NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT 328

# FORECASTING THE BASIC INPUTS TO TRANSPORTATION PLANNING AT THE ZONAL LEVEL

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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# FORECASTING THE BASIC INPUTS TO TRANSPORTATION PLANNING AT THE ZONAL LEVEL

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AREAS OF INTEREST

Planning
Forecasting
(Highway Transportation)

**TRANSPORTATION RESEARCH BOARD**
NATIONAL RESEARCH COUNCIL
WASHINGTON, D. C.
JUNE 1990

## NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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# FOREWORD

*By Staff*
*Transportation Research Board*

This report will be of interest to transportation planners who are concerned with the use or preparation of socioeconomic input data critical for estimating travel demand at the sub-county geographical level. The research reported here extends that of *NCHRP Report 266,* "Forecasting the Inputs to Transportation Planning," which provided guidance on the preparation of aggregate forecasts for sub-state areas. Guidance is provided in two broad areas: (1) planners are alerted to the sensitivity of urban area travel forecasts to various types and magnitudes of errors in the preparation of zone level socioeconomic input variables, and (2) forecasting/allocation methods currently used by urban agencies throughout the United States are identified and evaluated, thus providing planners with a good sense of the state of the art in planning methodologies applicable to the sub-county geographic level.

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Recent demographic trends have demonstrated that extraordinary changes in the relationships between population, households, and labor force are not effectively treated in many existing forecasting procedures. Many jurisdictions are encountering more volatile growth patterns that demand a greater sensitivity in forecasting methods. Moreover, changing demands on the planning process, including more project-oriented activities, and a frequent need for quick response have changed forecasting requirements.

Planning agencies face three types of circumstances in forecasting for sub-county areas: (1) top-down allocation mandated by the state in cooperation with the localities; (2) competing forecasts for localities, which must be reconciled; and (3) a lack of available forecasts from outside authorities. State and local planners need a basis for choosing techniques to respond to these problems. Research is needed to document techniques that: (1) have been usefully applied by planning agencies, (2) are applicable at any sub-county level of aggregation, (3) are accurate for intended purposes, (4) are responsive to current planning needs, (5) have well-defined areas of application, and (6) can be implemented and updated by users who do not possess a sophisticated demographic, economic, or statistical background.

Under NCHRP Project 8-24A, "Forecasting the Basic Inputs to Transportation Planning at the Zonal Level," research was undertaken by COMSIS Corporation, with the objective of extending the work documented in *NCHRP Report 266* by describing and evaluating techniques for determining and forecasting the input variables critical for estimating transportation demand at the sub-county geographic level.

To accomplish the objective the research was conducted in two general emphasis areas. In the first area the researchers examined the sensitivity of the Urban Transportation Planning Process (UTPP) to various types and magnitudes of errors in socioeconomic input variables at the zonal level. Using a calibrated and validated travel demand model for the Dallas/Fort Worth area, the researchers evaluated six basic test scenarios representing errors of different types and magnitudes in the socioeconomic data. Assistance with the testing was generously provided by the North Central Texas Council of Governments (NCTCOG). The traffic volume forecasts produced by the models were evaluated for various types of highway facilities. The tests yielded a great many valuable conclusions resulting in precautions for planners dealing with three common planning circumstances: regional freeway and expressway systems, corridor planning, and site-specific studies.

In the second area of research emphasis, six broad groups of socioeconomic input forecasting/allocation methods were identified, using a previous national survey's findings, a review of current practices, a literature search and interviews with various practitioners from federal agencies, state departments of transportation, and metropolitan planning organizations. A representative method from each group is described, with references, and, rather than recommend a best method, the four most promising methods are evaluated in detail by discussing their positive and negative characteristics.

In summary, the results of this research provide the urban planner with both a useful state-of-the-art review of the most important techniques applicable to sub-county area traffic forecasts and many precautions regarding the accuracy of the forecasts as a function of variations in the accuracy of the data inputs to the techniques.

## CONTENTS

## ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 8-24A by COMSIS Corporation. Arthur B. Sosslau and David M. Levinsohn were the principal investigators. The author of the report was Dr. Jitendra N. Bajpai. Other COMSIS personnel contributing significantly to this report were James Ryan and Michael Doherty. Gordon Schultz provided valuable comments at various stages of the research.

Our sincere thanks are extended to the Transportation and Energy Department of the North Central Texas Council of Governments and its staff who contributed significant time and effort in undertaking the sensitivity runs. Without their enthusiastic support and computer assistance during the course of this project, we would not have met the research objectives.

Sincere appreciation is expressed to all the agencies and individuals that provided input to the research. The agencies which completed the questionnaires and provided details on their procedures and models are the: Metropolitan Washington Council of Governments, Association of Bay Area Governments, San Diego Association of Governments, Middle Rio Grande Council of Governments of New Mexico, North Central Texas Council of Governments, and Regional Planning Council of Baltimore. We acknowledge the participation of Dr. Steven H. Putnam, S.H. Putman and Associates, and Fred A. Reid, Woodward-Clyde Consultants.

# FORECASTING THE BASIC INPUTS TO TRANSPORTATION PLANNING AT THE ZONAL LEVEL


## SUMMARY

The research conducted under NCHRP Project 8-24A provides a concise reference for transportation planners concerned with the use or preparation of socioeconomic inputs that are critical for estimating travel demand at the sub-county geographical level. This project has extended the work documented in *NCHRP Report 266*, which provides guidance on the preparation of aggregate forecasts for sub-state areas.

Research was conducted in two broad areas: (1) the sensitivity of urban area travel forecasts to various types and magnitude of errors in the preparation of zone level socioeconomic input variables, and (2) identification, selection, and evaluation of socioeconomic variable forecasting and allocation methods currently used by urban agencies throughout the United States.

Most agencies develop traffic zone level inputs in two steps: from region to district (or jurisdiction), and then from district to traffic zone. The sensitivity analysis indicated that the final output of the urban transportation planning process (UTPP), link traffic volumes, is sensitive to errors in the district level forecasting of population and employment. The degree of sensitivity varies across types of facilities and the overall magnitude of error. Transportation facilities serving interdistrict travel, such as major and minor arterials, are most susceptible to the district level forecasting errors. The affected transportation facilities are likely to be concentrated in the areas of large allocation errors. Planners undertaking corridor level studies should be most concerned about the reliability and accuracy of district socioeconomic level forecasts, particularly for those districts directly served by the corridor.

Local transportation facilities are most sensitive to the errors in the subdistrict (or zone) level forecast of socioeconomic variables. Occurrence of large errors (above $\pm 20$ percent) in subdistrict allocation could significantly affect the prediction of traffic on major and minor arterial facilities. Site-specific studies concerning local road design may be severely affected by data errors at the traffic zone level.

Because of the high uncertainties linked to new development in suburban areas, greater attention should be paid to the preparation of land use inputs for these areas. Planners undertaking design studies for corridors or local roads serving undeveloped suburban areas must be aware of the fact that the suburban districts and zones have potential for introducing large land use input errors.

Travel demand models must be applied using traffic zone level data, not district level data. The practice of expanding a district-to-district trip table to a zone-to-zone trip table may produce high estimates of vehicle-miles traveled and trip volumes on major facilities after the assignment of the expanded trip table.

A combination of an intuitive knowledge-based technique, such as the Delphi method, and formal analytical methods seems to be the most desirable approach to forecasting subregional level socioeconomic variables. Considering the resource requirements and complexity, sophisticated mathematical land use forecasting models seem suitable only for large urban areas. Small-size and medium-size urban area agen-

cies will find simple analytical methods and the Delphi method to be the most preferred techniques.

For selected urban areas, a formal comparison of subregional forecasts produced currently and 1990 census data should be undertaken. Techniques to project automobile ownership, household income, and household size from population and employment forecasts are highly recommended for future research. There are no current forecasting or allocation methods available to produce the above variables at the zone level.

CHAPTER ONE

# INTRODUCTION

## STATEMENT OF PROBLEM

The research problem, as defined by NCHRP, is as follows:

> Transportation planners forecast travel demand on the basis of anticipated changes in socioeconomic variables such as population, employment, vehicle availability, income, and household size. Errors in the forecasts of these variables can lead to substantial errors in information provided to decision-makers in the evaluation of transportation alternatives. NCHRP Project 8-24 investigated and reported on a portion of this problem area, specifically the preparation of aggregate forecasts for sub-state areas. It examined the sensitivity of the process (and particularly its first step, trip generation) to differences (or errors) in input. However, no analysis of the sensitivity of the process to disaggregation—or variation in aggregation—was performed. This continuation project investigates the availability and utility of methods to produce forecasts for units of sub-county levels of geography, typically traffic zones, either by downward allocation of sub-state forecasts or by direct means.
>
> A problem that frequently arises is that the various techniques used to forecast socioeconomic variables produce significantly different results. Some forecasting techniques produce data that are incomplete or lack sufficient detail for travel estimates and impact assessments.
>
> Recent demographic trends have demonstrated that extraordinary changes in the relationships between population, households, and labor force are not effectively treated in many existing forecasting procedures. Many jurisdictions are encountering more volatile growth patterns that demand a great sensitivity in forecasting methods. Moreover, changing demands on the planning process, including more project-oriented activities, and a frequent need for quick response have changed forecasting requirements.
>
> Planning agencies face three types of circumstances in forecasting for sub-county areas: (1) top-down allocation mandated by the state in cooperation with the localities; (2) competing forecasts for localities, which must be reconciled; and (3) a lack of available forecasts from outside authorities. State and local planners need assistance in choosing techniques to respond to these problems.
>
> Research is needed to document techniques that: (1) have been usefully applied by planning agencies, (2) are applicable at any sub-county level of aggregation, (3) are accurate for intended purposes, (4) are responsive to current planning needs, (5) have well-defined areas of application, and (6) can be implemented and updated by users who do not possess a sophisticated demographic, economic, or statistical background (*1*).

## OBJECTIVES AND SCOPE OF PROJECT

The stated objective of this research project is, "to extend the work documented in *NCHRP Report 266* to describe and evaluate techniques for determining and forecasting the input variables critical for estimating transportation demand at the subcounty geographic level."

The *NCHRP Report 266* (*1*) recommended research in disaggregating area level projections to subareas—tracts, districts, zones—and in examining sensitivity of the final estimates of travel demand as evidenced in output link and line volumes to the area level projections of socioeconomic data. Competent review and presentation of techniques for disaggregation, interpolation, and projection of appropriate variables were also recommended.

To accomplish the foregoing objectives, the scope of the project was defined to include the following:

- Identify, select, and describe procedures used for allocating and forecasting variables, such as population, households, and employment. The geographic level of interest will be subdivisions of larger areas (study areas, counties, etc.) such as tracts, districts, zones.
- Develop and identify criteria for evaluating applicable procedures and techniques for allocating or forecasting appropriate variables such as population and employment at the sub-county geographic level (zones, tracts).
- Describe, evaluate, and otherwise characterize procedures for allocating or forecasting transportation variables. This will include identification of differences between procedures, conditions under which they are most appropriately applied, type of skills required for application, adequacy of results expected, and advantages and disadvantages of each technique.
- Develop example applications of the most appropriate methods showing data input and sources, output results, software available for application, and availability.
- Examine the sensitivity of final estimates of travel demand, in terms of link and line volumes, to various types and magnitude

of errors in socioeconomic input variables at the sub-county level (zones, districts, subzones).

- Develop a final report that will be in a form suitable for use by state and local transportation planners.

## CURRENT PRACTICE

In practice, most agencies, regardless of the land use forecast or allocation method used, develop traffic zone level socioeconomic inputs in two steps: (1) from region to district (or jurisdiction) and (2) from district to traffic zone. Generally, district level allocation methods do not produce all required inputs for the travel demand prediction models. Hence, a postprocessing procedure is commonly applied to calculate the required inputs. The input variables frequently used by travel demand models, but usually not produced directly by allocation methods, are household income, car ownership, households classified by income and car ownership, and households by size. Most methods forecast distribution of population and employment by category.

The methodologies used to prepare subregional inputs are very diverse and their selection by an agency seems to be conditioned by local circumstances. Local preference, area size, data availability, available resources, and staff skills are among the factors in methodology choice. Smaller areas generally use simple analytical methods or the Delphi method. Mathematical models have been adopted primarily by large metropolitan planning organizations (MPOs) (e.g., Southern California Association of Governments (SCAG), North Central Texas Council of Governments (NCTCOG), Association of Bay Area Governments (ABAG), and so forth). Few agency employees have the requisite expertise to calibrate and apply these models. Much of the capability is therefore provided by the model developer, often on a consulting basis. This may be a reason for the number of agencies, including a few larger ones, that favor less mathematical procedures—for example, the Delphi method and certain analytical techniques (ratio techniques and carrying capacity methods).

Among the mathematical-model-based procedures, the trend appears to be away from the large models of a decade ago, such as PLUM (*2*) and EMPIRIC (*3*), with almost no current implementation of these found. Recently, interest seems to be in the EMPAL and DRAM models developed by Putman of the University of Pennsylvania. Considering the growing use of microcomputers and microcomputer-based software, GIS (Geographic Information System)-based data, and the availability of the 1990 census data and the Tiger/Line files in the future, mathematical-model-based procedures may become more readily and economically applied.

Numerous methods are in use to disaggregate input data from district level to traffic zone level. Most of these subdistrict allocation methods are driven by zone-specific supply side factors such as: proposals in "pipeline," zoning, past trends, amount of developable land and current land use distributions. However, their structures vary significantly. Larger MPOs often develop their own sophisticated analytical methods, whereas smaller agencies often rely on a manual technique. In both cases, a significant amount of personal judgment is exercised while distributing the district control totals to the zones comprising each district. Most of the subdistrict allocation procedures are similar to the analytical methods (ratio techniques and carrying capacity method) and are predominantly used by smaller areas to develop subregional forecasts. Because inputs provided by the local agencies, and their review, are crucial to the accuracy of the zonal allocation, local jurisdictions are often responsible for the task of subdistrict (or subjurisdictional) level allocation.

## RESEARCH APPROACH

The research was divided into two broad areas. The effort under the first area examined the sensitivity of the urban transportation planning process (UTPP) to various types and magnitudes of errors in the zone level socioeconomic input variables. Effort under the second area focused on the identification, selection, and evaluation of socioeconomic variable forecasting and allocation methods currently used by MPOs.

The principal purpose of the UTPP is to provide transportation facilities and services in the most cost efficient or effective manner to serve anticipated future travel demand. However, any significant error in travel demand forecast may lead to underdesign or overdesign of a facility and thus substantial misallocation of public resources. There are three well-recognized sources of error in a travel demand forecasting process: socioeconomic (or land use) inputs, sampling in travel surveys, and model specification. Because the focus of this research is on the first source (i.e., socioeconomic inputs), the research details the sensitivity of the travel demand forecasting process to typical errors in socioeconomic variable inputs at the subregional level.

