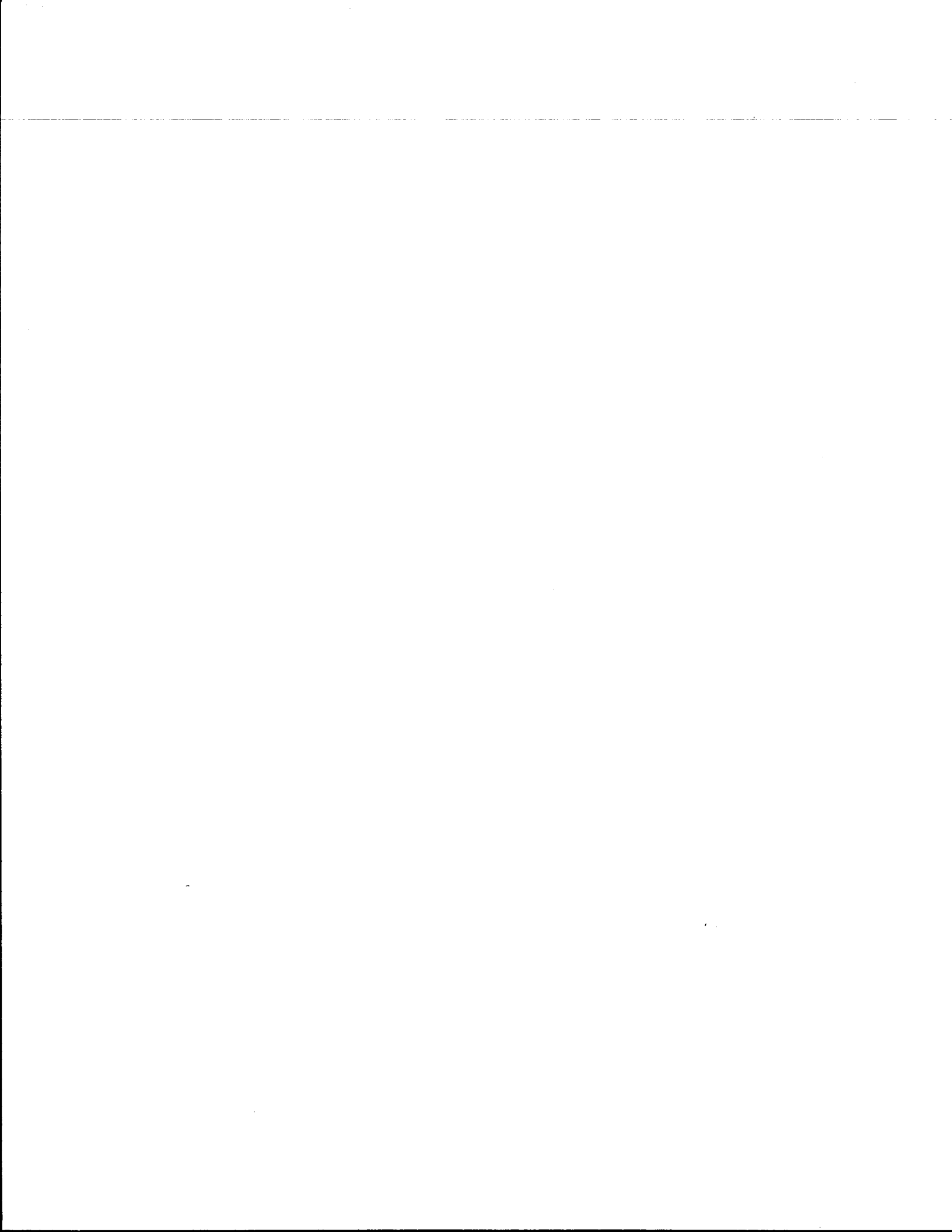| 1. Report No. TX-94/947-7	2. Government Accession No.	3. Recipient's Catalog No.
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16. Abstract

The Texas Package of travel demand forecasting programs is a mainframe mathematical model for forecasting travel in urban areas in the state of Texas. Interactive Lotus 1-2-3 spreadsheet templates have been developed to provide case study examples of the mathematical functions used in the Texas Package.

This manual is intended for use by the Texas Department of Transportation offices, Metropolitan Planning Organizations, municipalities, counties, and consultants contracted by public agencies in the state of Texas for training employees in the theory and application of the Texas Package travel demand forecasting model.

The information contained in the Lotus 1-2-3 modules and this manual can be used to train new staff members or to refresh employees who have been minimally exposed to the travel demand forecasting process. The models and formulas contained in the spreadsheet templates are not solely applicable to the Texas models but are examples of standard travel modeling practices used in other states as well.

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MANUAL FOR THE
INTERACTIVE TRAINING SYSTEM FOR TEXAS TRAVEL MODELS

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IMPLEMENTATION STATEMENT

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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 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 this project.
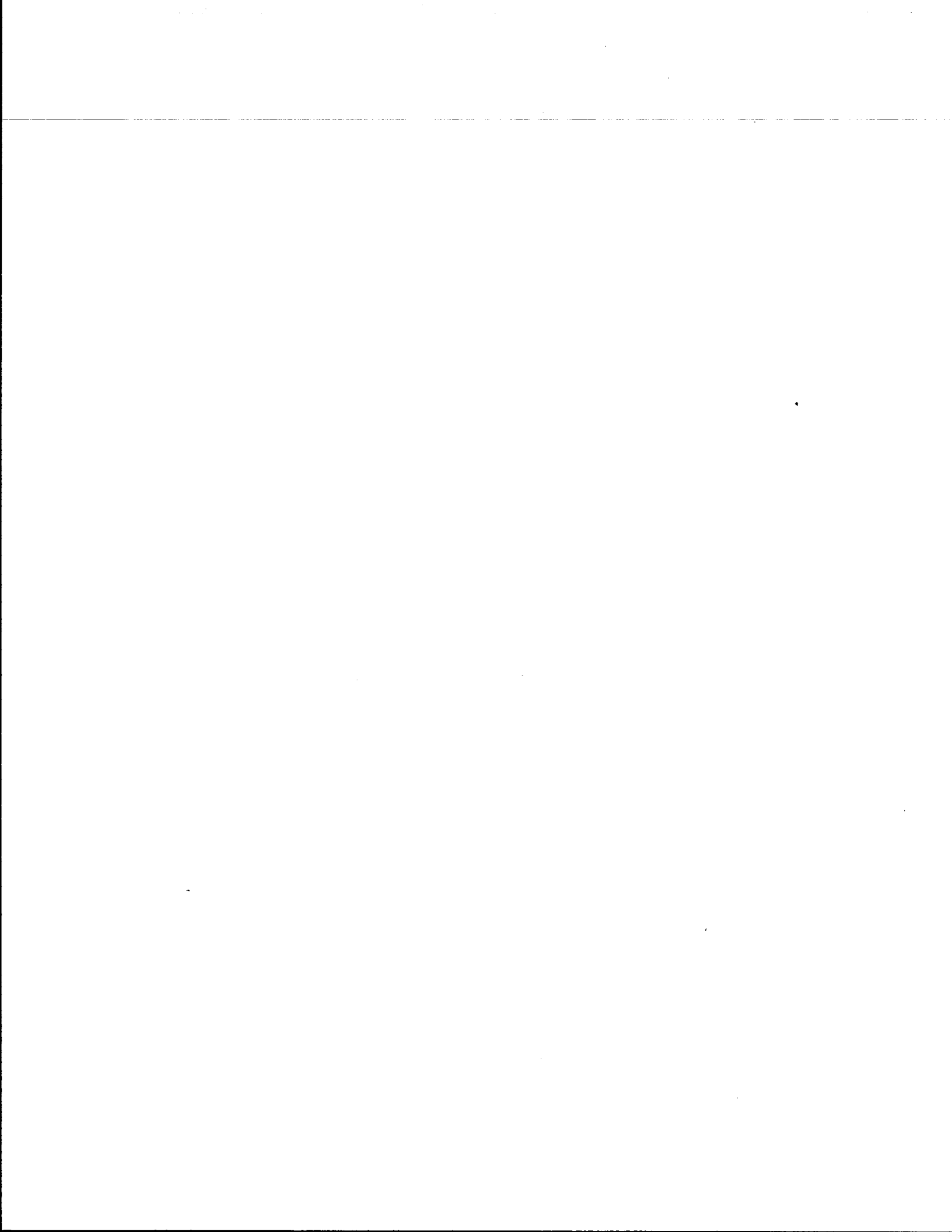
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CHAPTER 1
SUMMARY OF
TRAVEL DEMAND FORECASTING

This chapter describes the four-step travel modeling process used throughout the transportation planning profession. More specifically, the details of the modeling process as used in the state of Texas are discussed.

