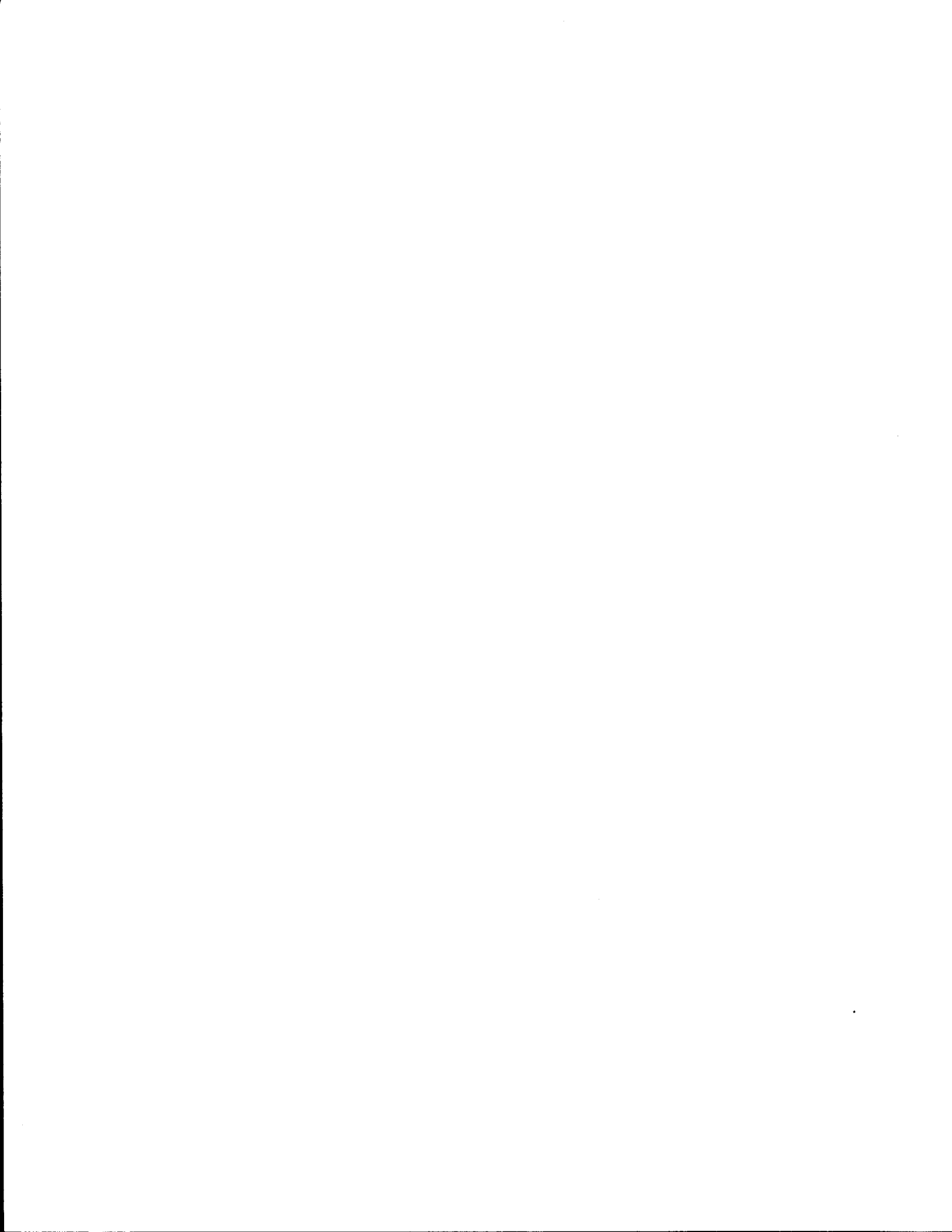


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16. Abstract This report documents an overview of the travel surveys done in Texas between 1984 and 1991 relative to the data requirements for development of travel demand models. A comprehensive review and evaluation of the methods and techniques for developing regional and zonal estimates of urban data for use in travel demand models is presented. This review and evaluation includes both theoretical considerations and the methods and techniques in use in urban areas within and outside of Texas. No single method or technique was found to be superior. The techniques in use vary considerably, depending on the urban area's size and complexity. Methods are recommended for the development of regional and zonal level estimates of population, households, employment, household income, and vehicle availability. These methods may not be applicable in all urban areas but may serve as useful guides for the development of local techniques in estimating the input data for travel demand modeling.			
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URBAN TRAVEL DEMAND MODELING DATA

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and

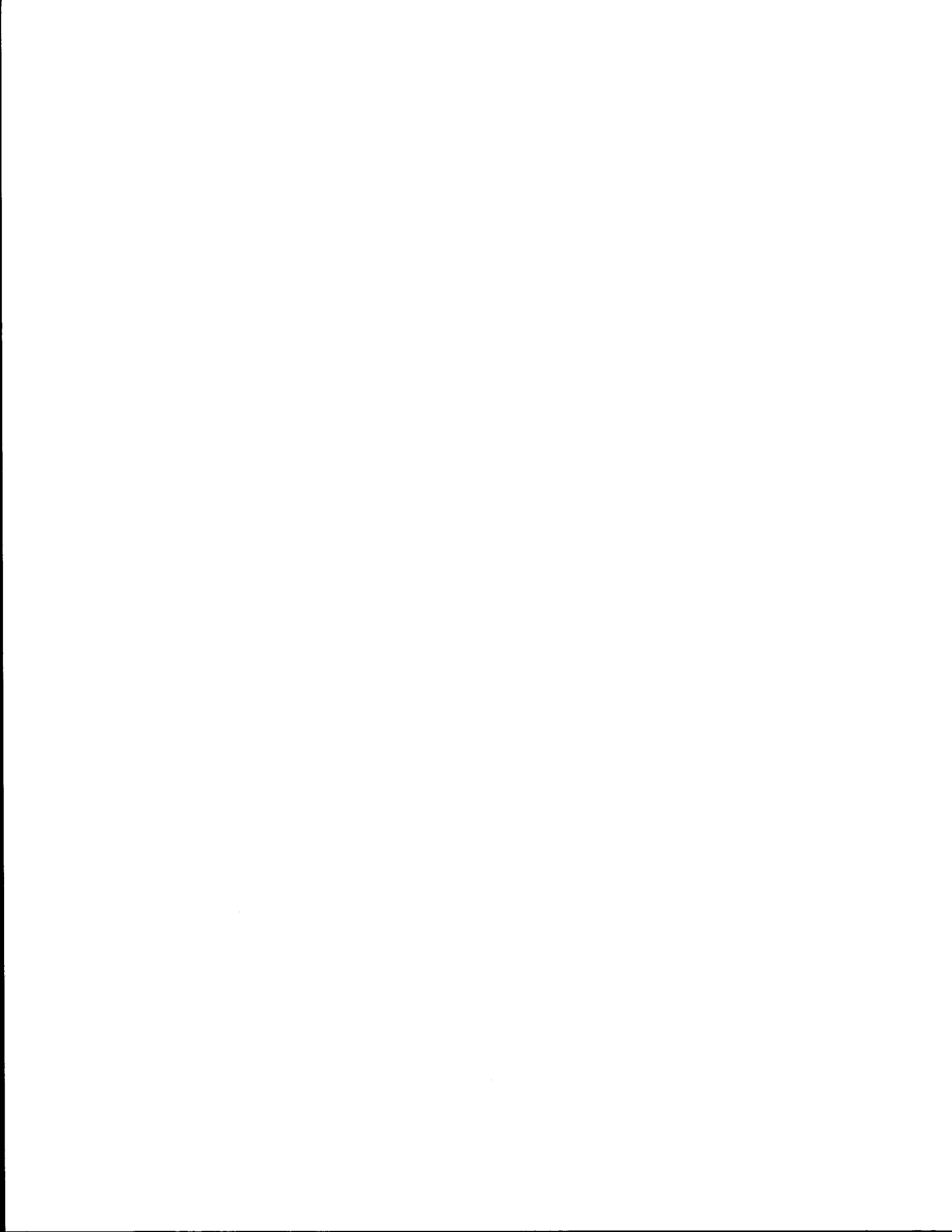
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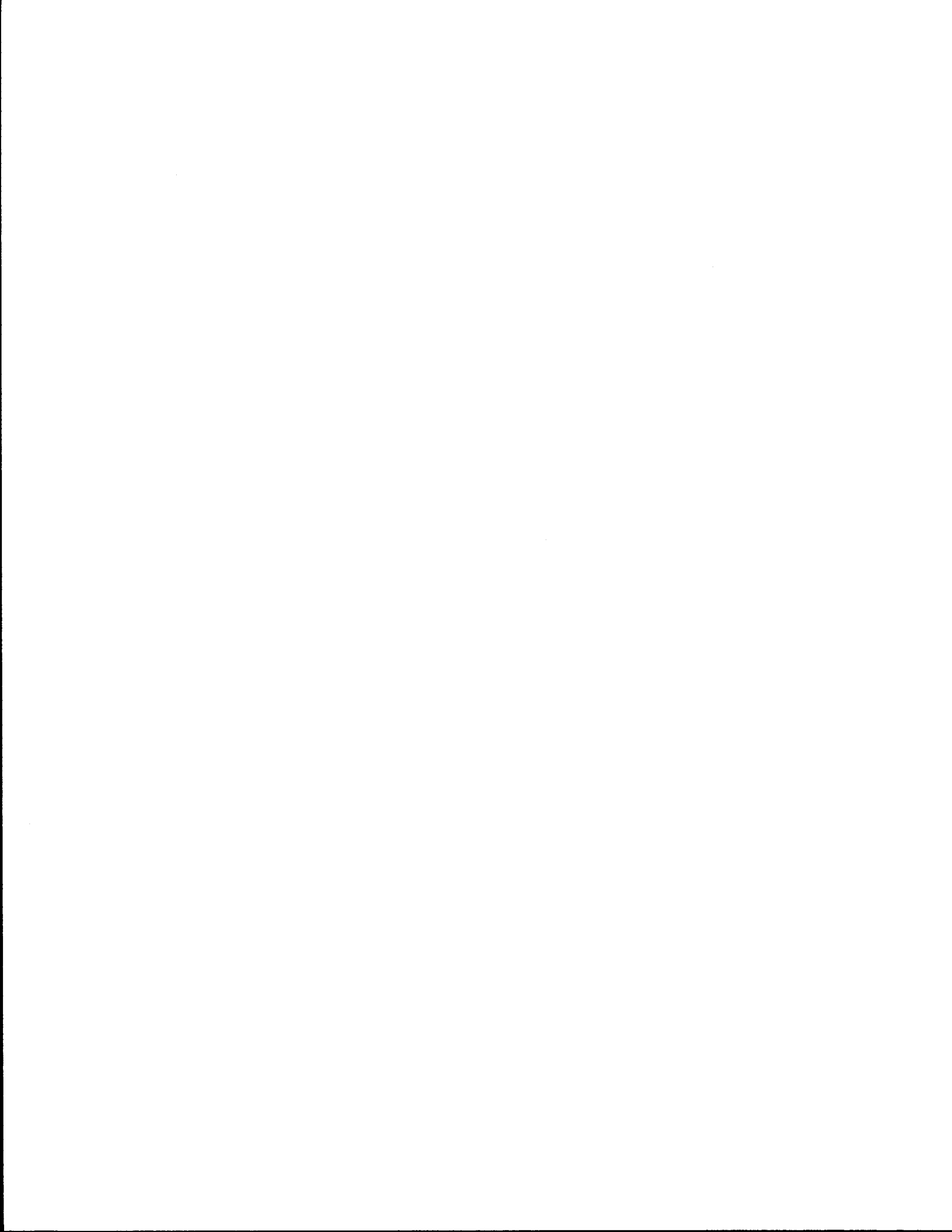
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IMPLEMENTATION STATEMENT

This report documents current practice in travel surveys and the development of urban travel demand modeling data. Specific recommendations are made relative to the development of urban travel demand modeling data at both the regional and zonal levels. These recommendations may be implemented by urban areas that are in the process of developing base and forecast year projections for transportation modeling purposes.



DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. Additionally, this report is not intended for construction, bidding, or permit purposes. George B. Dresser, Ph.D., was the Principal Investigator for the project.

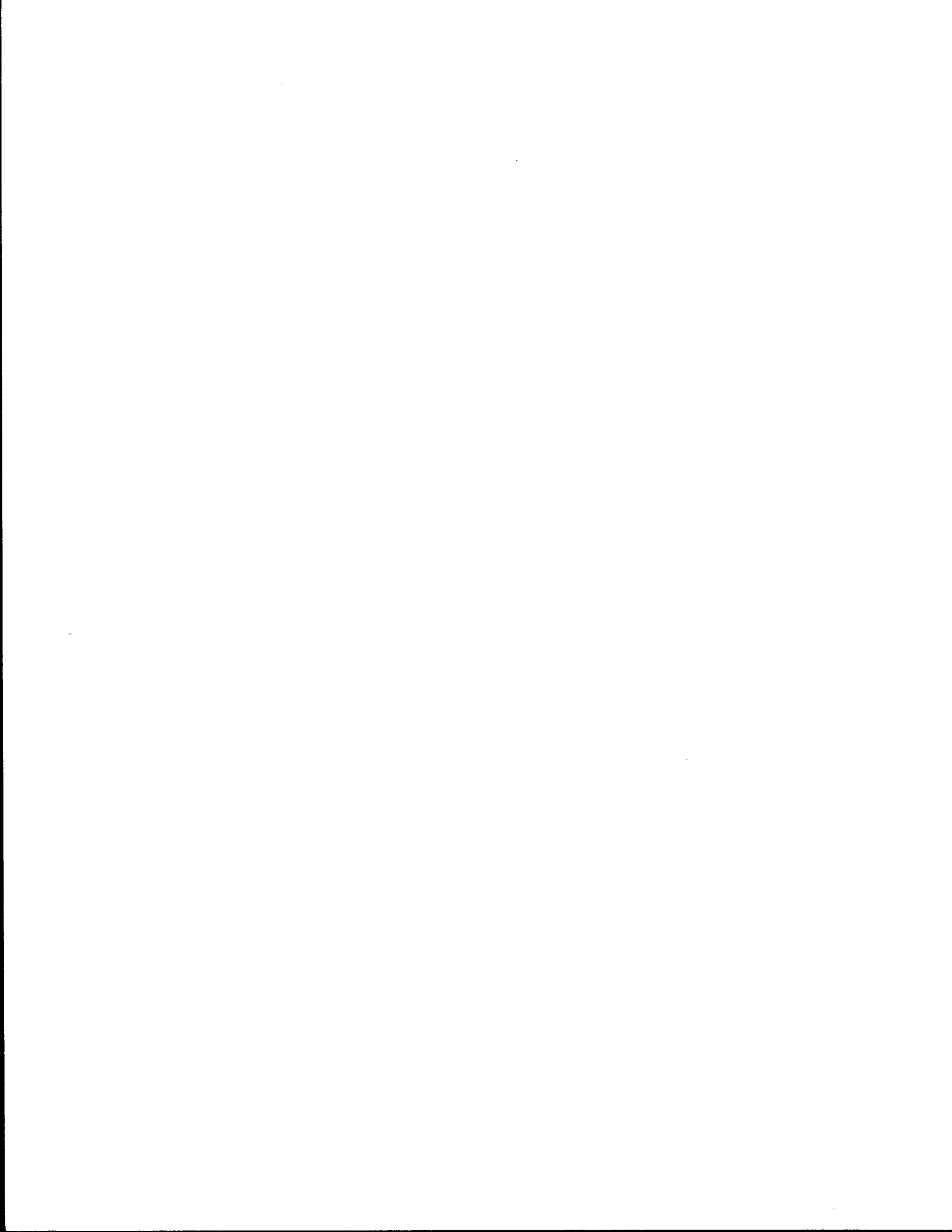


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SUMMARY

Travel demand modeling depends on the data that is used to develop the models themselves and the data ultimately input to the models. This report presents a review and analysis of two aspects of the process of estimating and predicting travel demand. The first is an overview of the methods used to develop the travel demand models (specifically the trip generation models), and was accomplished relative to the urban travel surveys that have been conducted in Texas. The second aspect is the development and projection of the input data for the trip generation phase of travel demand modeling.

Only a brief overview of the design and conduct of urban travel surveys in Texas is presented in this report because a detailed and comprehensive review of those surveys is documented in Research Report 1235-10. The primary purpose of this report is to document methods of developing the input data for the trip generation phase of travel demand modeling.

The principal components of data needed in trip generation are population, households, employment, household income, and vehicle availability (also referred to as auto ownership). The development of these data components was reviewed in terms of regional and zonal needs. Methods of prediction and allocation were reviewed and evaluated both in terms of theoretical and actual applications in urban areas within and outside of Texas. No one method or technique was found to be superior to others due to large differences between urban areas in terms of data needs and staff capabilities. Certain procedures were found in the development process that were used more often and appeared to have more applicability than others. Recommended procedures for the development of the input data for urban travel demand modeling are presented in the final section of this report. These recommendations deal with regional and zonal forecasts of population, households, employment, household income, and vehicle availability. These recommendations may not be applicable in all urban areas but may serve as guides for the establishment of local procedures.



INTRODUCTION

Urban travel demand is measured by the number of trips that people make or desire to make within an urban area. The determination and/or estimation of this demand provides the basis for evaluating transportation systems and determining the improvements needed on those systems. Projects are recommended, designed, and constructed based on the amount of travel demand the projects need to accommodate. Determining travel demand within an urban area plays a critical role in both maintaining an existing transportation system as well as ensuring that the system will be adequate to meet future needs.

Travel demand estimation 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 (zones), within the urban area. 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 available transportation mode. 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 typically is necessary before final estimates of the travel demand are developed.

In 1989, the Texas Department of Transportation (TxDOT) contracted with the Texas Transportation Institute (TTI) to review, analyze, and make recommendations for improving the transportation planning techniques used by the Department. The overall objective of the project is to ensure that the transportation planning techniques being used in Texas are state of the art and the best currently available. This report is only one of many produced as a part of that overall project. It 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 report deals with the design and conduct of urban travel surveys in Texas.

The second aspect of urban travel demand that is examined in this report is the development and projection of the input data which are used in urban travel demand modeling.

The importance of this information is readily apparent because it determines the output from the trip generation process.

This report is organized into three sections following the introduction. The first section discusses the development of urban travel demand models relative to designing and conducting urban travel surveys in Texas. The second section discusses the development and prediction of the primary input data to the urban travel demand models. The discussion is oriented toward a review of techniques and methodologies currently in use. The final section summarizes the previous two sections and presents the findings and recommendations.

DEMAND MODEL DEVELOPMENT

Travel demand models are used in trip generation to develop 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 (zones), within an urban area. These trips are classified into two principal categories, home based and non-home based. A home based trip is a trip for which either the origin or the destination of the trip is the home. All other trips are non-home based. 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 non-home based 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 non-home based 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 based on the characteristics of the household. Trip attractions are estimated using models based on the characteristics of the land use activities attracting the trips. The development of trip generation models, therefore, are 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, is dependent on the data available for developing and calibrating 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

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. For example, Table 1 shows production trip rates in terms of trips per household cross-classified by household income and household size. The estimation of the trips produced by a zone involves estimating the number of households in the zone which have the characteristics of the categories by which the trip rates are stratified. For example, the number of households with two persons in them and with 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.