The effects of typical input or allocation procedural errors on model output are examined using a calibrated and validated travel demand model for the Dallas/Fort Worth area. This investigation intends to identify the nature of precautions to be taken when preparing socioeconomic forecasting or allocation at the zonal level.

A preliminary list of socioeconomic input forecasting and allocation methods was developed based on (1) a national survey's findings—see Reaves (*4*); (2) on current socioeconomic variable forecasting practices at the subregional level; and (3) a literature search and interviews of various practitioners from federal agencies, state DOTs and MPOs. These methods are categorized later into six broad groups according to technique. Under each category, a method representing the current state of practice is selected for descriptive review. The results are presented as descriptions of each methodology with references for further information, and descriptions of six application examples of the forecasting process. Rather than recommend a best method, the four most promising methods are evaluated in detail, discussing their positive and negative characteristics.

Chapter Two presents the findings concerning UTPP sensitivity to errors in the socioeconomic inputs at the subregional level. The chapter also reviews available methods for preparing zone level socioeconomic inputs.

Chapter Three provides interpretation, appraisal, and applications of the socioeconomic forecasting/allocation methods. Conclusions and recommendations stemming from this research are presented in Chapter Four.

Application examples are provided in Appendix A. A comprehensive bibliography is included in Appendix B.

CHAPTER TWO

# FINDINGS

This chapter presents findings concerning UTPP sensitivity to various types of errors in the forecasting or allocation of socioeconomic input variables at the subregional level. The chapter also reviews six methods identified as currently available to planners for preparing zone level socioeconomic inputs.

## SENSITIVITY BETWEEN LAND USE ALLOCATION AND TRAVEL DEMAND

One task of the research was to explore UTPP sensitivity to various types of errors in the allocation of land use and socioeconomic input variables. The intent was to illustrate the effect of typical input or allocation procedural errors on the outputs of the UTPP through a set of sensitivity experiments. Figure 1 schematically illustrates the UTPP system as consisting of three basic components: input, process, and output. Most land use allocation methods produce zone level socioeconomic data, representing a major category of the UTPP system input. As the focus of the sensitivity test was to examine only the effects of input socioeconomic data changes on the UTPP outputs, the remaining inputs (network data, travel data and zone structure) were kept constant for all experimental test runs.

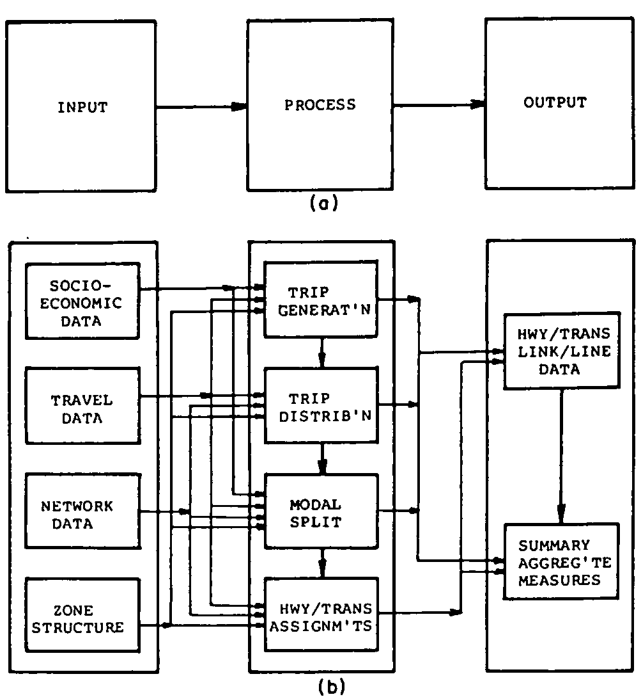



*Figure 1. Urban Transportation Planning Process.* (Source: Ref. 1)

The Dallas/Fort Worth area travel demand model was selected for the sensitivity tests. This selection considered the sophistication of, familiarity with, travel demand models as well as staff skill levels in their maintenance and operation. The foremost factor in this selection, however, was the willingness of the North Central Texas Council of Governments (NCTCOG) to assist in this analysis. The NCTCOG currently uses the DRAM/EMPAL models for the allocation of regional land use forecasts (*5*) for the nine-county Dallas-Fort Worth area to 170 forecast districts. These district forecasts are subsequently allocated to almost 6,000 traffic survey zones (TSZs). Travel demand simulation models produce assignments for transit and highway networks using the socioeconomic input variables (households, median income, employment by basic, retail and service categories), at the TSZ level, and mode-specific network attributes. The model generates interzonal trip tables for four income categories (low, low-middle, high-middle, and high) and four trip purposes (home-based work, home-based nonwork, nonhome-based, and other). The four-step modeling process (trip generation, trip distribution, mode choice, and network assignment) includes three sophisticated multinominal logit-type mode-choice models for each of the three trip purposes (excluding "other" purpose).

For the sensitivity tests, the mode shares (transit and highway) are assumed to be the same as in the base case, i.e., mode-split models are not used while running the entire model chain. The primary intent is to examine the effect of allocation errors on highway trip assignments.

### Test Scenarios

In practice, traffic zone levels inputs are usually prepared in two steps: first, from region to district; and second, from district to zone. Most agencies use two separate methods for each of the two steps of forecasting. The difference between the input forecasts and reality, referred here as errors in allocation or forecasting, can occur at either of the two steps, and can be of different magnitude and nature. The term "nature of error," as used here, means the pattern of error distribution in the geographical space. Errors can be concentrated in a few locations, thus reflecting some kind of a geographical bias, or be distributed in a random fashion. The contemporary phenomenon of rapid suburban growth, for example, can easily produce employment underprediction in the suburbs and overprediction in the central city. This can occur in an urban area if the forecasting or allocation method used for district forecasts fails to anticipate the magnitude and trend of suburbanization, in particular, in the high technology service jobs. Similarly, one or more biased parameters in an analytical method can produce allocation errors of almost random nature.

To illustrate the effect of errors (or changes) in socioeconomic input data on the UTPP outputs, five scenarios representing various types and magnitude of errors in district and subdistrict allocations were formulated. In addition, a separate test scenario was developed to examine the impact of assigning a zone-to-zone trip interchange table that is produced by disaggregating a district-to-district trip table instead of using a trip table generated directly by the application of travel demand models at the zone level. The main purpose of this scenario was to examine whether the practice among certain agencies to expand a trip table for developing a smaller, spatial unit level, trip interchange table is accurate. Usually a district level trip table, an output of either a trip distribution model or a land use simulation model (e.g., DRAM/EMPAL, POLIS, or PLUM), is disaggregated into a zonal trip table using a proportioning method.

Although a multitude of test scenarios could be evaluated, the following six tests addressed the aforementioned issues of land use allocation within the assigned budget:

1. *Test A*—Introduce ±20 percent random errors into land use forecasts at the district level.
2. *Test B*—Introduce ±40 percent random errors into land use forecasts at the district level.
3. *Test C*—Introduce geographical bias into land use allocation at the district level.
4. *Test D*—Introduce ±40 percent random errors into land use forecasts at the zone level.
5. *Test E*—Distribute district forecasts uniformly among zones comprising a district.
6. *Test F*—Disaggregate district level trip table to zone level.

For Tests A, B, and D, the distribution of error is created by randomly selecting one-third of the districts or zones for positive, one-third for negative, and one-third for no errors. The overall magnitude of positive error is kept equal to negative error and distributed in proportion to population and employment. In the case of Test C, the employment for the downtown district and the districts situated in the southwestern sector of Dallas is reduced by 20 percent, and the same magnitude of employment increase is allocated among districts located in the northwestern sector (Figure 2) in the same proportion as the existing employment. For developing uniform distribution under Test E, traffic zone level data are prepared by dividing the district forecasts by the number of zones (e.g., *P/N*, where *P* and *N* represent population and the number of zones in a district, respectively). In the case of Test F, an 800 × 800 trip interchange table is first collapsed into a 147 × 147 table and then expanded back to 800 × 800 table using zonal shares of households and employment in each district. The number of households and total employment are used as the proportioning factors for trip productions and attractions respectively.

### Traffic Impact Measures

For each test scenario the impact of introducing a certain type and magnitude of socioeconomic input errors on the final output of UTPP is measured at both the systemwide level and micro level. The output measures of individual test runs and the run without any error (base run) are compared to illustrate the magnitude of impact.

At the system level, root-mean-square error (RMSE), average trip length, and total number of trips are considered as aggregate output measures of UTPP. The final UTPP output is traffic volumes assigned on a particular transportation system network or a group of links. To check the accuracy of UTPP, however, the assigned link volumes are generally compared with the ground counts (or ridership counts in the case of transit). RMSE is usually calculated to indicate the overall "goodness of fit" between traffic counts and model assigned traffic volumes. It is measured in the following manner:

$$\text{RMSE} = \sqrt{\frac{(\text{Count} - \text{Assigned Volume})^2}{(N-1)}}$$

where $N$ represents the number of traffic count stations.

Because of the large number of trip interchanges in an area, average trip length is a commonly used summary measure of trip distribution patterns. Similarly, total number of trips is a simple measure of trip generation model output.

To examine the micro-level effects of each sensitivity test, "lane error," a measure reflecting the magnitude of difference between the test case assigned link volume and the base case (without error) link volume, is calculated for individual links. The "lane error" for a link is defined as:

$$\text{Lane Error} = \frac{\text{Test Case Link Volume} - \text{Base Link Volume}}{\text{Link Capacity* Number of Lanes}}$$

Link capacity is expressed in terms of vehicles per hour per lane. It varies with the type of facility (freeways, major arterial, minor arterial, and collector) and area type (downtown, suburb, etc.). The "lane error" is an easily understood measure of discrepancy in traffic volume by transportation planners and highway engineers. A road planning "rule of thumb" suggests that a forecast error not exceeding one half-lane (positive or negative) is tolerable without a high probability of under or over designing a facility. In other words, it reflects the magnitude of public resource misallocation that may occur because of the error in traffic forecasts.

### Test Results

#### *Errors in District Level Land Use Forecasts*

Tests A, B, and C in Table 1 represent three different scenarios of district level forecasting/allocation errors. The table shows the amount of population and employment moved under each of these scenarios, i.e., the magnitude of disturbance introduced in the land use allocation. Test B (±40 percent random error) introduces the largest amount of allocation errors followed by Tests A (±20 percent random error) and C (geographical bias). Test C causes minimum misallocation because only 4.3 percent of total regional jobs are moved.

Tables 2 and 3 summarize the results of the sensitivity test runs. Regionwide output comparisons between the base run (without error) and the three district level tests (A, B, and C) displayed no significant variation in total number of trips by purpose, average trip length by purpose, and percent of RMSE (Table 2). The possible explanation for this could be that, because of no change in the regional control totals, and the smoothing out of effects caused by positive and negative errors, the values of the aggregate sensitivity measures of each test run appear similar to the base run.

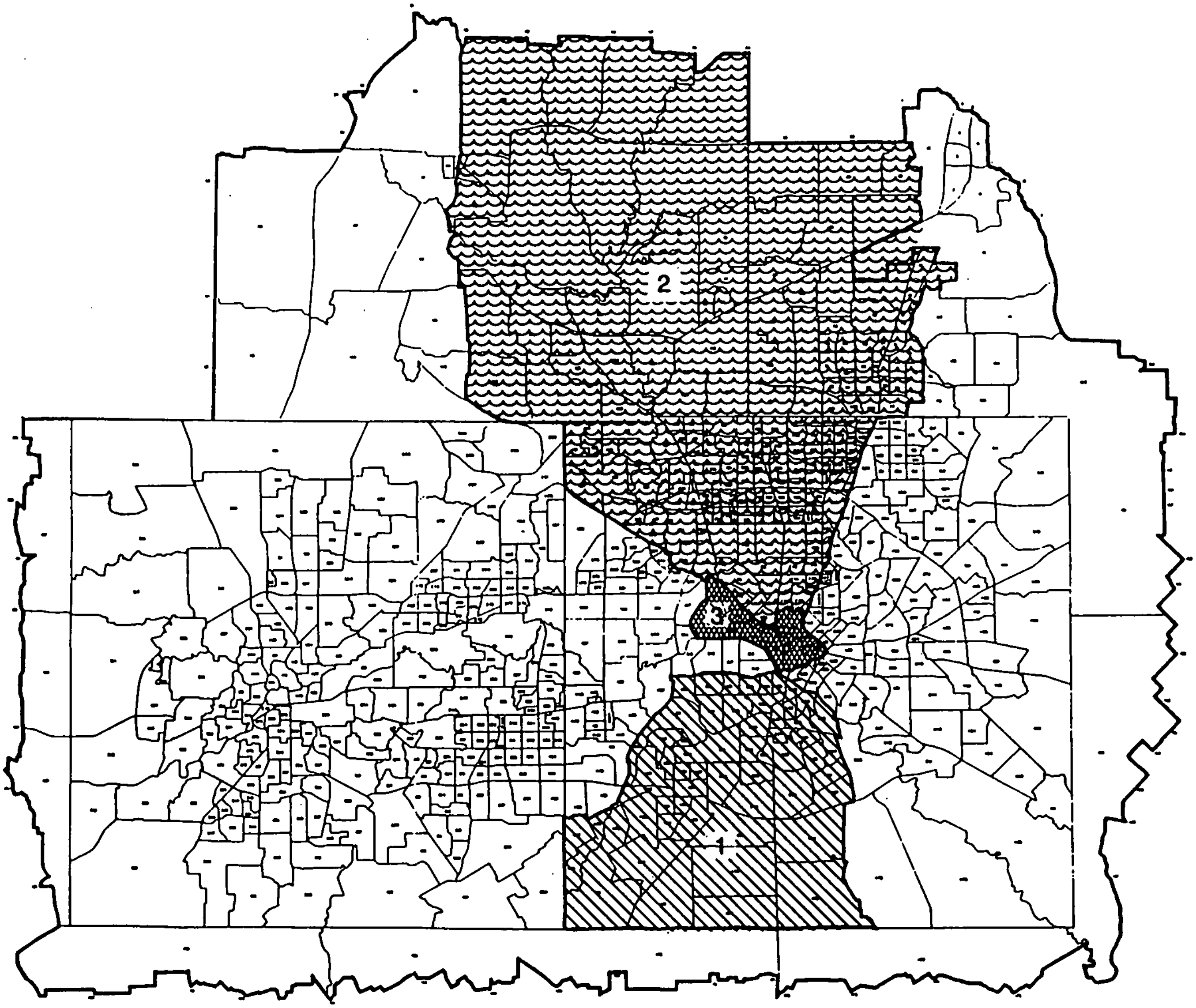



*Figure 2. Introduction of geographical bias into land use allocation (Test C).*

At the microlevel, however, the overall number of links affected by more than half-lane error varied across the three test runs, depending on the magnitude of activity allocation errors (see Table 3). For example, almost 13.7 percent of network links experienced more than half-lane error (positive or negative) under Test B ($\pm 40$ percent random error). Test A ($\pm 20$ percent random error) and Test C (geographical bias) outputs, however, displayed 5.36 and 2.68 percent, respectively, of links affected the same magnitude (Table 3). Similarly, for each facility type the proportion of links severely affected (more than half-lane error) consistently increases with the magnitude of input error across all three test runs.