THE FOUR-STEP TRANSPORTATION MODELING PROCESS

Travel demand forecasting attempts to quantify the existing and future interaction between the supply of and the demand for the transportation system. The supply of transportation is represented by the characteristics of the highway and transit networks. The demand for transportation is created by the separation and intensity of urban activities. Land use forecasts provide estimates of where people will live and where businesses will locate in the future. These forecasts include the intensity of activity in an area such as the number of households, employees, and demographic data concerning income levels and household size. These forecasts are prepared for small geographic areas called traffic serial zones. Descriptions of the service characteristics of the highway and transit networks and the land use forecasts are direct inputs to the travel demand forecasting model.

The traditional travel demand forecasting process has four principal components:

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

Much of the following discussion is excerpted from An Introduction to Urban Travel Demand Forecasting, A Self-Instructional Text, distributed by the U.S. Department of Transportation, 1977.

Trip Generation

Trip generation is the process by which the transportation planner translates the land use forecast into the number of trips in the study area's traffic serial zone for a typical day of the target year. Trip generation results in the total number of "trip ends" in the study area. A trip end is defined as the beginning or end of a trip. For example, a one-way trip from home to work has two trip ends. Trip generation models estimate total trip ends by applying trip generation rates to the land use forecast data.

A trip generation rate is obtained by dividing the number of trips made by a given activity by

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the amount of the activity. For example, common trip generation rates are trips per household and trips per employee. Trip generation rates are based on relationships between the amount or character of urban activity and the amount of trips generated. All else being equal, a zone with a larger number of households or employees will generate more trips than a zone with a smaller number.

Measures of the amount of activity usually are not enough to develop a good relationship between activities and travel. The character of activities is important, too. For residential land uses, character is described in terms of socioeconomic variables such as household size and income. Generally, large or high income households generate more trips than small or low income households. For non-residential activities, trip generation character reflects the type of activity (for example, retail and industrial). A major shopping center generates more trips than a warehouse of the same size.

In trip generation analyses, the number of trip ends in each traffic serial zone are estimated for each of a number of trip purposes. Usually, trip purposes include home based work trips, home based non-work trips, and non-home based trips. Other trip purposes which must be estimated are truck and taxi trips and trips with origins or destinations outside of the study area. The output of trip generation analysis is a table of trip ends that are produced from and attracted to each traffic serial zone categorized by trip purpose.

The most widely accepted technique for trip generation is cross-classification. This method estimates the characteristics of each household (or employee) and places them in a table. For instance, a two-way cross-classification may be estimated based on auto availability and income. A table is developed with number of autos available for columns and income groupings for rows. Then, the number of households falling into each cell of the table is estimated. Also, the number of trips generated by each category is estimated. For instance, the number of trips generated by one-car households of low income would be placed in the first cell of the table. As income increases and number of autos available increases, the trips generated also increases.

Trip Distribution

Trip distribution is the process by which the transportation planner links the production and attraction trip ends to form complete trips, thereby transforming trip ends into origin/destination pairs. Each zone's trip productions are connected to all zones to which they are attracted.

The most widely used trip distribution technique is the gravity model. The gravity model gets its name from the fact that it is conceptually based on Newton's law of gravitation, which states that the force of attraction between bodies is directly proportional to the product of the masses of the two bodies and inversely proportional to the square of the distance between them.

Similarly, in the gravity model, the interchange of trips between two areas is directly related to activities in those areas and inversely related to the separation between the areas, represented as a function of travel time. Consequently, areas with large amounts of activity tend to exchange more trips, and areas farther from each other tend to exchange fewer trips. Thus, the distribution model calculates the trip interchange volume based on the travel time to reach the potential destination and the attractiveness of that destination. Originating trips from any one zone are allocated to competing destinations based on this combination of relative trip lengths and relative attractiveness.

In practice, a separate gravity model is developed for each trip purpose, because different trip purposes have different distribution characteristics with respect to trip length. For example, a person who travels from one side of the city to the other for work will not travel as far to buy groceries.

The output of trip distribution is a set of tables for each trip purpose; the tables contain the travel flow between each pair of zones. The output is a representation of expected travel patterns; the origin and destination of every trip is modeled.

Mode Choice

The third step of the travel demand forecasting process is mode choice. Mode choice analysis is the process by which the transportation planner determines the amount of travel that will be made between each set of zones using each available mode of transportation. The specific modes that are analyzed typically include single-driver auto, various carpool categories, local and express bus, and fixed guideway transit.

Many factors affect mode choice. Two important factors are relative costs and travel times

of the available modes. A fast or inexpensive mode is more attractive to travelers than a slower or more expensive mode. In addition to these transportation system characteristics, the transportation planner considers characteristics of the traveler and characteristics of the trip. Studies have demonstrated that traveler characteristics such as income and number of available autos, are correlated to mode choice. Generally, people with high incomes and greater number of available autos are less likely to ride transit. Similarly, mode choice can be affected by trip characteristics such as trip purpose. For example, a person who rides a bus to work every day might not want to take a bus to see a movie on Friday night.

The output of mode choice analysis is tables representing the (1) number of vehicle trips between each pair of traffic serial zones utilizing the highway network and (2) the number of transit trips between each pair of zones which utilize the transit network.

Traffic Assignment

The fourth step in the travel demand forecasting process, traffic assignment, is the procedure by which the transportation planner estimates the volume of travel on each individual component of the transportation system. This involves "loading" the transit network with transit person trips by mode and the highway network with vehicle trips. Several techniques are available to determine which paths through the network are to be utilized by the transit and vehicle trips between zones. The most common type of trip assignment technique is the minimum path. Minimum path techniques are based on the assumption that travelers want to use the route of minimum impedance between two points. Impedance is usually measured in terms of time (for example, walking, waiting, and riding) and/or cost (for example, fares, operating costs, tolls, and parking costs). Minimum path techniques are generally used for transit assignment.

For highway assignment, minimum path algorithms can be refined by including capacity restraint techniques. Capacity restraint techniques reflect the finding that as the volume of traffic increases, the speed of traffic decreases. Capacity restraint attempts to balance the assigned volume, the capacity of the facility, and the resultant speed.

The output from the assignment step is an estimate of the total number of vehicle and transit trips for each segment of the highway and transit networks. The transportation planner's job does

not end with trip assignment. The results of the trip assignment process, like all other steps of the travel demand forecasting process, must be evaluated. For example, the transportation planner checks individual links, adjusts individual link values along a facility or within a corridor, and summarizes vehicle miles of travel (VMT) to assess the reliability of the assignment. As the desire for accuracy increases, the transportation planner must complete additional analysis and reliability checks.

CHAPTER 2
INTERACTIVE TRAINING
SPREADSHEETS

Chapter 2 introduces the transportation planner or engineer to the interactive training modules. The modules are Lotus 1-2-3 spreadsheets which can be used on a microcomputer to display example case studies of the travel modeling procedures.

COMPUTER SOFTWARE AND HARDWARE REQUIREMENTS

Interactive microcomputer-based training modules have been designed for each of the four steps in the travel demand forecasting process. These programs actually perform the modeling calculations using a 3-zone case study example. The user simply provides the inputs and parameters for the travel models. The student can view the effects of changes in the inputs or model parameters quickly and easily using the interactive training modules.

The interactive training modules are programmed as LOTUS 1-2-3 spreadsheets, providing a wide variety of options for graphing and performing "what-if" case studies. Version 2.4 of 1-2-3 is needed for the modules with the "WYSIWYG" add-in. Versions 3.0 and 3.1 will also be suitable. The reason for using these versions is the added capability of viewing graphs on the same screen as the worksheets. The effect of a change in the values in the worksheets can be easily viewed in the graphs on the same screen.

