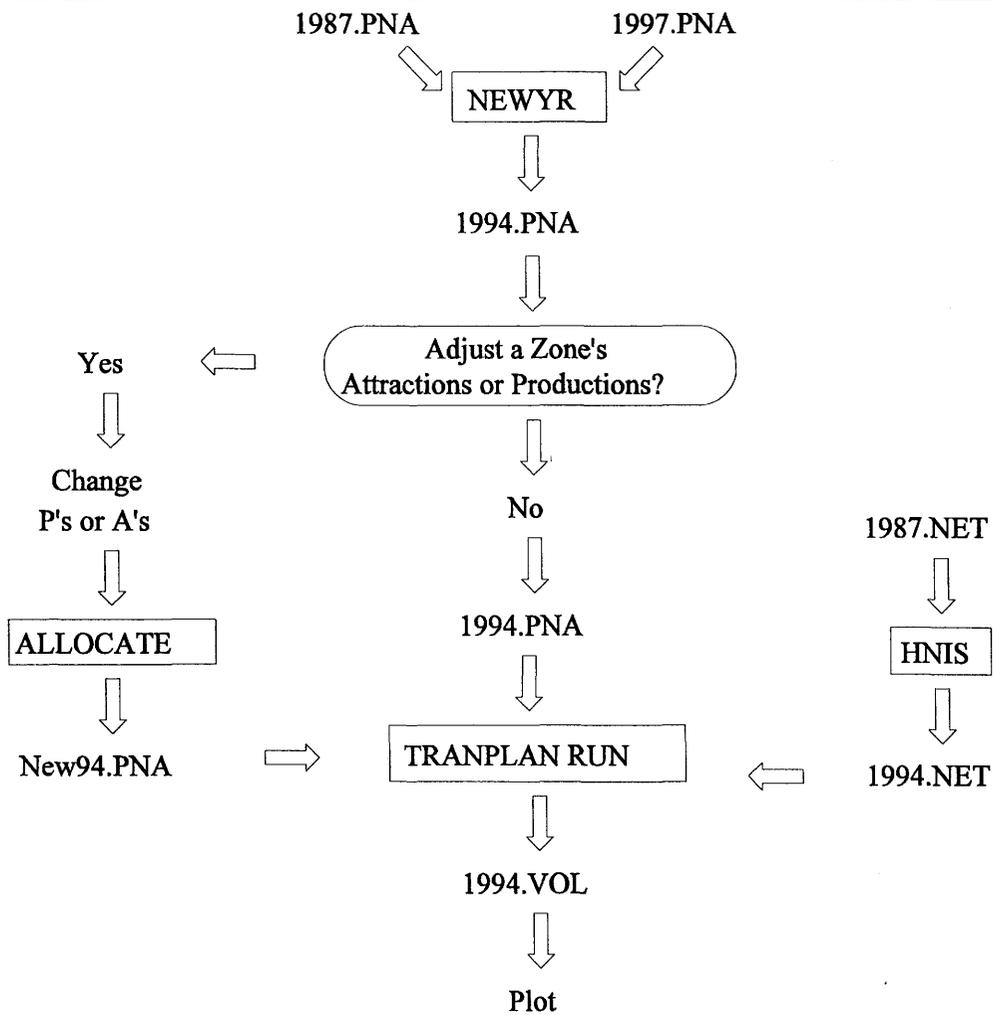
Figure 4. Flowchart of TRANPLAN corridor analysis method to obtain a current year traffic assignment.

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TRANPLAN Corridor Analysis

Texas Package Model Years: 1987, 1997, 2005
Current Year: 1994
Design Year: 2014

OBJECTIVE: GET DESIGN YEAR ASSIGNMENT

1987.PNA
2005.PNA ⟹ | NEWYR | ⟹ TEMP14.PNA

⇓

2014.PNA ⟸ | BALANCE |

⇓

Yes ⟸ (Adjust a Zone's Attractions or Productions?)

⇓

Change
P's or A's   No   2005.NET

⇓   ⇓   ⇓

| ALLOCATE | 2014.PNA | HNIS |

⇓   ⇓   ⇓

New14.PNA ⟹ | TRANPLAN RUN | ⟸ 2014.NET

⇓

2014.VOL

⇓

Plot
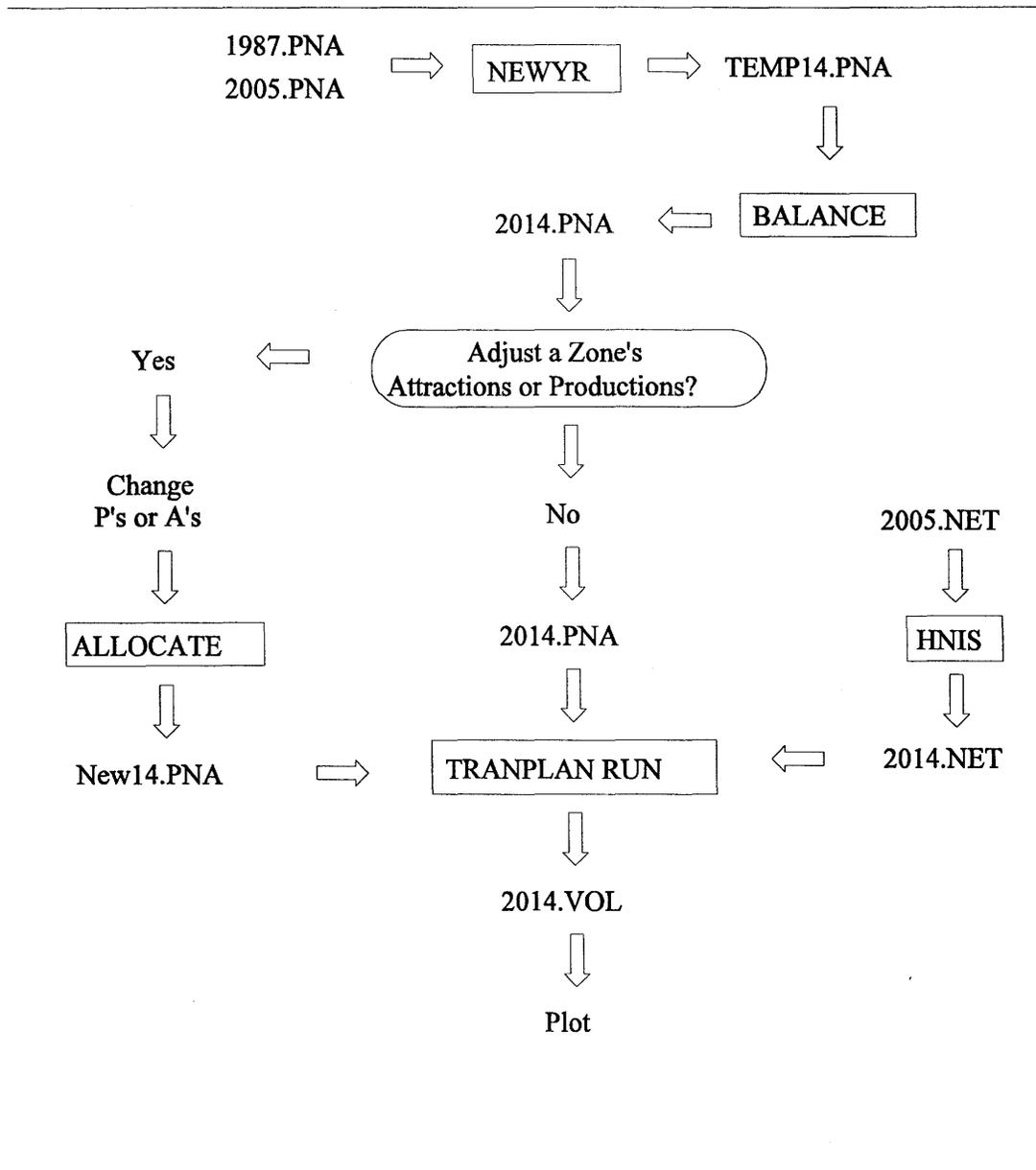
Figure 5. Flowchart of TRANPLAN corridor analysis method to obtain a future design year traffic assignment.

FACTORING PROCEDURE EXAMPLE

The following example illustrates the factoring procedure for developing future year turning movements:

Project: Determine year 2000 turn movements at the intersection of Texas Avenue and University Drive in the city of College Station using the factoring procedure.