The results of individual tests indicate that the effect of allocation error is not uniform across all types of road facilities. Under each of the three tests, the "lane error" is observed to be more pronounced in the links of major and minor arterials compared to the rest of the facility types (see Table 3). Freeways and freeway ramps are impacted least, suggesting that district level allocation errors produce limited impact on those high capacity facilities that serve mainly regional and interregional movements. Only in the case of Test B where very large error (±40 percent random error) is introduced, almost 100 (i.e., 1.02 percent as shown in Table 3) freeway links displayed more than half-lane error. Facilities serving local and within district movements, such as collectors, are affected significantly less compared with major and minor arterials. It seems that errors in link volumes gradually accumulate from local facilities to higher level facilities, such as major and minor arterials, that principally serve interdistrict travel.

To illustrate the impact of geographical bias in allocation, Test C results are further stratified by three geographical areas: areas with employment increase, areas with employment decrease, and areas with no change (see Table 4). It is interesting to note that most of the road links experiencing more than half-lane error are situated within areas where allocation errors are made. Links with positive (overestimation of traffic) and negative lane error are observed to be concentrated in areas with employment increase and decrease respectively. For instance, out of 455 road links with greater than half-lane error, 228 links serving the areas of employment increase show positive error, and 166 links situated within the areas where employment is reduced indicated negative error. As observed earlier, the most affected links are concentrated in the categories of major and minor arterials. Overall, although the percentage of links severely affected appears low (2.68 percent with more than half-lane error), because of a small magnitude of geographical bias in district inputs (Test

**Table 1. Magnitude of population and employment moved under district level allocation tests.**

| Test Scenarios of Errors in District Level | Population Moved Amount | Population Moved % of Region | Employment Moved Amount | Employment Moved % of Region |
|---|---|---|---|---|
| Test A (± 20% Random Errors) | 228,392 | 6.92 | 153,987 | 7.43 |
| Test B (± 40% Random Errors) | 456,820 | 13.82 | 307,991 | 14.86 |
| Test C (Geographical Bias) | — | – | 89,930 | 4.34 |

**Table 2. Aggregate outputs of sensitivity test runs.**

| | | Errors in District Level | | | Errors in Subdistrict Level | |
|---|---|---|---|---|---|---|
| Output | Base No Error | Test A ± 20% Random Error | Test B ± 40% Random Error | Test C Geo-graphical Bias | Test D ± 40% Random Error | Test E Uniform Distri-bution |
| Total Person Trips | 12,468,578 | 12,476,562 | 12,471,145 | 12,465,871 | 12,500,563 | 12,473,757 |
| Total Vehicle Trips | 9,638,826 | 9,662,462 | 9,662,935 | 9,654,295 | 9,674,076 | 9,749,958 |
| Average Trip Length by Purpose (in miles) | | | | | | |
| HBW-Low Income | 8.83 | 8.8 | 8.79 | 8.86 | 8.82 | 8.66 |
| HBW-Mid. Low Income | 10.52 | 10.46 | 10.47 | 10.54 | 10.52 | 10.43 |
| HBW-Mid. High Income | 11.65 | 11.58 | 11.54 | 11.63 | 11.61 | 11.61 |
| HBW-High Income | 12.10 | 12.03 | 11.98 | 11.95 | 12.03 | 12.01 |
| Home Based Non-Work | 6.29 | 6.16 | 6.06 | 6.27 | 6.04 | 6.26 |
| Non-Home Based | 6.90 | 6.75 | 6.70 | 6.79 | 6.78 | 7.01 |
| Other | 10.72 | 10.58 | 10.51 | 10.65 | 10.64 | 10.76 |
| % RMS | 60.2 | 61.23 | 64.38 | 59.19 | 61.6 | 60.77 |

**Table 3. Distribution of highway links by facility type and lane error.**

| | | Percentage of Links by Lane Error (±) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Errors in District Level | | | | | | Errors in Subdistrict Level | | | |
| Facility Type | Number of Links | Test A ±20% Random Error 0.5 Lane | Test A >1 Lane | Test B ±40% Random Error 0.5 Lane | Test B >1 Lane | Test C Geographical Bias 0.5 Lane | Test C >1 Lane | Test D ±40% Random Error 0.5 Lane | Test D >1 Lane | Test E Uniform Distribution 0.5 Lane | Test E >1 Lane |
| Freeway | 1966 | 0.00 | 0.00 | 1.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 |
| Major Arterial | 1789 | 12.75 | 2.73 | 22.47 | 16.60 | 8.50 | 1.34 | 11.29 | 5.76 | 19.17 | 13.53 |
| Minor Arterial | 3751 | 9.65 | 2.11 | 16.55 | 12.16 | 3.82 | 1.01 | 11.95 | 3.17 | 16.82 | 13.60 |
| Collector | 5964 | 2.16 | 0.39 | 5.42 | 2.65 | 0.96 | 0.18 | 3.79 | 1.46 | 6.56 | 4.59 |
| Freeway Ramps | 2107 | 0.24 | 0.00 | 1.04 | 0.19 | 0.14 | 0.00 | 0.10 | 0.00 | 1.04 | 0.05 |
| Frontage Roads | 1369 | 2.33 | 0.08 | 5.12 | 1.16 | 1.82 | 0.15 | 1.97 | 0.22 | 5.26 | 1.39 |
| Overall | 16946 | 4.46 | 0.90 | 8.16 | 5.49 | 2.24 | 0.44 | 5.34 | 1.84 | 8.62 | 6.17 |

**Table 4. Lane errors by geographical areas under Test C (geographical bias).**

| Facility Type | Number of Links | Areas with No Change +0.5 Lane | Areas with No Change ->0.5 Lane | Areas w/Employment Increase +0.5 Lane | Areas w/Employment Increase ->0.5 Lane | Areas w/Employment Decrease +0.5 Lane | Areas w/Employment Decrease ->0.5 Lane |
|---|---|---|---|---|---|---|---|
| Freeways | 1966 | 0 | 0 | 0 | 0 | 0 | 0 |
| Major Arterial | 1789 | 7 | 13 | 89 | 2 | 4 | 61 |
| % of Links | | 0.39 | 0.73 | 4.97 | 0.11 | 0.22 | 3.41 |
| Minor Arterial | 3751 | 6 | 1 | 86 | 2 | 0 | 86 |
| % of Links | | .16 | 0.03 | 2.29 | 0.05 | 0.00 | 2.29 |
| Collector | 5964 | 2 | 11 | 41 | 4 | 0 | 10 |
| % of Links | | 0.03 | 0.18 | 0.69 | 0.07 | 0.00 | 0.17 |
| Freeway Ramps | 2107 | 0 | 0 | 0 | 0 | 0 | 3 |
| % of Links | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 |
| Frontage Roads | 1369 | 2 | 6 | 12 | 1 | 0 | 6 |
| % of Links | | 0.15 | 0.44 | 0.88 | 0.07 | 0.00 | 0.44 |
| Total | 16946 | 17 | 31 | 228 | 9 | 4 | 166 |
| % of Links | 100.00 | 0.10 | 0.18 | 1.35 | 0.05 | .02 | 0.98 |

C), the affected number of links are significant enough (176 major and 181 minor arterial links) to cause major misallocation of public resources.

In summary, the test run results suggest that the severity of traffic prediction errors depends on the magnitude of district level input errors. The traffic impacts of allocation errors are not distributed uniformly across all types of facilities. Major and minor arterials are found to be most sensitive to input errors followed by local roads and expressways. Even a small magnitude of geographical bias in district forecasts can severely affect facilities situated in the proximity of districts with input errors. These findings are of great relevance to planners undertaking any corridor level planning because the design of a corridor can significantly be affected by the socioeconomic input errors in districts served by the corridor under consideration.

### *Errors in the Disaggregation of District Level Inputs to Zone Level*

Tests D (±40 percent random error) and E (uniform distribution) represent two extreme cases of subdistrict allocation errors. Test E presents a case where zone level forecasts are prepared with no consideration given to the zonal capacity, zoning policy, and other major factors influencing the attractiveness of a zone for development (e.g., transportation accessibility, availability of public services, existing development, and so forth). Test D, however, reflects a case of large random error in allocation. To illustrate the level of disturbance caused under each of these two scenarios, the R-square values for zonal population and employment are estimated by comparing the inputs for the base (no error) and individual test runs separately (Table 5). In this case, the R-square value reflects the strength of association between the base case inputs and a particular test run inputs. A value of one represents perfect match between the two sets and zero means no match. The higher values of R-square (0.917 for population and 0.915 for employment) observed under Test D (±40 percent random error), clearly indicate that this test does not cause as significant a deviation from the base case allocation as Test E (uniform distribution). Actually, uniform distribution under Test E causes an extremely large magnitude of error in zonal inputs.

**Table 5. Correlation between base year inputs and subdistrict allocation test case inputs.**

| Subdistrict Allocation Tests | R-Square Population | R-Square Employment |
|---|---|---|
| Test D (± 40% Random Error) | 0.917 | 0.915 |
| Test E (Uniform Distribution) | 0.683 | 0.714 |

A comparison between the base and test runs for total trips by purpose, areawide RMSE, and trip lengths by purpose displays no visible impact of input errors on the systemwide output measures (see Table 2). However, the "lane error" between the two tests varied with the overall magnitude of errors introduced under each test. For instance, the higher degree of allocation errors caused under Test E (uniform distribution) in comparison with Test D (±40 percent random error) led to the observed large difference in percentages of links severely affected (7.2 percent and 14.8 percent of links with more than half-lane error under Tests D and E, respectively; see Table 3).

The test results also suggest that much like the district level allocation tests, the magnitude of "lane errors" within each road facility class varied noticeably in all categories. Major and minor arterials are the most affected facilities. A comparison of the results of Test D and Test B, where ±40 percent errors are introduced randomly at the subdistrict and district levels respectively, indicates that the percentage of links showing more than half-lane error are much higher in the case of district level error (Test B) than subdistrict level (Test D). It is true across all road facility types (see Table 3). For example, compared to almost 17 percent of major arterial links affected by more than half-lane error under Test D (±40 percent random error at the district level), there are 39 percent of major arterial links affected under Test B (±40 percent random error at subdistrict level). However, if one compares the results of Test E (uniform distribution) and Test B, a more or less similar magnitude of lane errors are noticed across all facility types except for collectors. This is because, under Test E, an extremely large number of errors is introduced in zonal inputs. Moreover, collectors are expected to be more affected by errors in zonal inputs because they mainly serve local trips.

In summary, the traffic impacts of errors in subdistrict allocation are quite similar to the district allocation errors in terms of the facilities most affected and the association between the magnitude of input errors and traffic volume errors. The degree of sensitivity, however, seems to vary substantially. For example, major and minor arterials, and expressways, are more susceptible to errors in district level allocation than subdistrict allocation. Local roads, on the other hand, are more affected by the errors in zone level than they are in district level inputs.

In the real world, the likelihood for experiencing large subdistrict allocation errors of the magnitude as seen in the case of Test E (uniform distribution) is extremely low. There are two key reasons for this. First, most of the subdistrict allocation procedures distribute the incremental growth of a district among its zones and assume almost no change to the existing developments (except in cases where large renovations or revitalization schemes are planned). Second, these procedures, in general, take into account major factors influencing development in a zone (e.g., availability of public services, zoning, accessibility). The areas that have the greatest potential for experiencing large deviations from the anticipated growth are undeveloped areas usually located at the fringe of a city. In these areas, there are always uncertainties linked to market forces influencing the location of activities. Moreover, there is often more than one site competing for new development.

Occurrence of minor errors in zonal inputs is not expected to produce large discrepancies in traffic forecasts for those facilities serving interdistrict trips if district level forecasts are reasonably accurate. Site-specific planning studies must ensure that, first, the inputs for districts encompassing the site are accurate; and, second, that the subdistrict allocation procedure used for developing the zonal inputs accounts for key factors influencing development in those zones.

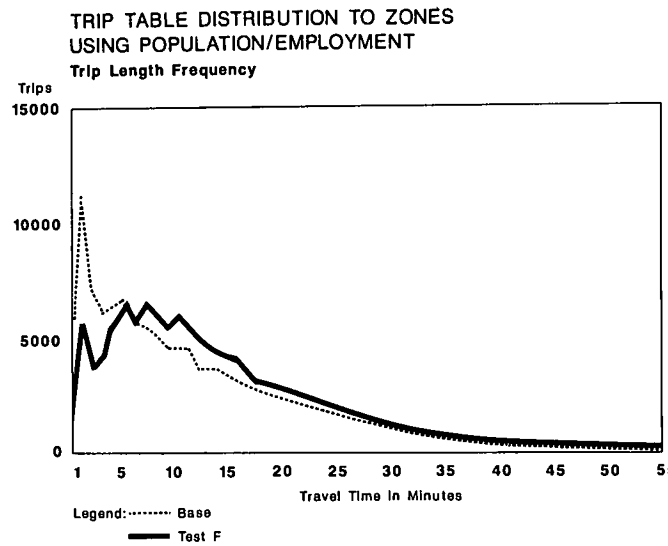



*Figure 3. Comparison of trip length frequency curves.*

**Table 6. Distribution of highway links by lane error under Test F.**

| | Percentage of Links | | | |
|---|---|---|---|---|
| Facility Type | Negative Error 0.5 Lane | Negative Error > 1 Lane | Positive Error 0.5 Lane | Positive Error > 1 Lane |
| Freeway | 0.00 | 0.00 | 0.51 | 0.00 |
| Major Arterial | 2.35 | 0.95 | 14.87 | 22.58 |
| Minor Arterial | 1.52 | 0.41 | 13.01 | 13.74 |
| Collector | 0.89 | 0.32 | 4.59 | 3.30 |
| Freeway Ramps | 0.05 | 0.00 | 0.81 | 0.05 |
| Frontage Roads | 1.02 | 0.00 | 6.22 | 6.90 |
| Overall | 0.99 | 0.29 | 6.44 | 6.76 |

*Disaggregation of District Level Trip Table to Zone Level*

Under Test F, a 800 × 800 trip interchange table is first collapsed into a 147 × 147 table and then expanded back to 800 × 800 table using the number of households and total employment in zones as the proportioning factors for trip productions and attractions respectively. Such a trip table expansion procedure assumes that the interzonal accessibility, usually measured in terms of travel time or cost, or both, does not influence the magnitude of interzonal interactions. In reality, however, it is common to observe an inverse relationship between the magnitude of interactions between areas and their spatial separation (or impedance). To check the validity of this assumption, the trip length frequency curves for the original trip table and Test F are compared, as shown in Figure 3.