INSTALLATION

To install the interactive training modules from the C:> prompt:

Type	**b:install**
Press	**Enter**

where "b:" is the drive letter of the drive with the floppy diskette containing the training module files. The computer will then copy the files from a floppy diskette to the hard disk drive C: of the microcomputer you wish to use and will create a subdirectory called "C:\interact".

TIPS

To begin operation of the interactive training modules, make sure the default directory is "C:\interact>" and then:

Type	**interact**
Press	**Enter**

The program will load LOTUS 1-2-3 and the main menu file to begin interactive training. If you find

using 1-2-3 easier, the files can be loaded and inspected individually rather than using the start-up program "interact."

Students who are familiar with LOTUS 1-2-3 should have no problem navigating the training spreadsheets. Care should be taken, however, not to erase any formulas as this will effect the calculations. To ensure that no errors are made, make a backup of the spreadsheets.

For ease of use, students who are not familiar with LOTUS 1-2-3 may use the menu system provided in the training spreadsheets. The menu system activates automatically when the spreadsheets are loaded. If you wish to exit the menu system to return to the "Ready" mode, use the menu option "Quit" which will allow you to enter the spreadsheet directly. Once in the "Ready" mode, pressing "ALT-Z" will re-activate and reset all parameters in the spreadsheet.

Students who wish to develop an in-depth understanding of the models can easily do so by reviewing the formulas coded into the worksheets. A knowledge of Lotus will be necessary for this type of study.

A main menu program has been written to help students navigate through all the training modules after starting up.
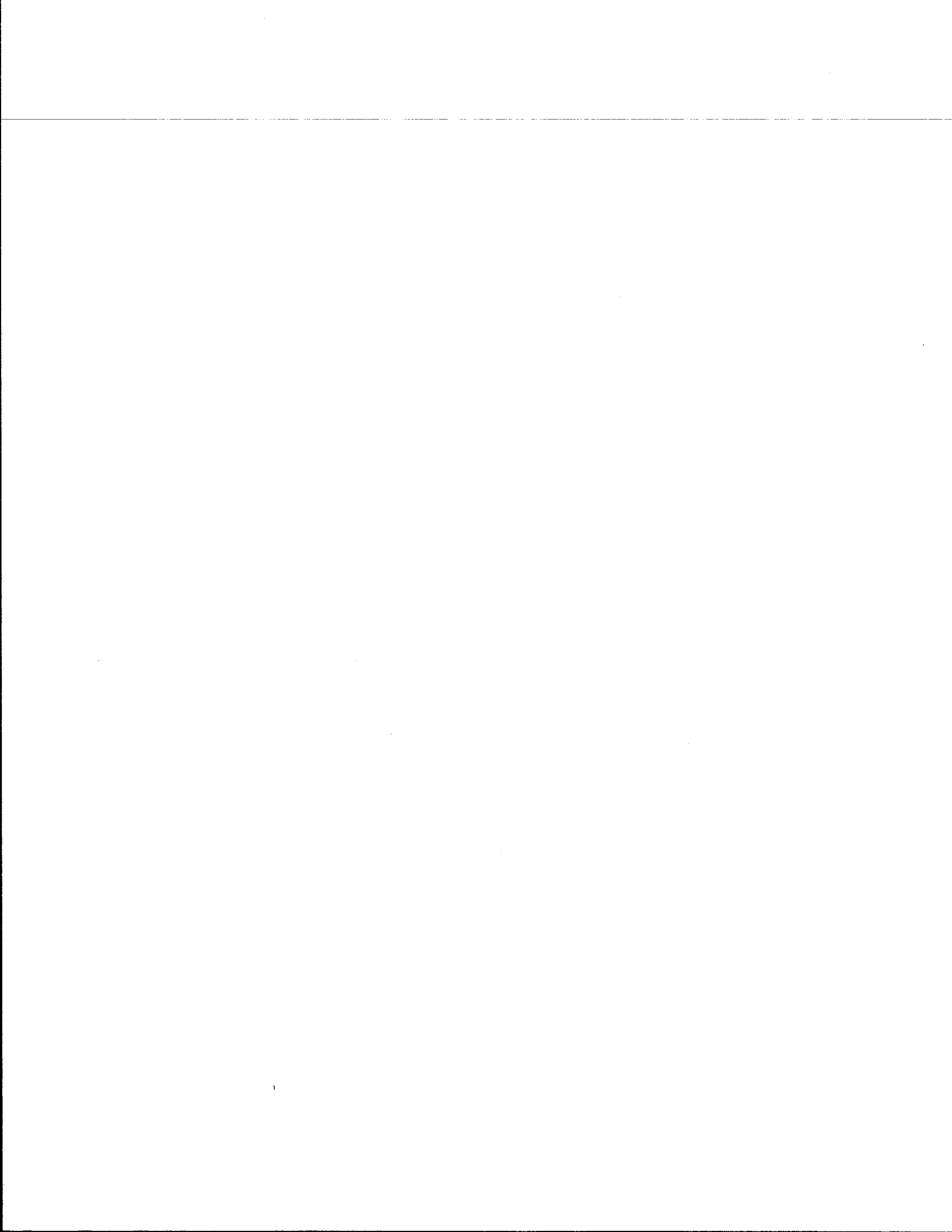
CHAPTER 3
TRIP GENERATION ANALYSIS

This chapter reviews the process of trip generation for travel demand forecasting in detail. A case study is developed using the interactive Lotus 1-2-3 spreadsheet. Development of the demographic data is covered in addition to a description of the generation of trip productions and attractions.

URBAN ACTIVITY SURVEYS AND FORECASTS

The term "urban activity" refers to the basic activities which take place in cities: shopping, working, going to school, etc. Transportation planners must estimate these basic activities and use them as indicators of travel. In essence, transportation planning is the prediction of the location and amount of urban activity and the application of the predictions as indicators of how, when, and where people will travel. In other words, the urban activity is the demand for travel and the transportation system is the supply.

One part of the urban activity survey is to find out where people live and where the growth in housing will take place. Another part of the urban activity survey is to find out where people work and what type of work they do. Generally, three categories of employment are used: Basic (jobs related to manufacturing or industry), retail (jobs where shopping takes place), and service (jobs such as office work, government work, or education).

TRAVEL SURVEYS

Travel surveys provide the basic information on how all of the urban activities interact and the amount of travel between them. For instance, a household travel survey is mailed to a sample of households asking each member of the family over the age of five to keep a diary of all the trips they make during a given day. From this information, transportation planners can determine the trip purpose. If a person made a trip to work, this would be a home based work (HBW) trip. If a person made a trip to go shopping or go to school, this would be a home based non-work (HBNW) trip. If the trip was recorded as beginning at another location besides the home, such as a trip from the office to go to lunch, the trip purpose is a non-home based (NHB) trip.

The household travel survey also finds out information about each trip-maker, such as their income. Each household will fall into categories, or ranges, of income predetermined by the planner. Also, the number of autos available is sometimes needed. Finally, the number of people residing in the household is necessary.

Other surveys are sometimes conducted at the workplace to determine the characteristics of

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the people working at a given site. Usually, planners want to know the income of people where they work, so that they can be matched with residential areas of the same income group. This will avoid the modeling problem of sending low-income workers to high income jobs, and vice-versa.

TRIPCAL5 AND OTHER SOFTWARE

TRIPCAL5 is the state of Texas' latest trip generation software. Trip generation is the process by which the urban activity is translated into travel activity. The result of trip generation is the number of trip ends accumulated in each zone of the city. A trip end is either the beginning of the trip (production) or the end of a trip (attraction). For instance, a typical round trip to work would create four trip ends: two productions (one beginning at home and one beginning at work), one for each leg of the trip, and two attractions (endings), one for each leg of the trip.

From the travel survey we find out how many trips of each purpose are made by each zone. For instance, if Zone 1 has 1,000 retail employees, and it attracts 2,000 trips, then the trip generation rate is said to be 2.00 trips per employee. Similarly, if the survey indicates that there are 10,000 trips made by 1,000 households of Income Group 1 and Household Size 2, the trip generation rate is 10.00 trips per household for that size and income group.