Data: Base year (BY) turning movement count (1985)
Base year (BY) turning movement assignment (1985)
Future year (FY) turning movement assignment (2000)

Method: Ratio: V_r = FY assigned turns * (BY count/BY assignment)
Difference: Y_d = FY assigned turns + (BY count - BY assignment)
Combined: $V_f = (V_r + V_d) / 2$

Table 13
Factoring Procedure Result

Approach	Turn Movement	BY Count	BY Assignment	FY Assignment	Adjusted Future Volume		
					Ratio Method	Difference Method	Combined Method
NB	Left	362	447	514	416	429	422
	Thru	805	1666	1965	949	1104	1027
	Right	399	424	508	478	483	480
SB	Left	148	195	234	178	187	183
	Thru	703	1611	1901	830	993	912
	Right	133	369	424	153	188	171
EB	Left	422	375	457	514	504	509
	Thru	763	799	951	908	915	912
	Right	249	581	703	201	371	336
WB	Left	433	436	527	523	524	524
	Thru	535	849	1010	636	696	666
	Right	164	184	224	200	204	202

DIRECTIONAL VOLUME ITERATIVE EXAMPLE

The following example illustrates the directional turning movement procedure where base year volumes are available:

Project: Determine year 2000 turning movements at the intersection of Texas Avenue and University Drive in the city of College Station using the directional iterative method.

Data: Base year (BY) turning movements (1985) and future year (FY) directional link volumes (2000) as shown in the figure below.

PEAK HOUR
5:30 TO 6:30
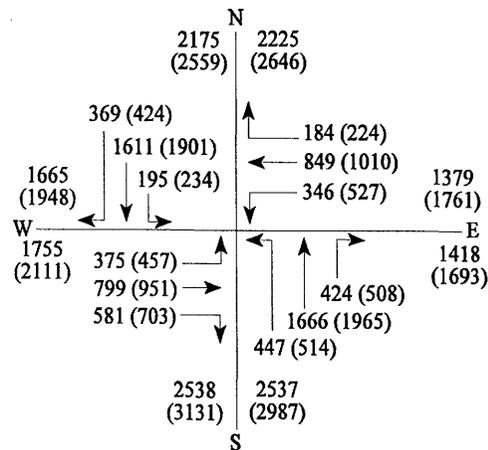
Table 14
Step 1: Initial Turning Movement Matrix

		Columns (Outflows) D_{jb}				Total Link Inflows O_{ib} (O_{if})
		To Link N	To Link S	To Link E	To Link W	
Rows (Inflows) T_{ijb}	From Link N	0	1611	195	369	2175 (2559)
	From Link S	1666	0	424	447	2537 (2987)
	From Link E	184	346	0	849	1379 (1761)
	From Link W	375	581	799	0	1755 (2111)
Total Outflows D_{jb} (D_{jf})		2225 (2646)	2538 (3131)	1418 (1693)	1665 (1948)	

Table 15
Step 2: First Row Iteration

		Columns (Outflows) D_{jf}				Total Link Inflows $O_{if}*$
		To Link N	To Link S	To Link E	To Link W	
Rows (Inflows) $T_{ijf}*$	From Link N	0	1895	229	435	2559
	From Link S	1961	0	500	527	2988
	From Link E	235	443	0	1087	1765
	From Link W	451	697	958	0	2106
Total Outflows $D_{if}*$		2647	3035	1687	2049	

Compare the adjusted future volume outflow for each link ($D_{if}*$) to the desired future volume

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outflow (D_{if}) in Step 1 (Table 14). As shown in Table 16 below, the adjusted volumes are within $\pm 10\%$ and the results are considered acceptable; no further iterations are needed.

Table 16
Comparison of Adjusted and Desired Outflows

	Columns (Outflows)											
	To Link N			To Link S			To Link E			To Link W		
	D_{jf}	$D_{jf}*$	% Diff.	D_{jf}	$D_{jf}*$	% Diff.	D_{jf}	$D_{jf}*$	% Diff.	D_{jf}	$D_{jf}*$	% Diff.
From Link N	0	0	0	1901	1895	-.3	234	229	-2	424	435	+3
From Link S	1965	1961	-.2	0	0	0	508	500	-2	514	527	+3
From Link E	224	235	+5	527	423	-20	0	0	0	1010	1087	+8
From Link W	457	451	-1	703	443	-37	951	958	+.7	0	0	0
	2646	2647	+.04	3131	2761	-12	1693	1687	-.3	1948	2049	+5

Table 17
Step 3: First Column Iteration

		Columns (Outflows) $D_{jf}*$				Total Link Inflows $O_{if}*$
		To Link N	To Link S	To Link E	To Link W	
Rows (Inflows) $T_{ijf}*^{new}$	From Link N	0	1955	230	414	2599
	From Link S	1960	0	502	501	2963
	From Link E	235	457	0	1033	1725
	From Link W	451	719	961	0	2131
Total Outflows $D_{if}*$		2646	3131	1693	1948	

Now compare the $O_{if}*^{new}$ to the O_{if} from Matrix 1 as shown in Table 18. If the results are acceptable (± 10 percent), no further iteration(s) are needed.

Table 18
Comparison of Adjusted and Desired Inflows

	Total Inflows		
	O_{if}	$O_{if}*new$	Percent Difference
From Link N	2559	2599	+1.5
From Link S	2987	2963	-.8
From Link E	1761	1725	-2.0
From Link W	2111	2131	+10

These values are within ± 10 percent. If the values are considered acceptable, the iterations are complete. If closer results are desired, the iterative process may continue by performing a second row iteration as in Step 2 (Table 15), a comparison of the D_{jf} and $D_{jf}*^{new}$, followed by a

second column iteration as in Step 3 (Table 17), a comparison of the O_{if} and O_{if}^{*new}, and so forth.

NONDIRECTIONAL VOLUME ITERATIVE EXAMPLE

The following problem illustrates the nondirectional iterative procedure:

Project: Determine the year 2000 turning movement at the intersection of Texas Avenue and University Drive in the city of College Station using the nondirectional iterative procedure.

Data: Future year 2000 nondirectional approach link volumes as shown below.

```
                    N
                   |3024
                   |
                   |
         1836      |         2185
   W  -------------+-------------  E
                   |
                   |
                   |
                   |2560
                    S
```
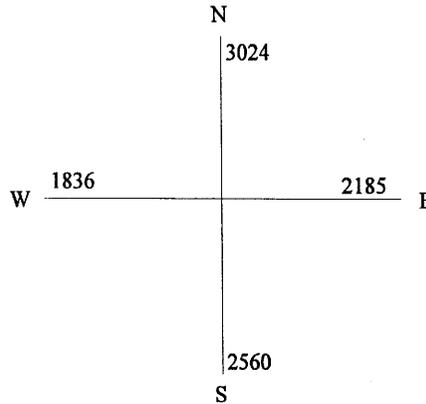
Step 1 - Estimate the Total Turning Percentage.

V_T = $3024 + 2560 + 2185 + 1836 = 9605$.
V_I = total inflowing volume (50% of total) = $9605/2 = 4802$.
V_{TP} = percentage of total inflowing volume making turns = 20%.
V_{Turns} = turning volume = $4802 * .20 = 960$.
V_{Thru} = through volume = $4803 - 960 = 3843$.

Step 2 - Calculate Relative Weight of Total Turning Percentage for Each Approach.

Approach E: 2185/9605 = 0.23
Approach N: 3024/9605 = 0.31
Approach W: 1836/9605 = 0.19

Approach S: 2560/9605 $=$ 0.27

Table 19
Step 3: Initial Allocation of Turns

From Approach	To Approach	No. of Turns
E	N	2185 * 0.31 = 677
	S	2185 * 0.27 = 590
N	E	3024 * 0.23 = 696
	W	3024 * 0.19 = 575
W	N	1836 * 0.31 = 569
	S	1836 * 0.27 = 496
S	E	2560 * 0.23 = 589
	W	2560 * 0.19 = 486

Average the volumes as shown below.

Step 4 - Adjust Turning Volumes Based on Turning Percentage.

(a) Total inflowing volume of turns = 4802.
(b) Total turn percentage = 0.20.
(c) Compute expected turn volume (a*b) = 4802 * .20 = 960.
(d) Sum of turn volumes from Step 3 (Table 19).
     572 + 491 + 687 + 590 = 2340
(e) Adjustment:

Difference method:
(960 - 2340)/4 = (-345).
Ratio method:
960/2340 = 0.41

N

(575 + 569)/ 2 = 572   (677 + 696)/ 2 = 687

W ———————————|——————————— E

(496 + 486)/2 = 491   (589 + 590)/2 = 590

S

```
                        N
                        |
          572           |          687
        * .41           |        * .41
        -------         |        -------
          235           |          282
                        |
W ----------------------+---------------------- E
                        |
          491           |          590
        * .41           |        * .41
        -------         |        -------
          201           |          242
                        |
                        S
```
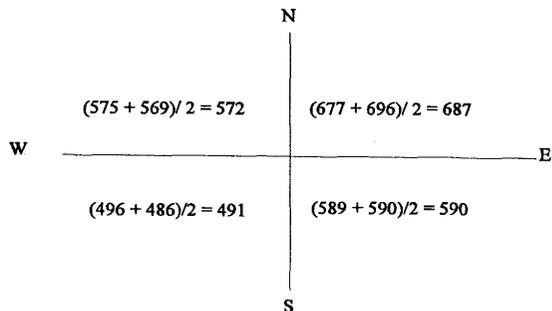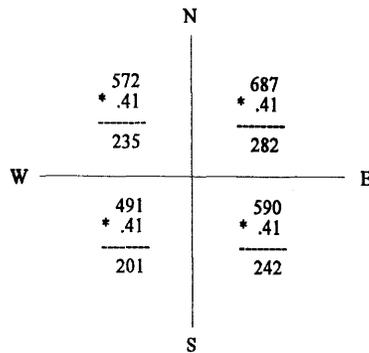
Step 5 - Balance Approach Volume and Adjusted Turn Volumes.