Table 1
Production Trip Rate
Cross-Classification Example

Income Range	Household Size			
	1	2	3	4+
0 - \$ 7499	0.31	0.37	1.60	1.44
\$ 7500 - \$ 9999	0.84	0.92	1.62	2.05
\$ 10000 - \$ 19999	1.11	1.36	1.55	1.66
\$ 20000 - \$ 29999	1.23	1.94	2.22	2.76
\$ 30000 & Over	1.50	2.13	2.28	2.43

The data in the trip generation model form the basis for developing and calibrating the model. These data generally come from travel surveys. Up until the mid-1980s, the trip rates and models used in Texas were based on origin-destination travel surveys conducted in the 1960s and early 1970s. Beginning in the 1980s, the Texas Department of Transportation 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, surveyors conducted 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 to obtain 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.

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. For this reason, the following sections present brief descriptions of the travel surveys conducted in Dallas-Fort Worth, Houston, and Texarkana.

Dallas-Fort Worth (1,2)

A regional travel survey was initiated by the North Central Texas Council of Governments in the Dallas-Fort Worth area in 1984. That survey consisted of three independent surveys designed to provide information by which the urban travel demand models in use at the time could be updated. The travel demand models in use had been originally developed based on an origin-destination travel survey conducted in 1964 and updated in 1973. The three surveys which were administered were a household travel survey, a workplace travel survey, and a special generator survey.

In the household travel survey, households were selected using a quota sampling technique. Using data from the 1964 survey, an analysis was performed to determine the number of households to be sampled. Households were stratified by size and auto ownership. The number of households in each cell (i.e., to be sampled) was based on the variance of trip rates for each cell (from the 1964 survey). Households were selected and contacted via a systematic random sampling technique using area telephone directories and asked to participate. For those agreeing to participate, household characteristics were obtained to determine in which stratification cell the household belonged. As quotas for each cell were reached, households were

excluded if they fell in a cell already filled. Additional effort was required to fill the necessary quotas for the zero-car households. Each household that agreed to participate was subsequently sent a letter and a set of travel diaries for recording their travel on a specified day. An interviewer then went to the household and interviewed persons over 16 years of age about their travel on the survey day.

The household survey consisted of two parts. The first was to obtain basic information concerning the characteristics of the household:

1. Household address and structure type.
2. Number of persons age five and older living at that address.
3. Number of out-of-town visitors staying at that address.
4. Number of vehicles available for use.
5. Household income.
6. Data on each person age five and older:
 - a. Relation to head of household,
 - b. Age and sex,
 - c. Licensed to drive,
 - d. Occupation,
 - e. Industry,
 - f. Whether they worked on the survey day, made trips while at work, and whether they made other trips that day.

The second part of the household survey dealt with the information on the number and type of trips made during the survey day by each person 16 years of age and older:

1. Address where trip began (i.e., origin) and address where trip ended (i.e., destination).
2. Purpose of trip.
3. The land use activity at the origin and destination ends of the trip.
4. The time the trip was started and the time the person arrived at the destination.
5. The mode of travel used for the trip.
6. If the person (i.e., making the trip) was the driver, the number of passengers in

the car, and the number of passengers in the vehicle if the trip was a carpool or vanpool.

7. If the mode of travel was transit, the mode used to access the transit system.
8. The cost for transit if the mode of travel was transit and the cost for parking if the mode of travel was by car.

In addition, the travel diaries were obtained from the survey respondents. The travel diary also included the person's age and sex along with the information listed above.

The workplace survey was unique in that it included a survey of the persons arriving at a selected establishment as well as a survey of the employees of the establishment. The arriving persons were interviewed to obtain the characteristics of their trips to the establishment. The employees were surveyed to obtain the characteristics of the trips they made to and from the establishment during the day. The surveys were self-enumerated. The employee surveys were distributed through the employer; the nonemployee surveys were distributed to all persons arriving at the establishment.

The establishments in the area were stratified by three industry types (basic, service, and retail) and by three area type categories (central business district and other business districts, urban residential, and suburban residential and rural). Quotas were established as to the number of establishments in each stratification cell to be surveyed. The actual establishments surveyed were selected by use of a systematic random sampling technique.

The employee survey obtained the following information:

1. The time the employee normally arrived at work.
2. Mode of transportation to work; if by auto, truck, or van, the number of persons in the vehicle.
3. If the employee was the driver of the vehicle, how much was paid for parking (if any) and how many blocks from work the employee parked.
4. If the employee traveled by bus to get to work, mode of transportation to the first bus stop.
5. The number and purpose of each stop made on the way to work and on the way home from work.
6. The number, mode, and purpose of any trips made during working hours.

7. The number of autos, pickups, and/or vans available to the employee for his/her use.
8. The employee's occupation, home address, and the annual household income.

After determining that a person was not an employee, the nonemployee travel survey obtained the following information:

1. The time of arrival at the establishment.
2. Where the trip began that brought the person to the establishment.
3. How the person traveled to the establishment, e.g., drove alone, drove car with other passengers, etc.
4. If travel was by auto, truck, or van, the number of persons in the vehicle and the number of blocks from the establishment the person parked.
5. If the person traveled by bus, mode of transportation to the first bus stop.
6. The reason for the person's trip to the establishment.

For each establishment surveyed, the survey attempted to gather information on the total arrivals at the establishment during the day of the survey. In addition, for a sub-sample of establishments, truck counts were also obtained by type of truck.

The special generator survey was an extension of the workplace survey. It was conducted in a similar manner with minor modifications in some instances due to the size and complexity of some of the generators. The only exception was the survey done at the Dallas-Fort Worth International Airport. That survey involved new questionnaires, forms, and procedures. The principal difference was in the nonemployee survey form which was modified to specific information on where the persons were going to park, how long they would be parked, and their reasons for traveling to the airport. The major difference between the special generator survey and the workplace survey was the selection and number of establishments to be surveyed. While the workplace survey included 400 establishments selected randomly and stratified by type of establishment and area, the special generators selected were based on judgment and were limited in number. Because special generators are typically considered unique and are treated separately in the travel demand modeling process, it was reasoned that a limited number would be sufficient for survey purposes. One special generator in each of the following categories was included in the survey: commercial airport, regional recreational facility, college, regional mall, truck

terminal, high school, and hospital. With the exception of the airport, these were surveyed using the same forms and procedures as used in the workplace survey.

Houston (3)

A regional travel survey was initiated by the Houston-Galveston Area Council (HGAC) in 1984. This household travel survey was designed to provide the information for updating the Houston-Galveston area travel demand models. Previous travel models were based on information from an origin-destination travel survey conducted in the 1960s.

The total number of households to be surveyed was estimated using modified coefficients of variation weighted by the proportion of households in each stratification by size and vehicle ownership. The needed number for the survey was estimated to be 1,200. A goal was set at 1,500, however, to ensure that the minimum of 1,200 would be obtained. Based on data from an earlier study in Dallas which analyzed the variability of the number of trips per household, three categories of households were identified; and census tracts in the Houston-Galveston area were grouped according to those categories (based on the number of households in the census tract that fell in each category; i.e., the category with the largest number was the one to which that census tract was assigned). Using data from the 1980 census, the number of households by household size and vehicle availability were computed for each category. An estimate of the trip variability per household for each of the three categories was developed by weighting the estimated trip variances per household by the estimated number of households in each household size and vehicle availability strata. The number of households to be sampled from each of the three categories was estimated based on the variability of trips per household and number of households in each category.

Households were selected randomly for ten replicates of 1,200 households. It was anticipated that up to 12,000 households would have to be contacted in order to obtain 1,500 that would participate in the survey. The procedures used to implement the survey consisted of two primary stages. Households were first contacted by phone and asked to participate in the travel survey. The telephone survey was used to screen the households to ensure that the number within each size and auto ownership stratification was obtained in terms of those agreeing to participate. The information obtained during the telephone interview verified the names and address of the

household occupants, the number of automobiles available, the number of household members, and whether or not the household would participate in the second stage of the survey.

The second stage of the survey consisted of mailing survey forms and instructions to each household that agreed to participate. The survey mailed to each household consisted of two parts. The first part requested information about the household and its members, while the second part requested information on the trips made by each member of the household. Each household member five years of age and older was requested to complete the trip survey forms for a selected day.

The household survey questionnaire asked that each household member be assigned a number and requested the following information:

1. The age and sex of each member of the household.
2. The relationship of each member to the first person in the household.
3. Whether that person was employed full time, part time, or not employed.
4. Whether that person did or did not travel on the designated travel day.
5. The combined annual income of all members of the household. Five income ranges were on the survey form and they were requested to indicate where their combined household income fell within those categories.

Each household member was given a different colored trip survey form to complete. The trip survey form requested the following information:

1. The travel day.
2. The location where the person's first trip began.
3. The address, building, or nearest intersection of each trip destination.
4. The time each trip began.
5. The purpose of each trip.
6. The mode of travel for each trip including whether the person was the driver or a passenger. If a driver or a passenger, the person was asked the number of other persons in the vehicle.

The households were asked to return the completed survey forms to HGAC by mail. The forms were processed; and, if necessary, the households were contacted by phone again to clarify any questions and/or missing information. It should also be noted that the households were contacted

prior to their travel day to ensure they had received the survey forms, determine if they had any questions, and remind them to complete the survey form on their travel day and return it.

Texarkana (4)

A regional travel study was initiated in the Texarkana, Texas, area in 1989 by TxDOT and the Arkansas Highway Department in cooperation with the Ark-Tex Council of Governments. The purpose of the study was to collect information by which the urban travel demand models for the Texarkana area could be updated. The travel study consisted of three independent travel surveys, a home travel survey, a workplace travel survey (which included a survey of special generators as a component), and a roadside travel survey.

In the household travel survey, households were selected randomly from the 1989 Cole Cross Listing Directory for the Texarkana Urban Area and Vicinity in accordance with a stratified sampling plan developed by TxDOT. A total of 626 usable household surveys were desired with the household stratified by vehicle availability (four classifications) and household income (four classifications). The number of households to be surveyed within each stratification category was estimated using the modified coefficient variation method (5) with nationally averaged modified coefficients of variation with cell frequencies for the income and vehicle categories for the Texarkana area. Households were randomly contacted based on the wealth rating of the census tract within which they were located. In an attempt to survey an even cross-section of the community, an effort was made to survey a proportionate number of households in each census tract based on the number of known households within the tract. The method used in conducting the household travel survey was a telephone/mail/telephone/mail technique. Households were contacted initially by telephone and asked to participate. Those agreeing to participate were asked basic information to determine the category the household was in. Households were mailed a survey packet with appropriate instructions; and later they were contacted twice by phone, once to remind them of their survey day (i.e., the day they were to record their trips and complete the survey forms) and to answer any questions concerning the survey and again after their survey day to determine if they had completed the survey and to remind them to return the survey. As surveys were returned and checked, some households were contacted again by phone to clarify or obtain missing information.

The household survey consisted of two parts. The first part was to obtain basic information concerning the characteristics of the household:

1. Household address.
2. Number of persons living in that household.
3. Number of persons in that household that were employed for more than 20 hours per week.
4. The number of cars, vans, and/or light trucks available for use by members of the household.
5. For each person in the household: age, sex, relationship to first person listed (usually the head of the household), employment (full time, part time, or not at all), and if that person traveled or not on the survey day.
6. Total annual income range earned by all members of the household (four ranges listed on the survey).

The second part of the household survey dealt with the travel information on the number and type of trips made during the survey day by each person five years of age and older:

1. The location where the first trip began and whether it was at home or the person's place of work.
2. The address of the destination of each trip and the time of arrival at that destination.
3. The purpose of the trip. (i.e., return home, work, work related, school, shop or meal, and other, e.g., social, recreation, personal, etc.).
4. The means of transportation for the trip, i.e., car, pickup, van, or motorcycle, and whether the person was the driver or a passenger; bus/school bus; commercial truck; taxi; or other (blank included for mode to be specified).
5. Total number of persons in vehicle.

The workplace travel survey consisted of two independent components, a survey of the employees at the workplace and a survey of the persons (i.e., nonemployees) traveling to the workplace. A total of 51 business establishments were surveyed. These establishments were stratified by three employment types, (basic, retail, and service) and by three area types (central business district, urban, and suburban). Included in the 51 establishments were six businesses

classified as special generators. In addition to the surveys at each site, traffic counts and person counts were obtained by TxDOT.

Survey questionnaires for the employees were distributed by the employer, and the employees were to complete the survey and return it to a location at the business where it would be picked up. Nonemployees were interviewed by the consultant staff and at times by the employer's personnel. The following information was obtained in the survey of the employees:

1. Usual time the employee arrived at work.
2. Usual time the employee departed work at the end of the work day.
3. How the employee traveled to work on the survey day. Three choices were indicated; personal vehicle, commercial truck, and other (blank provided).
4. If travel to work was by auto, pick-up, or van, the number of persons also in the vehicle (including employee).
5. Any stops on the way to work and the purpose of each stop. Purposes listed were work related, shopping, school, social/recreation, personal business, eat a meal, and pick-up or drop off a passenger.

There were some exceptions to the general procedure for conducting the employee surveys. At one location due to three different work shifts, the questionnaires were distributed by the consultant staff to workers on each shift as they arrived at work. The employees were asked to complete the survey and return it to their supervisor. Special generator locations were also allowed several days to complete their employee surveys due to the large number of employees.

The nonemployee survey was conducted by interview. Surveyors interviewed persons outside businesses and/or special generators. The following information was obtained:

1. Time the person arrived at the establishment where the survey was being conducted.
2. The address from where the person was traveling (i.e., where they began the trip).
3. Mode of travel to the establishment.
4. If traveling by auto, truck, or van, how many persons were in the vehicle (including the employee).
5. The purpose of the trip to the establishment.

6. The address or location of where the employee would be going upon leaving the establishment.

In some situations, the surveys were conducted by the businesses themselves; and for large companies with security gate entrances, the surveys were administered by the security guards at the gate. For area colleges, a selected number of students were surveyed as they arrived for or departed from classes. At high schools, campus personnel administered the survey to visitors and the seniors; and drivers education students were surveyed with a nonemployee survey. The procedures and forms used in the special generator surveys were essentially the same as the workplace surveys.

The roadside travel survey obtained information on travel into and out of the study area. Ten locations were identified at roadways which crossed the external cordon line of the study area. Surveys were conducted at each of these sites on vehicles in both directions. In addition, 24-hour traffic counts and 12-hour vehicle classification counts were taken at each location during the day the survey was conducted. At each station, surveys were handed to the drivers, who were asked to complete the survey and mail it back. The surveys were on a 5 1/2" by 8 1/2" postage paid postcard to facilitate the return of the completed survey. The following information was obtained:

1. Name and address of the last place they got into their vehicle before receiving the survey.
2. The time they began that trip.
3. The time they arrived at their destination.
4. The type of vehicle they were driving, i.e., passenger car/pickup/van/motorcycle, commercial truck, or other (blank space was provided).
5. If the trip had begun within the Texarkana urban area (defined as the area within eight miles of the downtown Texarkana Post Office). If they replied no, they were asked on what highway they entered the Texarkana urban area.
6. The number of persons (including themselves) in the vehicle during that trip.

Traffic control plans were developed and implemented at each location where the travel survey was conducted.

UNIFORM TRAVEL SURVEYS

As a result of the surveys conducted in the Dallas-Fort Worth, Houston-Galveston, 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 size 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.

As the first of several areas where travel surveys would be done, the San Antonio travel survey 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 was 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 that 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 coefficient of variation estimations 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., home based work, home based non-work, and non-home based) 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 acknowledged that to maintain the desired level of accuracy within the cells considered the most significant, 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. An example of possible sample sizes for the primary stratification are shown in Table 2. 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 values shown in Table 2 are examples. 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 were 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 San Antonio survey results which indicated that, using the variance of the trip rates, 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.

Table 2
Example Sample Sizes for Primary Household Stratification

Autos Owned	Household Size				Total
	1	2	3	4	
Zero	-	-	-	-	390
One	264	357	285	250	1156
Two	≤ 100	244	146	151	641
Three +	-	≤ 100	158	157	415

The determination of the information desired from the survey was fairly straightforward. Because substantial experience in household surveys was available from Dallas-Fort Worth, Houston-Galveston, 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 persons living at that address, number of persons five years of age or older, number of persons in the household that were employed, and 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 in 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 the travel day. The travel diary requested the following information:

1. The day the travel was recorded.
2. The location/address (i.e., origin) and departure time for the first trip.
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, respondents 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. Households included in the survey were selected using a stratified random sampling technique. These households were then contacted by phone and asked to participate in the survey. If contact 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 were 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 contact households initially and, in the follow up calls, collect the survey information. Following the initial contact, those households agreeing to participate were sent a household survey and travel diary with instructions to complete the survey forms and travel diary for a specific day. The household was contacted prior to the travel day to

remind them to complete the survey on their travel day and to ask if they had any questions concerning the survey information sent to them.

Two procedures have been used for collecting travel survey information from the household. In the first procedure, the household is contacted by phone the day after their travel day; and the household and travel information is obtained directly over the phone. The household is also asked to return the survey forms so that the agency will have documentation 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. Use of the first procedure with well trained interviewers has the potential of obtaining more accurate trip numbers, because the interviewer is 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 that 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 household survey implementation. 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 to 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 can be provided on nonresidential trip generation characteristics which are not 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 it 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 nonemployees 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, principally due to (1) the lack of prior experience in surveying workplaces, (2) the sample drawn being a cluster sample (i.e., relative to the employees), and (3) 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, determining the number of workplaces to be surveyed within each stratification is left to the proposer. The number, however, 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 area type categories: 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:

$$\text{Factor} = \text{Population Density} + B * \text{Employment Density}$$

where:

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

The constant B is calculated using the population and employment for the entire area and weights the population and employment variables. Work establishments are grouped by three types of industry (basic, retail, and service) and are defined by standard industrial classification (SIC) code numbers. Basic industries include SIC codes 1000 to 1799 and 2000 to 5199, retail industries include SIC codes 5200 to 5999, and service industries include codes 6000 to 6799 and 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 reporting survey results. This resulted in three categories for San Antonio and is considered to be reasonable for most areas. Table 3 shows the manner in which business establishments were stratified for sampling in San Antonio. The survey was to include all of the employees at the business establishment. The survey of nonemployees was dependent upon the establishment. Where possible, all nonemployees would be given a survey, and asked to complete and return it prior to leaving. Where there were large numbers of nonemployees, every "nth" nonemployee would be surveyed. The survey of the trucks and taxis consists of an actual count of the vehicles at those establishments that are freestanding. At non-freestanding workplaces, truck and taxi arrivals would be 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 expanding survey results, all persons and vehicles traveling to the business establishment were counted.

Table 3
Example Distribution of Workplace Survey

Area Type	Type of Employment			Totals
	Retail	Service	Basic	
CBD and CBD Fringe	31	42	20	93
Urban Residential	15	18	5	38
Suburban Residential and Rural	67	53	31	151
Totals	113	113	56	282

Source: San Antonio Travel Survey

The information considered necessary in the workplace surveys was that which would characterize the travel patterns of employees at the workplace, the characteristics of trips to the workplace by nonemployees, 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's 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 work related, school, social/recreation/shop/eat, pick up or drop off a passenger, 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 persons (including the employee) in the vehicle.
6. The parking cost, if 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 19 trips. The last question asked how many more trips the employee would make that day.