TRIPCAL5 is a mainframe computer program that will perform several different kinds of trip generation, one being the cross-classification technique as described in Chapter 1. The planner can provide TRIPCAL5 the results of the travel survey and the forecasted urban activity, and it will output the number of trip ends, or productions and attractions, for each zone.

CROSS-CLASSIFICATION TRIP GENERATION MODULE

The module for trip generation is designed for a two-way cross-classification production model and a two-way cross-classification attraction model. Enter the trip generation module at this point and study the input screen.

PRODUCTION VARIABLES

There are four basic input trip generation production variables:

♦ Population

- ◆ Households
- ◆ Zonal Median Income
- ◆ Regional Median Income

Review the trip generation rates for productions. From the menu:

Select   **Trip_Rates**

The production trip rates in our example are based on household size and income group. As household size gets larger, the number of trips increases. Similarly, as the income group gets larger, the trip rate increases. Income Group 4 is high income and Income Group 1 is low income. It is not necessary at this point to change the rates.

Select   **Quit** *to return to the menu*

Household Size

Although household size is surveyed for the base year (existing year), a distribution of various household sizes can change for forecast years. Therefore, a relationship is set up between the mean household size for a given zone and the distribution of one, two, three, four, five, and six-plus person household sizes. To view the curves for our example:

Select   **Graphs**

The curves shown are taken from the decennial census for each urban area. The zonal mean household size is forecasted and used to look up the distribution, or disaggregation, of total households into each of the six size ranges. This step is usually performed outside of the trip generation process but is fundamental to understanding the inputs to trip generation.

Press   **Enter (twice)** *to return to the menu*

Select   **View**

Select   **Household_Size** *to review the household size worksheet*

Review the worksheet for calculating household sizes for each zone. Note that it starts with total households and mean household size by zone, and the model calculates how many households fall into each group. To return to the main menu for trip generation:

Press   **Enter**

Select   **Quit**

Income Groups

The number of households that fall into each income group is determined in a similar manner to the household sizes. This is another process that is usually performed outside the trip generation program. To view the curves for disaggregation of households into income groups:

Select   **Graphs**

Press   **Enter** *to skip past the first graph*

Notice that the X-axis variable for income group disaggregation is the ratio of the zonal median income and the regional median income. In this case the relationship between zonal median income and the regional median income determines the breakdown of households into income groups. If the zonal median income is higher than the regional median, a typically larger fraction of the households will fall into the higher Income Groups 3 and 4.

Press   **Enter** *to return to the menu*

Select   **View**

Select   **Income_Groups** *to see the income group worksheet*

Review the calculation of the number of households in each income group by zone. The percentage in each income group is calculated by reading the graph and multiplying this factor by the total households in the zone.

Notice the worksheet titled "Normalized to Regional Distribution." The income groups are divided such that they fall into quartiles, or 25 percent in each group, on a regional basis.

Press   **Enter** *to move to the next worksheet*

Review the zonal income normalization worksheet. Using a straight calculation from the curves will not always provide for quartiles when added over the entire region. Therefore, a "normalization" is performed which forces each zonal distribution into amounts which will add up to 25 percent in each group for the region.

The method used to normalize, or redistribute, the households into quartiles is called the proportional weight procedure. This is done by dividing the sum of the households in each group by the desired amount of households in each group and redistributing the difference to each zone based on the amount already in each zone. If a zone has more households, it will receive more of the redistributed households.

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For instance, the desired percentage in each income group is 25 percent. Let's say Income Group 4 ends up with 29 percent after using the income group disaggregation curves. That means that 4 percent (29 to 25 percent) must be redistributed across all zones for Income Group 4. A zone with a higher proportion of households will receive more of the redistributed households. When finished:

Press	**Enter**
Select	**Quit** *to return to the menu*

Zonal Distribution

Now that we know how many households fall into each income group and household size, we must find out how many will fall into the combination of household group and household size. For instance, how many households are in Income Group 1 and have a Household Size of 2 for Zone 3? We know how many households are in Income Group 1, and, separately, how many households are in Household Size 2 but not the cross-classified category of Household Size 2 and Income Group 1. There is a method for doing this once we have divided them into household sizes and income groups.

Select	**View**
Select	**Zonal_Distribution**
Select	**Zone_3**

A series of three worksheets will combine the income groups and household sizes. We start with a surveyed distribution taken from the decennial census. We can see that on a regional basis, 6.64 percent of the households will be of Income Group 1 and Household Size 2. That may not be the exact proportion for Zone 3, however.

Press	**Enter** *to go to the next worksheet*

The proportional fit method is similar to a Fratar model. The desired and calculated row and column totals are compared and then distributed evenly across the rows and columns through several iterations until the desired totals are met. In our example, we do only one iteration.

Press	**Enter** *to see the column adjustment*
Press	**Enter** *to see the final distribution*

This will be the final distribution by household size and income group.

> **Press**   **Enter** *to see the trips for that cell*

These are the results of multiplying the number of households in each cell by the trip rate for that cell. This is the total trip productions for each zone by income group and household size.

> **Press**   **Enter**
>
> **Select**   **Quit (twice)** *to return to the menu*

ATTRACTION VARIABLES

Now take a look at the attraction methods.

> **Select**   **Trip_Rates** *to review the attraction rates*

The example provides for a two-way cross-classification of attraction trip rates by employment type and area type. Since the example rates provided are for HBNW trips, the attraction rates for the retail employment type are the highest. Area type is a measure of density, 1 being the most dense and, therefore, having the highest rates, except for retail employment. Retail employment in dense areas does not create as much trip activity as in suburban areas. Since we do not want to change any of the attraction rates at this time:

> **Press**   **Quit**

Area Type

> **Select**   **View**
>
> **Select**   **Area_Type** *to review the area type calculations*

Area type is a measure of density based on total activity for each zone. Total activity in our example model is calculated by taking the total population and the total employment for each zone and setting them equal by using the ratio of population to employment. This value is then divided by the number of acres in each zone to arrive at an activity density. Ranges have been set up to categorize each activity density into area types. If the area of a zone changes, like when splitting a zone for more detailed study, the concentration of population and employment may change and, therefore, the area type.

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Select   **Quit** *to return to the menu*

CASE STUDY: TRIP GENERATION

The case study example will use the default trip rates and production/attraction variables shown in Tables 1 through 3. By using the menus or entering the values directly into LOTUS, the same results can be obtained. To edit the population, households, income, employment, and area of each zone to match the tables:

Select   **Edit**

To edit the trip rates:

Select   **Trip_Rates**

Table 1
Default Production Variables

Zone	Production Variables				Trip Ends
	Population	Households	Mean HH Size	Median Income	Productions
1	**1,200**	**450**	2.67	**$37,500**	2,026
2	700	300	2.33	**$15,000**	957
3	900	600	1.50	**$23,000**	1,550
Total	2,800	1,350			4,533

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Table 2
Default Attraction Variables

| Zone | Attraction Variables | | | | | | Trip Ends |
| | Employees | | | | Area | Area Type | HBNW Attractions |
	Basic	Retail	Service	Total			
1	0	25	500	525	50	2	883
2	1,500	150	100	1,750	300	3	2,219
3	0	250	0	250	700	5	1,541
Total	1,500	425	600	2,525	1,050		4,644

Table 3
Default HBNW Trip Production Rates

Productions: Trip ends per household

| Household Size | Income Group | | | |
	1	2	3	4
1	2.185	1.620	1.724	2.455
2	3.167	2.791	2.740	3.145
3	3.524	4.028	4.205	4.527
4	4.500	5.628	6.500	6.840
5	4.833	8.000	8.478	8.927
6	6.875	7.700	8.385	14.143

Table 4
Default HBNW Trip Attraction Rates

Attractions: Trip ends per Employee

Employment Type	Area Type				
	1	2	3	4	5
Basic	0.653	0.622	0.500	0.400	0.339
Retail	0.811	1.144	8.796	8.060	6.164
Service	1.823	1.709	1.500	1.230	1.812

Changing Population and Households

The production rates in the case study are based on trips per household. The number of trips per household depends on the household size and the income level of the household. Change the population for one of the zones in the worksheet:

Select	**Edit**
Select	**Population**
Type	**New Population** *or press return to skip past*

Note that changing the population does not directly change the number of productions from a given zone. Changing the population will change the mean household size of the zone and, therefore, the category of household size if the change is large enough. This will shift the trip rate used, but it is *still applied to the number of households in the zone* since the trip rate is productions per household.