Difference method:

E: 2185 - 342 - 245 + 227 + 146 = 1971

N: 3024 - 342 - 227 + 146 + 245 = 2846

W: 1836 - 227 - 146 + 342 + 245 = 2050

S: 2560 - 146 - 245 + 227 + 342 = 2738

Ratio method:

E: 2185 - 282 - 242 + 235 + 201 = 2097

N: 3024 - 282 - 235 + 201 + 242 = 2950

W: 1836 - 235 - 201 + 282 + 242 = 1924

S: 2560 - 201 - 245 + 282 + 235 = 2631

Using either the ratio or difference method, compare the original approach volume difference between opposing approaches and the adjusted approach volume difference. In this example, the ratio adjusted volumes are used.

Table 20
Comparison of Approach Volumes

Approach	Original Volume Difference	Adjusted Volume Difference	Conclusion
E / W	2185 - 1836 = 349	2097 - 1924 = 173	Increase Difference
N / S	3024 - 2560 = 464	2950 - 2631 = 319	Increase Difference

Make adjustments as follows:

(a)   Sum original approach volumes.

$$E + W = 2185 + 1836 = 4021$$

$$N + S = 3024 + 2560 = 5584$$

(b)   Determine proportion of volume to opposing volume.

$$2185/4021 = .54$$

$$1836/4021 = .46$$

$$3024/5584 = .54$$

$$2560/5584 = .46$$

(c)   Determine approach volume difference.

E: 2185 - 2097 = 88

W: 1836 - 1924 = - 88

N: 3024 - 2950 = 74

S: 2560 - 2631 = - 71

(d)   Multiply difference by proportion.

E: 88 * .54 = 48

W: - 88 * .46 = - 40

N: 74 * .54 = 40

S: - 74 * .46 = - 34

(e)   Subtract value calculated in d above from the adjusted volume.

E: 2097 - 48 = 2049

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W: 1924 - (- 40) = 1964

N: 2950 - 40 = 2910

S: 2631 - (- 34) = 2665

2049 + 1964 + 2910 + 2668 = 9591

Now compare the total adjusted approach volumes from (e) above, 9,588, to the original total approach volumes, 9,605. The difference between these is only 17, or 0.18 percent, and is not considered to be significant. However, in many cases, additional adjustments may be needed.

Results:
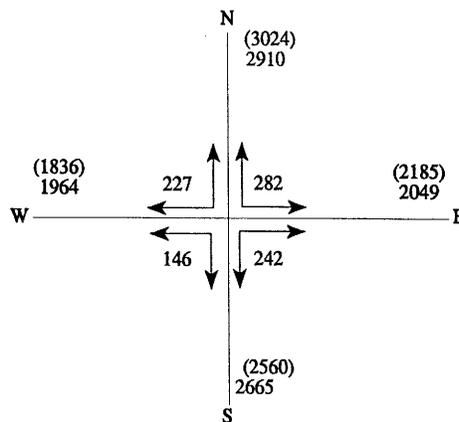
DIRECTIONAL "T" INTERSECTION PROCEDURE EXAMPLE

An example of the directional "T" intersection turning movement estimation procedure is given:

Project: Determine turning movements at the "T" intersection of Texas Avenue and Harvey Road in the city of College Station.

Data: Six directional link volumes for (1985).

One directional turning movement (1985 count).

N
3853 | 3785

D C

E
F
414

1331 E
1463

A B

2920 | 3011
S
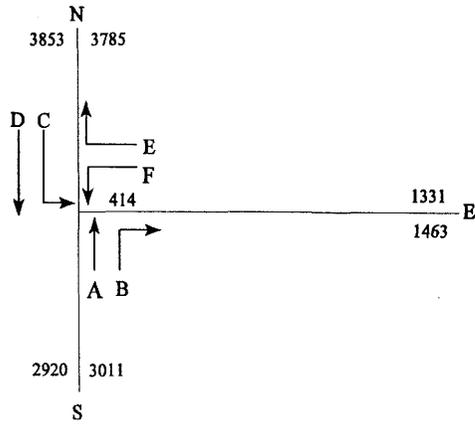
Volume E = 1331 - 414 = 917

Volume A = 3785 - 917 = 2868

Volume B = 3011 - 2868 = 143

Volume C = 1463 - 143 = 1320

Volume D = 3853 - 1320 = 2533

NONDIRECTIONAL "T" INTERSECTION EXAMPLE

An example of the nondirectional "T" intersection turning movement estimation procedure is given:

Project: Determine the turning movements at the intersection of Texas Avenue and Harvey Road in the city of College Station using the nondirectional "T" intersection procedure.

Data: Nondirectional link volume (1985).
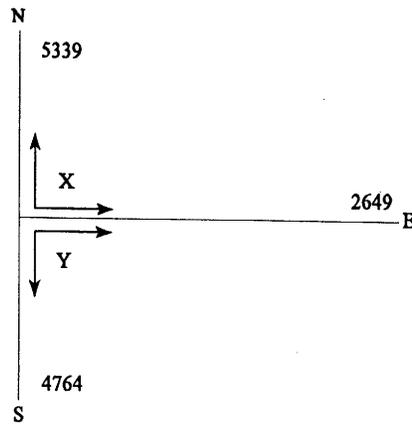
Calculation:

       X   =   (N - S + E) / 2.

       X   =   (5339 - 4764 + 2649) / 2 = 1612.

       Y   =   (E - N + S) / 2.

       Y   =   (2649 - 5339 + 4764) / 2 = 1037.

CHAPTER 15: TRAFFIC FORECASTING FOR
POLICY AND ADMINISTRATIVE FUNCTIONS*

PURPOSE

Accurate and timely traffic data are essential for strategic planning, fund allocation, project evaluation and prioritization, and program formation. Virtually every transportation decision is dependent on either estimates of current traffic or on forecasts of future traffic.

FUNCTIONS REQUIRING CURRENT TRAFFIC ESTIMATES
Strategic Planning

Strategic planning is almost completely dependent on traffic data. Traffic data on a system basis are most important to the Texas Transportation Commission because resource allocation is based on traffic.

Department of Commerce Projects

TxDOT cooperatively participates in Department of Commerce projects such as "Team Texas" (Texas's commitment to encourage specific economic development). TxDOT determines the amount and nature of traffic which will be induced by new traffic generators, such as new businesses, and investigates opportunities to accommodate these new generators with adequate transportation facilities.

Highway Performance Monitoring System (HPMS)

HPMS consists of all public highways or roads within the state with the exception of roads functionally classified as local (HPMS = 5,500 Texas samples). Approximately 100 data items are collected including traffic volumes, VMT, average annual daily traffic (AADT), vehicle classification, and truck weight. Average annual daily traffic is perhaps the most variable data item in the HPMS.

Bridge Needs Investment Program (BNIP)

The BNIP is a 100 percent Texas sample for traffic data purposes.

Funding Needs Determinations

Traffic data are used as important variables in determining both long- and short-range needs.

Project Selection-Prioritization-Programming (including cost effectiveness).

Every TxDOT program is based on traffic data.

Preservation of the System Allocation Programs

These programs use various combinations of lane-mile/traffic/population as basis for distributing funds to each program, as previously discussed.

District Allowable Obligation Authority (Letting Caps)

With the exception of preservation projects, the district allowable obligation authority is determined by a formula based on the percentage of district VMT to statewide VMT.

Cost Overrun Justification

Receipt of bids prior to letting of projects to construction occasionally indicates that the project will overrun the amount of funds set aside for that project. Evaluation of whether to let the project and justification of project overruns are based on the cost effectiveness of the project. Traffic data are essential to this evaluation process.

Modal Split

Classification counts and forecasts are important for evaluating the division of trips between modes of transportation.

Delegation Requests

Delegation requests are reviewed, and recommendations are sent to the Commission based on traffic and cost effectiveness.

Load Zoning and Structural Adequacy

Wheel load counts are very consequential in determining structural adequacy and the resulting TxDOT system load zoning.