The workplace nonemployee survey was designed as a questionnaire where an interviewer asks specific questions and records the answer. The following information was obtained in the nonemployee survey:

1. Whether the person being interviewed worked at the establishment. If yes, the interview was terminated to avoid duplication with the employee survey.
2. The next question was whether the person had traveled straight from home to the establishment or from another location.
3. The third question asked was the approximate time the person arrived at the establishment.
4. The fourth question was the 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, the person was asked how many persons including himself were in the vehicle. If the trip was by bus, how much bus fare was paid.
6. The sixth question asked the purpose of the person's 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 the person was going home immediately after leaving 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 distributed 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 conducting the survey.

The methodology used in the nonemployee 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 questions relative to use of the data being collected. Since many employers were reluctant to allow the survey because of the potentially 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 estimating or projecting travel demand with 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 among urban areas and are generally defined at the beginning of the survey with specific establishments identified for inclusion in the survey. Provision must be made for possible refusal to participate; and, when feasible, more than one facility may be identified. The survey of the special generators was similar to the workplace but allowed the unique characteristics of the generators to be considered. The information gathered enabled 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 nonemployee survey, and a truck-taxi survey or count. Because only one special generator is typically surveyed in each category, sample size was not a major determinant. 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 additional information needed for the special generators is based on the anticipated use of the data's anticipated use in developing 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. 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 names 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 that information will depend on the type of special generator and its attributes which may be explained relative to the number of trip productions and/or attractions.

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 regarding the trip purpose in the nonemployee survey at the hospitals was eliminated due to the potentially sensitive nature. 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 nonemployees.

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 nonemployee survey, at least 30 trips for each trip purpose and mode and 100 auto-driver and auto-passenger surveys were to be obtained if possible. If feasible, representative samples would be attempted with the truck-taxi surveys; and, as a minimum, truck counts would be done.

Truck Survey

The truck survey actually combined a commercial truck and taxi survey. The survey's purpose was to obtain information by which truck-taxi trip rates could be developed and to develop trip lengths and trip length frequency distributions.

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 their truck travel logs; and the survey data were 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, all one-ton or more payload capacity. This number has varied in some later surveys.

Prior to the survey, surveyors underwent training for both soliciting of firms' participation as well as the actual data collection. 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 manually 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 ensure safety for the interviewers and supervisors during the survey. Generally, traffic was narrowed into one through lane in the outbound direction, and one to three vehicles were moved out of the travel lane to the shoulder where the surveyors conducted interviews. After the survey was completed, the vehicles resumed their

travel; and another one to three vehicles were moved to the shoulder for the survey. If traffic congestion creates 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 (in San Antonio this number was 400 and in Amarillo the number proposed was 300) within a shorter time period.

In the San Antonio survey, two methods were pilot tested in the external survey. One was the roadside interview (as described above), and the other was the postcard method where motorists were handed postcard questionnaires as they traveled through the survey site, asked to complete it, and mail it. The results of the pilot tests indicated that the roadside interview produced what was considered more accurate and complete results than the postcard method. This was not, however, the method used in Tyler where, for safety reasons, the postcard survey method was used at locations where daily traffic exceeded 8,000 vehicles. At all other locations, the roadside survey method was used. Initial results indicated that a good response rate was achieved in Tyler with the postcard survey. The method used in Amarillo was the roadside interview.

The following information was requested and recorded in the San Antonio external survey:

1. The time of the interview, the number of persons in the vehicle, and the vehicle type, i.e., passenger car/truck/van/motorcycle, bus, taxi, school bus, commercial vehicle (over one ton), or other;
2. The final destination (city and state) for that day and whether the vehicle was traveling through the area in route to that destination or whether the vehicle began the trip in the San Antonio area;
3. If the vehicle was traveling through the San Antonio area (i.e., did not begin the trip in the San Antonio area), where the trip began and what highway was used to enter the San Antonio area; and
4. If the vehicle's trip began in the San Antonio area, the location of the last place where the driver got into the vehicles before receiving the survey card and what the approximate departure time from that location.

The survey proposed in Amarillo used a slightly different questionnaire. The principal differences were that the final destination was not requested and the city of origin was requested.

Surveyors and supervisors were trained prior to conducting the survey. The most critical aspects of the external survey were developing the traffic control plan and monitoring 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. 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 data collection was designed around particular types of models, a great deal of flexibility remains in using 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 the information necessary 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.

URBAN TRAVEL DEMAND MODELING DATA

Urban travel demand modeling data consist of those data necessary for developing 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 lies in the fact that they are the basis for the resulting estimates of travel demand. Their accuracy and spatial distribution determines 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 for the estimation of 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. A number of different travel demand models are used in urban areas with different input data requirements. This report will focus on the input data requirements of TxDOT 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.

This chapter presents a discussion of the different techniques and methods used in developing 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 forecasts of different variables at the regional level. The fourth section discusses the different allocation methods and techniques for developing input data estimates 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 of 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 to estimate trip productions. The trip attraction models require estimates of each zone's employment 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 (10). Other options are 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 because 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 the variable is estimated from other forecast variables. Employment is another variable which has three categories which must be estimated. These categories are basic employment, retail employment, and service employment. These categories are defined by standard industrial classification (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. That process generally consists of the following steps:

1. Developing estimates at the regional, subregional (sometimes referred to as district), and zonal level for the base year (i.e., existing conditions).
2. Developing projections of each variable for some future year for the region under study.
3. Allocating 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. Allocating 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.

FORECAST 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 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 estimate 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 dividing 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. Estimating households based on the estimated population will also be discussed.

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 large areas than small areas, and data are normally more readily available for large 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 (6). 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 fitting 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. Reference 6 gives a more detailed description of these relationships.

Component analysis methods base population projections 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 (6,7). 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 an area's population 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 from the area. There are some subtle variations in the components 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 because the method accounts for each possible change in population.

The method requires projecting 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 rate (based on the mortality 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 childbearing age (by five-year-age 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, employment estimates 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, in most cases, built around the concept of two types of economic activity; the activities serving the area outside the study area are referred to as "basic", while the activities serving the study area may be called "nonbasic", local, or secondary. Population growth 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 nonbasic activities. This estimate may be computed using 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 nonbasic industries. The changes in employment are related to the changes in population and form the basis for the population estimates in the future. This description is somewhat simplified; Reference 6 offers a more detailed description and list of other references on the subject.

Carrying capacity methods are based on the capacity of natural systems to carry a certain size and spatial organization of activities (6). 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 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 to 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 extrapolating to ensure that the future estimate is reasonable, because 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 most difficult tasks in developing 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 estimating travel demand has been firmly established.

Several techniques and methods may be used to estimate household income 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 discussing 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 calibrating the trip generation models. Some of the methods used to project income are:

1. Judgmental assumptions methods
2. Extrapolation 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 that incomes would be held constant. It would be necessary for the local analyst to assumed 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 that observed in the latest census.

Another judgmental assumption method is based on the assumption that the only change

in income will be due to new development. 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.

Extrapolation 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 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 each income ranges relative change (growth or decline) 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 generally involve the use of a forecast developed by an outside agency for different areas. For example, the Bureau of Economic Analysis (BEA) produces income projections for the United States, for states, for economic areas, for Metropolitan Statistical Areas (MSAs), and for 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 income forecast 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 combine historical trend forecasting and a mathematical formulation to estimate the households by household income distribution. Historical trends 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 calibrating 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 (15). There are some variations in this method. In one variation, 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 variation recently developed (13) estimates 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 (± 1 percent). Both variations produce distributions of households by household income with the projected mean household income.

Auto Ownership

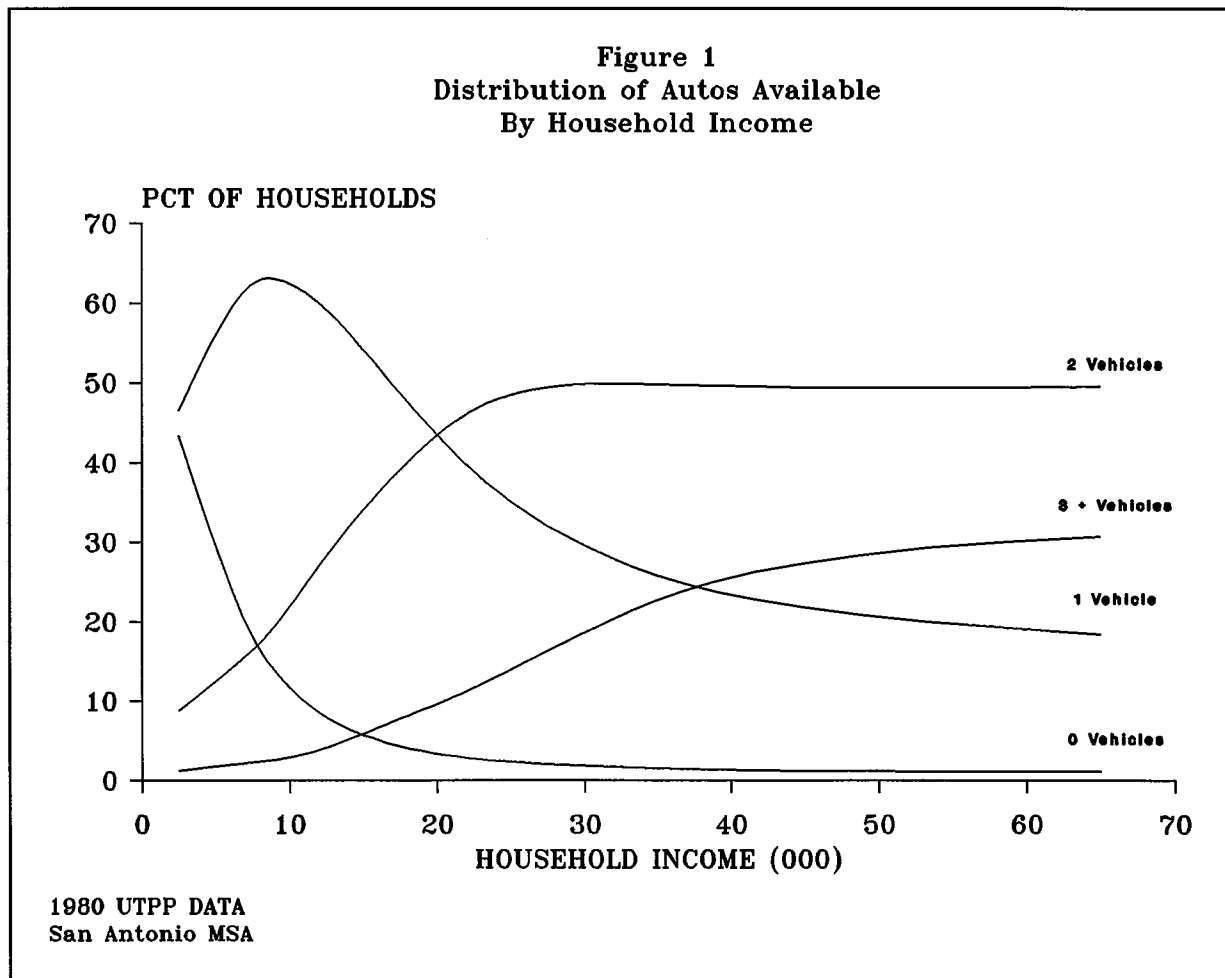
Auto ownership is used in some areas in lieu of income for trip generation models. In some cases, it is used in combination with income and other variables for estimating travel demand. The projection of auto ownership for a region may be done in the following ways:

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

The continuation of existing trends usually involves using 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. Figure 1 shows a plot of the percentage of households by auto ownership versus household income for the San Antonio MSA. Using Figure 1 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 (11,12). 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 (14). Average household income is used with observed relationships of auto ownership (e.g., Figure 1) 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:

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 employment share (or activity) 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 project, based on historical data or local considerations, a change in the proportion or ratio. One method of examining changes is through the use of shift-share analysis. That analysis examines 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 that it utilizes a projection for a larger area which is typically based on more rigorous models and on 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 nonlinear 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). They 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.

Economic base techniques involve a thorough analysis of an area's economic base. They are similar to other techniques in that they are 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 from 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 which 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 developing 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 region's economy, and the general model may be an over-simplification of the region's economy.

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 technique's premise is that the output for a particular industry is related to the amount of products produced by the industry absorbed by other industries and the amount of products produced by the industry which go 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 including 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 an 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, multiregional, or national scale. Considerable variation exists between the types of models within this general group (6). For example, some are considered "bottom-up," others "top-down," and others 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, multiregional, and national economies. A comprehensive review of the technical details

of these models is not possible in this report. Further information and other references may be found in Reference 6. These types of models are the most sophisticated both technically and theoretically, but they are also 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 data forecasts 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. This section presents some of the methods and techniques used to allocate regional forecasts to the subregional and zone levels. Much of the information presented in this section is summarized from Reference 16, and the reader is referred to that publication for additional information or clarification on the methods described in this section. 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 is the EMPIRIC model (17). The EMPIRIC model is actually a family of models designed to allocate projected regional population, employment, and land use growth between a set of smaller subregions or districts. It consists of a set of simultaneous linear equations which relate changes over time in the distribution of population, employment, and land use. Population is generally broken down by age, household size, and household income. Employment is 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 must be forecast for input to the model(s).

Spatial interaction models typically refer to models developed along the principles of the Lowry (16,18) 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 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 used. These include the Time Oriented Metropolis Model (TOMM) (16,19), the Projective Land Use Model (PLUM) (16,20), and the Integrated Transport and Land Use Package (ITLUP) (16,21). 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 due to their somewhat widespread use.

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 process allocates 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 district level data required for the base year calibration of the models consist of:

1. Population by district of residence
2. Employment by district of work for two different historical time periods (usually five to ten years apart)
3. Households by income quartile and group quarters population
4. Land use by district (total land area and unusable land)
5. Land area occupied by commercial land uses
6. Land area occupied by industrial land uses
7. Land area occupied by residential land uses
8. Forecast total usable land (developed plus developable)
9. Land area used for streets
10. Vacant and developable land
11. 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. First EMPAL distributes 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, a modified version of the singly constrained spatial interaction model has three primary modifications: use of a multivariate 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, also a modified version of the standard singly constrained spatial interaction model, has two primary

modifications: the use of a multivariate, multiparametric 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. The quantity being allocated could be households by type of housing and/or employment by sector. An optimized objective function is used subject to the constraints which ensure that all of the quantity being optimized is allocated, no supply side constraints are violated, and 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) (16,22) and Project Optimization Land Information System (POLIS) (16,23). POLIS is a nonlinear 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 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 is allocated for each time period; the relocation of base year employment is accomplished by increasing the number of jobs to be distributed. Examples of constraints applied during the allocation include:

- 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
- Allocation of employment and housing
- 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.

In developing this technique, a group of individuals must first be assembled to serve on the Delphi panel. This step is crucial and provides the basis for the method's ultimate success. 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 is best kept to 20 or less in order to facilitate the summarization of voting results (16).

One of the first tasks of the panel is to review and approve the regional forecast and the methodology used to produce that forecast. A package should be prepared for each member on the panel describing the forecasts and the methodology used, the Delphi process including the questionnaires to be used, the definitions of the measures used in the process, and the 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 the 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 evaluating several alternative development scenarios or even evaluating components of different alternatives. Panelists may be asked to respond by ranking each alternative (or component) as to the likelihood of it occurring or even relative to the desirability of it occurring. Ranking could be from 1 to 5, 1 to 10, or 1 to 20 depending on the items being evaluated and the local analysts' judgment. After each response, the results are summarized and given to the panelists for review and discussion. Following this, another survey (identical to the first) is completed by the panelists.

The process is repeated until a point is reached where the differences between the responses (from prior survey) are insignificant. Typically, the process should converge with the panelists reaching some consensus relative to the issues being addressed.

The third major step involves developing the forecasts for the subregional areas (i.e., districts). Prior to beginning the actual forecasting process, the staff should prepare the input data for the panelists. Those data typically consist of the control totals of projected population (and possibly households), employment, and income. Fact sheets should also be prepared for each district with information on 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 should 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. Members develop a forecast variable for each district based on their personal judgment. One method which might be used is to have 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 converge and stabilize.

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

Analytical methods are generally those 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 applying 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 either adjust the apportionment or 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 describes 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. No one description (even general) 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 remaining the same as observed in an earlier census. One 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 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.

STATE OF THE PRACTICE

The state of the practice in forecasting and allocating forecasts for the purpose of travel demand modeling is as varied as the methods and techniques available. This section attempts to describe in varying levels the methods and techniques that are being used in other areas for forecasting and allocating demographic variables for use in travel demand modeling. The first part of this section covers some of the methods used in areas outside Texas beginning with a discussion of a similar study done in Florida. The second part describes the methods and techniques used in different urban areas in Texas. It is not possible to describe or discuss the methods used in all urban areas. The purpose is to provide some indication as to the variety of

the methods employed and illustrate some of the more popular methods.

Florida (27,28,29,30)

The Florida State Department of Transportation funded a research project through the University of Florida Transportation Research Center on Simplified Zonal Data Development Techniques (27). That research focused on assembling an inventory of the techniques being used for the surveillance, measurement, and forecasting of socioeconomic variables by traffic analysis zone. The research was limited to those variables required for input to the Florida standardized trip generation models. Study findings included recommendations for forecasting techniques for Florida study areas. Included in that study was a survey requesting information on the type of data forecast and how they were forecast for use in transportation planning in Florida urban areas and across the nation.

Fifteen Metropolitan Planning Organizations (MPOs) in Florida were surveyed to determine the methods that had been used or were being used for forecasting future socioeconomic conditions. The techniques varied from subjective projection based on professional judgment and knowledge of local conditions to more elaborate allocation models. Many reported using regression analysis as one of their forecasting techniques, assuming continuation of existing trends. One MPO indicated the use of an S-curve pattern of growth. Other techniques included time series analysis, allocation approaches, relating state and national trends to local areas, and in-house programs. Some used forecasts prepared by other local agencies while others used forecasts prepared by either national or state agencies. One MPO had its own in-house program for forecasting socioeconomic conditions and one used a housing allocation program prepared by an outside consultant. Two reported they were in the process of developing models. One MPO used the Delphi technique for establishing a growth rate for their area. Several reported using cohort survival methods and economic base techniques for forecasting.

In addition to the survey of Florida MPOs, MPOs across the nation were also surveyed by mail. A total of 66 MPOs responded to the national survey. One of the findings was that the size and complexity of the urban area had some bearing on the level of sophistication of the forecasting techniques used. The larger urban areas tended to have developed and/or utilized

more elaborate models for forecasting. Overall, a variety of methods was used, with the choice of technique partially dependent on the major variable of concern. Cohort survival techniques were frequently used for forecasting population. Various forms of trend analysis were also used for forecasting population as well as household size, dwelling units, employment, and other variables. Some of the MPOs relied on other agencies to produce the forecasts they used. At least three MPOs used shift-share analytical methods for forecasting employment. Other ratio techniques were used to forecast population, employment, and land use changes from regional and sometimes national projections or trends. One-half of the respondents reported that they had used or were currently using an urban model for forecasting. The urban models included land use based socioeconomic models, spatial interaction models, and optimization models. Nineteen different urban models were discussed as a part of the research reported in Reference 27. The reader is referred to that reference for more detail as to the specifics concerning the models.