Select	**Quit**

Changing Median Income

Now try changing the median income of a zone.

Select	**Edit**
Select	**Income**

As the income is increased, the number of trips will also increase. Also try changing the regional median income. This will change the ratio (zonal median income divided by regional median income) used to determine the distribution of households by income group, and, if the change is large enough,

will change the trip rate used. Higher trips per household result from an increase in zonal median income.

Changing Number of Employees and Area

The trip attraction rates are based on trips per employee. Changing the number of employees will change the number of trips attracted to a zone directly. Also, if the increase or decrease in employees is large enough, the area type of the zone may change. Note that this will result in the use of a new cell in the trip attraction rate matrix.

In the same manner, a change in the area of a zone may result in a change in the area type and, therefore, the trip rate used. We know that zones do not change size over time, but sometimes planners are required to split zones for a more detailed analysis. This will change the area of the zone and may change the trip attraction rate used. Also, note that area type is calculated in our example using population as a variable for activity density. Thus, changing the population residing in a zone may change the area type of the zone and the trip attraction rate used.

In order to avoid some of the area type problems, many planners designate an area type to be contiguous over an entire section of the region. Typically, densities, or area types, should follow a pattern from highest (central business district) to lowest (rural suburban). Most trip generation programs, including TRIPCAL5, will allow for the manual designation of area type to a set of zones to override this type of calculation.

PRODUCTION/ATTRACTION BALANCING

The travel demand modeling process uses the term "balancing" in two different areas: trip generation and trip distribution. Balancing in trip distribution will be discussed in another chapter. Production/attraction balancing refers to the fact that the application of separate production and attraction rates will almost always result in a different number of productions and attractions for the region as a whole. The typical method of solving the problem is to use the production/attraction ratio to adjust the attractions so that they match the total productions. The proportional weight procedure is used to redistribute the attractions in proportion to the amount of attraction trip ends in each zone.

Select **Exit** *to return to the main menu module*
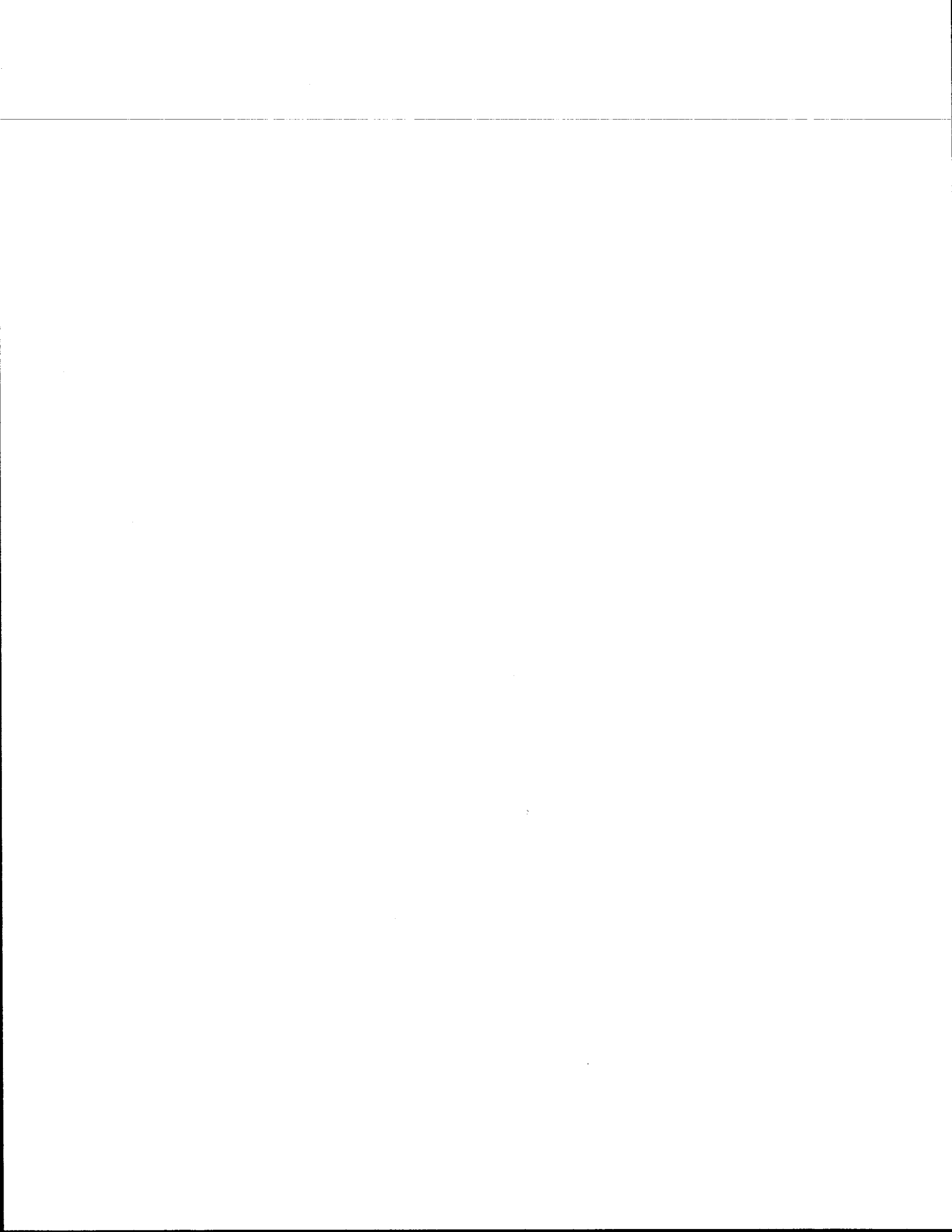
CHAPTER 4
TRIP DISTRIBUTION
ANALYSIS

Chapter 4 introduces the gravity model as a means of synthetic trip distribution for travel forecasting modeling. The Texas Package formulation is discussed, and a case study is performed as a self-calibrating gravity model.

THE TRIP DISTRIBUTION PROCESS

The basic inputs to the trip distribution model are the productions and attractions (from trip generation) for each zone, the minimum travel time between each zone, and the trip length frequency distribution. In Texas, the trip distribution model used is the gravity model. The Texas Travel Demand Package trip distribution model is essentially a gravity model with some modifications.

The gravity model formula is:

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

Where:

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

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

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

$t_{i,j}$ = the travel time in minutes between Zone i and Zone j (analogous to separation between bodies i and j).

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

K_{s_i , s_j} = specific zone-to-zone adjustment factor bias to allow for the incorporation of the effect on travel patterns of defined social and economic linkages not otherwise accounted for in the gravity model formulation.

$E_{i,j}$ = the interaction eliminator function which has a value of 1 if the

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interaction from Zone i to Zone j is used or a value of 0 if the interaction from Zone i to Zone j is eliminated.

X = all zones.

THE TRIP DISTRIBUTION MODULE

In the case study LOTUS module, we have eliminated the socioeconomic factor, K_{s_i , s_j}, and the interaction eliminator function, $E_{i,j}$, to result in the following simplified formula:

$$T_{ij} = \frac{P_i \, A_j \, F_{t_{ij}}}{\sum\limits_{x=1}^{n} A_j \, F_{t_{ij}}}$$

The travel time impedance, $t_{i,j}$, is the minimum travel time from each zone to all other zones and is set up in a matrix. In our example, the travel time matrices, or "skims," are placed in a three-by-three matrix because there are three zones. The values in the matrix are in minutes. The minimum travel time between zones is calculated from a program that builds minimum impedance "trees" from the coded network. For more information on the subject of building minimum impedance matrices, please refer to the FHWA document, Traffic Assignment, August 1973: Methods, Applications, Products.