Evaluation of Proposed Legislation

TxDOT is routinely called upon to evaluate the effects of legislation pertaining to maximum vehicle weights. Traffic data will be critical if the legislature attempts to statutorily return to a geographic area funding equivalent to the motor fuel tax revenue received from that area. In the absence of the ability to determine dollar income amounts, VMT in the area would be the logical basis for distribution of funds.

Accurate and timely traffic forecasts (particularly total statewide VMT) are essential for TxDOT to conduct its assigned mission of establishing the overall direction for the Department. Forecasting plays a fundamental role in predicting the future, setting goals to meet the prediction, and specifying strategies to implement the goals.

FUNCTIONS REQUIRING FUTURE TRAFFIC FORECASTS

Strategic Planning

It is essential for the Planning and Policy Division to know total statewide VMT in order to prepare plans for the State Comptroller's strategic goals, legislative appropriation requests, legislative liaison, special Commission requests, delegations appearing before the Commission, needs estimates, tactical plans, and budgets. The decision on an overall statewide VMT is so important that it should come from the highest level (Texas Transportation Commission) for final approval.

ISTEA Management Systems

The six management systems and the traffic monitoring system required by ISTEA will be a massive database that should be used in the strategic planning process.

Level of Service (LOS)

A proposed facility's LOS enters into Commission decisions for project authorization (comparative analysis).

Projected Highway Needs

HPMS and BNIP are used for needs analysis and to create the strategic mobility plan. Future highway project needs are used to determine overall funding requirements. These traffic variables are also used to prepare estimates of pavement deterioration under future conditions.

Environmental Analysis (Air Quality and Noise Studies)

Traffic data must be adequate to assess impacts under the CAA of 1990.

Interregional Demand Flows

Estimates of interregional demand flows and forecasts are currently conducted on a case-by-case basis. The standardized methodology for intercity route planning is outlined in Chapter 16 of this Guide.

TRAFFIC ESTIMATE AND FORECAST REQUIREMENTS

The traffic data that are required to conduct the various administrative and policy functions include:

- Current and future VMT for the state, individual Districts and specific facilities.

- Current and future average daily traffic for specific facilities.

- Current and future estimates of vehicle classification and truck weights.

- Current and future traffic parameters for specific facilities including the directional distribution and the percentage of traffic occurring in the design hour.

TRAFFIC ESTIMATE AND FORECAST METHODOLOGIES

The methodology used to develop the traffic information needed for administrative and policy decisions depends on whether current or future traffic data are required, whether the data needed are state- or district-wide or facility specific, and whether the traffic data are for an urban or rural project. The methodology for estimating current and projecting future statewide VMT is also presented. The recommended methodology for forecasting the directional distribution (D) and percentage of traffic in the design hour (K) traffic parameters is found in Chapter 13.

Methodologies for Estimating Current Traffic in Urban Areas

There are two major steps in the procedure for developing estimates of current traffic for specific projects in urban areas. Each of these steps is briefly described below. Instructions for the use of TRANPLAN, the DOS NEWYR, BALANCE, and ALLOCATE programs, and the screenline refinement procedure are detailed in Chapter 14.

Step 1. Prepare Base Year and Existing Year Traffic

In this first step, the base year (the year used for validation of the most recent transportation system forecast) and the existing year traffic information (current year or the year immediately preceding the current year) are developed.

a. Define the project study area and boundaries. The study area should be defined so that the major facilities which influence travel patterns within the area of the project are included. The size of the study area for each project will depend on the type of facility and the type of proposed improvements. A major freeway project will usually require a larger study area than a project on a minor arterial roadway. As a general rule, the study area should extend 2 to 3 miles either side of the project and 0.5 to 1 mile beyond the project termini. It should be remembered, however, that the study area boundaries may extend farther. It is important to include the major facilities, especially parallel facilities.

b. Prepare a plot of the base year traffic counts, base year capacities, and base year traffic assignment for the study area. Use TRANPLAN to plot the base year traffic counts, base year capacities, and base year validated assignment for the defined study area. The base year is the year used for the most recent transportation system forecast for the particular urbanized area.

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c. __Prepare a plot of the existing roadway network within the study area__. The network file used in this step will be either the base year network or the intermediate forecast year network, depending on which year is closest to the current year. The intermediate forecast year is the year for which the 10-year system forecast was prepared. Use HNIS in TRANPLAN to revise the selected network within the study area to accurately represent the existing network. If the base year network is used, changes or improvements that have been made to the roadways within the study area should be made. If the intermediate forecast year network is used, changes to the network might involve deleting planned improvements that have not actually been implemented or adding improvements that have been implemented but were not included in the last system forecast.

At this time, the coded capacity and speeds of the facilities in the study area network should be reviewed and revised as needed to reflect changed conditions. Typical capacities and speeds for the various types of roadways for each urban area can be obtained from the capacity/speed look-up table for that area. If no network changes have occurred and the network file being used is the base year, this step is not required. A copy of one of the base year plots prepared above can be used. If the intermediate forecast year network is used and accurately represents the existing network, then a plot of that network file is all that is needed.

d. __Make preliminary determination of screenlines__. Screenlines may be required in subsequent steps to check the assignment produced by TRANPLAN within the study area. The base year or current year plot of the study area prepared in one of the previous steps can be used to select the appropriate screenlines. Screenlines should be selected to include roadways that represent likely alternatives for directional traffic within the study area. Several general rules should be followed in the selection of screenlines:

- Avoid meandering or diagonal roadways.

- Do not include zone connectors that are crossed by the screenline in the analysis.

- Screenlines should cross a minimum of three roadways and preferably no more than seven roadways.

- Screenlines should be no longer than necessary.

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- Screenlines should be placed midway between major roadway crossings or every two miles, whichever is less.

e. Prepare a traffic assignment for the current year traffic on the existing network.

1. Use the DOS NEWYR program to develop a new production and attraction file for the current year. This program compares the base year or beginning year productions and attractions to the productions and attractions for the closest forecast year. It then interpolates the two production and attraction files to create a third production and attraction file for the current year in TRANPLAN format. This new production and attraction file will be based on the interpolation of productions and attractions at the zonal level by trip purpose from the base year and future year production and attraction files. NEWYR will also balance the attractions proportionally by zone and trip purpose to productions for the input files so that the new production and attraction file is balanced.

2. Run the long method of the TRANPLAN model.

3. Prepare a plot of the current year traffic assignment.

4. Check the assignment for reasonableness by comparing the assigned traffic to the base year traffic counts and base year assignment (as plotted in Step 1b) for each link. A useful check is to use the baseline assignment deviation analysis results in the screenline analysis spreadsheet. The rationale behind this check is that the maximum allowable deviation of a screenline traffic estimate should be such that a roadway design would not vary by more than one roadway lane. If the percentage deviation between the assigned volumes and current counts is unacceptable, correct the problem(s) in the modeling process. It may be that the level of growth anticipated during the system forecast was too little or too great compared to what actually occurred. Thus, the current year production and attraction file interpolated from the base year and intermediate forecast year may be reflecting too few or too many trips. Or, there may be coding errors in the network. If the productions and/or attractions in certain zones need to be changed to reflect more or less growth than previously forecast, use the ALLOCATE program to make the necessary revisions.

5. Make the appropriate revisions in the TRANPLAN process and rerun the assignment. Recheck the assignment. If the baseline deviation check is acceptable, continue with the next step.

Methodologies for Estimating Current Traffic in Rural Areas

Step 1. Existing Traffic on the Existing Network.

In this first step, a straightline network map of the existing roadway system is prepared and the existing average daily traffic with turning movements is posted on the straightline project network.

a. Prepare a straightline network map. The straightline map is a line drawing representing the roadway system within the project area. This map usually includes the major roads (freeways, arterials, and major collectors), but may be drawn in more detail to include lesser roads when required for the project. Straightline networks may be prepared using standard intersection and interchange drawings from Intergraph files compiled to represent the project system. For some projects, however, the typical drawings do not apply and the straightline network map must be prepared manually.

b. Compile existing traffic data from current and historical counts for the facilities included in the straightline network. The usual sources of existing counts include:

- Division files, such as the RI2T log of previously completed projects in the same corridor or in an adjacent corridor.

- Traffic maps or freeway ramp maps.

- Previous studies or counts of the facility made by the district office or other local agency.

Generally, existing traffic count data are considered out-of-date if they were not collected within the last five years. Even when count data are less than five years old, however, other information that may suggest recent traffic volume changes, such as major changes in the development or the road system within the project area, is carefully reviewed to assist the analyst in estimating changes in traffic patterns or volumes that may have occurred since the counts were made. This information along with historical traffic data is used to determine a reasonable average annual growth rate to estimate current year volumes from traffic counts made during a previous year.