The research in Florida found "that there are no proven but simple techniques in existence that would be directly appropriate for use in Florida urban areas for some variable" (27). The recommendations which were produced by that study were predicated on the following:

1. State law in Florida at that time provided for the establishment of comprehensive plans by the municipalities and counties throughout the state; and
2. The comprehensive plan for an urban area was expected to indicate future types of land uses permitted in each zone and overall future activity levels for the study area in the form of quantitative estimates of future population, employment, etc.

With that as a starting point, the study recommended that an activity allocation model allocate the space-related variables such as dwelling units, hotel/motel units, and employment. The other required variables could be estimated based on those variables. In their review of the practices in Florida and across the nation, no widely accepted and satisfactory model for forecasting urban activities was found. Most of the large scale models were too complicated and costly, and many areas were instead using present growth rates, trend extrapolations, and ratio estimators in conjunction with extensive judgment. The allocation model as proposed from that research was based upon the hypothesis that the change in the amount of development occurring over a certain time period was proportional to 1) the rate at which the zone was presently developing relative to the overall areawide development rate (as a function of time); 2) the amount of capacity in the

zone remaining for development; and 3) the relative attractability of the zone for development in comparison to all other competing zones. The model required calibration as well as the use of local planning judgment concerning certain parameters. This model was recommended with the additional use of trend extrapolation methods (for certain variables) in developing the zonal forecasts of the 25 variables required for the Florida trip generation model.

Denver, Colorado (31)

The employment and population projections for the Denver region were developed using a cohort/component model and economic simulation model. Two major assumptions were used: Net migration flows would narrow gaps in labor supply between regions in the nation, and migration to the Denver area would occur at a rate necessary to satisfy future labor market demands.

A standard cohort/component demographic model (computerized) was used to develop estimates of the projected population for the region assuming zero migration. This resulted in estimates of future growth due to natural increases (i.e., births minus deaths).

The employment projections for the region were developed using the Colorado Forecasting and Simulation (COFS) model maintained by the University of Colorado Center for Economic Analysis. That model uses a complex set of simultaneous equation models driven by levels of economic activity in the nation, in the state of Colorado, and in the Denver region. Projected employment changes were added to the employment estimates of the Denver Regional Council of Governments to arrive at the forecast year estimates of employment. The population and employment projections for the region were integrated by running the cohort/component demographic model again.

Population and employment projections were distributed to subregional areas using different techniques. Population was distributed using a share analysis technique. Using historical data, factors influencing residential growth were identified; and regression equations were calibrated relating the subarea share of growth to the identified factors. The subareas were grouped into three area types: rural, suburban, and urban. Regression equations were developed for each area type and used to project the share of growth for each subarea. The criteria for each area type was based on population density (persons per square mile). The factors included in the

growth shares computation included historical data on growth (existing and prior population growth share), socioeconomic and land use characteristics, and growth prerequisites (e.g., highway access, freeway interchanges, water service availability). Growth was constrained by the assumption that a sufficient supply of land had to be available to adjust growth for new development or redevelopment.

A two-stage step-down approach was used in distributing employment. Regional totals were first distributed to county levels and then to the Regional Statistical Areas (RSAs). The initial distribution of forecast employment (by type) to the county level involved five techniques: linear extrapolation, linear extrapolation of the county share of regional employment, constant rate of growth based on the 1970-80 rate, constant rate of regional growth based on the 1970-80 rate, and industrial sector employment distribution among counties same as in 1980. A review of the results indicated that no one method was satisfactory for all types of employment. Subsequently, different methods were used to distribute different sectors of the employment. For example, the linear extrapolation method was used only for distributing wholesale trade employment. In some cases, major changes that were pending were taken into account and the initial distribution adjusted accordingly. In one case, the projections for transportation, manufacturing, and wholesale trade were adjusted so that 55 percent of the total employment growth would occur within a pending beltway corridor. In all, 12 categories of employment were forecast and distributed to the county level. These 12 categories were combined into five categories for distribution of the RSAs. Three methods were used to distribute the five categories of employment at the county level to the RSA level. These were linear extrapolations of 1976-80 growth, assuming the growth rate for each RSA stayed the same and assuming the distribution by RSA within each county remained the same as in 1980. These results and methods were used as guidelines for a qualitative assessment of the distributions for each development type. This assessment, with information on known developments and future land use identified in local comprehensive plans, was used to modify the distributions. The distributions were modified further in the review and approval process.

Phoenix, Arizona (32)

The Phoenix, Arizona, metropolitan area is located in Maricopa County; and the socioeconomic data forecasts described in this section were reported for the Maricopa Association of Governments. Regional population and employment projections were prepared by outside agencies, and the methodology was not reported in Reference 32. The forecast population and employment are distributed in a step-wise fashion utilizing a regression relationship which allocates a particular variable according to certain independent variables identified as influencing the location of that land use type. In addition, the model as developed for the Maricopa County area takes into account active developments and known definite planned activities, other planned and proposed activity and redevelopment activity, as well as any leased lands or other growth restrictions. Typical life cycle for the development of small areas follow an "S" shaped relationship. Office employment is allocated first followed, in respective order, by industrial employment, public/quasi-public employment, low/medium density residential housing units and population, high density residential housing units and population, retail employment, other employment, nonbasic government employment, nonbasic retail employment, and nonbasic other employment. The last variables allocated are other resident population, housing, and income variables.

Average household income was projected for each zone using a linear relationship developed from the 1980 census data and supplemented with information from an update to the socioeconomic data base in 1988. The dependent variable is average household income. The independent variables are the proportion of housing stock that is less than five years of age in the zone and the population potential index for the zone. The population potential index represents a distance weighted aggregation of all other zone population levels adjusted by travel time to the zone in question. In addition, average income was assumed to increase three percent every five years to reflect a gradual increase in real household incomes. Average household income was used with relationships developed from the census to estimate the number of households within specified income ranges for each zone. Table 4 shows the relationship between average household income and the distribution of households by income category.

In updating and compiling the extensive data base for study, a model was developed to estimate the number of private registered vehicles in each zone. That model used the number of

vehicles as the dependent variable; the independent variables were population, households, households per square mile, and total zonal household income. This model is applicable in forecasting registered autos at the zone level.

Table 4
Distribution of Households by Income Range
and Average Household Income
1979

Average Household Income (Dollars)	Percentage Distribution of Households by Income Category					
	Under \$10,000	\$10,000-\$17,499	\$17,500-\$24,999	\$25,000-\$34,999	\$35,000 And Up	Total
< 7,499	75.7	15.4	7.0	1.4	0.6	100.0
7,500-9,999	65.7	20.5	8.5	4.0	1.4	100.0
10,000-12,499	52.5	27.3	12.3	5.4	2.5	100.0
12,500-14,999	41.5	30.2	16.1	8.5	3.7	100.0
15,000-17,499	33.4	29.5	18.7	11.5	6.8	100.0
17,500-19,999	25.5	28.0	21.4	16.1	9.1	100.0
20,000-22,499	17.7	25.7	25.6	18.9	12.1	100.0
22,500-24,999	16.6	20.4	23.7	23.4	15.9	100.0
25,000-27,499	13.1	18.0	22.4	25.1	21.4	100.0
27,500-29,999	10.3	14.4	20.2	28.0	27.1	100.0
30,000-34,999	12.2	13.4	16.3	24.1	34.1	100.0
35,000-39,999	10.9	11.5	13.3	21.2	43.2	100.0
40,000-49,999	8.7	10.2	11.6	17.5	51.9	100.0
50,000-74,999	7.9	8.0	10.2	11.7	62.3	100.0
75,000 +	0.8	1.2	4.3	7.1	86.6	100.0

Note: Rows may not add to 100 due to rounding.

Source: Reference 32

Based on the allocation of population and number of households to each zone in the study area, an average household size can be computed for each zone. This could be used for estimating the number of households by household size. Based on census data, a table similar to Table 4 was developed which related the distribution of households by household size to the average household size for a zone. The model and values are shown in Reference 33.

Portland, Oregon/Vancouver, Washington (34)

The first forecast done in the Portland, Oregon/Vancouver, British Columbia metropolitan area was the employment forecast, because it was necessary input to the population forecasting process. The regional employment forecast was developed using a step-down procedure beginning with a state forecast developed by the Bonneville Power Administration and Northwest Power Planning Council. That forecast for the state, based on an economic model developed from an analysis of individual sectors of the economy, reflected the results of a national forecast developed by an economic forecasting consultant. The share technique was the basic methodology for developing the regional forecast. It involved the following four steps:

1. Forecast wage and salary employment - The wage and salary employment forecast was derived as a share of the state wage and salary employment using historical trends as the basis for the estimation.
2. Derive historical sectoral employment shares - Based on historical data between the region and the state economies, the share of wage and salary employment represented by each sector of employment was developed based on each sector's shift-in-share of regional employment over time and how closely those regional shifts correlated with changes in employment for the state as a whole.
3. Produce forecast of wage and salary employment for each sector of employment - This was produced by applying the shares developed in Step 2 to the total employment developed in Step 1.
4. Develop final total employment - The final estimates of total employment included the addition of agriculture and self-employed persons to the totals from the previous steps. Agriculture employment was estimated independently of the state estimates because of the disparity between the region and the state in that sector

of employment. The forecast was done by extrapolating historical trends. The projection of self-employed persons was based on an analysis of historical trends and a review of other agency forecasts concerning this sector of the economy.

The projection of regional population and households was dependent on the results of the employment projections. The economy's strength was a primary factor affecting the variability of the population forecast model. The following steps were used to develop the regional population and housing forecasts:

1. Determine jobs available to the residents of the region - This required the removal from the employment estimates of the employment expected to be satisfied by net inward commuting (i.e., persons who live outside the region but work inside the region). An average annual increase was assumed with data from the census used as the beginning estimate for the base year.
2. Estimate the population supported by the projected economic base - This was accomplished using a cohort survival model which incorporated assumptions on fertility rates, labor force participation rates, death rates, and migration.
3. Determine the need for housing - Deducting the population estimated to be in group/institutional housing from the total estimated population leaves the estimated population that will be housed in single-family and multi-family housing units. The population estimated to be in group/institutional housing was assumed to be two percent of the total population.
4. Determine the future need for housing by type - The number of detached houses and attached (multi-family) dwelling units was estimated using assumptions concerning vacancy rates, percentage splits between attached and detached housing, and household size. Vacancy rates were assumed to follow past trends. The percentage splits between single- and multi-family housing units were also based on a continuation of historical trends. Average household size was estimated by extrapolating historical trends.

After completing the regional forecasts, the process of allocating those forecasts to subareas within the region was begun. That allocation process consisted of three distinct step-down allocations, first to economic submarkets, then to county subareas, and finally to census

tracts (as defined in the 1980 census). The allocations were made by local jurisdictional planners in growth allocation workshops. The general assumptions guiding these allocations were:

1. The regional land use plan was the composite of all city and county comprehensive plans, and future land development would be consistent with those plans.
2. Currently adopted policies of jurisdictions influencing regional growth and development would not change significantly in the future.
3. Current or projected transportation deficiencies were not considered to be restraints on the future land development patterns.

With those assumptions as a foundation, population was allocated based upon each subarea's potential for residential development based primarily on the planner's knowledge of their local areas with the historical growth of the subarea. Dwelling units needed to house the growth in population were allocated first. Population was then estimated based on the subarea's average household size and on assumptions concerning vacancy. Beginning with historical data, the participants considered factors affecting past trends and the likelihood that the trends would continue to adjust the historical data either up or down. Growth in each subarea was limited to the holding capacity of the subarea. A subarea was considered built out when 95 percent of the single-family holding capacity had been reached and 100 percent of the multi-family holding capacity had been reached. The process was repeated for each subarea, and the sum of the population in the subareas was compared with the regional forecast. The entire process was repeated until the subarea allocations matched the regional forecast.

Employment growth was allocated to areas using a Delphi process. The process was built on the use of time series data, vacant land potential, and the allocation workshop participants' judgment regarding location choices of industries moving into or within the region.

Seattle, Washington (35)

The socioeconomic forecasting for the Seattle, Washington, metropolitan area is conducted by the Puget Sound Council of Governments. The area included is the central Puget Sound region, its counties, and sub-county areas. Forecasts of population, single- and multi-family households, employment by industry, civilian labor force, average household size, personal

income, per capita income, and over 100 other economic and demographic variables are developed using a regional econometric model called STEP86. The model is a simultaneous system of linear and nonlinear equations which uses parameters estimated on annual data collected over a 26-year period. The model uses 65 exogenous variables in its computations which represent economic conditions in the United States and in the state of Washington. The model is built on the premise that economic growth (in output, jobs, or income) is related to growth in the basic industry sector. An expansion (or decline) in exports from the basic industries in the region triggers a re-spending process in the regional economy that leads to a rise (or fall) in production, jobs, and earnings in the nonbasic sector of the economy. Population and labor force are dependent on the number of jobs in the region over time. The iterative model uses initial estimates as input and repeats the computations until the system reaches a set of stable values.

Allocating regional projections to small areas within the region is accomplished using the DRAM and EMPAL urban activity models, DRAM85 and EMPAL85. DRAM85 and EMPAL85 allocate households and job locations to 152 zones within the region. The models have been developed and calibrated for use in the Puget Sound region. The basic theory of the models is similar to the previous descriptions of DRAM and EMPAL. The models are considered to be Lowry type models which relate household demand for sites and transportation accessibility of locations to jobs and residences within the urban area.

Abilene, Texas (36)

The City of Abilene is the designated Metropolitan Planning Organization (MPO) for that area. Population estimates were derived using a computer-based cohort survival model. Land use information by zone is maintained in a computer data base program. Small area land use plans were developed and used as the basis for allocating population estimates to the zones. The allocation process was accomplished using professional judgment concerning where growth was most likely to occur within the time frame under consideration. Current land use information was periodically updated using building permits, platting records, and tax records. Estimates of households were derived using census persons per household rate(s). These estimates were also adjusted based on local knowledge. Employment estimates for the base year 1990 were updated

using information from Dunn & Bradstreet in combination with a mailout survey. No employment projections had been done at the time this information was obtained. Income projections were done using an inflation factor which was applied to the 1980 data from the census to develop estimates for their base year 1990.

Amarillo, Texas (37)

The City of Amarillo is the designated MPO. Base year estimates of population and housing units were developed using data from the 1980 census, aerial photos, and other local data. Total population for the study area was projected using a cohort survival model. The allocation of the projected population was accomplished by first estimating the number of dwelling units based on an average persons per dwelling unit. The city had previously adopted a comprehensive land use plan based on existing land uses as well as zoning requirements and policies. This, in combination with professional judgment, was used to allocate the projected dwelling units to the zones. Consideration was also given to differences between different types of dwelling units in reference to the average persons per dwelling unit. Multi-family dwelling units were found to have lower per person averages than single-family units. Judgment was used in terms of allocating which type was likely to occur in the zones relative to the amount of developable land available in each zone. Growth is now monitored on an annual basis through building permits and plats.

The travel demand model being used at the time did not use employment as a basis for estimating attractions. It did use acres of land by land use at the zone level. Using data from the 1980 census, aerial photos, the land development plan for Amarillo, and the amount of vacant land, acres of development were estimated by zone based on local knowledge of growth and proposed development. This method was used to update the base data from 1980 to 1985 and project it to the year 2005.

Income estimates for the base year 1985 were developed using the 1980 census data and applying the consumer price index. Projections were developed using historical trends. Data from the United States Department of Housing and Urban Development were also used in updating the income estimates.

Austin, Texas (38,39)

The MPO for the Austin study area is the Austin Urban Transportation Study Policy Advisory Committee. Population projections were available from a number of sources including the City of Austin Planning Department which used a cohort-component methodology for projecting population in 1982 and a Delphi method to update the 1982 forecasts to 1984. A 12-member panel of experts was given three rounds of questionnaires and asked to react to the 1982 forecasts concerning where growth patterns might have changed. After each survey, each member was given the results of the previous survey for comparison. Population projections were also available from the Texas Natural Resource Conservation Commission (TNRCC) which used a cohort-component method for forecasting. The Bureau of Business Research/Data Resources, Inc., produced population projections for the Austin MSA using a step-down approach with a system of simultaneous regression equations which related the Austin economy to that of the state and the United States. The regression relations were based on historical population and employment data. Projections were also available from the BEA, U.S. Department of Commerce, which used a step-down approach based on estimates of Austin's share of the Gross National Product. Three levels of growth were projected based on different assumptions concerning the amount of growth in Texas that Austin would capture. A fifth set of projections was available from the local private sector (Texas Update, Inc.) based on local projections of housing growth and absorption rates. Those projections were based on trends in housing absorption, utilities, other services, and projections of employment growth. All of these regional projections were employed to develop growth scenarios for the region.

Allocating the regional projections to zones in the Austin study area was done in a step-down process. This was initially done using a Garin-Lowry type model which considered population, employment and transportation in allocating population and service employment to sectors within the study area. The model was modified to incorporate different parameters in the allocation. Projections of basic employment which had been developed using regional projections made by the U.S. Department of Commerce, BEA, were input to the Garin-Lowry model. Those projections had been distributed using a limited Delphi technique where selected individuals were surveyed as to their judgment on what was likely to occur in the future. Those responses were compared and refined to reflect a consensus as to the likely location of the projected basic

employment. The Garin-Lowry model uses basic employment projections to iteratively generate population and service employment estimates required to support the basic employment based on historical relationships. The population is distributed to residential areas and the service employment to commercial areas using a gravity model based on the transportation system and the area's relative attractiveness. The relative attractiveness was measured by the area's capacity to absorb additional urban development which was based on the existing population and an increment of population defined by a shift in the density gradient. The theory was that gross residential densities decrease as distance from the central city increases; and the gradient change shifts as well, thus, increasing densities as the city's population increases. The resulting allocations to the sectors were checked for reasonableness, based on total land area of the sector, existing densities, and any existing conditions which might impede development.

The final allocation to zones within each sector was accomplished using a zone based land use information system. That system included information on subdivision activity, utility plans, office floor space, apartment buildings, retail floor space, industrial employers, state/federal employment, university employment, land area, and any existing characteristics which might impede development. The allocation was based on the planned development in the zone and the potential growth of the zone given its land area, current density, and development limiting characteristics. Average household size from the 1980 census was used to convert the zonal population estimates to dwelling units in areas that were developed in 1980. Suburban household size rates from the 1980 census were used in the newly developing areas in the suburbs.

Household income was assumed to be constant, and no shifts in income were projected. The only exceptions to this were the suburban areas which were projected to be developed. In those areas, the type of housing stock expected and the suburban household size were used to estimate the income.

Beaumont-Port Arthur, Texas (40)

The MPO for the Beaumont-Port Arthur area was the South East Texas Regional Planning Commission. Population, employment, and income were projected for three different growth scenarios: high, medium, and low. The model used for developing the regional population projection was a cohort survival model. The same fertility and mortality rates were used in all

three projections with the only difference being the assumptions that were input relative to migration variables. The migration variables were determined based on an analysis of the migrational behavior patterns over the previous 30 years. Allocation of the regional projections were made using a limited Delphi-type technique. Survey forms were sent to local planning staffs asking them to classify their growth expectation for each zone into one of six categories: large decrease (greater than ten percent), small decrease (one to less than ten percent), stable (zero percent change), small increase (one to ten percent), moderate increase (11 to 20 percent), and large increase (greater than 20 percent). These zonal growth projections were collectively used as the basis for allocating the regional population projections to the zones. Estimates of the number of dwelling units in each zone were based on the zonal population in combination with past and current occupancy rates, past and current housing mix, and dwelling unit replacement and loss percentages. The sources for these items were the census estimates of household size, local real estate marketing reports, county and local housing reports, and local building permit statistics.