The friction factors, $F_{t_{ij}}$, are simply a weight given to the minimum travel times. The weight for each unit of travel time is adjusted using an iterative process until the correct pattern of trip lengths and interaction is achieved. The correct pattern of interaction (distribution) is measured by the trip length frequency distribution. A surveyed (observed) trip length frequency distribution is used as a goal. When the modeled trip length frequency distribution matches the observed frequency distribution (curve), the model is said to be calibrated.

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From the main menu screen:

Select   **Trip Distribution** *to enter the next module*

Note on the input screen of the trip distribution module that the modeled curve does not match the observed trip length frequency distribution curve. Also note that the mean (average) trip length does not match the observed conditions, either. Therefore, we can assume that the existing friction factors, or weights for the travel times, must be adjusted such that the parameters converge.

Select   **Edit**

Input the following productions, attractions, and impedances (travel times) into the trip distribution worksheet.

Select   **Quit** *when finished*

Table 5
Default Trip Matrix

TRIPS	To			
From	1	2	3	Total
1	381	958	665	**2,004**
2	183	459	319	**960**
3	297	746	518	**1,560**

Initial Attr:	**883**	**2,219**	**1,541**	4,524

Table 6
Default Travel Time Matrix

MINUTES	To		
From	1	2	3
1	**1**	**3**	**5**
2	**4**	**7**	**9**
3	**6**	**9**	**2**

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Model Calculation

Now that we are familiar with the gravity model formula:

Select   **View**

Select   **Model_Calculation**

The worksheet contains several columns of data including the friction factors. Note that the beginning default friction factors are all the same and are set at 1,000. The next column of data is the friction factor multiplied by the attractions for that zone. This value is sometimes referred to as the "accessibility index" for the zone. The trips are calculated by simple mathematics, taking the ratio of the accessibility index for a given zone and dividing it by the sum of the accessibility indices for all other zones. This ratio results in the fraction of trip productions which should be sent to the attraction zone.

Press   **Enter** *to return to the menu*

Friction Factor Calibration

The Texas Package gravity model is a self-calibrating model. This means that the desired trip length frequency is provided as an input and the program executes several iterations until a specified convergence is met.

Select   **View**

Select   **Friction_Factors**

Review the friction factor calibration worksheet. The first column is the percent of trips observed for each travel time interval. The next column is the percent of trips calculated by the gravity model for each travel time. In our example, the ratio between the two columns is used as an adjustment factor for the most recent set of friction factors. The calibration process will:

- ♦ Calculate the gravity model using the latest friction factors,
- ♦ Adjust the friction factors according to the difference between the observed and the calculated trip length frequency at each time interval, and
- ♦ Calculate the gravity model again and iterate through the process a specified number of times.

The next step is calibrating the friction factors to distribute the trips which will match the observed trip length frequency distribution.

> **Select** **Calibrate_Factors**
>
> **Select** **3 or 4**

There will probably be little difference between running three or running four iterations. You should see the trip length frequency curve for the model calculation get closer in shape to the observed curve as the process continues. Also, glance at the mean trip length value. The calculated mean trip length should be closer to the observed mean when the iterations are finished.

Trip Summary and Squared Deviation

> Now let's see what happened during the calibration process.
>
> **Select** **View**
>
> **Select** **Trip_Summary**

The trip summary worksheet will show the calculated trips for each time interval and the desired observed trips for each time interval. The next two columns of information are used to calculate the mean trip length, weighting the trips by travel time. The final column is a measure of error between the modeled trips and the observed trips. The difference between the number of trips for each time interval is squared (to get a positive value). Then the values are summed over all time intervals. The lower this summation is, the better "fit" we have for the modeled trips to the observed trips. The sum of squared deviations measure of error is also found on the main input screen.

> **Press** **Enter** *to return to the menu*

Attraction Error

> After calibrating the friction factors to match the observed trip length frequency distribution and the mean trip length as closely as possible, you will notice that the resulting attractions are in substantial error when compared to the input attractions for each zone. Remember that during trip generation we calculated the total attractions for each zone based on the total employment and

surveyed trips per employee. Therefore, the gravity model has produced an attraction error through the process of distributing the trips to match the correct trip lengths.

Correcting the attraction error may result in a lesser fit to the trip length frequency distribution, but doing so is common practice.

> **Select** **View**
>
> **Select** **Attraction_Balance**

Review the process used to correct attraction error. The method used is an iterative proportional fit process which adjusts the trip matrix columns and rows to match the desired total column sums.

> **Press** **Enter (three times)** *to page through the process*

Run about three iterations on attraction balancing, and then review the attraction error and trip length error at the end of the process.

> **Select** **Balance_Attractions**
>
> **Select** **3**

Notice that the trip length frequency distribution will change, since the trip matrix is being adjusted.

Calibrating the Model

The calibration process assumes that you begin with the same number of total productions as attractions across the study area. As mentioned before, attractions are usually adjusted prior to the trip distribution model to match total productions.

There are several different methods and combinations of iterations on friction factors and attraction balancing, usually defined by the program you are using. A common combination is to iterate once on friction factors, then once on attractions, and so on until a good fit is achieved. Any method or combination is probably suitable as long as the model is ultimately calibrated to the analyst's satisfaction.

> **Select** **Exit** *to return to the main menu module*

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CHAPTER 5
TRAFFIC ASSIGNMENT

This chapter reviews the iterative traffic assignment process as used in the Texas Package. A Lotus 1-2-3 interactive training module is presented as a means to study the differences between the iterative capacity restraint procedure and an all-or-nothing traffic assignment methodology.

The final step in traffic modeling is assigning the trip table to a coded highway network. For an explanation of coding highway network links and nodes, refer to the FHWA document, <u>An Introduction to Urban Travel Demand Forecasting, A Self-Instructional Text</u>. The traffic assignment process is the process of using the estimated demand, or trip table, and applying it to the estimate of transportation supply, or coded network.

ALL-OR-NOTHING ASSIGNMENT

The traffic assignment process involves selecting a minimum path through the network from each zone to all other zones. Then the trips for each origin and destination pair are loaded onto the minimum path. The minimum path is selected by a computer algorithm called a "tree" builder (a refined method is called the "vine" builder). It is called this because the resulting network looks like a tree or vine stemming from the origin zone, or "root" node.

After the minimum path is found between two zones, the trips between the two zones are assigned to all links in the path. When 100 percent of the trips are assigned to the minimum path, the traffic assignment is called "all-or-nothing." This means that, unless a link is on the minimum path, it will not receive any trips. This has been found to be an ineffective estimate of the actual traffic patterns in an urban area. Because of congestion delay and user-preference based on other factors, the minimum path may vary considerably. Since congestion usually occurs during peak hours in the morning and evening, the minimum paths will be different than other times of the day. Minimum paths are based on travel time which is calculated from the speed associated from a given amount of congestion on each link.

The networks coded for the Texas Package are given speeds derived from urban area speed surveys. These speeds are assumed to be taken at an average level of daily congestion, or a volume to capacity (V/C) ratio of about 0.85. This means that the traffic on the links surveyed is about 85 percent of the level of traffic which the link could theoretically tolerate.

Travel modeling in Texas is usually performed for an estimate or forecast of average daily traffic. Typically, all trips made from a given origin and destination pair will not follow the same path and will be influenced at different times of day by varying traffic levels. As the traffic on the roadways increases, the speed typically decreases.