The result of this comparison indicated that the average trip length increased from its original value of 13.62 to 15.30 minutes after applying the disaggregation procedure, as evident from the trip length frequency curves shown in Figure 3. This may be explained by the fact that, because of the omission of accessibility effect from the zone level trip distribution, the trip interchange volume between zones that are highly accessible to each other is likely to be underestimated, and volumes between those zones that are farther apart will be overestimated. The end result is an overall increase in the proportion of longer trips.

As expected, because of the increase in the share of longer trips, the highway assignment produces a significant amount of positive lane error within each class of links (see Table 6). Both major and minor arterials experienced substantial increase in traffic, almost as high as seen under Test B (± 40 percent random errors in district level). Actually, the proportion of links with more than one lane error is extremely high under this scenario compared to all earlier tests. For instance, the percentages of major arterial links showing above half-lane error under Test B and Test F are 39.07 and 40.75, respectively (compare Table 3 and Table 6). But the percentage of links with more than one lane error is 16.6 and 23.53 for Tests B and F, respectively. It is obvious that the above kind of trip table stratification procedure can cause substantially high prediction of trip volumes on major facilities leading to their overdesign.

Test results illustrate that a procedure used for the disaggregation of a district level trip to zone level must account for the interzonal accessibility. Exclusion of accessibility variation among zones may produce large errors in the UTPP outputs. The magnitude of overall error will greatly depend on the size of districts, i.e., the magnitude of expansion (ratio of total number of zones and district). In general, the smaller the size of the districts, the lower the potential for introducing large errors in the trip table splitting process. This is true because the smaller districts would account more for greater variations in the interzonal accessibility than the larger districts.

In light of the above findings, it is highly recommended that travel demand models (for instance, UTPP) be applied at the traffic zone level, so that interzonal trip tables are produced directly and the need for trip table stratification is avoided. In the case of site level analysis (or local area network planning), sometimes, traffic zones are further broken into smaller spatial units and the zone-to-zone trip table is once again disaggregated to develop a new trip table. Due to the splitting of smaller zones, the potential for large errors is reduced, although they are not fully eliminated.

### Summary

Most agencies develop traffic zone level socioeconomic inputs in two steps: first, from region to district and second, from district to zone. Usually future events influencing the location of economic activities and population are difficult to predict with precision. Hence, allocation errors are inevitable in either of the two steps of forecasting basic inputs for travel demand models, such as population and employment. Acknowledging this, it becomes imperative for a transportation planner to understand the implications of various types and magnitude of land use allocation errors on the prediction of travel demand. Large differences between the predicted and actual traffic for a facility can lead to underdesign or overdesign of that facility, resulting in substantial misallocation of public resources.

To illustrate the effect of changes in socioeconomic input data on the estimation of network traffic volumes, five scenarios representing various types and magnitude of changes, referred here as errors, in district and subdistrict allocations were tested (see Table 7). The Dallas/Fort Worth area was selected as the test case site. Three out of five scenarios reflected the random nature of allocation errors. These scenarios were created by randomly selecting one-third of districts or zones for positive, one-third for negative, and one-third for no errors. One of the district level allocation scenarios replicated the phenomena of geographical bias in land use allocation that may occur because of the rapid flight of jobs to the suburbs. The test represents the contemporary problem of land use forecasting in urban areas that are witnessing unexpectedly high suburban growth and a decline or modest growth within the central city. The scenario considered here illustrated the impact of employment underprediction in one of the suburban sectors and overprediction in the CBD and one of its adjacent sectors. Among subdistrict allocation scenarios, one test showed the effect of distributing district level inputs equally (or uniformly) among the zones of each district. It represented a special case of subdistrict allocation where zone- specific land use forecasts are completely insensitive to the zone capacity, zoning policy, and major factors influencing the potential for development in a zone (existing development, availability of utilities, accessibility, and so forth).

In addition, a separate test was performed to examine the impact of assigning a zone-to-zone trip interchange table that is produced by disaggregating a district-to-district trip table instead of using a trip table generated directly by the application of travel demand models at the zone level.

For each scenario the demand sensitivity of facilities was measured in terms of the proportion of links experiencing large differences in traffic volumes (increase or decrease by more than half-lane capacity) after the introduction of input errors. To generalize the results, the findings of the sensitivity runs are summarized in the following. Five broad conclusions drawn from the sensitivity tests are:

1. The severity of traffic prediction errors increases with the overall magnitude of activity allocation error, but not uniformly across all types of road facilities. Major and minor arterials are found to be most sensitive to input errors followed by local roads and expressways.

2. Errors in district forecasts and zone level forecasts influence each facility type differently. Facilities serving major interdistrict movements, such as major or minor arterials and expressways, are more sensitive to errors in district level allocation than subdistrict (or zone level) allocation. Local roads, on the other hand, are affected more by the errors in zone level rather than district level inputs.

**Table 7. Findings of sensitivity tests between travel demand and land use allocation errors.**

| Allocation Error | | | Traffic Impact on Facilities | | |
|---|---|---|---|---|---|
| Type | Nature | Magnitude | Expressway | Major/Minor Arterial | Collectors |
| From Region to District | Random | Small | Not significant | Moderate | Low |
| | Random | Large | Low | High | Low/Moderate |
| | Geographical Bias | Small | Not Significant | Moderate but concentrated in areas with input errors | Low |
| From District to Zones | Random | Large | Not Significant | Moderate | Low/Moderate |
| | Uniform | Large | Low | High | Moderate |
| Splitting of Trip Table | | | Low | High | Moderate/High |

**Table 8. Precautions in preparing land use inputs for various planning circumstances.**

| Nature of Planning | Agencies Responsible for Land Use Forecasts | Suggested Precautions |
|---|---|---|
| Regional Freeways | Regional Planning/MPO's | • Large errors in district level forecasts should be avoided.<br>• Suburban districts are potential sites for introducing large input errors. |
| Corridor Studies | Regional Planning/MPO's | • Minimize errors in district level forecasts, particularly for districts directly served by the corridor under study.<br>• Greater attention must be paid to suburban districts where future development is most likely to occur.<br>• Use of an appropriate method for district level allocation/ forecasting is of utmost importance for agency developing inputs. |
| Site Specific Studies | Local Planning/MPO's/ Developers | • Land use forecasts for the district(s) encompassing the site must be reviewed for accuracy before initiating a site study.<br>• Errors in zone level allocation for the district encompassing the site must be minimized.<br>• Since the likelihood of introducing large errors within undeveloped suburban districts is high, greater attention must be paid while developing inputs for a site specific study located in the suburbs. |

3. A small magnitude of geographical bias in district level forecasts may not produce significant systemwide impacts, but it can severely affect facilities situated in the proximity of the districts with input errors.

4. Subdistrict allocation procedures must take into consideration the zonal capacity and factors influencing the attractiveness of a zone for development. Insensitivity to these may produce very large errors in zonal inputs and, in turn, traffic forecasts across all types of facilities.

5. The practice of trip table expansion (or splitting) to develop trip interchange tables for smaller spatial units introduces large errors in traffic forecasts. This is mainly due to the omission of an accessibility factor influencing trip interchanges.

These conclusions are of great relevance for the nature and scale of planning commonly pursued by planners. Table 8 presents a list of recommended precautions for planners dealing with three planning circumstances: regional freeways and expressways system, corridor planning, and site-specific studies.

For the freeway or expressway system planning, large errors in the district level input forecasts must be avoided. Any significant overprediction and underprediction of traffic on freeway links will translate into large sums of public resource misallocations, even though only a few freeway links might be affected. The potential for experiencing large errors in land use forecasts is usually high in the suburban districts. Large errors are often caused by the unanticipated events resulting from the volatile nature of the real estate market in these areas. Moreover, because of the sparse nature of road networks in the suburbs, errors in traffic volumes quickly accumulate on a few freeways serving these areas. On the other hand, with compact urban areas, excluding the CBD and districts with a concentration of jobs, freeways are less likely to be affected. This is mainly because of the dissemination of travel demand errors among several facilities and, to some extent, the smoothing out of the effects caused by positive and negative errors.

Planners undertaking a corridor study must be cautious of district level allocation errors because of the high susceptibility of major or minor arterials to such errors. Precautions must be taken to minimize errors in land use forecasts for districts directly served by the corridor under study. Suburban districts deserve special attention because most of the future growth is likely to be concentrated there.

Since the main source for district level input errors would be the procedures applied for forecasting, the choice of the appropriate subregional land use forecasting or allocation method is of utmost importance for a planning agency furnishing inputs to a corridor study.

For site-specific or local network planning studies, care is warranted to minimize errors in subdistrict (or zonal) land use allocation or forecasting, particularly for district(s) encompassing the site. The subdistrict allocation procedures, in general, distribute the incremental growth of a district among its zones. Moreover, they take into account major factors attracting development in a zone (e.g., concentration of existing activities, zoning, proportion of developable land). Therefore, in partially developed areas the probability of introducing large errors in zonal inputs is usually low. On the other hand, in undeveloped areas uncertainties linked to new developments are often high. Hence, a site planning study for a suburban site usually demands greater scrutiny of land use inputs both for its zones and for the district in which the site is situated.

It is highly recommended that travel demand models be applied at the traffic zone level so that the need for trip table stratification will be completely eliminated.

## DESCRIPTIVE REVIEW OF LAND USE ALLOCATION METHODS

This section presents a brief description of the methods currently used for allocating the regional control forecasts to a level below region, such as jurisdiction or district and, in some cases, traffic analysis zones. These methods are categorized into six groups, depending on the technique or general approach they follow. Subsequently, an approach that represents the current state of practice is selected and discussed for each category. References to a more complete description of each method are also provided. Chapter Three provides a systematic assessment of the methods described below.

### Identification of Methods

To examine the current practice in land use allocation to subregion level, several secondary sources of information were reviewed including the Highway Research Information System (HRIS) data and a nationwide survey (see Reaves (*4*)) undertaken by the Southern California Association of Governments (SCAG). According to the SCAG telephone survey, 45 out of 105 agencies contacted used models for land use allocation, and the remaining respondents indicated no use of applicable models. Agencies in the latter category consisted primarily of state DOTs, local transportation providers, and state and local agencies without transportation functions. The COGs and MPOs falling into this category generally reported use of forecasts provided by other agencies. Agencies using land use allocation methods were grouped by technique as shown below:

| | Number | Percentage |
|---|---|---|
| Land-Use-Based Socioeconomic Model | 5 | 11 |
| Land Use Allocation Models | 3 | 7 |
| Optimization Models | 2 | 4 |
| Delphi Method | 5 | 11 |
| Shift Share, Component of Change, Other Methods | 30 | 67 |

This survey painted a broad picture of current nationwide practices, but could not provide an accurate count (in percentage) of agencies falling into each method category. To further our investigation, representatives of several federal agencies (including FHWA and UMTA) and local MPOs of different sizes were interviewed.

### Categorization of Methods

Recognizing the multitude of land use allocation methods used now and in the past, these methods are first categorized into six groups. Within each group, although there are methods with wide variations in procedures, only the most popular of the currently used methods are selected for discussion. The categories identified for reporting purposes are: (1) land-use-based socioeconomic models, (2) spatial interaction models, (3) optimization models, (4) Delphi methods, (5) analytical methods, and (6) nonmodeling approaches.

#### *Land-Use-Based Socioeconomic Models*

In general, the regression-analysis-based models developed during the 1960s to explain the spatial distribution of socioeconomic activities (see Lakshmanan (*6*) and Hill (*3*) fall under this category. These models used population, employment, or housing in each zone as the dependent variables and a set of independent variables that determines the required spatial distribution. Often, the effect of transport costs on land use is represented by a gravity-concept-based accessibility measure. The model can be applied for population and employment stratified into groups.

EMPIRIC (Putman (*7*) and Hill (*3*)) was the most widely used land use model during the late 1960s. This model is usually developed as a set of linear difference equations and deals simultaneously with both residence location and employment location. Two-stage least-squares and ordinary least-squares estimation procedures are commonly used for the parameter estimation for EMPIRIC. Table 9 displays the structure of an EMPIRIC model calibrated for Minneapolis-St. Paul region.

Although EMPIRIC can be developed and implemented with ease, the forecasting ability of the model raises serious doubts about its usefulness. Stokes (*4*) found that while the model could replicate the data against which it was calibrated fairly well, it failed badly when used for forecasting. This was principally due to the assumption of constancy in the regression coefficients, which prevents the effect of variations in the interaction between the variables considered or new factors.

EMPIRIC was used by several agencies including the Bay Area Transportation Study Commission, and has been gradually replaced by new models. However, lessons learned from the implementation of EMPIRIC have significantly influenced the development of several new models, particularly those developed for forecasting the location of basic employment, such as EMPAL (*8*).

#### *Spatial Interaction Models*

The best known land use models based on the notion of spatial interaction (or gravity) are derivatives of the Lowry (*9*) model, the Model of Metropolis. This model was conceptually simple and was used for the allocation of growth in Pittsburgh. The model can be described as follows.