Employment projections were developed using generally assumed characteristics for each of the growth scenarios and an analysis of historical employment patterns for the area. The analysis included a review of local comprehensive plans, local zoning maps, floodplain maps, and the historical employment shift in the area based on the employment categories established by the Standard Industrial Code (SIC). Using the employment growth patterns with state and national data from the Texas Employment Commission, Department of Labor Employment and Earnings Statistics, and the Department of Commerce's Bureau of Economic Analysis (BEA), three different employment scenarios were established. These projections were also compared for reasonableness with other nationally developed projections.

Household income projections were developed using the same basic methodology as in the population and employment projections. A review and analysis of the historic pattern of mean household income over the previous 30 years was done. Using the general income parameters for the medium and high growth scenarios with other variables (e.g., inflation factors, state income growth rate averages) based on data collected from the Texas Employment Commission and the Department of Labor's Employment and Earnings Statistics, the projections of mean household income were developed. The low growth scenario income parameters were

set by assuming no significant growth in income except for inflation.

Bryan-College Station, Texas (41)

The Bryan-College Station MPO served as the Urban Transportation Study Steering Committee. Land use and development is monitored through the use of building demolition and construction permits. Population and employment projections are developed by the respective cities and compared to growth curves developed at a zonal level which are used to make the final projections. Employment data from the Texas Employment Commission and the local Chamber of Commerce are also used in the analysis and projection process. Allocations are made using existing land use in combination with professional judgment and consultation with local developers in the communities. Census data are used to develop average household size and household income at the zone level. Average household size is used to convert population figures to households. Household income is assumed to remain constant for future projections of travel demand.

Dallas-Fort Worth, Texas (42)

The MPO for the Dallas-Fort Worth area was the North Central Texas Council of Governments. Population and employment projections at the county level were obtained from another agency, Data Resources, Inc. These projections were allocated to districts within the study area (a district was a combination of several zones) using DRAM and EMPAL. The sequence of use for DRAM and EMPAL typically requires EMPAL to be run first since its output is used in the DRAM.

The first step in developing and allocating employment forecasts was the compilation of accurate existing employment estimates at both the district and traffic analysis zone level. Estimates of existing employment by major industry at the district level were developed using establishment level employment data from Dunn & Bradstreet and/or the Texas Employment Commission as allocators for employment control totals at the county level which were obtained from the BEA. These control totals included proprietors, self-employed persons, and part-time jobs. This process resulted in estimates of employment by major groups at the district level for 1970 and 1980.

The forecast of regional employment at the county level by major industry group did not include proprietors and self-employed workers. Historical data from the BEA were used to develop ratios of total employment and of wage and salary employment. Linear regressions were used to project those ratios which were then used to adjust the county-level projections to estimate total employment by industry group. The allocation of the county level forecasts to the district level was accomplished using the urban simulation model EMPAL. EMPAL allocates each industry group's employment by income quartile to the districts. The basis for the allocation is the base year (ten years prior to the forecast year), district attractiveness characteristics, the proximity to employment in surrounding zones, and the forecast district-to-district travel times as a measure of accessibility to households. The allocation of the district-level forecasts to the traffic analysis zones was done using a probabilistic allocation program, heavily influenced by zone characteristics including existing commercial and residential space inventory, development announcements, and municipal land use plans. The district forecasts were allocated to the zone-level land use parcels on a successively lower development priority; first to existing space, then to announced developments, and then to vacant land designated for the appropriate land use by a municipal land use plan in five successively lower development priority categories. Assignment of development priorities and future land use mix was determined jointly with local planners.

The county-level population forecasts were allocated to the district level using the urban simulation model DRAM. DRAM develops forecast year probabilities of household location for households by income quartile based on a travel impedance function to all workplace districts and on an attractiveness index of the residence district. The travel impedance function reflects decreasing utility as travel time or costs from district to district increases. The attractiveness index combines the proportions of lag year (ten years prior) households in each income quartile in the district, the amount of residential land in the district in the lag year, and a composite land index. The composite index combines the lag year proportion of the district which was developed, the proportion of the lag year households which were multi-family, and a general accessibility index which approximates a land rent surface for the district. DRAM predicts district shares of households by type; these shares are multiplied by the total households in the district to obtain estimates of households by type and income quartile for the district.

Disaggregation of the district-level forecasts to the Traffic Survey Zones (TSZ) was done

using a probabilistic allocation program based on the characteristics of the TSZ, which included the inventory of existing commercial and residential space, development announcements, and municipal land use plans. District forecasts were allocated based on successively lower development priority, first to existing space, then to announced developments, and finally to vacant land designated for the appropriate land use by a municipal land use plan in five successively lower development priority categories. The assignment of priorities and future land use mix was a joint effort with local planners when the land use plans were coded for use by the computer program. When land use plans were not available, a default plan was used that was based on the current mix of land use in the TSZ, remaining vacant acreage, and the degree of development which had occurred since 1980. Since both EMPAL and DRAM develop estimates and distribution of employment and households by income, household income is generated by those programs.

El Paso, Texas (43)

The MPO for the El Paso area was the City of El Paso. Current population and housing unit estimates are updated approximately every six months by monitoring building permits and certificates of occupancy. These updates are at the census tract level. Other measures such as births, deaths, marriages, divorces, occupancy rates, aerial photos, and utility connections are also monitored and used to update and project population and housing units. Projections are developed using several different techniques. Cohort survival, historical trend analysis, outside data sources such as the Texas State Data Center, ratio method, etc., are some of the techniques used for developing population projections. Once developed, the coefficient of variation is computed for all projections. Those projections falling outside the acceptable range as determined by the coefficient of variation are dropped from further analysis. The remaining projections are averaged; the average projection is used for further analysis. Allocations of projections to census tracts and zones are made using existing data, local surveys, and Delphi techniques in combination with local professional judgment.

Employment estimates are obtained from a variety of sources including Dunn & Bradstreet, State Comptroller, telephone directory, Texas Employment Commission, and local surveys. An arrangement was made with the city fire department to survey businesses when

building inspections were conducted. This has significantly increased the number of employers recorded in the data base. Employment projections were to be done using some type of a ratio technique. The MPO had not forecast income but had updated the 1980 income data to 1987 using a Delphi technique. They anticipated forecasting income by categories (e.g., low, low medium, etc.) and not by specific dollar amounts.

Houston-Galveston, Texas (44)

The MPO for the Houston-Galveston area was the Houston-Galveston Area Council of Governments (HGAC). Regional population and employment projections were obtained through a study conducted jointly by a local agency called the Interagency Data Base Task Force (IDBTF), a data base review committee, and the HGAC. That study reviewed and analyzed four different projections for the Houston-Galveston region which had been developed by the HGAC, the Rice Center, the TNRCC, and the National Planning Association. The results of that study were three growth scenarios; one was adopted for use in transportation planning. The allocation of the regional projections was done in a two-step process, first to the census tracts within the region and second to the transportation serial zones in each census tract. The initial allocation to the census tract levels was done using the growth allocation model, GAP. This model used regression techniques to allocate population, housing, and employment to the census tract level. The independent variables included accessibility, developed land, past growth, infrastructure, schools, etc. The allocation to the zone level was based on an analysis of existing land use and an assessment (based on professional judgment) as to the share of growth (or decline) each zone was likely to experience. Land use and employment was updated on an annual basis at the zone level which provided a good base for performing these assessments.

The income forecast was developed in a manner similar to household and employment allocation to the zone level. An assessment (based on professional judgment) was made of each zone based on where the zone was likely to fall relative to household income; for example, a zone might be projected to consist mostly of medium income households. This assessment would take into account the projected growth (or decline) for the zone in terms of households and employment. Using relationships established from census data, a distribution of households by household income was estimated based on the projected general income category of the zone.

It should be noted that the HGAC is currently developing and calibrating DRAM and EMPAL models for use in allocating projection updates.

Laredo, Texas (45)

The MPO for the Laredo area was the Laredo Urban Transportation Study Steering Committee. Population projections are developed using a standard cohort survival model with local historical birth and death rates and migration rates from the U.S. census. Results are compared for reasonableness; forecasts are done by the TNRCC and the Texas State Data Center. Estimates of current population at the serial zone level are developed using census data updated by building/housing permits and residential water hookups. Projection allocations are anticipated to be done by analyzing buildable acreage within each serial zone in combination with the zone's allowable population density based on zoning ordinances. Where no zoning ordinances apply (i.e., suburban areas), an analysis will be done on the buildable acreage and on local judgment used relative to the likelihood of development within the time frame under study. Average number of dwelling units per acre and persons per dwelling unit as reported in the census will be used to develop estimates of dwelling units per zone.

Longview, Texas (46)

The MPO for the Longview area was the City of Longview. Regional population projections are developed using a cohort survival model. Disaggregation to the zone level was done by considering water hookups, the area's socioeconomic makeup, migration, and local, professional judgment. Estimates of dwelling units were developed using base year data, census household size data, socioeconomic makeup, and local, professional judgment. For undeveloped areas in the base year that were forecast to be developed, rates for similar type areas were used to estimate dwelling units. Employment was not used in prior studies. In those studies, land use had been forecast and used in the travel demand models. The MPO, however, purchased employment data from Dunn & Bradstreet and were anticipating using a Delphi technique to project employment. Allocations were based on judgment, considering services available and the amount of land that was developable.

The estimation of household income was based primarily on census data. Zone maps were

overlaid on the census tract maps, and the census data were adjusted based on housing value and local knowledge. Income projection was based on what was anticipated; low income areas were left the same and areas that were anticipated to develop were moved up. Local, professional judgment was used in the decision process.

Lubbock, Texas (47)

The MPO for the Lubbock area was the Lubbock Urban Transportation Study Steering Committee. Population forecasts were updated yearly using trends in employment, housing counts, residential telephones, water meters, and historical population. Allocations were made to what is termed "planning units" (about one square mile in area) based on the number of dwelling units by type per planning unit and average number of persons per dwelling unit type. A proposed land use plan was also used which was developed based on historical trends.

San Angelo, Texas (48)

The MPO for the San Angelo area was the city of San Angelo. Regional population forecasts were obtained from the Texas State Data Center. Estimates of current population were developed using water and sewer connections. Land use forecasting was based on discussions with local developers, and historical trends were based on local, professional judgment. Employment and income forecasting were done by trend line projections combined with local judgment.

San Antonio, Texas (49,15)

The MPO for the San Antonio area was the San Antonio Urban Transportation Study Steering Committee. Regional population projections which had been developed using a cohort survival model were obtained from the TNRCC. These projections were allocated to census tracts within the Bexar County area based on an analysis of the historical population and household trends of each census tract and on local judgment concerning development patterns within the area. The census tract population and household estimates were allocated to the serial zones using census block information and local judgment.

Total employment for the study area was projected based on an analysis of historical

trends relating employment, civilian labor force, and labor force participation rates. Much of this analysis was done using regression models. Employment projection by category was also based on a regression analysis of the total employment within each category over time. Each category was projected independently to develop an initial estimate of employment. These estimates were used to develop the proportion of the total employment in each category and were applied to the projected total employment for the study area to develop the employment estimates within each category. Employment projections by category were combined into the three groups needed for the travel demand models. An analysis then examined each zone in the study area and developed a list of attributes for each zone. These attributes were those characteristics which were felt to have an influence on the development potential for the zone. An initial estimate of the employment for each zone was also made based on the 1980 employment in the zone and the overall developability of the zone based on the analyst's judgment. After these estimates were made, a comparison was made between the total employment computed by summing the initial estimates of employment for each zone with the projected control totals for the study area. The allocation of the difference in employment (the difference between the study area control total and the total zonal estimates) was done in a two-step process. The first step was the allocation of employment by category to 45 large subareas within the study area. Employment data from the 1980 census were analyzed to identify the combined attributes of the zones within each large subarea which correlated with the employment within the subarea. The zone's attributes considered included accessibility, population, development potential, stability, and infrastructure. Many of these attributes had been determined for each zone based on professional judgment. Those attributes which had a strong correlation with the 1980 employment data were used to allocate the remaining employment. A similar type analysis was done for each subarea to determine those attributes which correlated with the 1980 employment levels at the zone level for the study area. These then became the basis for allocating subarea employment to the zones within each subarea. Special generators were not included in this process; employment for special generators (including those anticipated to be constructed by the forecast year) was estimated individually based on historical trends and added to the projected employment at the zone level.

Household income was projected using historical trends in combination with a

mathematical model to predict the distribution of households by household income. Historical trends in per capita income (in constant dollars) were used with regression analysis to project the per capita income for the study area. This estimate, multiplied by the projected population, yielded an estimate of total income for the study area which, when divided by the estimated number of households, produced an estimate of the average household income for the forecast year. This estimate was used with a calibrated Gamma distribution (calibrated on 1980 census data) to produce an estimate of the distribution of households by household income. An analysis of the projected distribution with the 1980 distribution resulted in initial estimates of income growth for selected income ranges. These were then applied to the 1980 zonal estimates of average household income to compute initial forecasts of the average household income for the forecast year. A distribution of households by household income was next computed for each zone based on the forecast of average household income (using the previously calibrated Gamma curve relationship). The zonal distributions were summed and the total compared with the forecast distribution for the study area. Correction factors were computed for each income range and applied to the zonal distributions. New estimates for the zonal mean household incomes were computed (based on the adjusted distribution) and used to estimate a new income distribution for each zone. This process was repeated iteratively until the distribution obtained by summing the zonal distributions closely matched the projected distribution for the study area. The zonal distributions were then used to compute the final projections of average household income for each zone.

Texarkana, Texas (50)

The MPO for the Texarkana area was the Ark-Tex Council of Governments. Population projections were previously done using historical trend analysis. Indications are, however, that future projections will be done using a cohort survival model. Allocations to zones will be done using a computer-based program which allocates population on the basis of the relative attractiveness of competing areas. Households were estimated using census data at the census tract level. It was anticipated that a land use plan would be developed using a retail market study, a housing needs study, and an analysis of zoning regulations; professional judgment would be used for projecting the future land use. A method for projecting employment had not been

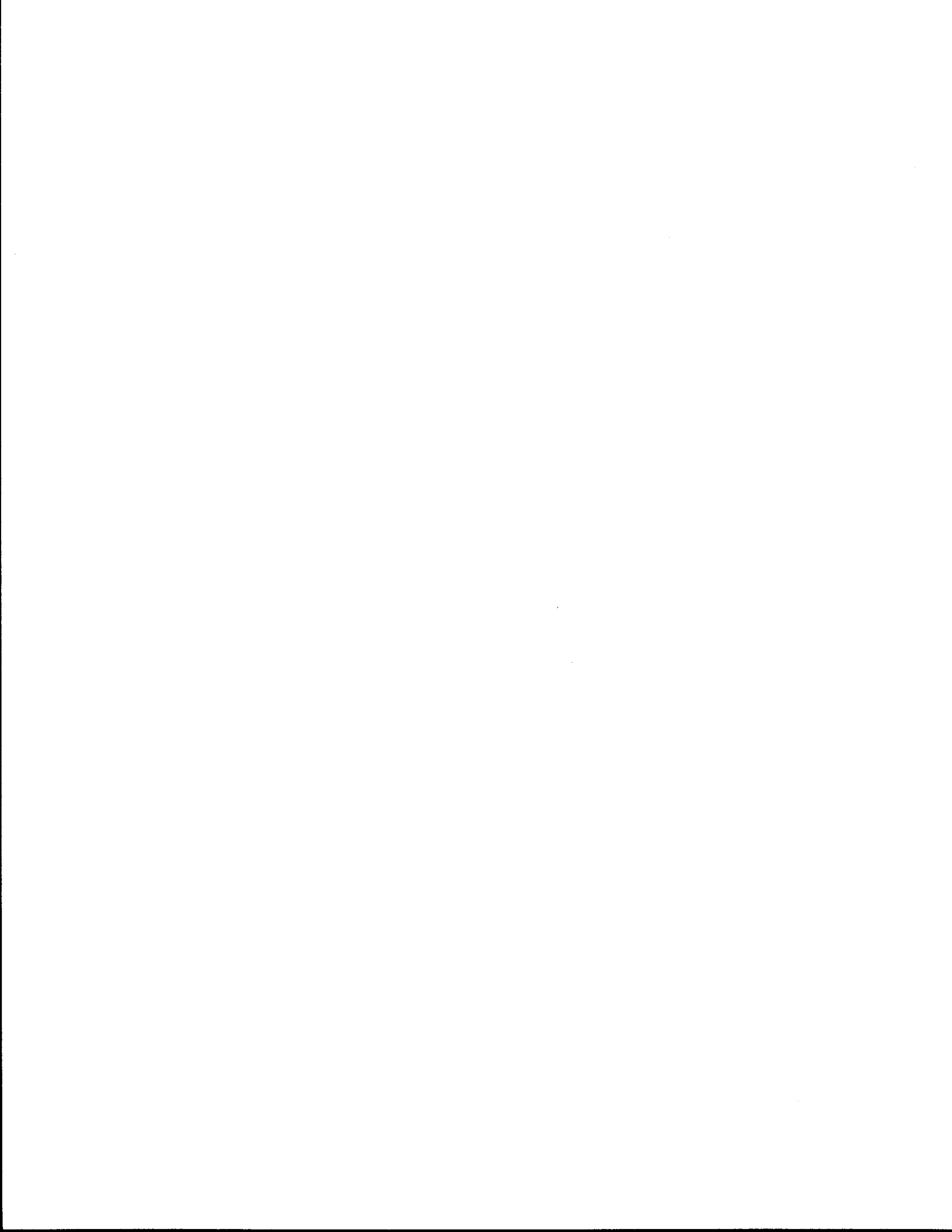
decided.

Household income would be estimated using a shift share model based on state and national growth. It was anticipated that an economic base study would also be done. The method for estimating income at the zone level had not be decided.

Wichita Falls, Texas (51)

The MPO for the Wichita Falls area was the City of Wichita Falls. Existing year population estimates were developed using five techniques: censal ratio method using civilian labor force estimates, censal ratio method using school enrollment for kindergarten through eighth grade, housing method based on number of dwelling units, a combination of net natural change with historical rate of migration method, and a cohort component method. The projections from each of these methods were analyzed and compared. The final estimate was an average of all or some of the results from the methods depending on the variation in the estimates. Population projections were done using a cohort survival model with varying migration assumptions. The final selected projection(s) was allocated to sectors within the study area based on housing stock currently available, projected new construction, changing family size based on the age of the sector's existing population and stability, physical constraints, and the potential for bringing in future development. Allocations to census tracts and subsequent allocations to serial zones within the sectors were done using a similar type analysis. Population estimates were converted to households based on the average persons per household at the census tract level. Employment projections had not been done.

The technique used to estimate household income was based on an analysis of the 1980 census data and historical trends in income for the area. Each census tract was analyzed in terms of its likelihood of growth or of remaining stable. Five categories of income were used, and the final projection was based on professional judgment combined with historical trends and local knowledge of the area.