The V/C ratio is the measure used by the traffic assignment model to calculate congestion levels and, accordingly, adjust the speed and travel time on each link. The relationship between V/C ratio and speed is plotted and used during traffic assignment. This function, called the impedance adjustment function, is shown in Figure 1.
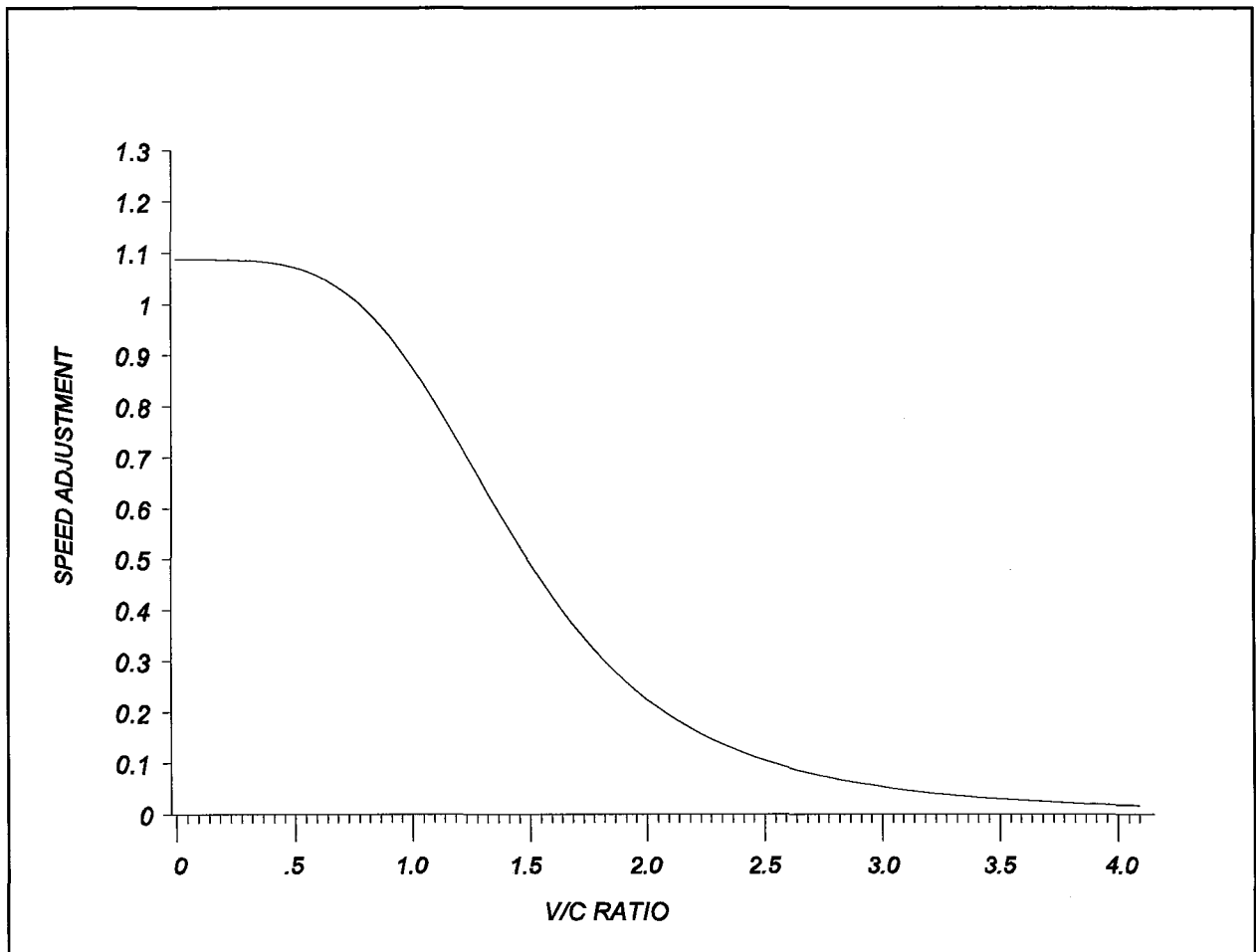

Figure 1. **The Texas Package impedance adjustment function**

Capacity restraint assignment is performed by adjusting the speed and, therefore, the time on each link in relation to the congestion occurring on the link. The speed is adjusted according to the impedance adjustment function (Figure 1). The Texas Package uses a method called iterative assignment. The process for the iterative assignment is as follows for a given origin and destination zone pair:

1) Load 100 percent of the trips from Zone A to Zone B on the minimum path calculated from the input speeds.

2) Calculate the new V/C ratios for each link in the network.

3) Using the new V/C ratios, look up the speed adjustment from the impedance adjustment function and place the new speeds on all network links.

4) Load 100 percent of the trips along the new minimum path (if different).

5) Perform Steps 1 through 4 for a specified number of iterations, usually three to five, saving the volumes on each link for each iteration.

6) Take a pre-specified percentage of each iteration's volume to calculate the weighted final volume. The recommended percentages are 15 percent, 15, 20, 20, and 30 percent.

After each trip loading iteration, the volume used to calculate the V/C ratios on each link is a weighted average of all the preceding iterations.

THE TRAFFIC ASSIGNMENT MODULE

The last module in the interactive training process is an iterative traffic assignment procedure applied to a simplified network. The network consists of three zones with three two-way links connecting them. Review the simplified map in Figure 2.
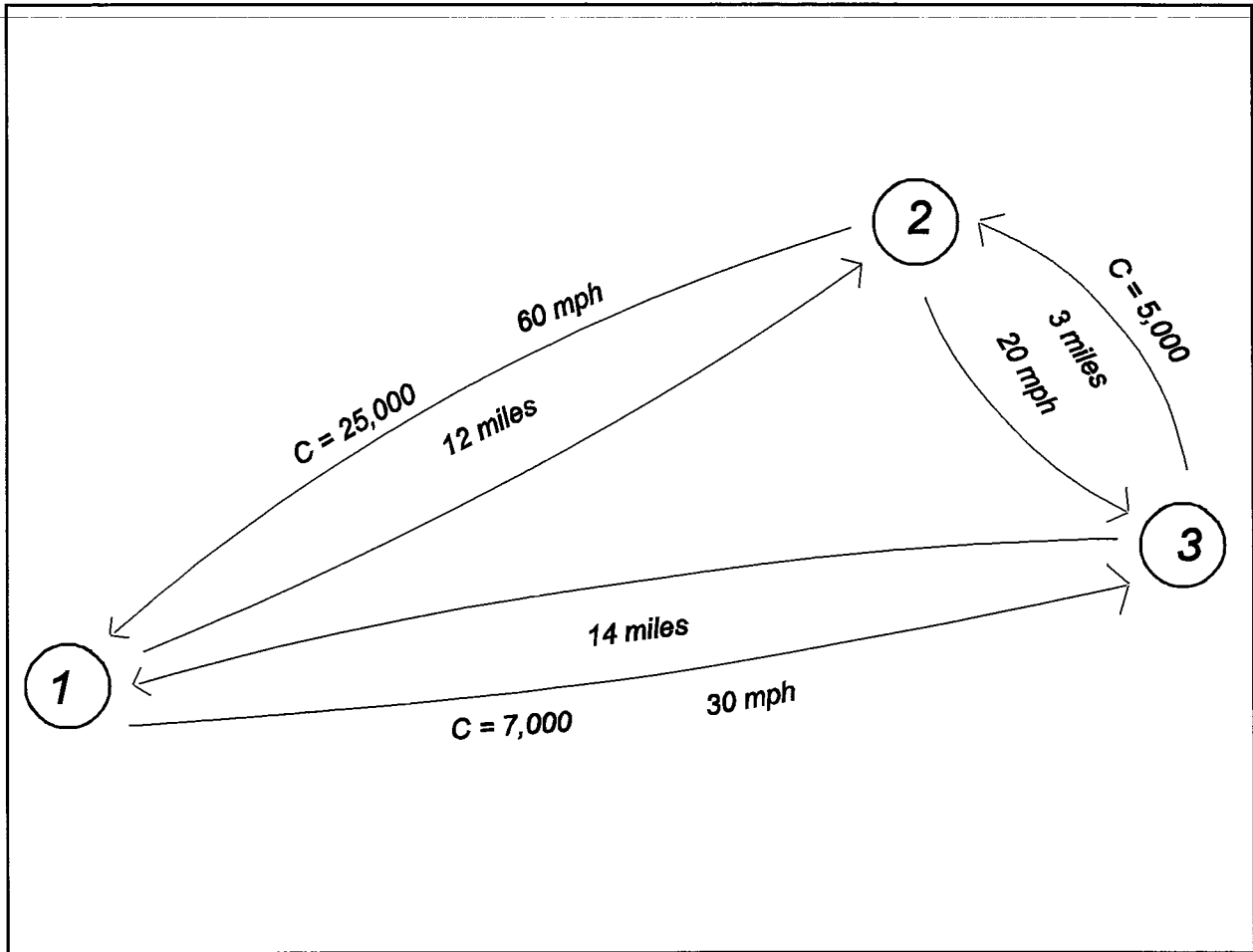
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Figure 2. **Example network for the traffic assignment training module**