When suitable counts for a project are not available, 24-hour counts are made. Usually, automatic count equipment is used to count through movements. Turning movement counts generally are not made but estimated through visual observation of an intersection.

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If counts cannot be made for the facility, current traffic may be estimated by using a linear regression equation to figure a growth rate for facilities that exhibit linear growth. Growth rates for facilities that do not exhibit linear growth are estimated using professional judgment with regard to current and historic traffic counts, existing and anticipated land use, and expected population and employment trends. For new facilities, the growth rates for similar facilities within the area are used as the basis for estimating the growth rate. Generally, lower growth rates are used in developed areas, intermediate growth rates are used in partially developed areas and higher growth rates are used in largely undeveloped areas.

c. Apply the growth rates developed in Step 1a above to the existing traffic on the existing network. Traffic is forecast to the current year by multiplying the most recent count volumes by the average growth rate. Link and turning movement volumes are refined.

d. Post the link volumes on the straightline network and estimate turning movements. The count data compiled in Step 1b above is refined and posted on the straightline map. If turning movement counts are not available, turning movements are estimated. The methodology used to estimate nondirectional turning movements is described in Chapter 14.
A discussion of the requirements and recommended practices for developing estimates of traffic parameters is found in Chapter 13.

Methodologies for Forecasting Future Traffic in Urban Areas

The 10- and 20-year forecasts developed for each urban area in the system planning process can provide forecasts of each facility included in the network. If the year for which the traffic forecast is needed is different than the system planning forecast year or if a facility is not on the network used for the system planning forecast, the methodology for forecasting traffic for project planning as described in Chapter 13 under project planning should be used.

Methodologies for Forecasting Future Traffic in Rural Areas

Forecasts of future traffic on rural facilities may be made following the procedures outlined in Chapter 12, *Forecasting For Rural Area Projects*. A discussion of the requirements and recommended practices for developing estimates of traffic parameters is found in Chapter 13.

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CHAPTER 16: INTERCITY ROUTE STUDIES[*]

BACKGROUND

TxDOT distinguishes between two types of intercity route studies. These are route studies (new facilities or new alignments) and feasibility studies (upgrading an existing facility). The phrase "intercity route study" refers to both interchangably. In the past, these studies have been conducted on an "as needed" basis in response to requests brought before the Texas Transportation Commission or in response to directives received from TxDOT administration. The reasons most frequently cited to justify new or improved intercity highways are the need to achieve improved traffic movement and/or the need to promote economic development.

With the development of a State Highway Trunk System Plan, intercity route planning is becoming more system-oriented. As a result, TxDOT has already faced the need to expand and refine its basic methodological framework for conducting intercity route studies. The standardized methodology which is sensitive to traffic, economic development, and system connectivity is summarized in this chapter.

STUDY DESIGN

Because the effectiveness of planning depends very much upon the existence of a good data base and sound analytic methods, designing a data collection, data analysis, and project management plan is an important initial task in all planning activities. This plan, or study design, should identify data requirements, specify data analysis procedures, provide a work completion schedule, and assign agency responsibilities with regard to these and other relevant aspects of the study.

The development of the study design for intercity route studies should commence with an initial planning meeting involving representatives of the Department divisions and districts that will be participating in the study. The objective of this meeting should be to identify and assign responsibilities for the following aspects of the study:

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[*]The material in this chapter is an excerpt from Robert W. Stokes and George B. Dresser, *Guidelines for Intercity Route Studies Including Necessary Statistics for Texas Counties*, Research Report No. 1235-9, Texas Transportation Institute, College Station, TX, September 1991.

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1. Study area boundaries.

2. Data requirements, data sources, and data collection procedures.

3. Data analysis procedures.

4. Work completion schedule.

The scope of individual intercity route studies and the level of detail required by their respective study designs, of course, will vary depending upon whether the route in question is a new facility on a new alignment or an improvement in an existing facility. In either case, the importance of developing a study design which will ensure an efficient and timely completion of the problem under investigation cannot be overemphasized.

The following section of this chapter provides guidelines concerning the basic data requirements for intercity route studies.

INVENTORY OF CURRENT CONDITIONS

A number of factors can influence the demand for, and feasibility of, intercity highway improvements. The identification and quantification of these factors provide the basis for developing the study design and, to a large extent, defines the nature of the analytic methods which can be employed in subsequent phases of the study. The initial inventory of current conditions in the study corridor should focus on determining the availability of, or feasibility of obtaining, the following basic information.

Traffic/Transportation System Data

1. Inventory of existing highway facilities in the study corridor (functional class, cross-sections, etc.).

2. Proposed and programmed roadway and traffic operations improvements in the study corridor.

3. Historical traffic volume trends on the roadways in the study corridor. The availability of data concerning ADT, peak/design hour traffic, turning movements, vehicle classifications, and vehicle occupancy rates should also be investigated. The volume of traffic, both present and projected, is an important factor in determining the need for highway improvements.

4.   Corridor travel patterns. Depending upon the scale of a particular intercity route study, data on the number of trips (vehicles and persons) between the major origins and destinations in the study corridor may be required. In the absence of existing data or procedures for synthesizing O-D data, O-D surveys may need to be conducted at critical points on the highways in the study corridor.

5.   Current LOS provided by roadways in the study corridor.

6.   Historical and current traffic accident data for the roadways in the study corridor. Highway safety is a major consideration in establishing a highway project's priority. Accident rates are typically calculated on the basis of accidents per 100 million VMT. The accident rate for a particular roadway can be compared with the statewide average for the same type of highway facility to determine whether a disproportionate number of accidents have occurred on the roadway in question.

Demographic and Land Use Data

1.   Population trends. The location of intercity highways in relation to population centers affects both the nature and magnitude of the traffic on the facility.

2.   Land uses and economic activity (existing and proposed). The type of highway facility needed to serve a particular area is largely a function of land use. Land use information is needed to identify traffic generators and to assess the access requirements of intercity highway facilities. In addition, land use information is needed to estimate the cost of purchasing any additional right-of-way which may be required. Finally, the land use inventory identifies special and/or environmentally sensitive areas (parks, wildlife refuges, wetlands, churches, cemeteries, historical, recreational, and scenic sites) that can affect route alignment considerations.

DATA SOURCES

The primary source for traffic and transportation system data is the TLOG maintained by TxDOT. This Log provides historical and current traffic information for the existing State and Federal-Aid Highway Systems as well as projected design year ADT and other design data for this highway network. (The procedures used to project the design year traffic are described below.)

For each control-section on the State Highway System, the 20-year design data in the TLOG are developed from traffic information obtained at permanent automatic traffic recorders, from manual classification counts, and from truck weight studies. The data include the K-factor,

directional distribution factor, percentage trucks in both ADT and DDHV, the average of the 10 heaviest wheel loads daily (ATHWLD), the percentage of tandem axles in this average, and a structural design pavement analysis for flexible and rigid pavements. Other TLOG data sets contain physical descriptions and accident data for the highways on the State Highway System.

Information concerning programmed roadway improvements can be found in the TxDOT Project Development Plan (PDP).

Sources of historical and projected population for Texas include the Texas State Data Center (TSDC), Texas A&M University, Bureau of Business Research (BBR), Texas Department of Health (TDH), Texas Natural Resource Conservation Commission (TNRCC), U.S. Bureau of the Census (BC), National Planning Association (NPA), Woods and Poole (WP), and the Governor's Office. Of these agencies, TSDC, NPA, TDH, TNRCC, and WP make projections by counties. Further, TDH and BBR make annual projections of statewide population, while TDWR and NPA make only five-year projections. The BC and WP make 10-year population projections.

The current landuse information needed for intercity route studies should be obtained through field surveys. The analyst should also contact local planning and economic development agencies and TxDOT District office personnel to obtain information concerning current and proposed land uses in the study corridor.

FORECASTING FUTURE CORRIDOR TRAFFIC

Unlike the advanced, relatively sophisticated computer modeling programs used for urban traffic forecasting, procedures for forecasting traffic on rural highways are relatively simplistic. These procedures typically involve determining a simple trend using historical data and may vary only in terms of whether a simple or compounded growth rate is used.

The procedures summarized here are intended to assist the analyst in forecasting the general magnitude of future rural traffic volumes. Preliminary procedures for adjusting these basic forecasts to account for changes in land use, certain demographic factors, and the traffic diversion potentials of new or improved intercity highway facilities are also presented. These procedures, when combined with the intelligent application of judgment and experience, should result in reasonably accurate forecasts of future traffic.

Given the relatively slow, uniform traffic growth rates experienced on most rural highways where traffic volumes are generally low enough that modest errors in forecasting are not likely to substantially alter basic design decisions, these simple procedures are entirely appropriate in terms of their level of accuracy for most intercity highway planning studies.