SUMMARY AND RECOMMENDATIONS

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 of equal importance as the model itself. If the model is good, and incorrect information is input to the model, the results are 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.

This chapter presents a summary and various recommendations with respect to the input data for predicting urban travel demand. Another report (Reference 55) documents a comprehensive analysis of the travel surveys, survey methodologies, and recommendations for improving the surveys. As in the previous sections, the discussion will be directed toward the input data for the trip generation models used by the Texas Department of Transportation (TxDOT).

URBAN DEMAND MODELING DATA

As discussed previously, a large number of methods and techniques are available and have been used to develop and project the input data needed for travel demand modeling. The primary data that this study addressed were the development of population, households, household income, auto ownership, employment (by three categories), and area type estimates at the zone level. The zone level is the level at which trip productions and attractions will be estimated in the trip generation phase of the urban travel demand modeling process. The purpose for the review and analysis of the different techniques and methods was to identify a method or technique which

could be expected to produce the best results. Based on the review of the methods and techniques presented in the previous section, no one method or technique was found that could be considered superior to the others. This finding is similar to the finding in the study done in Florida (30). The review, however, did indicate certain elements in the process for developing the data are used more often and appear to be superior to other procedures. Certain techniques also appear to have more applicability than others in the development of estimates for travel demand modeling. As a result, it was possible to develop a specific set of recommendations and guidelines for the development of the necessary forecasts for urban travel demand modeling.

The development of a recommended procedure with methodologies for use in Texas was accomplished within the limitations of the following guidelines:

1. The process and methods used should be sound in logic and reasoning. This basically says that the steps involved in the process should be logical. The methods for developing the estimates should be reasonable and have a strong theoretical base.
2. The application of the process and methods should be straightforward with no unusual requirements and/or stipulations.
3. The process and method should be commensurate in detail with the size and complexity of the area under study. This implies that the general process and/or methods recommended may be amended or adjusted in accordance with the needs of the area under study.
4. The process and method(s) should require input data that are readily available from existing sources. Any procedure or method applied should use available information and not require the development of extraordinary input data.
5. The process and method(s) should give reasonable results within the limits of expectation of the area under study. Any procedure and/or method used to develop estimates for the purpose of travel demand modeling will have certain limitations. These should be recognized relative to the detail, complexity, and accuracy of the selected procedure and method(s).

These guidelines are intended to assist in developing a process and methodology that would have broad applicability, produce reasonable results, and be easy to implement. It is recognized that the resulting process and method(s) are not applicable in all situations, and some urban areas will continue to develop their urban modeling data using procedures and techniques developed locally.

The general process which is recommended for the development of the input data for urban travel demand modeling is as follows:

1. Obtain base year estimates of each data element at the zone level.
2. Develop regional estimates of employment by category.
3. Develop regional estimates of population and households.
4. Allocate the regional estimates of employment, population, and households to subregions within the study area.
5. Allocate the employment, population, and households to the zones within each subregion.
6. Develop regional estimates of households by household income.
7. Develop zonal estimates of households by household income.
8. Develop regional estimates of households by auto ownership.
9. Develop zonal estimates of households by auto ownership.

The rest of this section discusses the recommended procedures and methodologies involved in accomplishing each step.

Step 1: Base Year Data Estimates

This data item is considered critical for understanding what exists within a study area and for giving the analyst an intuitive basis for the forecasting process in later steps. This data will normally be available, since it is usually maintained at the zone level by local agencies. It is anticipated that TXDOT will purchase the 1990 Urban Transportation Planning Package (UTPP) for each urban area in Texas with a population greater than 50,000. This will be the source for the base year estimates for most urban areas. The level of detail may vary with regard to whether the data are available at the zone or census tract level. Each MPO should be encouraged to obtain the UTPP information at both the census tract and zone level. The specific data items that are expected to be included in the UTPP at the zone level are population and households, employment, household income, and auto ownership. The 1980 UTPP included a breakdown of households by household size, household income, and auto ownership. This information, with secondary sources, will provide a base for the development of the zonal projections for the urban area.

Step 2: Regional Estimates of Employment

The second step is to develop regional projections of employment. The three types (i.e. categories) of employment recommended for use in Texas are basic employment, retail employment, and service employment. The description of these are shown in Table 5 with the appropriate standard industrial classification (SIC) code ranges associated with each category. It is difficult to say whether one technique or another is better in the development of employment forecasts due to the complexity of factors that influence employment and the overall economy of an area and how that economy is interrelated and interacts with other regional economies, the nation, and the world. Few, if any, areas are isolated and not influenced, in some form or fashion, by events in the nation and/or world. Consequently, the options open to an urban area when faced with the need to develop employment forecasts at the regional level can be narrowed to three choices: 1) a local agency develops the forecasts using either a local model or other technique, 2) a consultant or outside firm/agency is hired specifically to develop the forecasts, or 3) forecasts that have already been prepared by another agency, firm, or governmental entity are used. Due to the complexities and amount of data involved as well as the general lack of resources of many agencies to undertake the process of employment forecasting (using a reasonably sound theoretical model), it is recommended that local agencies utilize the projections that are developed by an outside firm (i.e., option 3). Forecasts may be purchased from firms which conduct economic forecasting. Another option is to use forecasts that have already been done by agencies such as the BEA, U.S. Department of Commerce. The BEA produces projections of employment, population, and income for the United States for 40 years into the future and updates the projections every five years. These projections are then allocated to the states and subsequently to Metropolitan Statistical Areas (MSA) within each state. The BEA projections are suggested since they are developed at a national level using population projections (developed by the census bureau) and gross national product (GNP) and are updated on a regular basis. They will be used in this report for the example presented illustrating the recommended procedures. In most situations where projections are being used that were developed by another agency, it will still be necessary to analyze the projections to ensure that they are consistent with what is known about the area and to adjust the projections to incorporate known local conditions that may not have been considered in the original projections.

**Table 5
Employment Categories**

Employment Category	SIC Range	Industry(s)
Basic	1000 - 1499	Mining
	1500 - 1799	Construction
	2000 - 3999	Manufacturing
	4000 - 4999	Transportation, Communications, and Public Utilities
	5000 - 5199	Wholesale Trade
Retail	5200 - 5999	Retail Trade
Service	6000 - 6799	Finance, Insurance, and Real Estate
	7000 - 8199	Hotels, Personal, Business, etc. Services
	8200 - 8299	Education Services
	8300 - 8999	Social, Miscellaneous, etc. Services
	9000 - 9799	Government

Step 3: Regional Population/Household Estimates

The third step is the development of regional population and household projections. As with employment, three options are available to a local agency. The first is to hire an outside firm/agency to develop the regional projections. The second is for the local agency to develop the regional projections. The third is for the local agency to use forecasts that have already been developed by another firm/agency. The recommendation is for the local agency to review the population forecasts for their regional area that have been developed by outside agencies (e.g., the BEA) and compare the forecasts with their own historical databases to decide if the forecasts appear reasonable. If the forecasts are not considered reasonable and consistent with local knowledge, it is recommended the local agency develop the population forecasts themselves, because the local agency is more aware of what has been and is happening within their urban area in terms of population and housing changes. If a local agency does not feel it has the staff or

expertise to accomplish this in house, it is recommended they use a forecast developed by another firm/agency. These may be purchased or obtained free of charge in some cases.

If the local agency elects to develop their own regional forecast, the recommended methodology is the cohort survival technique. This is recommended because it has a sound theoretical basis; and if the assumptions used are correct, the forecast will be correct. The data needed for doing the forecast are the existing base year population by sex and age cohort (five-year cohorts are recommended), fertility rates for each childbearing-age cohort (generally ages 15 through 44), survival rates by sex and age cohort, and historical information on net migration by sex and age cohort for the area. The most difficult item to obtain has typically been that for migration, especially by age and sex cohort. Historical information on migration may be obtained from the census bureau.

After the regional population, household, and employment projections have been completed, the data should be reviewed for consistency prior to formal adoption by the planning agency. This review should consider total population as it relates to total employment. For example, total employment should be reasonable in terms of both total population and the population within the labor force (i.e., the population which falls between the ages of 16 and 65). Historical labor participation rates should be obtained and the projected labor participation rates reviewed to ensure that they are consistent or reasonable in respect to the historical data.

Once the regional projections of population and employment are completed, it is recommended that they be formally presented and adopted by the appropriate planning agency prior to proceeding to the next step.

Step 4: Allocation to Subregions

The first step in allocating regional forecasts to subregions is to define the subregions. The number of subregions to use is entirely dependent on the urban area and the planning agency responsible for the allocation. Because the number of zones within an urban area may range from a few hundred to several thousand, the number of subregions will vary. For example, an area consisting of 200 zones might establish five to ten subregions (aggregations of zones) for the initial allocation. The boundaries should be consistent with zonal boundaries, taking into consideration natural geographical boundaries, general population and employment characteristics

within the area, and political jurisdictions. For example, it would not be recommended that large industrial areas be split unless there were particular reasons for splitting them.

Two methods of allocation are considered appropriate. One is the use of a computerized model such as DRAM or EMPAL. These models appear to be gaining widespread use in many urban areas. The drawback to their use is the data requirements and staff expertise required for model calibration and maintenance for future use. The use of such models is suggested for those urban areas large enough to warrant the cost and training necessary to develop and maintain them. This would typically be areas exceeding 500,000 population.

The second method of allocation considered appropriate is a Delphi technique. This method is considered applicable in nearly any size area and especially in areas with less than 500,000 population. The Delphi technique is a means of establishing qualitative measures of potential for growth (at subregional and zonal levels). A panel of local individuals is used to establish the potential for growth and perform the actual allocation. The information used for that allocation is typically historical data (population and employment by category) and the local knowledge of the panel members. The reader is referred to Reference 56 for a description and illustrative example of the use of the Delphi technique.

Step 5: Allocation to Zones

Following the initial allocation to the subregional areas, an additional allocation may be accomplished to allocate the subregional estimates of population and employment to smaller areas within the subregions. While it is possible to allocate directly to the zones within the subregions, it is suggested that an additional allocation step be performed prior to allocating to the zones. This would involve the allocation of population and employment to subareas within the subregions. Again, these are defined based on the same types of considerations as the subregions. The number of subareas within each subregion will vary depending on the subregions size and characteristics. For example, one subregion typically consists of the downtown area (i.e., all the zones which make up the central business district). Depending on its size, there may be only two to four subareas within that subregion. Other subregions may be further subdivided into as many as five to 15 subareas. The recommended method for allocating the subregion population and employment to the subareas is the Delphi technique. This technique is considered appropriate

for both large and small urban areas.

Following the allocation to the subareas within the subregions, the final allocation is made to the zones. Due to the large number of zones in most urban areas, it is recommended that the allocation of the subarea population and employment to the zones be based on local staff professional judgment. The final allocations should be reviewed by the panel used in the Delphi process for comment, discussion, and concurrence.

Step 6: Regional Estimates of Households by Household Income

For base year conditions, it is assumed that data from the census will be used. For 1990, the data from the Census Transportation Planning Package (CTPP) will provide the number and percentage of households distributed by household income. These data are essential as a basis for developing projections of household income both at the regional and zonal levels.

The first step in developing regional estimates of households by household income is to develop the estimate of average household income. The recommended procedure for developing this estimate is to use historical data and project the average household income using a regression equation. Historical data may be obtained from the census data. Two adjustments will be necessary for the data to be used. One is to adjust from family income (as reported in the pre-1980 census) and the other is to adjust for the year to put all income data in terms of the same value (i.e., constant dollars). The first adjustment may be made by examining the ratio of family to household income as reported in the 1980 and 1990 censuses. This ratio may be applied directly to earlier estimates of family income or may be slightly modified and then applied. If a significant difference is observed in the 1980 and 1990 ratios, it may be necessary to adjust the ratio before applying it to the earlier census estimates of family income.

The second adjustment is to place all income data in terms of the same relative value or in terms of constant dollars. It is recommended that the Consumer Price Index (CPI) developed by the Department of Labor, Bureau of Labor Statistics, be used for this purpose. The development of regression equations for estimation purposes may be done in several ways. For example, the average household income may be used as the dependent variable; and the independent variables may be year, population, average household size, or combinations of these variables. It should be remembered that whichever variable is used will also have to be forecast

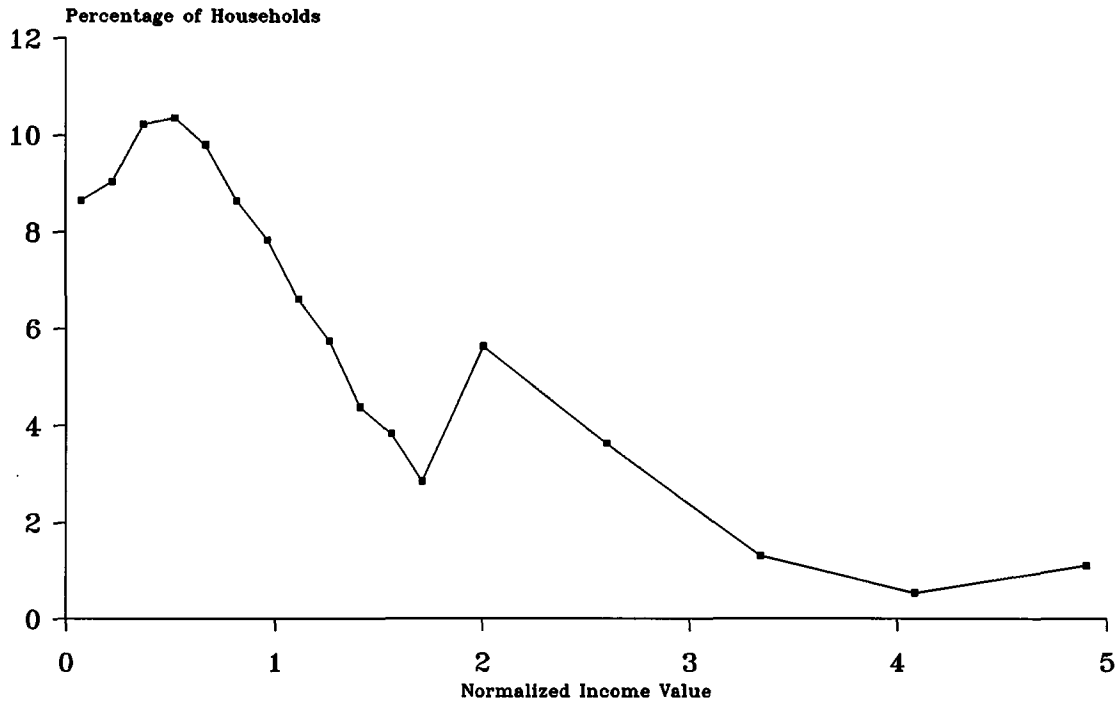
for use in projecting the dependent variable. Another method which has been used is to convert household income to per capita income by multiplying the total number of households by the average household income and dividing the result by the total population. Per capita income may then be used as the dependent variable in developing the regression equation. It is suggested that plots be made of both average household income and per capita income over time to visually determine which will produce the better results.

Projected average household income can also be determined by using secondary sources such as the BEA. The BEA also projects per capita personal income (in constant dollars) which may be used to develop an estimate of the average household income for a future year. In using secondary sources, it is suggested that comparisons be made with both local and census data to ensure that the projections (and historical data) are consistent.

After obtaining an estimate of the average household income, the next step is to develop an estimate of the number (or percentage) of households by income range for the projected average household income. While a number of methods probably exist for accomplishing this task, only two are mentioned in this report. The first is discussed and described in detail in Reference 9. It also includes a discussion of developing estimates of average zonal household income. The reader is encouraged to review that paper for more detail. Briefly, the methodology is based on the use of the projected mean household income and historical cumulative household distributions to develop a projected distribution of households by household income and growth factors for applying to zonal incomes. In many ways, the method described in that reference is similar to those presented here with the major difference being the method for estimating the future distribution and the zonal incomes.

Two methods are described, each of which gives acceptable results. One is a manual method, and the second is a mathematical method. The manual method begins with the tabulation of an existing distribution of households by household income. For example, Table 6 presents the distribution of households by household income for the San Antonio Metropolitan Statistical Area (MSA) as reported from the 1990 census (note the income ranges have been aggregated from the categories used in the census). The 1989 mean household income was \$33,646, and the 1989 median household income was \$26,092. Table 7 shows the same numbers as Table 6 except each income range has been normalized by dividing the mid-range value by

Figure 2
Distribution of Households by
Normalized Income Ranges



Based on 1990 Census Data
 San Antonio MSA

the mean household income. The results of plotting the percentage of households versus the normalized range values are shown in Figure 2. For purposes of definition, the plot in Figure 2 may be referred to as a master curve. It is used to develop a projected distribution of households by household income based on a projected mean household income. To illustrate how this is done, assume the projected household income for the year 2020 in the San Antonio MSA is \$37,011 in 1989 dollars. Each mid-range income value is divided by the projected mean household income. These values are then used with the data in Table 6 to develop a projected distribution of households by household income. For example, Table 7 shows the results of dividing each income range mid-value by the projected mean household income. Also shown in Table 7 are the percentage of households estimated using those relative values (i.e., the mid-income range divided by the projected mean income) and the corresponding Y-value (i.e.,

percentage households) estimated from the data shown in Table 6. For example, the first X value is 0.0675. The corresponding Y value (or percentage of households) is estimated by straight line interpolation using the data from Table 6. The resulting estimate is 7.86 percent. Assuming that each data point (from Table 6 plotted in Figure 2) may be connected by a straight line, the estimate of the percentage of households for each relative value shown in Table 7 may be estimated by mathematical interpolation. The following equation illustrates the relationships involved:

$$\frac{Y_i - Y_{i-1}}{X_i - X_{i-1}} = \frac{Y'_i - Y_{i-1}}{X'_i - X_{i-1}} \quad (\text{Eq 1})$$

where:

Y_i = *Percentage of households at relative income value X*

X_i = *Relative income value (mid-point value divided by mean income)*

Y'_i = *Projected percentage of households at new relative income value*

X'_i = *New relative income value (mid-point value divided by projected mean income)*

i = 1, 2, 3, . . . , 17

Rearranging Equation 1 to yield a value for Y'_i which is the estimate of the percentage of households at the new relative income value, results in the following:

$$Y'_i = \frac{(Y_i - Y_{i-1}) * (X'_i - X_{i-1})}{(X_i - X_{i-1})} + Y_i \quad (Eq 2)$$

Table 8 presents the computations for the first iteration. This is somewhat cumbersome but may be computed by hand. The resulting estimates that were computed are shown in Table 7. It will be noted that these estimates do not add to 100 percent. An adjustment factor is computed and applied to each percentage to ensure the total will add to 100 percent. The resulting mean household income must next be computed to ensure the distribution will yield the correct mean as projected, in this example \$37,011. Multiplying the percentage households in each range by the mid-range value and summing yields a mean income (using the percentages shown in Table 7 and Table 8 of \$35,144 which is less than that projected). The above procedure is repeated interpolating within the distribution computed each time. Six iterations were required to yield a distribution which closely approximates the projected mean household income. Figure 3 shows the original distribution and the forecast distribution.