For an exogenous input of basic employment distribution by zones, workers' residences are first located using a gravity model, and then dependent families of these workers are generated by applying the inverse activity rate (defined as the ratio of total population to total employment). Since population demands ser-

**Table 9. EMPIRIC model—Minneapolis-St. Paul region. (Source: Ref. 8)**

$$
\begin{aligned}
\Delta\mathrm{LIQ} &= 0{\cdot}407\Delta\mathrm{LMIQ} - 0{\cdot}377\Delta\mathrm{HIQ} + 0{\cdot}106\Delta\mathrm{LGOVED} - 0{\cdot}415\mathrm{LIQ} \\
&\quad + 0{\cdot}357\mathrm{LMIQ} - 0{\cdot}890\Delta(\mathrm{HAEMP} * \mathrm{USEDAC}) + 0{\cdot}269\Delta\mathrm{SEWER} \\
&\quad + 0{\cdot}060(\mathrm{SEWER} * \mathrm{VACAC}) + 0{\cdot}112(\mathrm{TOTEMP}/\mathrm{TOTHU}) \\
\Delta\mathrm{LMIQ} &= 0{\cdot}299\Delta\mathrm{LIQ} + 0{\cdot}425\Delta\mathrm{UMIQ} + 0{\cdot}092\mathrm{UMIQ} - 0{\cdot}109(\mathrm{AEMP} * \mathrm{USEDAC}) \\
&\quad + 0{\cdot}300\Delta(\mathrm{HAEMP} * \mathrm{USEDAC}) \\
\Delta\mathrm{UMIQ} &= -0{\cdot}144\Delta\mathrm{LIQ} + 0{\cdot}415\Delta\mathrm{LMIQ} + 0{\cdot}261\Delta\mathrm{HIQ} - 0{\cdot}163\mathrm{LIQ} \\
&\quad + 0{\cdot}058(\mathrm{SEWER} * \mathrm{TOTAC}) + 0{\cdot}104(\mathrm{UMIQ}/\mathrm{TOTHU}) \\
\Delta\mathrm{HIQ} &= -0{\cdot}416\Delta\mathrm{LIQ} + 0{\cdot}01\Delta\mathrm{LMIQ} + 0{\cdot}830\Delta\mathrm{UMIQ} + 0{\cdot}248\Delta\mathrm{SEWER} \\
&\quad - 0{\cdot}260(\mathrm{HIQ}/\mathrm{TOTHU}) + 0{\cdot}274(\mathrm{INDUS}/\mathrm{TOTEMP}) \\
\Delta\mathrm{MISC} &= 0{\cdot}44\Delta\mathrm{RET} + 0{\cdot}20\Delta\mathrm{SVCFIR} - 0{\cdot}026(\mathrm{TOTEMP}/\mathrm{TOTHU}) \\
&\quad + 0{\cdot}112(\Delta\mathrm{SEWER} * \mathrm{TOTAC}) - 0{\cdot}256\mathrm{MISC} - 0{\cdot}096\mathrm{SVCFIR} \\
&\quad + 0{\cdot}109(\mathrm{NIA} * \mathrm{VACAC}/(\mathrm{USEDAC} + \mathrm{VACAC}) + 0{\cdot}094\mathrm{TAHU})) \\
\Delta\mathrm{MFGW} &= 0{\cdot}013\Delta\mathrm{SVCFIR} + 0{\cdot}190(\mathrm{SEWER} * \mathrm{TOTAC}) + 0{\cdot}254\mathrm{SVCFIR} \\
&\quad - 0{\cdot}189\mathrm{MFGW} - 0{\cdot}268\mathrm{NCA} - 0{\cdot}531(\mathrm{USEDAC}/(\mathrm{USEDAC} \\
&\quad + \mathrm{VACAC})) - 0{\cdot}248(\Delta\mathrm{HAHU} * \mathrm{USEDAC}) + 0{\cdot}52\mathrm{HAHU} \\
\Delta\mathrm{TCU} &= 0{\cdot}737\Delta\mathrm{RET} + 0{\cdot}919\Delta\mathrm{SEWER} + 0{\cdot}249(\mathrm{NIA} * \mathrm{VACAC}/(\mathrm{USEDAC} \\
&\quad + \mathrm{VACAC})) - 0{\cdot}352\mathrm{MFGW} + 0{\cdot}60\mathrm{USEDAC}/(\mathrm{USEDAC} + \mathrm{VACAC}) \\
&\quad + 0{\cdot}1827\mathrm{CU} - 0{\cdot}53(\mathrm{TOTEMP})/(\mathrm{NIA} + \mathrm{NCA} + \mathrm{NPA}) \\
&\quad + 0{\cdot}31(\mathrm{TOTEMP}/\mathrm{TOTAC}) - 0{\cdot}423(\mathrm{NCA} * \mathrm{VACAC}/(\mathrm{USEDAC} \\
&\quad + \mathrm{VACAC})) \\
\Delta\mathrm{RET} &= 0{\cdot}473\mathrm{SVCFIR} + 0{\cdot}518\Delta\mathrm{LMIQ} + 0{\cdot}077\mathrm{NCA} * \mathrm{VACAC}/(\mathrm{USEDAC} \\
&\quad + \mathrm{VACAC}) - 0{\cdot}32\mathrm{RET} + 0{\cdot}291\mathrm{AHU} * \mathrm{USEDAC} \\
\Delta\mathrm{SVCFIR} &= 0{\cdot}169\Delta\mathrm{UMIQ} + 0{\cdot}202\mathrm{MFGW} + 0{\cdot}344\mathrm{RET} - 0{\cdot}154\mathrm{GOVED} \\
&\quad - 0{\cdot}228\mathrm{SVCFIR} + 0{\cdot}236\mathrm{RET} \\
\Delta\mathrm{LGOVED} &= 0{\cdot}29\Delta\mathrm{LIQ} + 0{\cdot}313\mathrm{TAHU} + 0{\cdot}214\mathrm{NCA} - 0{\cdot}539\mathrm{LGOVED}
\end{aligned}
$$

| Variable | Definition |
|---|---|
| LIQ | households in lowest income quartile |
| LMIQ | households in lower-middle income quartile |
| UMIQ | households in upper-middle income quartile |
| HIQ | households in highest income quartile |
| MISC | construction and other miscellaneous employment |
| MFGW | manufacturing and wholesale employment |
| TCU | transportation, communications, utilities employment |
| RET | retail employment |
| SVCFIR | service, finance, insurance, real estate employment |
| LGOVED | local government and education employment |
| HAHU | highway accessibility to households |
| TAHU | transit accessibility to households |
| AHU | composite (sum of highway and transit) accessibility to households |
| HAEMP | highway accessibility to employment |
| AEMP | composite accessibility to employment |
| SEWER | percentage of district 'sewered' |
| NCA | net commercial area |
| NIA | net industrial area |
| NPA | net public and semipublic area |
| NRA | net residential area |
| USEDAC | used area (= NCA + NIA + NPA + NRA) |
| VACAC | vacant or agricultural area |
| DEVAC | developable area (= USEDAC + VACAC) |
| TOTAC | total area of the district |
| TOTHU | total housing units |
| TOTEMP | total employment |
| Δ | indicates 'change-in-share' variables; all others are base year shares. |

vices, workers linked with the service (or nonbasic) employment are located by means of another gravity model. The residential location of these workers and dependent families are located in a manner similar to the workers in the basic sector. This leads to further generation of nonbasic workers and dependent families. The cycle continues until the increments become insignificant.

The Time Oriented Metropolis Model (TOMM) of Crecine (*10*), and the Projective Land Use Model (PLUM) of Goldner (*2*), are later versions of the Lowry model; see Goldner (*11*) and Batty (*12*). Later an incremental version of PLUM (IPLUM) was developed into the Integrated Transport and Land Use Package (ITLUP) by Putman (*8*). This package incorporated the effects of congestion on the road network by using capacity restraint assignment. The most recent version includes the Disaggregated Residential Allocation Model (DRAM) and the Employment Allocation Model (EMPAL) (*8*). The past modifications have tended to improve the transport side by incorporating modal split and congestion effects, the residential location by disaggregating population by income or social groups, and the model calibration procedures. The DRAM and EMPAL models, which are submodels of ITLUP system, are discussed in detail below.

DRAM forecasts residential location by income quartile; EMPAL forecasts employment location by industry. These models predict interactions and location patterns of households and jobs based on the standard notion of the spatial interaction model. The general procedure and data requirements are presented in the following paragraphs. Appendix A contains application examples of both models.

Employment and population forecasts for the region serve as

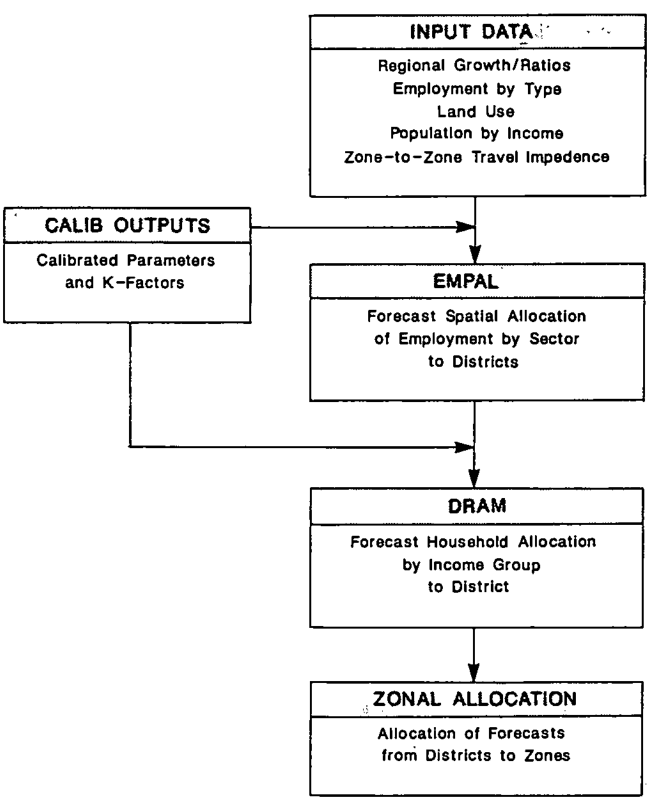



*Figure 4. Forecasting procedure using DRAM and EMPAL models.*

control totals that are allocated by DRAM and EMPAL to the individual districts. Districts are the next level of division, and their boundaries are established to maximize the amount of available information at the smallest possible geographic subdivision. These boundaries generally fall along census tract boundaries. The final and smallest division is the small area or traffic zone.

Although DRAM and EMPAL can forecast at the zonal level, they are not usually used for this purpose because the required data for model calibration is available only at the census tract or district level. For the disaggregation of district level forecasts to spatial units smaller than census tracts (e.g., zones), a separate process is used. Regional agencies often develop their own district-to-zone allocation processes, depending on individual circumstances.

Staging the forecasting process offers opportunity for local review at each stage of the process. Larger (and therefore fewer) districts make this review process easier, although using larger districts may introduce aggregation errors into the forecasts. The final step of splitting district forecasts to the zone level is once again accomplished with the assistance of local representatives or by the individual jurisdictions themselves.

Figure 4 shows the general and specific steps involved in land use allocation. The first step is base-year data collection, an important step as demonstrated by a glance at the data list. The data requirements are extensive and, hence, may not be readily available in every community. As the U.S. Census remains a prime source for a large portion of the required base-year data, a census year is a good base-year candidate.

The second step is to determine the behavioral parameters and *K*-factors for both EMPAL and DRAM. The parameters are estimated to adjust the equations to better reflect local conditions. The program CALIB, a module of the Department of Transportation's UTPS package (*13*), is commonly used to estimate the parameters which produce the best fit between the forecast and observed activity location.

The third and fourth steps involve the application of the EMPAL and DRAM models. EMPAL distributes each category of employment among districts. DRAM then uses the EMPAL results to forecast the residential location of workers. Further geographical stratification of the data can be accomplished in a number of ways. The chosen technique is often conditioned by the availability of data in a community and the structure of its zone system.

Two types of regional data are required for each forecast period. The first type represents the regional ratios: percent unemployment, by sector; employees per household, by income quartile; jobs per employee; and conversion matrix-employment type to income group.

The second type of regional inputs are either developed especially for the model application or obtained from secondary sources, such as earlier regional studies or forecasts prepared by public or private agencies. The required control forecasts under this category are: total employment for each employee type and total population.

The following district level information, excluding the employment, is required for the base year only: population, by district of residence; employment, by district of work, for two different historic time periods for calibration purposes; households, by income quartile and group quarters population; land use by district (total land areas, unusable land (i.e. park, watershed, resource lands), land area occupied by commercial land,

land area occupied by industrial land, land area occupied by residential and the forecast, total usable (developed + developable) land, land used for streets, and vacant and developable land); and zone-to-zone travel time or costs for base year calculated from the highway and transit networks.

The household and population information is generally available from the U.S. Census Bureau. The acreage by land use type data is usually extracted from the accessor's data files/maps. Employment data by place of work is generally the most difficult to obtain. Calibrating the EMPAL model requires employment data for the base year and a year 5 to 10 years earlier.

The CALIB program (*13*), estimates parameters and *K*-factors that are finally used by the DRAM and EMPAL models. CALIB is the first program run. Parameters are estimated in a nonlinear search procedure. Generally, a location forecast is first prepared using a preliminary set of parameters. Next, this forecast is compared with the observed location choices. Several model runs are made. The parameters are successively adjusted under each new run. The process is iterated until the best fit between the forecast and observed location choices is obtained. For a complete discussion on the CALIB algorithm, refer to Ducca (*14*) and DOT (*13*).

CALIB then attempts to overcome the problem of unexplained variation between the observed and model estimated values. For this purpose *K*-factors are created for each district. The factors causing the unexplained variation could be: location of airports or ports, size of land holdings (for example, if one owner holds 100 acres, development would be more likely), crime, effects of income on employment location, quality of schools, and others. Errors in measurement and random data effects may also contribute to the unexplained variation.

The *K*-factors for each employment type by district are calculated using the following equation: .

$$K_i = \frac{A'_i}{A_i} \tag{1}$$

where: $K_i$ = *K*-factor for zone *i*, $A'_i$ = observed base-year employment in district *i*, and $A_i$ = estimated base-year employment in district *i*.

A similar procedure is used to develop *K*-factors for each district by income group.

The Employment Allocation Model, EMPAL, is a modified version of the singly constrained spatial interaction model. There are three main modifications: (1) a multivariate index of zone of attractiveness is used; (2) a separate, weighted lagged variable is included outside the spatial interaction formulation; and (3) a constraint procedure is included in the model, allowing zone and/or sector-specific constraints. The model is normally used to locate 3–5 employment sectors whose parameters are individually estimated.

The EMPAL model can be expressed as follows:

$$E_j^{t+1} = W_1 * \Sigma_i V_i * \frac{c^{-a}{}_{ij} * L^b{}_j * E^d{}_j}{\Sigma c^{-a}{}_{ik} * L^b{}_k * E^d{}_k} + W_2 * E'_j \tag{2}$$

where: $E_j^{t+1}$ = employment in district *j* at time $t + 1$, $t + 1$ = future time period, $t$ = base year, $W_1$, $W_2$, $a$, $b$, $d$ = empirically derived parameters, where $W_1 + W_2 = 1$, $E'_j$ = total employment (place of work) in zone *j* at time *t*, $c_{ij}$ = impedance between zone *i* and *j* at time $t + 1$, $V_i$ = total population of zone *i* at time *t*, and $L_i$ = total land area of zone *i*.

Equation 2 consists of two components. The first represents the portion of the total employment in zone *j* in the future year, which will relocate in response to changes in the population accessibility. The second component locates the portion of the employment that remains in place once it has been located.

Both $W_1$ and $W_2$ are developed during the CALIB model runs. $W_1$ is the percent of the employment that is located in a zone because of changes in the future and $W_2$ is the percent that will remain in its current location. These parameters are developed for each employment sector. Appendix A illustrates a step-by-step application procedure for the EMPAL model.

DRAM is a modified version of the standard, singly constrained spatial interaction model. There are two modifications. The first is to include a multivariate, multiparametric attractiveness function which represents inherent attractiveness of an area for residential location. The second modification refers to a procedure that permits district and sector-related constraints. The model is normally used for four household types (income groups) whose parameters are individually estimated.

There are two components of the attractiveness function: one represents the size or capacity of the zone for residential location and the other reflects the socioeconomic composition of an area. A high degree of correlation between the income distribution and residential quality (educational facilities, public services, and housing prices) of an area is often observed in U.S. cities. Hence, DRAM uses the income variable as a surrogate for residential quality.