Estimating and Forecasting Intercity Traffic Volumes

To estimate and forecast intercity highway traffic volumes, the Department uses essentially manual procedures which rely heavily on historical trends observed in counted traffic volumes. Intercity traffic volumes are currently estimated on the basis of the "lowest ADT" on a particular roadway. The reasoning implicit in this approach is that intercity traffic on a particular roadway cannot be more than the lowest ADT on that roadway. Regression models developed from historical traffic data are used to forecast future intercity traffic volumes. While this lowest ADT includes local as well as intercity traffic, it probably represents a reasonably accurate planning level estimate of intercity traffic volume.

The minimum ADT approach has been challenged on the basis that it is overly simplistic in as much as it does not segregate the local and intercity components of ADT and does not explicitly account for the various sociodemographic variables which can affect current and future intercity traffic volumes. However, until more refined procedures can be developed, and in those situations where O-D data for the corridor in question are not available, the analyst should continue to use the minimum ADT approach to estimate intercity traffic volumes. Procedures for developing forecasts of future intercity traffic volumes are outlined below.

Trendline Forecasting Procedures

Perhaps the most commonly used rural traffic forecasting procedure is trendline analysis. This type of analysis uses historical traffic trends to develop an estimate of annual growth which is likely to occur in the future. Typically, trendline analysis is used to develop traffic forecasts for rural highways which are not part of computerized networks.

The annual growth rates used in trendline analysis are determined by examining a plot of the historical traffic data, by using simple linear regression analyses to fit a line through the data, or by simply choosing two data points which define the most appropriate trend and calculating

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an average growth rate. The growth rate, expressed as an average percentage, is found through the use of the following equation:

$$\text{Average Percentage Growth} = ((X_2 - X_1)/X_1 N) \times 100\%$$

where:

X_2	=	Final data point
X_1	=	Initial data point
N	=	Number of years between X_1 and X_2

The resulting growth rate is then multiplied by the number of years between the most recent data point and the forecast year. This total anticipated percentage growth is then multiplied by the value of the initial data point to yield the anticipated increase or decrease. By adding the anticipated growth to the initial data value, the forecast value can be obtained. This process is summarized in the following equation:

$$\text{Forecast Value} = [(AGP)(N)(X_1)] + X_1$$

where:

AGP	=	Average percentage growth
N	=	Number of years between initial year and forecast year
X_1	=	Initial data value

It should be noted that this growth rate is linear with a constant amount of growth assumed each year. Such a forecast might be most appropriate in a region which can support only a finite amount of annual growth. As an example, if a region's real estate market could absorb only X number of housing or office units per year, but growth at this rate could be maintained during the entire forecast period, this type of trend analysis could be very appropriate.

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If the historical data indicate a nonlinear growth rate, a forecast based on a compound percentage growth may be more appropriate. The compound growth rate is calculated with the following equation:

$$\text{Average Compound Growth Rate} = (X_2/X_1)^{1/N} - 1$$

where:

X_2 = Final data point

X_1 = Initial data point

N = Number of years between X_1 and X_2

The resulting compound growth rate is used to forecast future traffic through use of the following equation:

$$\text{Forecast Value} = (X_2)(1 + ACG)^N$$

where:

X_2 = Most recent data value

ACG = Average compound growth rate

N = Number of years between the most recent data observation and the forecast year

Caution should be used in applying compound growth rates to long forecast periods, because compounding results in progressively larger increases in growth each succeeding year. The use of a combination of linear and compound growth rates may be appropriate for some long-range forecasts. The Florida DOT, for example, uses a compound growth rate for the first 10 years of the forecast and a linear growth rate thereafter. While this guideline should not be taken as a hard-and-fast rule, it points out the need for the analyst to employ professional judgment to assess the reasonableness of long-term traffic forecasts.

The design year (20-year) traffic forecasts in the TLOG were developed using growth factors developed from one of the following methods: (1) site-specific growth rates based on regression analysis of traffic volume trends over the past 10 years; or (2) county-wide average traffic growth rates based on analysis of traffic volume trends over the past 10 years (this approach is used if the "scatter" in the historical data is too wide for regression analysis). The regression model is of the form:

$$Y = \beta_0 + \beta_1 X$$

where:

Y	=	ADT
$\beta_0\ \beta_1$	=	regression coefficients
X	=	Traffic year (0 = current year, ..., 9 = 9 years prior to current year)

The historical traffic data in the TLOG have been used to estimate the model coefficients (β_0 and β_1). For those estimates which were statistically significant, the resulting regression models were used to develop the forecasts of future (design year) traffic contained in the TLOG.

Demographic-Based Forecasting Procedures

Traffic growth factors based on historical traffic data inherently capture the combined effects that population changes, economic activity, and other factors have on traffic growth rates. The use of traffic trending methods to forecast future traffic volumes assumes that the growth rates and relationships reflected in the historical traffic data will remain constant through the forecast year. If population and/or employment, for example, are projected to grow at a rate different than observed in the past, the trendline traffic forecasts should be modified to account for these differences.

The feasibility of developing demographic/elasticity-based forecasting models for TxDOT is being evaluated. In the meantime, the simple approach outlined below can be used to adjust trendline traffic volume forecasts to account for population and employment growth rates which differ from historical growth rates. TxDOT uses county population projections developed under

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contract for the TSDC, Texas Department of Commerce, by the Department of Rural Sociology, Texas Agricultural Experiment Station, The Texas A&M University System. These projections are published in the report, "Projections of the Population of Texas and Counties in Texas by Age, Sex, and Race/Ethnicity for 1990-2030," February 1992.

The assumption implicit in trendline forecasts is that past trends (including population growth) will continue unchanged into the future. To validate this assumption, the analyst should compare historical and projected population data.

Sometimes it is necessary to adjust the trendline traffic forecasts to account for population growth at the corridor level. For example, assume the corridor population grew at a rate of 6 percent per year between 1970 and 1980. The 2000 projections, however, indicate a growth rate of only 2.1 to 2.3 percent. In this case, the analyst should give consideration to adjusting the county's traffic forecast growth rate to account for this projected decline in the county's population growth rate. A simple factoring process, based on the ratio of projected to historical population growth rates can be used. The basic approach is summarized in the following equation:

$$ADT2GR = ADT1GR \ (PPGR/HPGR)$$

where:

ADT2GR	=	Adjusted traffic forecast growth rate
ADT1GR	=	Trendline traffic forecast growth rate
PPGR	=	Projected population growth rate
HPGR	=	Historical population growth rate

This approach can be extended to include other socioeconomic factors (such as employment) as shown below:

$$ADT2GR = ADT1GR \ (PPGR/HPGR \ x \ PEGR/HEGR \ x \ ...)$$

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where:

    PEGR   =   Projected employment growth rate

    HEGR   =   Historical employment growth rate

A shortcoming of the simple factoring procedure outlined above is that it assumes a constant, one-to-one relationship between changes in traffic volume and other factors (e.g., population and employment growth). There is considerable evidence that the relationship between travel demand and certain socioeconomic factors is "elastic" (i.e., a 1 percent change in certain demographic factors produces a greater than 1 percent change in travel demand). For example, preliminary analyses of historical traffic and population trends in the I-35 corridor indicate that for every 1 percent increase in corridor population, traffic on I-35 increased by 2.5 percent. This elasticity can be used to adjust trendline forecasts using the following equation:

$$ADT2 = ADT1 \, [1 + 0.025 \, (\% \text{ change in PGR})]$$

where:

    % Change in PGR   =   % change in projected and historical population growth rates

This elasticity equation was estimated using data from only one rural interstate highway corridor which experienced population growth. The equation should not be used for non-interstate highways or in other interstate highway corridors which have not experienced population growth. The recommended application of this elasticity equation is in conjunction with the simple factoring procedure presented in the previous paragraphs to develop a range of ADT forecasts.

In applying the methods presented in this section, the analyst will need to rely upon professional judgment to determine the geographic area (urban area, county, corridor, etc.) that will be affected by the project. The construction of a major new roadway, for example, can have regional impacts; and the analysis should be conducted at that level. For site-specific projects,

the impacts will be more localized; and the analyses should be conducted at the urban area or county level.

Adjustments for Proposed Land Uses

Just as the analyst should review trendline forecasts in terms of historical and projected demographic factors in the study corridor, the extent to which traffic forecasts capture the effects of new land uses in the corridor should also be evaluated. Because traffic forecasts based on historical trends implicitly assume that these past trends, including land development trends, will continue into the future, the analyst must assess the extent to which the proposed land-use change in question differs from the types of developments which have occurred in the corridor in the past. If the proposed land use is "typical" of past development patterns in the corridor, then the trendline forecasts probably represent to some extent the effects of the proposed development. If, on the other hand, the proposed land use differs substantially from past patterns in terms of its magnitude or nature, then the traffic forecasts will need to be adjusted accordingly. No hard-and-fast guidelines concerning the need for these adjustments can be offered, and the analyst must rely upon personal knowledge of the study area and professional judgment to resolve this issue.