Table 6
Distribution of Households by Household Income
San Antonio MSA

1989 Income Range	No. Households	Percentage	Cumulative Households	Cumulative Percentage
\$ 0 - \$ 4,999	38,496	8.52	35,424	8.65
\$ 5,000 - \$ 9,999	40,812	9.04	79,308	17.56
\$ 10,000 - \$ 14,999	46,177	10.22	125,485	27.78
\$ 15,000 - \$ 19,999	46,774	10.35	172,259	38.13
\$ 20,000 - \$ 24,999	44,276	9.80	216,535	47.93
\$ 25,000 - \$ 29,999	39,010	8.64	255,545	56.57
\$ 30,000 - \$ 34,999	35,376	7.83	290,921	64.40
\$ 35,000 - \$ 39,999	29,810	6.60	320,731	71.00
\$ 40,000 - \$ 44,999	25,905	5.74	346,636	76.74
\$ 45,000 - \$ 49,999	19,775	4.38	366,411	81.12
\$ 50,000 - \$ 54,999	17,280	3.83	383,691	84.95
\$ 55,000 - \$ 59,999	12,867	2.85	396,558	87.80
\$ 60,000 - \$ 74,999	25,445	5.63	422,003	93.43
\$ 75,000 - \$ 99,999	16,399	3.63	438,402	97.06
\$100,000 - \$124,999	5,886	1.30	444,288	98.36
\$125,000 - \$149,999	2,455	0.54	446,743	98.90
\$150,000 Plus	4,988	1.10	451,731	100.00
Total	451,731	100.00		

Table 7
Normalization of 1990 Distribution of
Households by Household Income
(Example)

1989 Income Range	Income Range Mid-Point	1989 Mean Household Income	Relative Value ¹	Percentage Households
\$ 0 - \$ 4,999	\$ 2,500	\$ 33,646	0.0743	8.65
\$ 5,000 - \$ 9,999	\$ 7,500	\$ 33,646	0.2229	9.04
\$ 10,000 - \$ 14,999	\$ 12,500	\$ 33,646	0.3715	10.22
\$ 15,000 - \$ 19,999	\$ 17,500	\$ 33,646	0.5201	10.35
\$ 20,000 - \$ 24,999	\$ 22,500	\$ 33,646	0.6687	9.80
\$ 25,000 - \$ 29,999	\$ 27,500	\$ 33,646	0.8173	8.64
\$ 30,000 - \$ 34,999	\$ 32,500	\$ 33,646	0.9659	7.83
\$ 35,000 - \$ 39,999	\$ 37,500	\$ 33,646	1.1145	6.60
\$ 40,000 - \$ 44,999	\$ 42,500	\$ 33,646	1.2632	5.74
\$ 45,000 - \$ 49,999	\$ 47,500	\$ 33,646	1.4118	4.38
\$ 50,000 - \$ 54,999	\$ 52,500	\$ 33,646	1.5604	3.83
\$ 55,000 - \$ 59,999	\$ 57,500	\$ 33,646	1.7090	2.85
\$ 60,000 - \$ 74,999	\$ 67,500	\$ 33,646	2.0062	5.63
\$ 75,000 - \$ 99,999	\$ 87,500	\$ 33,646	2.6006	3.63
\$100,000 - \$124,999	\$112,500	\$ 33,646	3.3436	1.30
\$125,000 - \$149,999	\$137,500	\$ 33,646	4.0867	0.54
\$150,000 Plus	\$165,000	\$ 33,646	4.9040	1.10
Total	-	-	-	100.00

¹Mid-point of income range divided by mean household income

Table 8
Estimation of Forecast Distribution of
Households by Household Income
(Example - First Iteration)

2010 Income Range (1989 Dollars)	Income Range Mid-Point	2010 Mean Household Income (1989 \$)	Relative Value	Estimated Percentage Households ² (1st Iteration)
\$ 0 - \$ 4,999	\$ 2,500	\$ 37,011	0.0675	7.86
\$ 5,000 - \$ 9,999	\$ 7,500	\$ 37,011	0.2026	8.99
\$ 10,000 - \$ 14,999	\$ 12,500	\$ 37,011	0.3377	9.95
\$ 15,000 - \$ 19,999	\$ 17,500	\$ 37,011	0.4728	10.31
\$ 20,000 - \$ 24,999	\$ 22,500	\$ 37,011	0.6079	10.03
\$ 25,000 - \$ 29,999	\$ 27,500	\$ 37,011	0.7430	9.22
\$ 30,000 - \$ 34,999	\$ 32,500	\$ 37,011	0.8781	8.31
\$ 35,000 - \$ 39,999	\$ 37,500	\$ 37,011	1.0132	7.44
\$ 40,000 - \$ 44,999	\$ 42,500	\$ 37,011	1.1483	6.40
\$ 45,000 - \$ 49,999	\$ 47,500	\$ 37,011	1.2834	5.56
\$ 50,000 - \$ 54,999	\$ 52,500	\$ 37,011	1.4185	4.36
\$ 55,000 - \$ 59,999	\$ 57,500	\$ 37,011	1.5536	3.87
\$ 60,000 - \$ 74,999	\$ 67,500	\$ 37,011	1.8238	3.92
\$ 75,000 - \$ 99,999	\$ 87,500	\$ 37,011	2.3642	4.43
\$100,000 - \$124,999	\$112,500	\$ 37,011	3.0396	2.25
\$125,000 - \$149,999	\$137,500	\$ 37,011	3.7151	0.92
\$150,000 Plus	\$165,000	\$ 37,011	4.4581	0.79
Total	-	-	-	104.79

²Estimated by reading values off curve shown in Figure 3

Table 9
Interpolation Example
(First Iteration)

i	X_i	Y_i	X'_i	$X_i - X_{i-1}$	$Y_i - Y_{i-1}$	$X'_i - X_{i-1}$	Y'_i
0	0.0000	0.00	0.0000	NA	NA	NA	0.00
1	0.0743	8.65	0.0675	0.0743	8.65	0.0675	7.86
2	0.2229	9.04	0.2026	0.1486	0.39	0.1283	8.99
3	0.3715	10.22	0.3377	0.1486	1.18	0.1148	9.95
4	0.5201	10.35	0.4728	0.1486	0.13	0.1013	10.31
5	0.6687	9.80	0.6079	0.1486	-0.55	0.0878	10.03
6	0.8173	8.64	0.7430	0.1486	-1.16	0.0743	9.22
7	0.9659	7.83	0.8781	0.1486	-0.81	0.0608	8.31
8	1.1145	6.60	1.0132	0.1486	-1.23	0.0473	7.44
9	1.2632	5.74	1.1483	0.1487	-0.86	0.0338	6.40
10	1.4118	4.38	1.2834	0.1486	-1.36	0.0202	5.56
11	1.5604	3.83	1.4185	0.1486	-0.55	0.0067	4.36
12	1.7090	2.85	1.5536	0.1486	-0.98	-0.0068	3.87
13	2.0062	5.63	1.8238	0.2972	2.78	0.1148	3.92
14	2.6006	3.63	2.3642	0.5944	-2.00	0.3580	4.43
15	3.3436	1.30	3.0396	0.7430	-2.33	0.4390	2.25
16	4.0867	0.54	3.7151	0.7431	-0.76	0.3715	0.92
17	4.9040	1.10	4.4581	0.8173	0.56	0.3634	0.79

Table 10 presents the resulting values for each iteration and the mean household income.

The previous method presented for developing a projected distribution of households by household income is somewhat cumbersome but is amenable to implementation using a computer-based spreadsheet. Another option is a mathematical method using relationships calibrated on

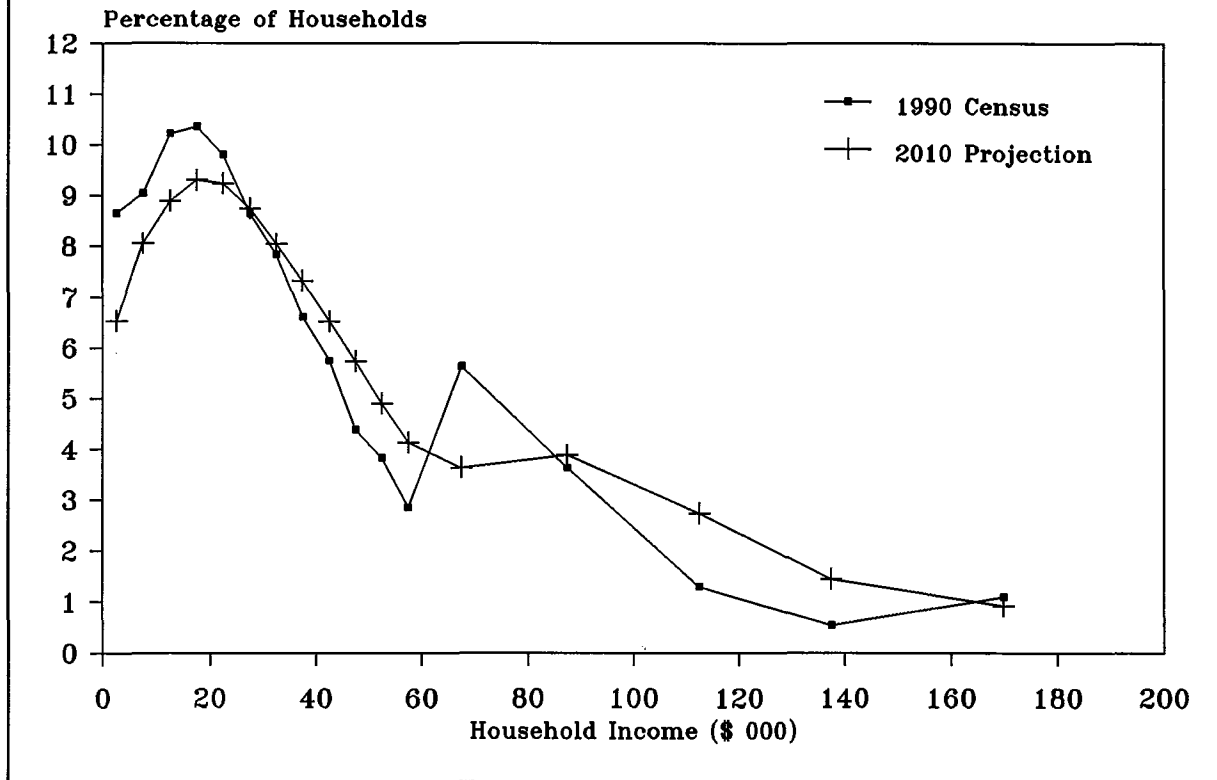
Table 10
Iteration Results

Income Range Midpoint	Base Year Distribution ³	1st Iteration	2nd Iteration	3rd Iteration	4th Iteration	5th Iteration	6th Iteration
\$ 2,500	8.65	7.50	6.94	6.70	6.60	6.55	6.53
\$ 7,500	9.04	8.57	8.28	8.14	8.08	8.06	8.05
\$ 12,500	10.22	9.50	9.14	8.99	8.93	8.90	8.89
\$ 17,500	10.35	9.84	9.53	9.39	9.33	9.31	9.30
\$ 22,500	9.80	9.57	9.38	9.29	9.25	9.24	9.23
\$ 27,500	8.64	8.80	8.78	8.76	8.74	8.74	8.74
\$ 32,500	7.83	7.93	8.01	8.03	8.04	8.04	8.04
\$ 37,500	6.60	7.10	7.22	7.27	7.29	7.30	7.31
\$ 42,500	5.74	6.11	6.37	6.46	6.50	6.51	6.52
\$ 47,500	4.38	5.30	5.55	5.66	5.70	5.72	5.73
\$ 52,500	3.83	4.15	4.64	4.80	4.86	4.89	4.90
\$ 57,500	2.85	3.70	3.86	4.02	4.09	4.12	4.13
\$ 67,500	5.63	3.74	3.63	3.63	3.64	3.64	3.64
\$ 87,500	3.63	4.22	4.01	3.93	3.90	3.89	3.88
\$ 112,500	1.30	2.15	2.55	2.67	2.71	2.73	2.74
\$ 137,500	0.54	0.88	1.20	1.35	1.42	1.44	1.45
\$ 247,000	1.10	0.94	0.91	0.91	0.92	0.92	0.92
Mean Income	\$ 33,646	\$ 35,144	\$ 36,171	\$ 36,657	\$ 36,864	\$ 36,951	\$ 36,988

Note: All iterations were adjusted to sum to 100 percent.

³Percentage of households

Figure 3
Distribution of Households by
Income (1989 \$)



historical data for urban areas in Texas. That method is described in some detail in Reference 52, so the discussion here is limited to the steps necessary to use the method. The method is based on a modified form of the Gamma function expressed mathematically as follows:

$$f(X) = (X)^{\alpha - 1} e^{-\alpha X}$$

where:

α = Shape parameter

X = Relative income value (range midpoint value divided by mean income)

$e = \text{Natural log constant } 2.71828\dots$

$f(X) = \text{Estimated percentage of households}$

The shape parameter alpha is estimated using the mean household income as input to the following linear equation:

$$\alpha = 0.000242 * \text{Mean Household Income} - 0.3006$$

The mean household income used in the above equation must be converted to represent 1967 dollars using the consumer price index (CPI). For example, using the previous projection of mean household income of \$37,011 (1989 dollars) and the 1989 CPI of 3.715, the projected mean household income in 1967 dollars would be \$9,963. In application, a distribution is computed for income ranges in \$1,000 increments up to \$50,000 where the income represents 1967 dollars. The results are converted to base year dollars (for our example the base year would be 1989) using the CPI and the percentages estimated for varying income ranges based on the assumption of equal distribution within a range. For example, suppose 5 percent is estimated for the income range \$0 to \$1,000 and 7 percent is estimated for the income range \$1,000 to \$2,000. The income range for the base year which overlaps these two is for \$0 to \$1,250. The estimated percentage for this range would be 5 percent plus 250/1000 times 7 percent which would result in an estimate of 6.75 percent for the income range \$0 to \$1,250.

Using the projected mean income of \$9,963 results in an estimated value for alpha of 2.11. Using this value and the modified Gamma function resulted in the projected distribution shown in Table 11. The projected distribution using this method is very different from that using the master curve method, as may be seen by comparing the distribution shown in Table 10 with that in Table 11. Both yield approximately the desired projected mean income. It is not possible to say which would be the most accurate. The primary advantage to using the mathematical relationships is the ease by which the procedure may be programmed and used for evaluating several forecasts. Either method should produce acceptable results.

Table 11
Projected Distribution of Households
Using Modified Gamma Function
(Example)

2010 Income Range (1989 Dollars)	Income Range Mid-Point	2010 Mean Household Income (1989 \$)	Relative Value	Estimated Percentage Households
\$ 0 - \$ 4,999	\$ 2,500	\$ 37,011	0.0675	2.91
\$ 5,000 - \$ 9,999	\$ 7,500	\$ 37,011	0.2026	6.73
\$ 10,000 - \$ 14,999	\$ 12,500	\$ 37,011	0.3377	8.96
\$ 15,000 - \$ 19,999	\$ 17,500	\$ 37,011	0.4728	9.93
\$ 20,000 - \$ 24,999	\$ 22,500	\$ 37,011	0.6079	9.87
\$ 25,000 - \$ 29,999	\$ 27,500	\$ 37,011	0.7430	9.31
\$ 30,000 - \$ 34,999	\$ 32,500	\$ 37,011	0.8781	8.37
\$ 35,000 - \$ 39,999	\$ 37,500	\$ 37,011	1.0132	7.44
\$ 40,000 - \$ 44,999	\$ 42,500	\$ 37,011	1.1483	6.44
\$ 45,000 - \$ 49,999	\$ 47,500	\$ 37,011	1.2834	5.42
\$ 50,000 - \$ 54,999	\$ 52,500	\$ 37,011	1.4185	4.61
\$ 55,000 - \$ 59,999	\$ 57,500	\$ 37,011	1.5536	3.83
\$ 60,000 - \$ 74,999	\$ 67,500	\$ 37,011	1.8238	7.83
\$ 75,000 - \$ 99,999	\$ 87,500	\$ 37,011	2.3642	5.76
\$100,000 - \$124,999	\$112,500	\$ 37,011	3.0396	1.84
\$125,000 - \$149,999	\$137,500	\$ 37,011	3.7151	0.56
\$150,000 Plus	\$247,000	\$ 37,011	6.6737	0.19
Total	-	-	-	100.00

Step 7: Estimate Zonal Household Incomes

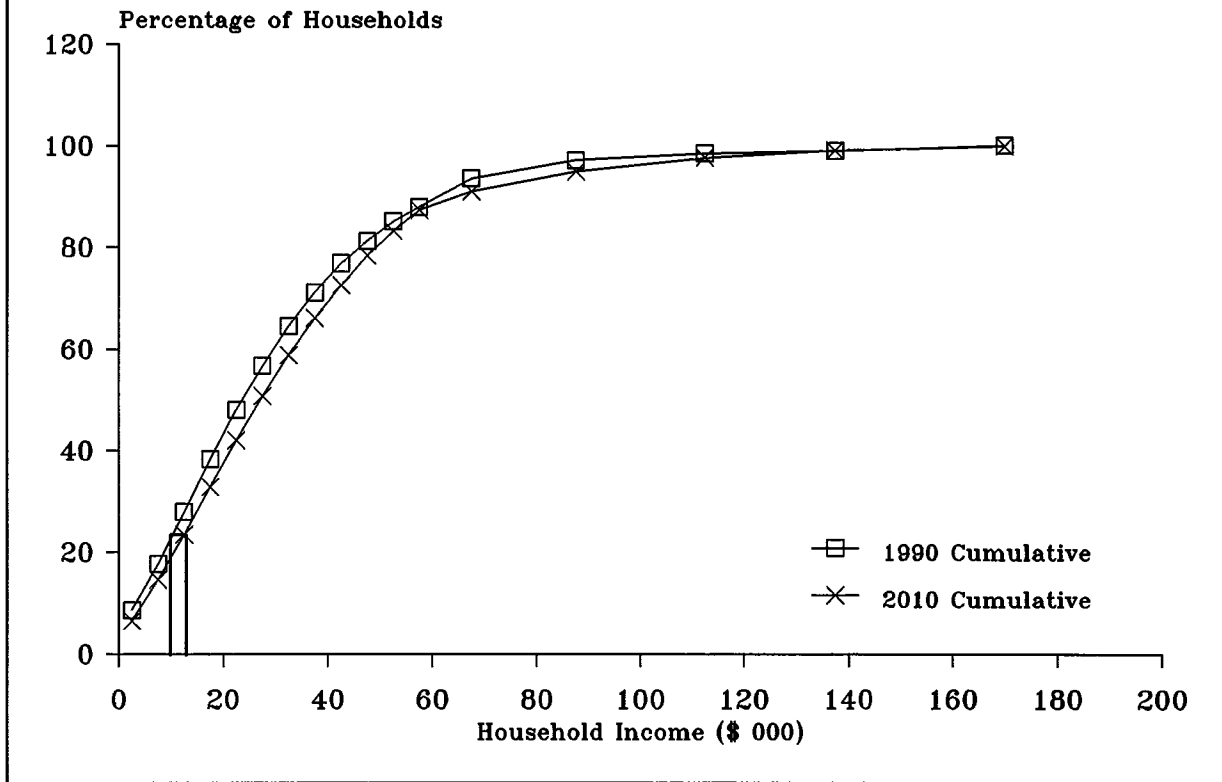
The previous step results in an estimate of the distribution of households by household income for the entire study area. The next step is to estimate the mean (or median) household income for each zone in the study area. As a starting point, estimates of the mean (or median) household income for each zone should be available for the base year. While several methods

may be used to project a zone's mean or median household income, the resulting estimates for all zones should be compatible with the results from Step 6, i.e., the regional distribution of households by household income. The method discussed here will achieve this result. Since the projection is for some time in the future, there is a possibility that some zones are completely (or mostly) undeveloped in the base year and would not have any base year estimate of household income. These same zones may be developed in the projection. A base year estimate of income for those zones is necessary for the methodology described here. It is recommended that the best estimate to use for those zones is an average of the developed zones surrounding it, the assumption being that the zone will most likely develop in a compatible manner with those zones around it. Analysts must use their judgment in this matter, since there are probably certain areas that may not follow this pattern.