The example network is designed in a manner that will provide only one alternative path for each zone pair. For instance, looking at the Zone Pair 3 to 1, the two possible paths are 3 to 1 and 3 to 2 to 1. Thus, as one of the paths becomes congested, the trips from Zone 3 to Zone 1 will be assigned to the alternative path. Now enter the traffic assignment training module:

Select **Traffic Assignment** *from the main menu module*

CASE STUDY: TRAFFIC ASSIGNMENT

Network Variables

The main screen of the traffic assignment module is organized into:

♦   A link report and input worksheet showing the speeds, distances, capacities, and assignment results (volumes) on each link;

♦   A trip table, showing the input trip demand for all zones;

♦   An assignment summary, showing the summary results of the traffic assignment, vehicle miles traveled (VMT), vehicle hours traveled (VHT), and average V/C ratio; and

♦   An iteration weighting worksheet showing the input weights for each iteration and the number of iterations performed.

Change the beginning speeds, distances, and capacities to the default values shown in Table 7.

Select	**Edit**
Select	**Speeds, Distances, Capacities** *choose one*
Select	**Quit** *when finished*

Table 7
Default Link Values

Link	Speed	Distance	Capacity
1-2	60	12	25,000
1-3	30	14	7,000
2-1	60	12	25,000
2-3	20	3	5,000
3-1	30	14	7,000
3-2	20	3	5,000

When the speed or distance is changed on any of the links, the travel time across the link is

calculated. When any of these variables are changed, the worksheet is reset and all values are initialized to zero for the iterative traffic assignment output. This can also be accomplished by choosing "initialize" from the menu.

Input Trip Table

Now look at the input trip table. Recalling the output trip table from the trip distribution process, the trips going in one direction (origin to destination) may not equal the trips in the opposite direction (destination to origin) as output from trip distribution. On a daily basis, however, both directions should be equal, because all trips return to their origins. Referring to the input trip table for the example traffic assignment module in Table 8, both directions are equal.

<div align="center">

Table 8
Default Trip Table

Trip Table	To Zone		
From Zone	1	2	3
1	200	5,000	12,000
2	5,000	300	1,000
3	12,000	1,000	200

</div>

The traffic assignment module will allow input to only one direction: origin to destination. The module will then set the opposite direction equal to the trips input in the origin-to-destination direction. The process in fully functional models is to take an average of both directions as output from the trip distribution process. For instance, if there were 5,000 one-way trips from origin to destination, and 1,000 one-way trips from destination to origin, the model would average both values to 3,000 one-way trips.

Change the trip table to the default trips in Table 8:

Select   Edit

Select   Trips

Type	New trips for each zone
Select	Quit *when finished*

Impedance Adjustment Function

The impedance adjustment function can be edited and reviewed:

Select	Edit
Select	Impedance

The screen should now show a graph of the impedance adjustment function. The parameter values can be edited or simply skipped over and should probably be set to the default values as shown on the screen (try changing a few values and see what happens to the shape of the curve). This function is used to update the speeds and, therefore, the travel times on each link as the traffic assignment model goes through all iterations.

Note that the adjustment value (y-axis) is greater than 1.0 for V/C ratios of 0.85 or less. This is because the speeds coded on the network in the Texas Package are observed average daily speeds at an assumed V/C ratio of 0.85 (or level of service C). When the iterative assigned volume on a link results in a V/C ratio less than 0.85, the speed must be increased; therefore, the factor is greater than 1.

Press	Return (three times) *to return to the menu*

All-or-Nothing Assignment Example

The default traffic assignment in the module is an all-or-nothing assignment. Note that links 1 to 3 and 3 to 1 do not receive any traffic volumes in the column labeled "All-or-Nothing."

Select	View
Select	Path_Trace

The cumulative path trace worksheet is a list of all possible paths through the network for each origin to destination (O-D) pair and their associated travel times. An all-or-nothing traffic assignment assigns all trips from one zone to another to the shortest possible time path. All routes which traverse link 3 to 1 or 1 to 3 (look in the "Path" column) have longer travel times (using the observed speeds) than the alternative routes, 1 to 2 to 3 and 3 to 2 to 1. Thus, all traffic is assigned

to the routes with the shortest cumulative travel time.

Press   **Enter** *to return to the main screen*

Iterative Assignment Example

The iterative assignment process will assign trips to the minimum time routes as calculated by adjusting the travel time on all links in the path based on the current V/C ratio. As mentioned previously, the Texas Package, as well as the example module, use an average weighted volume to calculate the latest iteration's V/C ratio. Under the column heading "Calculations," the current V/C ratio, the current weighted average volume on all preceding iterations, and the current iteration link travel time are listed. To perform a typical 5 iteration assignment:

Select   **Run_Assign**

Select   **5**

Select   **Edit_Weights**

The cursor should move to the first iteration weighting. Change the weighting for each iteration to match the default in the Texas Package, and press return after each entry. The defaults are 15, 15, 20, 20, and 30 percent for Iterations 1 to 5. After you have finished entering the iteration weights, the first iteration is executed. If you are satisfied with the current weighting scheme, you may choose "Same_Weights". If you want to see an even weighting scheme for the number of iterations you selected, choose "Even_Weights".

Note that after one iteration, the "Weighted Volume" column has been filled. These values are the volumes assigned to the minimum paths multiplied by the iteration weight, in this case, 15 percent. There will be no volume assigned to the 1 to 3 link or the 3 to 1 link because the 1 to 2 to 3 and the 3 to 2 to 1 route is a shorter cumulative travel time (before the volumes were assigned). Also, the current V/C ratio and the current travel time on each link have been updated.

Before pressing return for the next iteration, notice that the cumulative travel time on links 3 to 2 and 2 to 3 has been updated to 70 minutes. This is because of the high V/C ratio (2.60). The alternative route from Origin 3 to Destination 1 will be across link 3 to 1 which will have a travel time of 26 minutes, much less than the 3 to 2 to 1 route with a cumulative travel time of 70 + 11 = 81 minutes.

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Be careful not to attempt to run six iterations, or you will select a menu item. If this happens, simply press "Quit" to return to the main screen.

Now look at the results of the iterative assignment example. Notice that the resulting volume is more evenly distributed across the network than the all-or-nothing volumes.

Select   **View**

Select   **Link_Summary**

The link summary worksheet shows the results of each iteration during the assignment. The volumes assigned to each link are listed in the first table, and the link travel times associated with the current iteration link V/C ratios are shown on the second table. The final weighted volume is calculated by multiplying the iteration weight by the current iteration volume assigned to each link. This process is intended to give a more realistic loading on each link when compared to its capacity and travel speed.

Press   **Enter** *to return to the main screen*

Select   **View**

Select   **Weighted_Averages**

The weighted average volume on each link is calculated after each iteration and is used to get a weighted average V/C ratio at each iteration. The V/C ratio is then used to find an impedance adjustment factor (travel time adjustment factor) to update the travel times on each link. The average weighted volume in the example module is calculated according to the following formula:

$$New\ Volume = \sum_i^n \frac{V_i}{\sum_i^n V_n} \cdot V_i$$

Where:

v   =   assigned volume

i   =   the current iteration.

n   =   total of all iterations performed.

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Different scenarios can be performed using the iterative traffic assignment module. Try using an adjusted impedance function or different link characteristics, and see how the assigned volumes change.

TRAFFIC ASSIGNMENT VALIDATION

Traffic assignment models are calibrated to match existing observed traffic counts. Several adjustments to the entire modeling process may need to be performed in order to match ground counts for a given base validation study year. After the model is brought within an acceptable level of precision, the parameters can be transferred and used to forecast traffic.

Refer to the document, <u>Calibration and Adjustment of System Planning Models</u>, December 1990, US DOT, FHWA for a discussion of techniques used to validate traffic assignment models.