The mathematical formulation of the DRAM model for each household category can be expressed as follows:

$$N_j = \Sigma_i n_{ij} * \frac{c^{-a}{}_{ij} * L^d{}_{Rj} * D^c{}_j * P1^d{}_j * P2^e{}_j * P3^g{}_j}{\Sigma_k c^{-a}{}_{ik} * L^d{}_{Rk} * D^c{}_k * P1^d{}_k * P2^e{}_k * P3^g{}_k} \tag{3}$$

where: $N_j$ = total number of workers living in district *j*, $n_{ij}$ = workers employed in district *i* living in district *j*, $c_{ij}$ = impedance between district *i* and *j* at time *t*, $L_{Rj}$ = residential land in district *j*, and

$$D_j = \frac{L_{Rj} + L_{Cj} + L_{Sj}}{L_{Rj} + L_{Cj} + L_{Sj} + L_{Vj}} + 1 \tag{4}$$

in which: $D_j$ = the developability index of district *j*, $L_{Cj}$ = commercial land in district *j*, $L_{Sj}$ = service land in district *j*, and $L_{Vj}$ = vacant land in district *j*.

### *Optimization Models*

An optimization model is designed to produce the optimal allocation of a particular quantity, such as households by type of housing and employment by sector, subject to a set of constraints. The quantity to be allocated is incorporated into an objective function which is optimized with respect to the constraints which, in general, ensure that all the quantity being optimized is allocated, that no supply side constraints are violated, and that allocations are non-negative.

The model of Herbert and Stevens (*15*), originally developed as part of the Penn-Jersey Transportation Study, is an early example of this category of models. Among the recent operational versions of programming models are: Technique for the Optimal Placement of Activities in Zones (TOPAZ)—see Dickey and Leiner (*16*); and Project Optimization Land Information System (POLIS—see Prastacos (*17*). TOPAZ was developed in Australia (see Brotchie (*18*)), and was applied to a variety of problems such as determining the optimal growth pattern for Melbourne (see Sharpe (*19*)) and the effects of upgrading the Melbourne-Sydney link.

POLIS represents the most recent large-scale effort in the United States to implement a nonlinear programming-based land-use allocation model. It was developed by the Association of Bay Area Governments (ABAG)—see Prastacos (*20,21*)—and has replaced the Projective Land Use Model (PLUM), which was developed in 1970. In POLIS, activity patterns are influenced by locational decisions of two decision-makers: individual selecting a job and nearby house to live in, and firms choosing the site to locate new employment. The model simulates the changes between two states of development. At each time period, only the new increase in employment opportunities and household is allocated; relocation of base-year jobs is accomplished by increasing the number of jobs to be distributed.

The mathematical representation for POLIS is:

$$\max Z(T_{ijm}, S^K{}_{ij}, \Delta E^n{}_j, \Delta H_i) = (-1/\beta^w) \sum_{ijm} T_{ijm} \left[\ln\left(\frac{1}{W_i}\sum_m T_{ijm}\right) - 1\right] - \frac{1}{\lambda}\sum_{ijm} T_{ijm}(\ln T_{ijm} - 1) - \sum_{ijm} T_{ijm}c_{ijm} - \sum_{k\epsilon K}(1/\beta^S{}_k)\sum_{ij} S^k{}_{ij}\left[\ln(S^k{}_y/W^k{}_j) - 1\right] - \sum_{ijk} S^k{}_{ij}c_{ij} + \sum_{i,n\epsilon K}(f^n{}_i)^{\alpha n}\Delta E^n{}_i \quad (5)$$

subject to:

1. Origin-destination constraints for work trip $T_{ijm}$. Work trips out of a zone are related to the number of households through a trip generation rate $a_i$

$$\sum_{jm} T_{ijm} - a_i(H^o{}_i + \Delta H_i) = 0 \quad (6)$$

Work trips in a zone are realted to employment through a trip attraction rate $b^n{}_j$:

$$\sum_{im} T_{ijm} - \sum_n b^n{}_j(E^{no}{}_j + \Delta E^n{}_j) = 0 \quad (7)$$

2. Origin-destination constraints for shopping trips $S^k{}_{ij}$. Shopping trips out of a zone are related to the number of households through a trip generation rate $e^k{}_i$:

$$\sum_j S^k{}_{ij} - e^k{}_i(H^o{}_i + \Delta H_i) = 0 \quad (8)$$

Shopping trips in a zone are related to retail employment through a trip attraction rate $h^k{}_j$:

$$\sum_i S^k{}_{ij} - h^k{}_j(E^{ko}{}_j + \Delta E^k{}_j) = 0 \quad (9)$$

3. Land use density constraints for employment and housing. Available land limits the number of jobs and households to be allocated in a zone:

$$\sum_n d^n \Delta E^n{}_j \leq \overline{L}_j \quad (10)$$

$$\Delta\overline{H}_{i,lb} \leq \Delta H_i \leq \overline{V}_i \quad (11)$$

4. Allocation of all employment and housing. All regional employment and housing units must be allocated:

$$\sum_j \Delta E^n{}_j - \overline{E}^n\cdot = 0 \quad (12)$$

$$\sum_i \Delta H_i - \overline{H}\cdot = 0 \quad (13)$$

5. Spatial-sectoral constraints for county employment. Employment in one sector is related to employment in other sectors:

$$\sum_{j\epsilon Pc} \Delta E^n{}_j - \sum_{q\epsilon Q}\sum_{j\epsilon Pc} c^q \Delta E^q{}_j - y^n{}_c = 0 \quad (14)$$

6. Exogenous location of employment and housing (policy constraints). A priori allocate a certain number of jobs and housing units in some zones:

$$\Delta H_{i,lb} \leq \Delta H_i \quad (15)$$

$$\Delta\overline{E}^n{}_{j,lb} \leq \Delta E^n{}_j \leq \Delta\overline{E}^n{}_{j,ub} \quad (16)$$

$$T_{ijm}, S^k{}_{ij}, \Delta H_i, \Delta E^n{}_j \geq 0 \quad (17)$$

where: $S^k{}_{ij}$ = number of shopping trips from zone $i$ to service activities of sector $k$ in zone $j$, $\Delta E^n{}_i$ = number of new jobs for sector n in zone $i$, $\Delta H_i$ = number of new housing units (households) in zone $i$, $\overline{L}_j$ = area of land available for employment growth in zone $j$, and $\overline{V}_i$ = vacant residential land in zone $i$.

A standard nonlinear programming algorithm is a preferred method to estimate the dual problem of the above equations. However, because of the lack of such an algorithm during the model development stage, the current version of POLIS employs the Bender's partitioning algorithm to exploit the structure of the primal. Using data from two different time periods, 1975 and 1980, the complete model was calibrated for the San Francisco Bay Region. The nine counties of the Bay Area were divided into 107 zones, each representing an aggregation of census tracts. Two modes, automobile and transit, and four employment sectors (manufacturing: transport, finance insurance real estate, retail trade, and services) were represented in the model.

### *Delphi Method*

The Delphi method is a technique for obtaining and refining the opinions of a group of experts or informed individuals, usually referred to as the Delphi panel. The method has been used in a wide variety of circumstances and areas of application as related in Linstone (*22*). In recent years, a number of urban and regional planning agencies have adopted this method as a technique for allocating their regional forecasts of land use and socioeconomic variables to smaller spatial units. At a traffic zone level, forecasts often follow a two-stage allocation process comprising two separate groups of experts.

The first group of experts develops a most probable (or possible) future scenario for a region, based on their experience, information on past growth trends, and an in-depth knowledge about the events and the context in which they occur. Following an iterative process of consensus building, the panelists generate a set of land use forecasts for superzones or districts comprising the study area. Once the superzone forecasts are complete, traffic zone allocations are made.

The zone level allocation procedure can be based on either the Delphi method or a well-defined allocation rule. In the former case, the Delphi process relies heavily on the expert judgment of local planners representing the jurisdictions located within the study area. In cases where an allocation rule is used, a procedure or an index reflecting the potential for development in a zone is applied to allocate growth among zones.

Broadly, the Delphi process for forecasting land use and transportation impacts can be summarized in the following four steps.

*Step 1: Establish A Delphi Panel.* The Delphi method depends primarily on the composition of the panel and the commitment and competence of its individual members. Therefore, the selection of panelists is a crucial component of the process. The group assembled to predict or anticipate the future must be knowledgeable about the full spectrum of development-related issues and the history of the development process that has occurred within the study area. The composition of the panel should not be biased in the direction of professional technocrats lest it lead to more policy-driven forecasts with less consideration given to market forces. Ideally, a panel should consist of local government officials, land use and transportation planners, representatives of utility companies, neighborhood association and citizen groups, private consultants, academics, and business representatives, and school district officials.

The total number of panel members is best kept below 20 to facilitate quick summarization of voting round results. Occasionally, the initial group may expand over the course of the exercise to obtain the fullest possible representation of expertise needed in the process.

The basic function of the panel is to review and approve the forecast methodology prepared by the regional planning agency. A preliminary package describing the process and containing the basic instruments to be used in the Delphi technique should be developed. The package includes questionnaires that elicit quantitative responses to specific questions, definitions of all quantitative measures used to allocate land use, and specifications of criteria to be used to stop the cycle or rounds of panel response seeking. The preliminary package is provided in advance of meetings to all selected panel members so that they qualify as "fully informed" members of the Delphi process.

The preliminary package should also include a summary of policy alternatives, a set of external factors, and a set of forecasts influencing future events. This usually includes regional control population and employment forecasts in several categories, as well as other relevant external factors—for instance, fuel prices, planned infrastructure investments (e.g., light rail system, highway projects), local urban conditions, and anticipated demand for certain commodities influencing the local economy. Description of the policy alternatives may cover a set of scenarios of the "probable future" or a predefined scenario for growth along with a set of assumptions pertaining to general economic conditions, regional conditions, and land use policies. Several graphic aids including maps of the study area, proposed land use maps, and transparent overlays indicating transportation alternatives may also be enclosed with the package.

*Step 2: Develop A Most Probable Scenario.* The main objective of this step is to establish a most probable development scenario for the study area using the Delphi method. Some agencies develop an initial urban form scenario based on goals and policy statements adopted by the various local governments in the area. Broadly, the scenario spells out the general content of the urban form assumptions covering major components: land use distribution and density, demographic characteristics, travel characteristics, and potential sites for unique activity centers. For instance, conceptually, the urban form assumptions may envision a polycentric or radial urbanization. Panel members may also be asked to rank alternatives of a particular component.

There could also be many probable futures subjected to a detailed forecasting exercise using the Delphi method. In such cases, panelists are asked to rate each scenario component in terms of its potential importance. Following this, participants rate each of the several future states for each component in terms of likelihood of occurrence ("likelihood ratings"). Table 10 presents the scenario components considered in a land use transportation interaction study and their importance ratings on a scale of 0 to 20 for each component submitted by the panelists. A scale value of 20 represents "extreme importance" and 0 represents "no importance." The scheme adopted for rating the likelihood of the states was a five-point scale ranging from "very unlikely" to "very likely." The results of the likelihood rating on a scale of 0 to 5 characterizing a "future" state that would have a fairly high likelihood of occurring are given in Table 11. Using both importance and likelihood ratings is a simple way of formulating alternative scenarios.

*Step 3: Develop Forecasts for Superzones or Districts.* Before initiating the forecasting process, the planning agency staff prepares the input data including control totals for population, employment, and income projections, and fact sheets on each superzone. Existing and accepted state and county projections usually form the basis for developing the control totals for variables to be forecasted. Some discussion and interplay between the agency staff and the Delphi panel may be warranted at this stage, particularly to finalize these totals in cases where either the projections have to be apportioned to the study area or partially modified in light of recent trends.

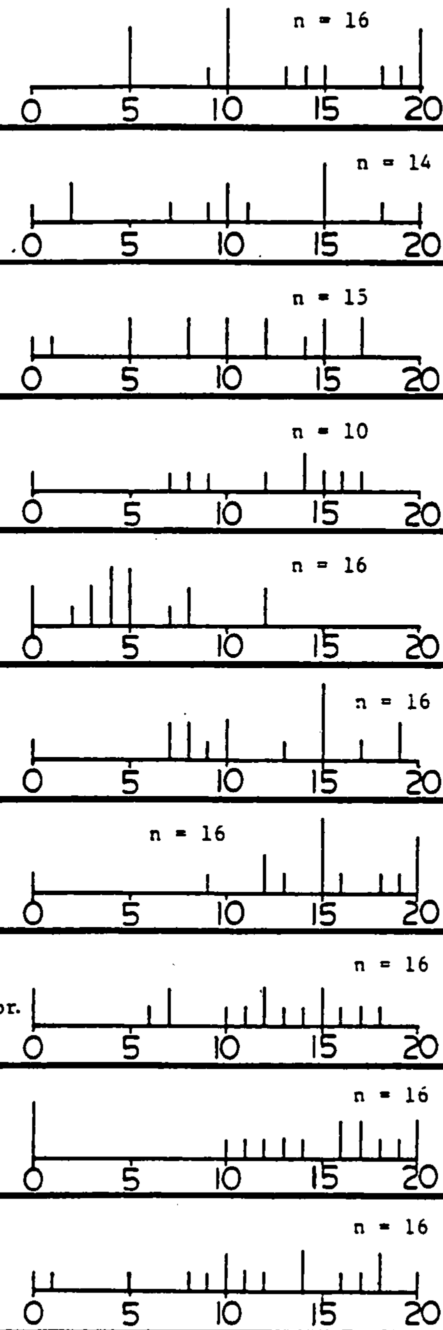
For each superzone, the fact sheets provide all relevant information on the development trends of variables (e.g., annual growth rates for housing, population, employment, auto ownership, income, commuting patterns), existing stage of development, and development capacity. Development capacity represents a measure of the amount of vacant developable land existing within a superzone for a particular land use or set of land uses. Furthermore, information on special characteristics and constraints to development (e.g., land ownership patterns, proximity to utilities, transportation access, ethnic mix, and topographical constraints), and a brief description on the zoning pattern of each superzone is extremely valuable to the Delphi panel.

Prior to converting the allocation control totals of population and employment to acreage, any-site specific employment allocations made under step 2 (i.e., Develop A Most Probable Scenario) are first deleted. Moreover, because the allocation procedure only distributes growth and activities, the land use currently established and unlikely to change during the forecasting period is considered as given.