The full method for estimating zonal incomes as discussed here is not amenable to implementation by hand. A portion of the method involves iterations and the complexity of these combined with typically several hundred zones does not lend itself to hand computations. The first steps, however, may be done by hand and, depending on the time frame and schedule, may yield results that are acceptable.

The first step is to develop a growth factor for each zone. The method used may be either a graphical method or an interpolation method. Using the example developed in the previous step, Figure 4 shows the base year and forecast year distributions of households by household income plotted in cumulative form. Using the mean household income for each zone, the percentage of households at that mean income for the base year may be identified. Using that percentage and moving horizontally on the graph to the forecast distribution, an income may be found where that percentage lies on the forecast distribution, for example, if the base year mean income for a zone was \$10,000. Using Figure 4, the percentage of households at that income for the base year would be roughly 22 percent. At that percentage of households on the forecast distribution, the income is roughly \$13,000. The growth factor for zones with an average base year income of \$10,000 would then be $\$13,000/\$10,000$ or 1.3. As can be seen from Figure 4, this is a rough approximation due to the scale and difficulty in reading the graphs. This method can also be tedious when dealing with a large number of zones. An alternative method is interpolation, which is also programmable in a spreadsheet and more accurate than the graphical

Figure 4
Cumulative Distribution of Households by
Income (1989 \$)



method. Table 12 shows the cumulative distributions for both the base year and the forecast year. In the base year, the percentage of households at an income level of \$10,000 would be estimated by interpolating between the income values of \$7,500 and \$12,500. In this example, the percentage would be 22.8 percent. This percentage lies between incomes of \$7,500 and \$12,500 in the forecast distribution as well. Interpolating again using the percentage of 22.8 results in an income estimate of \$12,123 in the forecast distribution. The growth factor for zones with incomes of \$10,000 would then be \$12,123/\$10,000 or 1.21. Typically, higher growth factors will be computed for zones with low incomes and smaller factors for zones with high incomes. This is one of the disadvantages with this method; it nearly always produces a positive growth in income for every zone. The analyst may wish to adjust the results after all the zones have been done to reflect known situations which do not follow this trend in the urban area.

The method to ensure that the zonal forecasts are compatible with the regional forecast

distribution involves the use of the mathematical relationships previously discussed in Step 6. In essence, a distribution of households by household income is computed for each zone using the initial forecast of mean income for the zone. These zonal distributions are summed to yield a composite distribution for the urban area. This composite distribution is compared with the regional distribution forecast from Step 6 at each income interval. Adjustment factors are computed for each income interval and applied to the zonal distributions. The adjusted distributions for each zone are then used to compute a new mean income estimate for the zone. This becomes the projected income for the zone. This procedure is not amenable to being implemented by hand and can be easily programmed in a spreadsheet by the analyst. The final results should be reviewed carefully by the analyst to ensure they are reasonable and consistent with trends in the urban area.

Table 12
Base Year 1990 and Forecast Year 2010
Cumulative Distribution of Households
(Example)

2010 Income Range (1989 Dollars)	Income Range Mid-Point	1990 Cumulative Distribution of Households	2010 Cumulative Distribution of Households
\$ 0 - \$ 4,999	\$ 2,500	8.52	6.53
\$ 5,000 - \$ 9,999	\$ 7,500	17.56	14.58
\$ 10,000 - \$ 14,999	\$ 12,500	27.78	23.47
\$ 15,000 - \$ 19,999	\$ 17,500	38.13	32.77
\$ 20,000 - \$ 24,999	\$ 22,500	47.93	42.00
\$ 25,000 - \$ 29,999	\$ 27,500	56.57	50.74
\$ 30,000 - \$ 34,999	\$ 32,500	64.40	58.78
\$ 35,000 - \$ 39,999	\$ 37,500	71.00	66.09
\$ 40,000 - \$ 44,999	\$ 42,500	76.74	72.61
\$ 45,000 - \$ 49,999	\$ 47,500	81.12	78.34
\$ 50,000 - \$ 54,999	\$ 52,500	84.95	83.24
\$ 55,000 - \$ 59,999	\$ 57,500	87.80	87.37
\$ 60,000 - \$ 74,999	\$ 67,500	93.43	91.01
\$ 75,000 - \$ 99,999	\$ 87,500	97.06	94.89
\$100,000 - \$124,999	\$112,500	98.36	97.63
\$125,000 - \$149,999	\$137,500	98.90	99.08
\$150,000 Plus	\$247,000	100.00	100.00
Total	-	-	-

Step 8: Develop Regional Estimates of Households by Auto Ownership

The term "auto ownership" as used in this report is synonymous with vehicle availability. Auto ownership has been found to be highly correlated with household income. The estimates

desired in this step are the number (or percentage) of households in the region with 0, 1, 2, or 3 or more vehicle available for travel. Analysis of data from the 1980 census resulted in the development of a model for estimating the average vehicles per household based on per capita income and household size (52). That relationship is as follows:

$$AAPH = 0.4594 * \ln (PINC) + 0.2245 * HHS - 3.088$$

where:

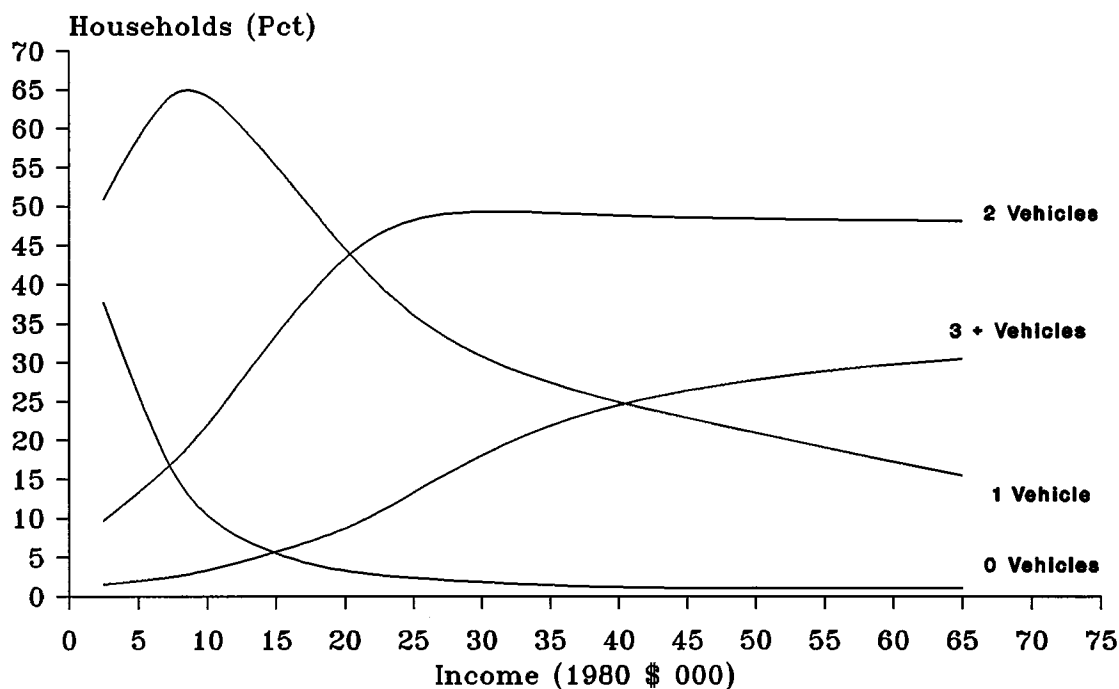
AAPH	=	average vehicles per household
PINC	=	per capita income
HHS	=	average household size
ln	=	natural logarithm

For the region, the percentage of households with 0, 1, 2, and 3 or more vehicles may be estimated using the relationships shown in Figure 5. The data shown in Figure 5 are for 1980 and represents average values for four urban areas in Texas. The relationships for all four areas were similar. An initial estimate of the percentages of households with 0, 1, 2, and 3 or more vehicles available may be obtained based on the mean household income for the region from Figure 5. The average number of vehicles per household may be estimated from this distribution (i.e., the percentage of households with 0, 1, 2 and 3 or more vehicles). This should be compared to the estimate computed using the equation above. The distribution may be adjusted by hand to approximate the desired average vehicles per household based on the analyst's judgment. It is recommended that the analyst compare both projections with historical data from the census in making that decision. The result of this step should be an estimate of the distribution of households by vehicles available for the urban area.

Step 9: Develop Estimates of Zonal Households by Auto Ownership

There are a number of ways to develop the zonal distributions of households by auto ownership (i.e., vehicles available). All use household income as the primary independent variable. Two methods are presented here with both considered to produce reasonably good results.

Figure 5
Distribution of Households by Income and
Vehicle Availability



Source: Averages From 1980 CTPP Data
 for Dallas-Ft. Worth, San Antonio,
 Austin, and Texarkana

The first method is a graphical method based on census data. If data from the census are not available, data from another similar urban area may be used. Data from the 1990 Census Urban Transportation Planning Package contain the distribution of households by vehicle availability at the census tract level. In some areas these data were tabulated at the zone level as well. Using those data and the mean household income (median household income may be used where preferred by the analyst), four graphs may be plotted using either census tract data or zonal data. The first will be a plot of the percentage of zero vehicle available households versus the mean household income. The remaining three plots will be essentially the same as the first, except each will be for a different level of vehicle availability. The data points in each graph are for individual census tracts or zones. Curves are then hand fitted to the data and tables of income and percentage of households developed using the curves for each level of vehicle availability. Once the values are tabulated, it is necessary for the analyst to sum the percentages

for each income level and ensure they add to 1.0. Where necessary, the analyst should adjust to ensure the numbers sum to 1.0 considering the preceding and following values for each level of vehicle availability. For example, Table 13 shows the tabular data developed from the curves shown in Figure 5. Note that the income values shown are in terms of 1980 dollars since this was the year the data were collected. Because income is used in developing these estimates, it is essential that estimates developed from the data use constant dollars for the same year the data were developed. Given the mean income for a zone, the estimated percentage of households with 0, 1, 2, and 3 or more vehicles available may be taken directly from the table.

The second method is similar to the method used for developing the regional distribution except it is more detailed. The first step is to estimate for a given zone the desired average number of vehicles available using the zone's mean income and the equation previously presented. The second step is to use the mean income for the zone and obtain an initial estimate of the distribution of households by vehicles available from a table similar to Table 13 (this would be developed in Step 8 for the region). The average vehicles per household should be computed for the initial distribution and compared with the desired average. It will then be necessary to adjust the distribution to ensure the distribution will have the desired average vehicles per household. The recommended method for doing this is to simply move households from one side of the average to the other. For example, if the desired average vehicles per household for a zone was 1.5, the zone would have 116 households with an average household income of \$7,000. The initial distribution of households by vehicle availability from Table 13 would be 18.53 percent, for 0-vehicle households, 62.99 percent for 1-vehicle households, 16.02 percent for 2-vehicle households, and 2.42 percent for 3-or-more- vehicle households (for computational purposes, 3.5 is used for the 3-or-more-vehicle category). This distribution has an average of 1.04 vehicles per household. The method of adjustment to obtain a distribution with the desired average vehicles per household is to simply move households from one side of the mean to the other. In this example, 95 households are in the first two categories (i.e., 0- and 1-vehicle households). The assumption is made that households moved from one side of the mean to the other will be distributed in the same relation as in the initial distribution for the categories involved. This allows two unknown variables and two equations to be developed

Table 13
Percentage of Households by Auto Ownership and Income

Income 1980 \$	0-Autos	1-Auto	2-Autos	3+-Autos
1000	45.18	45.90	7.65	1.27
2000	40.92	48.60	9.00	1.48
3000	35.25	52.58	10.32	1.85
4000	30.60	55.48	12.01	1.91
5000	26.26	58.03	13.71	2.00
6000	21.31	61.43	15.05	2.21
7000	18.53	62.99	16.06	2.42
8000	14.91	64.59	18.02	2.48
9000	12.50	64.90	20.00	2.60
10000	11.18	64.35	21.22	3.25
11000	9.34	62.64	24.29	3.73
12000	7.74	61.56	26.38	4.32
13000	7.29	59.35	28.66	4.70
14000	6.28	57.16	31.39	5.17
15000	5.63	55.05	33.68	5.64
16000	4.98	53.54	35.26	6.22
17000	4.51	50.77	37.86	6.86
18000	3.89	48.68	39.94	7.49
19000	3.74	46.83	41.19	8.24
20000	3.53	44.22	43.54	8.71
21000	3.10	42.50	45.00	9.40
22000	2.81	41.34	45.73	10.12
23000	2.61	38.93	47.15	11.31
24000	2.50	37.54	47.55	12.41
25000	2.45	36.28	48.14	13.13
26000	2.32	34.83	48.52	14.33
27000	2.20	33.77	48.82	15.21
28000	2.10	32.57	49.05	16.28
29000	1.96	31.37	49.30	17.37
30000	1.85	30.67	49.36	18.12
31000	1.77	30.02	49.45	18.76
32000	1.66	29.54	49.33	19.47
33000	1.49	28.94	49.23	20.34
34000	1.34	28.25	49.07	21.34
35000 +	1.26	27.67	49.09	21.98

which can be solved simultaneously. In the example shown, Y can represent the number of households in the 0- and 1-vehicle categories and X the number of households in the 2- and 3-or-more-vehicle categories. In the initial distribution (from Table 13), 22.7 percent of Y fell in the 0-vehicle category, and 77.3 percent fell in the 1-vehicle category. Similarly, 86.9 percent of X fell in the 2-vehicle category, and 13.1 percent fell in the 3-or-more-vehicle category. The desired average number of vehicles per household was 1.5 which for 116 households yields a total of 174 vehicles. The following two equations result:

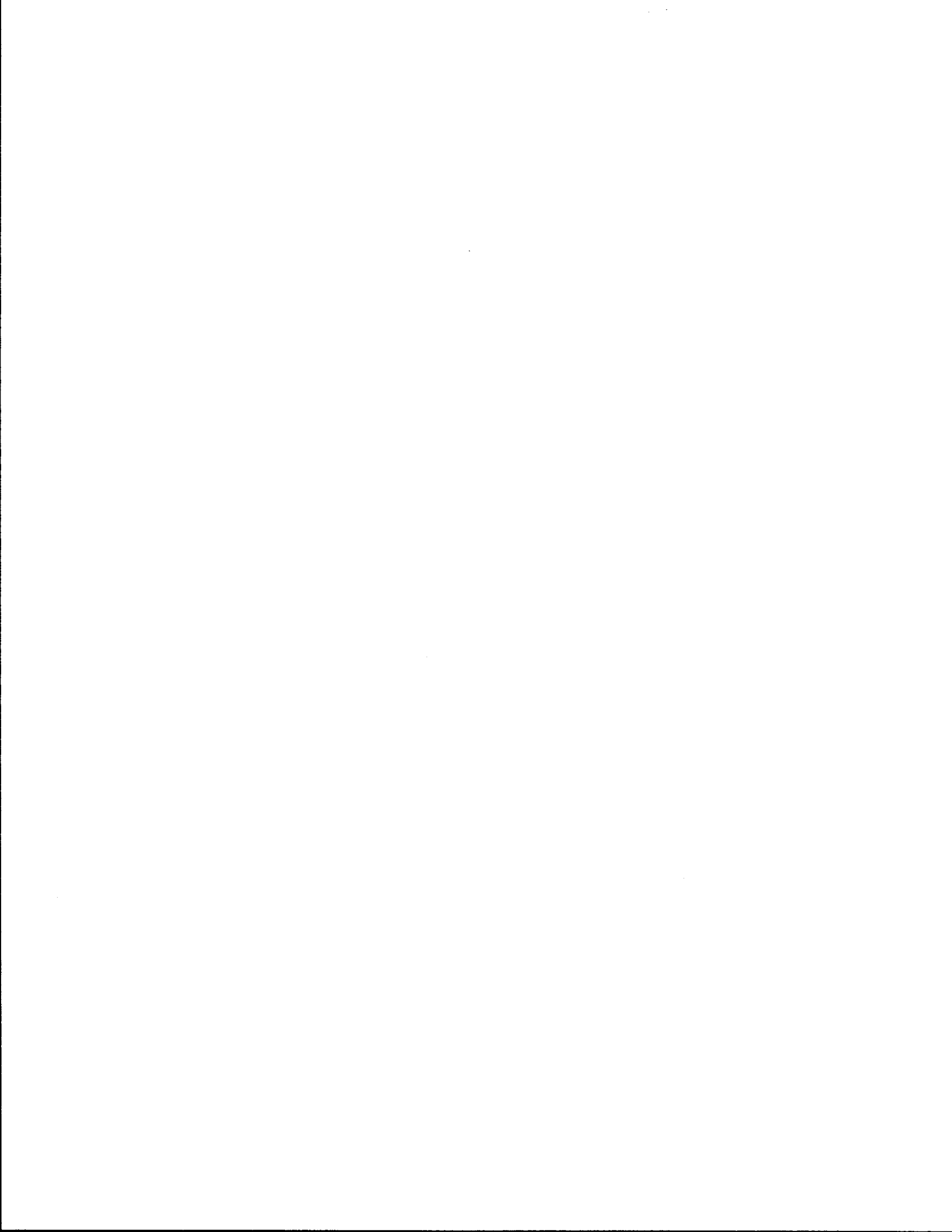
$$0*(0.227) * Y + 1*(0.773) * Y + 2*(0.869) * X + 3.5*(0.131) * X = 174$$

$$Y + X = 116$$

Solving the above equations simultaneously result in an adjusted distribution with 11.2 percent for 0-vehicle households, 37.1 percent for 1-vehicle households, 44.8 percent for 2-vehicle households, and 6.9 percent for 3-or-more-vehicle households. This method is more detailed and cumbersome by hand for a lot of zones, but it is easily programmed to be done using a microcomputer. After all zones have been done, it will be necessary to sum the individual zonal distributions and compare to the regional distribution. Adjustment factors should be computed for each category of vehicle availability and applied to all zonal distributions to ensure they sum to the regional total. Final estimates should be checked to ensure they are reasonable and result in reasonable estimates of average vehicle availability at the zone level.

SUMMARY

The procedures for developing the forecast data necessary for travel demand modeling that have been presented in this section are not the only methods by which forecasts may be developed. They are presented as examples of how the data forecasts may be developed. Care should always be exercised regardless of the method(s) used and the analyst should review the final forecasts carefully to ensure that they are reasonable for the urban area under study.



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