Adjustments for Diverted Traffic

The construction of a new roadway, or a major upgrading of an existing roadway, can significantly alter travel patterns and traffic volumes in a corridor. The analyst should consider the shift (diversion) of traffic between facilities that can result from the construction of new roadways or from the major reconstruction of an existing roadway.

A literature review identified the following six non-network-based traffic diversion procedures:

1. AASHTO diversion curves.
2. California time and distance diversion curves.
3. Ratio diversion procedure (also referred to as the "easy" method).
4. All-or-nothing diversion.
5. Bureau of Public Roads (BPR) diversion curve.
6. Dial's probabilistic diversion procedure.

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Of these six procedures, only procedures (1) through (4) appear to have been tested against actual survey data to determine their relative accuracy. As a result, only these four procedures are described in detail in this section of the Guide.

It should be stressed that none of these procedures have been tested in Texas. Moreover, the use of these procedures requires knowledge of the number of trips between the major origins and destinations in the study corridor. In the absence of O-D data for the study corridor, or procedures for synthesizing these data, the lowest ADT on a particular highway can be used as a preliminary estimate of intercity traffic volumes. It is recommended that two or more of these procedures be used to develop a range of estimates of the traffic diversion potentials of intercity highway improvements.

1. AASHTO Diversion Curve.

Percent Use = $1/(1 + T^6)$

Where T is the ratio of the travel time via the facility under study to the time via the best alternate route. (Note: distances can be substituted for time in this equation.)

2. California Time and Distance Curves.

Percent Use = $50 + [[50(d + 0.5t)]/[(d - 0.5t)^2 + 4.5]^{0.5}]$

Where "d" is the distance saved by the route under study compared to the best alternate, and "t" is the time saved by the route under study versus the time for the best alternate route. Both "d" and "t" may be negative. When the percentage of use is calculated using the time differential of the best alternate, the distances associated with the same minimum alternate paths should be employed to obtain "d." This is necessary because the time and distance paths frequently do not coincide for either the minimum or best alternate path.

3. The "Easy" Method.

Percent Use = $50 + 250[(B - A)/(B + A)]$

Where "A" is the travel time via the route under study and "B" is the travel time via the alternate route. It is recommended that the percentage of use be set at 0 if (B - A)/(B + A) is less than -0.2, and at 100 if this quantity exceeds +0.2.

4. All-Or-Nothing Technique.

In this technique, all trips are assigned to the path that provides the minimum absolute time or distance between origin and destination and no trips are assigned to the alternate route.

All four diversion techniques perform reasonably well providing diversion estimates which ranged from 90 to 119 percent of the survey volumes. The AASHTO method (using time as the parameter) exhibited the lowest standard error, though the results of the California method best matched the aggregate survey data.

Based on this rather limited data, it is recommended that the analyst use the AASHTO and the California techniques to estimate the traffic diversion potentials of intercity highway projects in Texas. The traffic forecasting procedures described in previous sections of this Guide can be used to develop forecasts of future traffic on the highways in question.

PROJECT EVALUATION

Level of Service Analysis

The traffic forecasts developed using the procedures described above provide the basis for assessing the adequacy of existing and proposed highway facilities in the study corridor to accommodate the anticipated future traffic volumes. The LOS threshold values presented above should be used to perform the LOS analysis. The LOS analyses should be performed on the existing highway network (i.e., without the proposed improvement[s]) as well as on the proposed network(s) (i.e., with the proposed improvement[s]). Assessing the adequacy of the existing network to accommodate the projected (design year) traffic volumes provides an indication of the magnitude of any improvements that might be needed in the study corridor.

To the extent feasible, the LOS analysis should also reflect the effects of TxDOT policies concerning access control/restriction to intercity highways and bypass routes. These guidelines are based on the findings and recommendations of the Trunk System Task Force.

Cost-Effectiveness Indices

In assessing the need for new or upgraded intercity highways, the Department considers the following factors: traffic volumes, LOS, population trends, land use, economic development, and safety. While factors other than traffic are considered (e.g., population, land use, and economic development), they are not incorporated directly into the final project evaluation process. For example, previous intercity highway study documents prepared by the Department typically include a summary of historical and projected population in the study corridor, an

inventory of significant/sensitive land uses, and a brief discussion of the potential linkages between highway investments and economic development. In the final analysis, however, the feasibility of intercity highway projects is assessed on the basis of cost per vehicle mile traveled. The specific cost-effectiveness indices used by TxDOT vary by project type, as described below.

Capacity Increase Projects

Capacity increase projects typically involve widening the cross-section of an existing highway. These projects are evaluated on the basis of the Congestion Relief Index (CRI). This method is based on the current (base year) ADT and is calculated by dividing total project cost (construction and right-of-way) by existing traffic in excess of LOS C-D plus latent traffic demand times the length of the project, as shown below:

CRI = [Construction + Right-of-Way Costs]/[(Existing Traffic > LOS C-D + Latent Demand)(Length)]

The LOS threshold volumes used by the Department in these analyses are those described above. The latent demand (LD) term in the denominator is calculated from the following equation. This equation was estimated by using the Department's existing urban traffic assignment models to calculate the additional traffic volume that would result from various added capacity scenarios.

LD = 5 + 0.126(VOL1) + 3170(VC1) + 3945(FWY) + 0.231(CDIF) - 0.177(CAP2)

where:

LD	=	latent demand.
VOL1	=	base year traffic (ADT).
VC1	=	base year volume/capacity ratio.
FWY	=	facility type (1 = freeway, 0 = non-freeway).
CDIF	=	increase in capacity (ADT).
CAP2	=	roadway capacity after improvement.

New Location Projects

New location projects are evaluated on a cost per vehicle-mile (C/VM) basis. This method is based on base year traffic and is calculated by dividing total project cost (construction and right-of-way) by the existing traffic times the length of the project, as shown below:

$$C/VM = (Construction + Right-of-Way\ Costs)/[(Existing\ Traffic)(Length)]$$

The Department uses a threshold value of $400/VM for identifying cost effective new location projects.

New Loop and Bypass Projects

These projects are evaluated on the basis of C/VM_L, with an adjustment for truck traffic (2.4 passenger cars/truck), as shown below:

$$C/VM_L = (Construction + Right-of-Way\ Costs)/[(Existing\ Traffic + Truck\ Equiv.)(Length)]$$

The Department currently uses a threshold value of $600/VM to identify cost effective bypass route projects.

Principal Arterial System Gap Projects

These projects are intended to add missing or needed links in the state's principal arterial system. Arterial system gap projects are evaluated on a C/VM basis using the same equation as new location projects. The Department uses a threshold value of $350/VM to identify cost-effective arterial system projects.

Economic Evaluation Models

In addition to the cost-effectiveness indices described above, the Department also utilizes the Highway Economic Evaluation Model (HEEM) to calculate benefit cost ratios for proposed highway improvements. The HEEM uses data on values of time, vehicle operating costs, accident

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costs, construction and right-of-way costs, auto and truck traffic volumes, and type of existing and proposed highway facilities in calculating the benefit cost ratios.

Another economic evaluation model considered for possible use in Texas is the Regional Economic Impact Model for Highway Systems (REIMHS). In addition to the basic factors considered in the HEEM, the REIMHS provides an estimate of the employment impacts associated with expenditures for highway improvements. This model can be useful in estimating the economic development impacts of intercity highway improvement projects.

BYPASS ROUTES

Purpose of Bypass Routes

Bypass routes are typically intended to accommodate traffic that passes through towns or cities but have no destination within the community. Bypass routes, when properly planned and operated, can reduce the amount of traffic on city streets and reduce the delays experienced by through traffic. However, a bypass typically attracts a number of highway-oriented land developments. These developments are primarily commercial in nature and, in some cases, can negate much of the delay savings that through traffic would otherwise realize. Moreover, the construction of bypass routes can significantly alter the functioning of the bypassed community's economy.

The planning, construction, and efficient operation of bypass routes must address a number of technical, economic, and political issues. The technical issues center around determining the amount of traffic and delay savings necessary to justify the construction of bypass routes and the type of access control strategies which should be implemented to ensure that the trip desires of external traffic are served in an efficient manner.

The primary economic issues concern the cost effectiveness of the bypass route and the effect(s) the bypass might have on the local community's economy. Assessing the former involves employing objective criteria, while the latter is largely a political matter which is addressed on a case-by-case basis.

In addition to the political issues which arise in connection with the process of determining the need and/or feasibility of bypass routes, questions concerning the amount and type of access control to be enforced on bypass routes is largely a political/policy matter. It is

useful to have in place general policies that provide guidelines concerning access control for its various types of highway projects.