The panel members review all inputs and evaluate the development probability for each superzone. Subsequently, individual

**Table 10. Importance ratings of scenario components. (Source: Ref. 23)**

| No. | Scenario component | m | IQR | n |
|---|---|---|---|---|
| 1. | Future cost of automobile transportation. | 11.5 | 9.5 - 18.5 | 16 |
| 2. | Future demand for electronic goods of the type produced in Santa Clara County. | 10 | 7 - 15 | 14 |
| 3. | Future size of the housing stock in neighboring cities. | 10 | 5 - 15 | 15 |
| 4. | Future monthly cost of housing in neighboring cities. | 13 | 8 - 15 | 10 |
| 5. | Future retail and service opportunities in neighboring cities. | 4.5 | 3 - 8 | 16 |
| 6. | Future employment opportunities in neighboring cities. | 11.5 | 8 - 15 | 16 |
| 7. | Future employment opportunities in San Jose. | 15 | 12.5 - 18.5 | 16 |
| 8. | Future land use policies affecting land outside the immediate impact area of the proposed transit corridor. | 12 | 7 - 15 | 16 |
| 9. | Future land use policies affecting land in the immediate impact area of the proposed transit corridor. | 15 | 10.5 - 17.5 | 16 |
| 10. | Future transportation policies affecting the immediate impact area of the proposed transit corridor. | 11.5 | 8.5 - 16.5 | 16 |



m = median

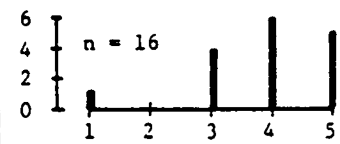
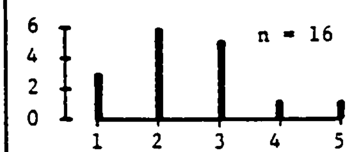
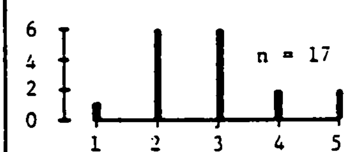
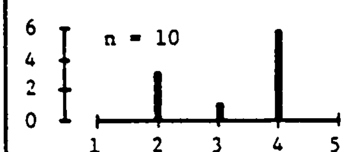
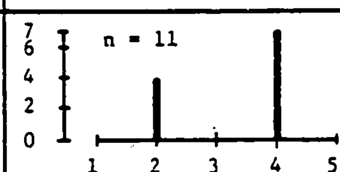
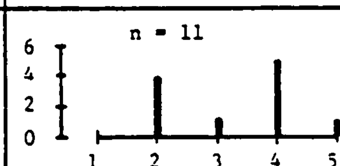
n = Total responses

IQR = interquartile range = lower quartile - upper quartile

members forecast each variable by superzone, based on their personal judgment. An attractiveness index, a dimensionless measure of all factors influencing the development probability, is generally adopted as the basis for allocation. Then, the panel members are asked to assign an integer value on a scale of zero to ten as the development attractiveness index for each superzone. An index of zero may indicate no development potential for a particular land use, while an index of ten may represent almost certain development probability. The allocation procedure used for the Albuquerque Urban Area by the Middle Rio Grande Council of Governments (*24*) is a simple proportioning equation, which distributes to each superzone a percentage of the control total based on its share of the summed product of the attractiveness indices times the development capacities for all superzones. The equation can be expressed as follows:

$$LU(s,l) = \{((AI(s,l))^{d}) * DC(s,l)) \ / \ \text{Sum}\ (AI(l)^{d} * DC(l)\} * NRC(l)$$

**Table 11. Likelihood ratings of alternative transportation policies affecting the immediate impact area of the proposed transit corridor—scenario component 10. (Source Ref. 23)**

| | | |
|---|---|---|
| a) Complete Hwy 85, Routes 101/280/680 interchange, and Route 87 from I-280 to downtown San Jose. |   | UNCERTAIN - LIKELY |
| b) Expand bus system to 500+ buses by 1980 and to 750+ buses by 1990 with service to downtown San Jose and BART. |   | LIKELY |
| c) Light Rail system built along Routes 87 and 85 from the downtown area to Oakridge Shopping Center and IBM. |   | UNCERTAIN - UNLIKELY |
| d) Upgrading of Southern Pacific Service between San Francisco and San Jose. |   | UNCERTAIN - UNLIKELY |
| e) Upgrading of Routes 87 and 85. |   | UNCERTAIN - LIKELY |
| f) Allow for future use of cars and buses on Route 87. |   | UNCERTAIN - LIKELY |
| g) Widen Highway 17 from San Jose to Fremont. |   | UNCERTAIN |

1 — very unlikely; 2 — unlikely; 3 — uncertain; 4 — likely; 5 — very likely

6 4 2 0 — number of responses at each likelihood level

n = total number of responses

where: $LU(s,l)$ = the acreage of land use l allocated to superzone $s$, $AI(s,l)$ = the development attractiveness index for land use l in superzone $s$, $DC(s,l)$ = the development capacity expressed in acres for land use l, $NRC(l)$ = the net regional control total for land use l, and $d$ = the dispersion exponent.

The dispersion exponent acts as an additional means of weighing the attractiveness index. The higher the value of $d$, the more influential will be the attractiveness index and, hence, less influential will be the holding capacity. It will lead to progressive concentration of a particular land use in zones with higher attractiveness index values.

To attain the final forecasts, the Delphi questionnaire is circulated in several rounds until panelist responses to particular questions (in this case, the value of forecast variable for each superzone) converge and stabilize. The objective of the iterative process is to obtain a satisfactory agreement on all questions and to facilitate communication among panelists while maintaining the anonymity of individual members. When the responses reflect increasing agreement among the panelists, they are said to converge. On the other hand, stability refers to the degree to which responses change from one round to the next.

The literature on the Delphi techniques (see Linstone (*22*) and Dajani (*25*)) provides several quantitative measures of stability and convergence to terminate a Delphi study. However, one of the simple measures is the median, an appropriate indicator of central tendency. The median, and the movement of responses in the upper and lower quartiles, are monitored from round to round. For instance, suppose the upper and lower quartiles are stable or shifting inwardly from round-to-round towards a stable median. Then, one can infer that the panelists are gradually moving towards a stable overall response. As the magnitude of shifts begins to decrease, little information is gained by conducting further rounds. Fatigue is an equally important consideration in terminating the process. In practice, three to four rounds are usually sufficient to attain a stable value for the statistical descriptors of response distributions.

*Step 4: Allocate Superzone Totals to Traffic Zones.* The ultimate purpose of the entire exercise is to obtain the land use forecasts at the traffic zone level so that they can be used to make future traffic projections. Growth and change at a smaller scale are heavily dependent on both the supply of land and existing and anticipated local market forces influencing the attractiveness of a location for a particular activity. Supply can easily be estimated in terms of available land for particular land uses based on an inventory of existing land use, development announcements, and municipal land use plans.

However, the assignment of development priorities and future land use mix within a superzone cannot be ascertained without some subjective judgment. Usually, it is determined through a process of working with local planners or developers. In practice, most of the allocation procedures use the notion of relative attractiveness of each zone for different types of development. An attractiveness measure for a zone reflects the assigned probability for development in a zone, based on past land development trends, current development characteristics, proximity to transportation and major employment centers, local plans and zoning, and development capacity. The future attractiveness measures are usually developed through a Delphi process or a series of brain-storming sessions using a panel. The process could be similar to the one discussed under step 3. Panel members for the task may represent either in-house experts or local planners, officials, and developers.

Once the indices have been assigned, traffic zones within each superzone are grouped into three or four categories (high to low probability of development) for the hierarchical allocation of growth. In some cases, the traffic zone forecasts are later checked for their reasonableness. In the case of the Albuquerque urban area, a trend forecast for population and employment was prepared from the regression equations that were calibrated from 1970 to 1980 data for one-fourth of the zones. Such a check might lead to minor manual adjustments to earlier allocations made by the Delphi panel.

*Analytical Methods*

A number of agencies use simple analytical methods which can, broadly, be considered "models" but lack the mathematical complexity of the urban development models. Most of these methods (see Perloff (*26*), Chapin (*27*), Krueckeberg (*28*), and Helly (*29*)) employ some rule of apportionment to distribute regional controls to smaller areas. Considering their apportionment procedures, these methods can be grouped into ratio methods and carrying capacity methods. However, there are many instances where an allocation method of this category is comprised of a combination of techniques from the above two groups.

Although these approaches lack a very sound theoretical foundation, their simplicity makes them the most popular land use allocation methods. Often, planning agencies use a combination of the Delphi method and one of these methods. Usually, first-iteration land-use allocations are produced using this approach, which are then operated upon by the Delphi panel members to develop final land use allocations.

*Ratio Methods.* Under ratio projection methods, smaller spatial units (or districts) are presumed to share in the effects of economic and demographic change projected for the region. Usually, for each spatial unit, first base-year ratios between the smaller area and the region are established. The forecast for the smaller area is estimated by multiplying the regional forecast by the base-year ratio for that area. The technique may be applied in a single or multiple step-down from region to zones. In the multiple step-down approach, a regional forecast is multiplied by ratios for one or more intermediate areas. The technique may also be applied to changes in levels of a variable (population or employment). In other words, the subarea share of the change in population or employment experienced by the region is projected.

Two widely used ratio methods for employment projections are the constant share methods and shift-share methods (see Perloff (*27*), and Krueckeberg (*28*)). The assumption of constant shares implies that districts (or regions) export for an industry grows at the same rate as the growth of the regional (or national) "import" demand for that industry's output. For instance, if the regional 5-year growth rate projection for the manufacturing is 0.0276, and a district's current industrial sector exports has been $60, the districts growth in industrial sector export according to constant share method will be $16.56 (0.276*$60).

In reality, a district may grow at a rate slower or faster than the regional average. It can happen because: (1) a district may have a mix of industries strongly weighted toward the slow or fast growth type; or (2) a district's internal supply advantages (quality of labor, technology, etc.) have declined or improved in relation to those offered in other districts. The shift-share analysis permits one to identify which of these two effects has been responsible for the district's recent relative growth rate.

Under the shift-share analysis, first the district's output increase for each industry is calculated assuming that each industry had grown at the same rate as total regional output. By subtracting the industry's hypothetical growth from the growth that actually occurred, the industry's total shift ($S_{id}$) is determined. Empirically, it can be expressed as follows:

$$S_{id} = \Delta Q_{idt} - (\Delta Q_{rt}/Q_{rt\text{-}n}) * Q_{idt\text{-}n}$$

where: $\Delta Q_{idt}$ = total growth in output of the *i*-th industry in *d*-

th district during $t$ period, and $Q_{rt-n}$ = total regional output for ($t$-$n$) period.

The total shift can be split into two parts: one part called a proportionality shift $P_{id}$, and another part called the differential shift $D_{id}$. The splitting determines the magnitude of total shift that was due to forces operating on the industry at the regional level and district level separately. The two shifts can be measured as follows:

$$P_{id} = ((\Delta Q_{ir}/Q_{irt-n}) - (\Delta Q_r/Q_{rt-n})) * Q_{idt-1}$$
$$D_{id} = ((\Delta Q_{id}/Q_{idt-n}) - (\Delta Q_{ir}/Q_{irt-n})) * Q_{idt-n}$$

A district with a rapid growth industry will have positive value for the bracketed term in the proportionality shift. Similarly, if the bracketed term in the differential shift is positive, it means that the industry finds the local district to be a better environment than the region. The shift-share analysis is, therefore, a very useful approach for understanding the causes of recent district level economic changes.

The shift-share analysis has also been adopted for projecting the growth of a district's or region's industries. To illustrate this, let us assume that during the last 5 years a district's manufacturing sector grew less rapidly than did manufacturing at the regional level by 1.6 percent. If the regional manufacturing sector growth rate projection for 5 years is 0.276 and the current sectoral output for the district manufacturing equals $280, the 5-year growth in district level manufacturing will be:

$$\Delta Q_{mfg,d} = (0.276\text{-}0.016)\$280 = \$72.8$$

In the foregoing example, the district growth rate presents the summation of the regional growth rate projections and the recent differential growth rate for the district. Note that the constant-shift method differs from the constant-share method and appears more reasonable than the latter. But researchers have found that the industry-specific differential growth rates are often unstable over time. Therefore, it is safe to conclude that the constant share is better than the constant-shift method.

Under the shift and share analysis, the projected shift method assumes that the differential growth rate term should not be constant. In this case, for each industry the differential growth rate is a projection of the growth rates of district level resource supplies (e.g., skilled labor or capital invested in infrastructure) relative to the aggregated growth rate of similar resources in all districts, together, that export the output. For example, if one assumes just one resource such as labor, $L$, is scarce, then the differential growth rate is defined as:

$$D_{id}/X_{idt} = (\Delta L_d/L_{dt}) - (\Delta L_r/L_{rt})$$

where $X_{idt}$ represents export output in the $i$-th industry, in district $d$ during time period $t$.

*Carrying Capacity Methods.* Carrying capacity methods focus on the population and employment holding capacity of the subareas, given the land use policy, available land, predominant densities, and environmental considerations. For small area analysis, often density models are applied to allocate population (see Khisty (*30,31*) and Chapin (*27*)). Zones or census tracts are first grouped into a series of concentric zones around the central business district. The gross density and the percentage of total metropolitan area population are computed for each concentric zone for past census periods and extrapolated. The extrapolated densities for zones are adjusted to account for the holding capacities and housing vacancy rates, and these results are used to adjust percentage of total metropolitan population expected to be located in each ring. The future population is apportioned to various rings using the adjusted percentages. The concentric zone totals are apportioned to smaller areas following a similar procedure.

Carrying capacity methods are commonly used to check the reasonableness of results from other methods. For instance, the projection of shares or ratios to a future year obtained by extrapolation techniques, when applied, may produce forecasts higher than the capacity of certain subareas. In such cases, the complete set of subarea ratios or shares has to be adjusted while maintaining the target control totals. The adjustment process may use either expert opinion (e.g., local planners or Delphi panel members) or a weighing scheme. Usually, these weighing schemes are a function of the current population or employment distribution, the distribution of available land for activity under consideration, the location of large employment centers, and planned and proposed developments within the region. For employment allocation, special attention must be paid to the type and/or size of firms. Firms that employ large work forces will usually locate in the fringe of the urban area because they require large parcels of land. Conversely, office employment can be expected to concentrate within the employment cores of the urban area.

*Nonmodeling Approaches*

Many urban areas produce estimates of population, employment, and households based on methods that are classified as judgmental; that is, they do not rely on a model or formal Delphi approach. These urban areas are usually smaller ones where the intermediate step of allocation between the region and jurisdiction or districts may be skipped and allocation made directly from region to zone.

Some of these "nonmodeling" approaches do rely on analytical calculation and computer manipulation, but they are generally simple and lack any sound theoretical basis.

The best way to summarize these approaches is to provide excerpts from material used to describe the approaches by those using them.

*Example 1.* For an area with about 100,000 population and 210 zones, the following was reported:

> Once areawide dwelling unit projections were developed, they were disaggregated to the traffic zone level based on characteristics of existing development, remaining land available for residential development, applicable plans and policies (including neighborhood rehabilitation programs and the countywide water and sewer plan) and the planner's general knowledge of development patterns in the area. A census tract-traffic zone equivalency list was developed as an intermediate control measure. The zone projections were aggregated to this level for comparison with historical and projected trends in each area. Individual zone projections were adjusted as necessary to bring the total for a given area in line with the tract total for that area.