The following sections outline a basic framework for developing guidelines for planning bypass routes. The intent is to identify the key issues which need to be addressed and to outline various alternative policy and technical scenarios which can be considered.

Determining the Need for Bypass Routes

The need for bypass routes should be assessed on the basis of the following three factors:

1. Level of Service. In assessing the LOS impacts of proposed bypass routes, the impacts of removing (diverting) through traffic from local streets and the LOS impacts of alternative access control strategies should be considered. A set of minimum (threshold) values of travel time savings which must be achieved to justify bypass routes is used as an additional guideline for bypass route decisions.

2. Cost Effectiveness. The Department evaluates the effectiveness of new loop and bypass projects on the basis of C/VM_L, with an adjustment for truck traffic (2.4 passenger cars/truck). The cost effectiveness index for new loop and bypass routes is calculated as follows:

$C/VM_L = $ (Construction + Right-of-Way Costs)/[(Existing ADT + Truck Equiv.)(Length)]

A threshold value of $600/VM is used to identify cost-effective bypass route projects.

3. Community Impacts. In addition to LOS and cost effectiveness considerations, bypass route studies should also address the impacts that such routes can have on bypassed communities. The impacts of bypasses on the local economy is largely a function of the level of access control exercised along the bypass route. Complete control (restriction) of access is needed to ensure that the LOS objectives of bypass routes are achieved. However, unless some degree of access is provided, economic development and the local economy, in general, could suffer. The primary community impact concerns which need to be addressed center on the extent to which local communities should be involved in the planning process and the tradeoffs (in terms of LOS and cost effectiveness) associated with various departmental policies concerning access control for bypass routes.

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It is useful to have a set of specific policies and procedures for (1) assessing the local impacts of various alternatives concerning the location and operation (i.e., access control) of bypass routes and (2) determining the degree to which local communities should be involved in decisions concerning the planning and operating strategies of bypass routes.

Economic Impacts of Bypass Routes

The majority of past studies have focused almost exclusively upon the economic effects on small- to medium-sized communities caused by rerouting a highway around the town to avoid central area conflicts and congestion. These studies have typically been conducted for public information and public relations purposes. The studies reduce the friction and controversy arising mainly from business interests in the bypassed town which fear that removal of through traffic from the main street will undercut their sales and impair the local economy. As a result, most bypass studies have been designed to address the following questions: Are retail sales harmed by bypassing? Does the economy of the bypassed community suffer? What, if any, specific types of businesses are disadvantaged by bypass routes?

Though it is difficult to identify and isolate the economic effects attributable solely to bypasses, the evidence from past studies strongly suggests that bypass routes do not have a measurable, negative impact on the economy of the bypassed community. In fact, an early study (2) of bypass routes in 72 communities suggests that any losses in sales due to the rerouting of through traffic may well be offset by an extension of the local trade area. That is, more remote areas can be drawn into the local trade area as a result of improved highways which provide less congested business districts for shopping.

A recent study of 40 bypass route projects in Texas found that bypass highway improvements have a statistically significant and positive influence on county employment levels. Bypass routes were also found to have a positive, though "not quite statistically significant," influence on city manufacturing employment and county real wages.

Access Control Considerations

If the primary objective of bypass routes is to reduce the delays experienced by through traffic, then access to these routes needs to be limited. However, controlled-access roadways

require considerably more right-of-way than other types of roadways and, as a result, are much more costly than comparable facilities with less restrictive access controls. This additional right-of-way is needed to control and/or prevent land development adjacent to the bypass route and/or to accommodate frontage and service roads. Moreover, controlled-access bypass routes are likely to generate more local resistance and controversy than other less restrictive facilities.

Unrestricted access typically attracts highway-oriented commercial land developments that can negate much of the delay savings which bypass routes are intended to provide unless a supporting system of access and circulator roadways (e.g., frontage roads) is provided. When access to bypass routes is not restricted or accommodated in an efficient manner, the commercial activities of the bypassed community may simply move to the bypass route. In such situations, bypass routes can have a substantial economic development impact yet fail to effectively serve the movement of through traffic.

From a purely technical standpoint, then, bypass routes should be planned and operated so as to facilitate the movement of through traffic. To achieve this objective, access to bypass routes should be completely restricted. From a political and economic standpoint, however, this may not be feasible.

WORKS CONSULTED

1990 Texas State Profile. Woods & Poole Economics, Inc. Washington D.C. May 1990.

Bass, Patricia. *Traffic Forecasting Requirements by Project Type.* Texas Transportation Institute. College Station, Texas, 1994. Research Report FHWA/TX-94/1235-8. August 1994.

Bass, Patricia. *TRANPLAN Corridor Analysis Procedures.* Texas Transportation Institute. College Station, Texas, 1994. Research Report FHWA/TX-94/1235-16F. September 1994.

Bates, J. J. and M. Dasgupta. *Review of Techniques of Travel Demand Analysis: Interim Report.* Transport and Road Research Laboratory, Crowthorne, Berkshire, 1990.

Ben-Akiva, Moshe E. and Steven R. Lerman. *Discrete Choice Analysis: Theory and Application to Travel Demand.* MIT Press. Cambridge, MA, 1985.

Calibration and Adjustment of System Planning Models. U.S. Department of Transportation, Federal Highway Administration. Publication No. FHNA-ED-90-015.

Harvey, Greg and Elizabeth Deakin. *A Manual of Regional Transportation Modeling Practice for Air Quality Analysis.* National Association of Regional Councils. July 1993, Version 1.0.

Highway Traffic Forecasting Guide. New York State Department of Transportation, Data Services Bureau, Transportation Statistics & Analysis Section. October 1986.

Ismart, Dane. *Calibration and Adjustment of System Planning Models.* Federal Highway Administration, U. S. Department of Transportation. December 1990. (FHWA-ED-90-015)

ITE Trip Generation Manual, 5th edition. Institute of Transportation Engineers, 1991.

McFadden, Daniel. "Conditional Logit Analysis of Qualitative Choice Behavior". *Frontiers in Econometrics.* Paul Zarembka, editor. Academic Press. New York, 1973.

Meyer, M.D., and E.J. Miller. *Urban Transportation Planning: A Decision Oriented Approach.* McGraw-Hill. New York, 1984.

Ortuzar, J. de D. and L. G. Willumsen. *Modeling Transport.* John Wiley & Sons. West Sussex, England, 1990.

Pearson, David. *Urban Travel Demand Modeling Data.* Texas Transportation Institute (forthcoming).

Prashker, Joseph N. *Multi-Path Capacity-Limited Transit Assignment.* Transportation Research Record 1283. Transportation Research Board. Washington, DC, 1990.

Procedures and Technical Methods for Transit Project Planning. U.S. Department of Transportation, Urban Mass Transportation Administration. PB91-183152.

Quick Response Urban Travel Estimation Techniques and Transferable Parameters. National Cooperative Highway Research Program Report 187. Transportation Research Board. Washington, DC, 1978.

Schultz, Gordon W. "Development of a Travel Demand Model Set for the New Orleans Region". *Transportation Research Record 944.* Transportation Research Board. Washington, DC, 1983.

State of California Department of Transportation Travel Forecasting Guidelines. California Department of Transportation. November 1992.

Stokes, Robert W. and George Dresser. *Elasticity-Based Traffic Forecasting Models for Rural Highways in Texas.* Texas Transportation Institute. College Station, Texas, 1991. Technical Note, Research Study 2-10-90-1235. September 1991.

Stokes, Robert W. and George Dresser. *Guidelines for Intercity Route Studies.* Texas Transportation Institute. College Station, Texas, 1991. Research Report FHWA/TX-91/1235-9. Stopher, Peter R. & Arnim H. Meyburg. *Urban Transportation Modeling and Planning.* Lexington Books. Lexington, Massachusetts, 1975.

Travel Demand Forecasting Processes Used By Ten Large Metropolitan Planning Organizations. Institute of Transportation Engineers. August 18, 1993.

Voorhes, Alan M. & Associates. *Factors and Trends in Trip Length.* National Cooperative Highway Research Program Report 48. Transportation Research Board. Washington, DC, 1968.

Wade, Montie. *Policy and Administraative Requirements of Traffic Data.* Texas Transprotation Institute. College Station, Texas, 1993. Technical Note, Research Study 2-10-90-1235. Aprol 14, 1993.

Williams, Tom A. and George Dresser. *Summary Documentation for the Texas Travel Demand Package.* Texas Transportation Institute. College Station, Texas, 1992. Research Report TX-92/1375-1.

WORKS CITED

1. Woods & Poole Economics, Inc. *1990 Texas State Profile.* Washington, D.C., May 1990.

2. Horwood, E.M., C.A. Zellner, and R.L. Ludwig. "Community Consequences of Highway Improvement." *NCHRP Report No. 18.* Highway Research Board. Washington D.C., 1965.