Although some detail was provided on areawide employment projections, no further detail was available on distribution to zone. It appears that a process similar to that used for dwelling units was used.

*Example 2.* Many applications were reviewed where "previous" forecasts provided the basis for new zonal estimates. In an area with close to 400,000 population, forecasts were made for

36 jurisdictions, which were then allocated to the zone level. Forecasts were made for 13 variables (including population, dwelling units, autos, employment by four categories, four categories of floor area and/or acres). For population, the following was reported:

1. Calculate a population for each jurisdiction which results in future population being distributed by the same percentage as the 1980 census;
2. Calculate a population for each jurisdiction which results in future population being distributed by the same percentage as an old forecast (for a period 10 years earlier than the current forecast year);
3. Determine an average population for each jurisdiction from the above two factors;
4. Distribute the population growth for the region between the base year and forecast year by the same percentage as the old forecast growth. Add this to the current population to obtain a new estimate;
5. Average the values from steps 3 and 4; and
6. Adjust the final results as needed.

The political unit employment forecasts were developed by adjusting growth previously developed for each political unit to meet the new county-wide control total. The results were reviewed for reasonableness, and adjustments were made where proposed developments warranted. Similar approaches were undertaken for the other variables.

*Example 3.* For an area of 300,000, the following was reported:

Future estimates of zonal socioeconomic data are determined primarily through an allocation type procedure. Future quantities of population and employment are allocated to traffic zones based upon the land-use plan. Future estimates of vehicles/DU, persons/DU, and income are usually based on professional knowledge and judgment, historical census tract information, and/or data provided by the origin and destination survey.

## METHODS FOR DEVELOPING OTHER SOCIOECONOMIC VARIABLE INPUTS

Most of the socioeconomic (or land use) forecasting and allocation methods discussed in earlier sections provide general, district level projections of population or household and employment stratified by SIC code. There are a few exceptions. For instance, DRAM and EMPAL can output distribution of several types of households (e.g., income). However, because most of the travel models require more detailed characteristics of population and, in some cases, employment, it is imperative for transportation planners to reprocess the primary outputs of the socioeconomic forecasting and allocation method and develop the projections of "secondary" variables.

Review of various transportation studies and a survey of several agencies suggest that some of the most frequently used household characteristics by travel demand models are auto ownership, household income, household size, number of school-age children in a household, and household income by persons per household. Currently, there are several procedures in use by planners to stratify and convert the projected population and employment into a desired variable. These techniques vary in their sophistication and purpose. A review of these techniques is presented in the following sections.

### Developing Other Variables from Known Variables

Given a population or an employment projection, several variables required as inputs for travel models can be estimated using future values of rate, ratio, or proportions. For instance, by multiplying an estimated future auto-to-household ratio to projected households, the number of autos in each zone can be projected. Such a conversion technique may be applied at the zone or district level to total population/employment or to specific population/employment groups, such as household size, military personnel, or students. A typical application of the latter approach could be the estimation of number of school-age children from each zone given the distribution of households by size. In this case, a rate or ratio of school-age children to household for each category of households must be developed first. For each category, the rate or ratio is subsequently multiplied by the projected number of households to calculate number of school-age children. The results are summarized by adding the numbers calculated for each category to arrive at the zone or district level forecast of school-age children.

Obviously, the critical element of the foregoing conversion technique is the determination of future rate, ratio or proportion parameter values. Wherever the future values of the regional or jurisdictional rates are available, usually the change in these rates from the base (or existing) data are estimated and applied uniformly to the base rates of individual spatial units. Two other familiar approaches for developing the future rate or ratio or proportion are extrapolations of past trends for the study area or jurisdictions and borrowing of values from an area with similar population or economic characteristics.

The quality of projections produced by a conversion technique evidently depends on the quality of projected rate-ratio-proportion and the projection of population or employment at subregional level.

### Developing Distribution for Known Mean Value

A widely used technique is to disaggregate population (or household) into a specified number of discrete categories of a variable, such as household size, by 1, 2, 3, 4+ persons per household, auto availability by 0, 1, and 2+ auto per household, and income into three or four categories, given the mean value for that variable. Generally, census data are used to develop the stratification procedure. For each census tract, the percentage of dwelling units falling into each category of selected variable (e.g., occupancy or income or auto ownership) is plotted against its respective mean value. Following this, smooth curves are hand-fitted to the data. Manual adjustments to these curves become necessary if they do not satisfy the following two criteria: (1) for each point on the abscissa (X-axis), the sum of the values of the ordinates (Y-axis) for all curves should total 100 percent; and (2) the calculated mean value from the curves must be equal to the mean used as independent variable.

Figure 5 shows a model developed by COMSIS (*32*) for the Charlottesville Area Transportation Study area to distribute households by number of autos owned as a function of average autos per dwelling unit using the 1980 census data. The most crucial input for the application of the model at the zone or district level is mean values of the variable by zone or district. These values are usually developed, separately, based on the regional projections or extrapolation of observed rates developed from the longitudinal data or an established relationship (e.g., relation between average income and auto ownership). In the case of a household income distribution model developed by Barton Aschmann Associates (*33*), relationships are developed

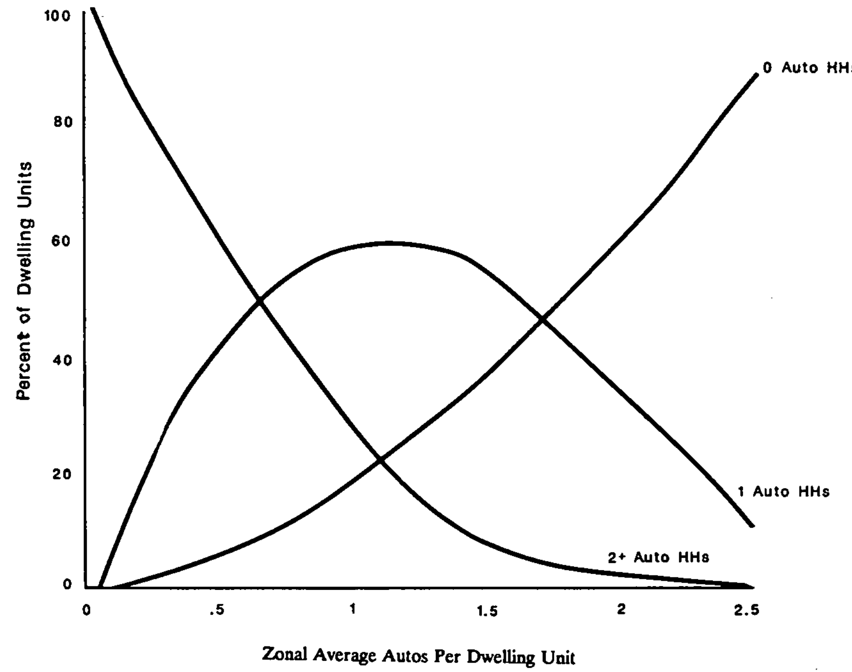



*Figure 5. Route 29 corridor study—auto ownership model.* (Source: Ref. 32)

between the percent of households in each income category and income ratio (i.e., average zonal income/average regional income). Because average regional income projections are readily available from the state/regional agencies or OBER-CITE Projections, distribution of households by income for each spatial unit can be easily predicted assuming the temporal constancy of the income ratio. Trip generation analysis (see COMSIS (*34*)) describes an alternative approach to forecasting household income based on the past trend of changes in the distribution of households by income.

Two inherent assumptions of the foregoing technique are, first, the existing relationships between the distribution and mean values will hold true in the future and, second, there is no other factor influencing the observed distribution (or relationship). Errors in projections would be inevitable if these assumptions were violated. Users of this technique must be aware of the fact that in many cases several variables related to household characteristics are found to be interrelated—for instance, household income and household size.

### Developing Joint Distribution for Known Individual Distributions

In order to estimate the joint distribution of the household forecast for each combination of two variable classes (e.g., income and auto availability, income and household size, and household size and income), the procedure discussed previously for developing individual distribution is further extended as follows:

*Step 1*—Develop the individual distribution model for each of the two variables following the procedure discussed earlier (i.e., developing distribution for known mean value).

*Step 2*—Develop a "seed table" of joint distribution (i.e., percentage of total households in each cell) as observed in base year. Such a table can be generated from a regional household travel survey data or recent census data.

*Step 3*—Apply the base year "seed table" to develop future joint distribution of households.

*Step 4*—Compare the estimated column and row totals of joint distribution produced under step 3 with the individual distributions developed under step 1. If individual column and row totals do not match with the estimates produced under step 1, balance the matrix until they equal.

The matrix balancing technique follows an algorithm similar to FRATAR in the MINUTP (*35*), TRANPLAN (*36*), and FHWAPLANPAC (*37*); or UMCON in the UTPS travel forecasting software packages. Because the above model is applied for each traffic zone, usually MPOs use their own program to prepare the inputs for the travel demand models.

The above procedure can be further extended to develop a three-way classification of households; for example, a three-way cross-classification model of auto ownership (autos per household) using income and household size variables.

### Disaggregate Models

In recent years, disaggregate models based on discrete choice analysis methods, such as logit models, have been used to develop socioeconomic characteristics of households. A discrete choice analysis treats each individual household as a decision-maker and models it as selecting the alternative with the highest utility among those available at the time a choice is made.

This technique is frequently used to predict the probability of choosing to own zero, one, two, and three or more autos as a function of a set of variables that enters in the utility function.

The commonly used variables are household income, fixed cost of automobiles, household size, workers per household, population density, travel times on urban roadways, and public transit service (see Golob (*38*)) and the Metropolitan Transit Commission (MTC) (*39*). Recognizing that auto ownership is an outcome of a household's joint decisions pertaining to the residential and job locations, Lerman (*40*) developed multinomial logit models for nine market segments (four life cycle and two employment groups) using variables reflecting locational attributes, housing attributes, socioeconomic characteristics, auto-ownership costs, and level of transportation service to work. This method has also been used to develop other household characteristics. For instance, MTC (*39*) applies a disaggregate model to predict the zero-worker and the one-or-more-worker households.

Among the techniques discussed, the disaggregate models are theoretically the most sound. They permit the inclusion of various factors explaining the household level decision-making behavior and, hence, the resulting characteristics of a household. However, because of the complexity of the model calibration and the need for household level data, application of these techniques has been limited among small-size and medium-size urban areas.

CHAPTER THREE

# INTERPRETATION, APPRAISAL, AND APPLICATION

Chapter Two presented the project findings with respect to the sensitivity of UTPP to various errors in forecasting/allocating socioeconomic input variables at the subregional level. Also examined were various methods available for forecasting/allocating socioeconomic data at the traffic zone level. Of the six methods reviewed in the previous chapter, four methods are identified as having potential for future applications and are evaluated in this chapter. This evaluation will highlight the positive and negative characteristics of these methods rather than recommend a best method. This chapter also describes six examples of the forecasting and allocation process currently practiced in metropolitan planning organizations.

## EVALUATION OF METHODOLOGIES

This section presents a systematic assessment of four methods (DRAM/EMPAL, POLIS, Delphi method, and simple analytical methods) based on the following categories of criteria: the transportation planning process, the projection method, the resources required, and the transferability logistics.

No attempt has been made to quantify the evaluation of these methods or to rank them in order of preference. The specific circumstances of the user will dictate method selection. Moreover, considering the subtleties of the individual techniques and wide variation among individuals' perceptions, the reader must exercise judgment when selecting a particular land use allocation method. With this in view, the purpose of the evaluation is to present the advantages and disadvantages of the individual techniques according to the aforementioned criteria.

### The Transportation Planning Process

*Production of the Desired "Input" Variables*

Several agencies were requested to provide the variables they used as input to travel demand models (trip generation and mode choice). In addition, several study reports were reviewed to obtain this information. The findings suggest that the most frequently used variables are employment by sector (e.g., retail, industrial, services), number of dwelling units or households, population, auto ownership, and income. These are the most important input variables for explaining the variation in trip generation. Moreover, variables explaining household characteristics, such as income, auto ownership, and household size, are equally important as inputs for mode choice models.

Land use allocation methods do not generally predict all the variables required by the travel demand models. Postprocessing procedures are usually applied to calculate the remaining needed variables. Given the regional controls, most methods forecast only population and employment by spatial units. The questions then are: Which of the remaining variables are forecasted directly by each method and are the desired input variables produced in the required form?

Except for the DRAM/EMPAL models, no method discussed here produces households' socioeconomic variables directly. Users often develop their own area-specific models to stratify the allocated total households into auto ownership and/or income categories. The census and the departments of motor vehicles are two major sources of data for these models. DRAM is one of the methods capable of directly predicting up to four categories of households (usually by income variable) by zone. Unlike other methods that treat socioeconomic stratification separately, the household allocation procedure in DRAM considers socioeconomic characteristics of households.

In those other methods, for each spatial unit, the distribution of households in a joint distribution, for example auto ownership or income by household size, is commonly computed by an iterative technique (FRATAR method). For a known distribution of households by individual variables (marginals for the cross-classification), this technique permits estimation of cell values (for details see Chapter Two). For example, suppose a 2 $\times$ 3 matrix of household distribution by auto ownership and income is known for time *t*:

| Auto Ownership | Income | | | |
|---|---|---|---|---|
| | Low | Medium | High | Total |
| 0 | 10 | 10 | 0 | 20 |
| 1 | 5 | 60 | 15 | 80 |
| Total | 15 | 70 | 15 | 100 |

To calculate cell values for a future year ($t+1$), the Fratar Method requires the projected marginal distributions as displayed below:

| Auto Ownership | Income | | | |
|---|---|---|---|---|
| | Low | Medium | High | Total |
| 0 | 10 | 0 | 0 | 10 |
| 1 | 0 | 75 | 15 | 90 |
| Total | 10 | 75 | 15 | 100 |

Obviously, the accuracy of such a method depends on the accuracy of the marginal distribution for each variable. No allocation method discussed here produces data in a joint distribution format. Moreover, because of their aggregate forecasts of households by spatial unit, most of these methods do not even produce the marginal distributions by spatial unit, resulting in a separate set of models being applied to develop the marginal distributions. Since these methods do not account for the relationship between the choice of residential location and a household's social status, inaccuracies may creep into the marginal distributions. DRAM implicitly treats this relationship and produces at least one marginal distribution (usually households by income). Hence, DRAM's estimated joint distribution can be expected to be more accurate compared to one produced by other methods.

On the employment side, most of the methods are capable of dealing with several categories. Availability of data by industrial sectors remains the major determinant of a stratification scheme.

One critical requirement of travel demand models is to have input variables by traffic zone. A two-step allocation is usually made to produce zonal level data, first, from region-to-district; and, then, from district-to-zone. Because most of the land use allocation methods produce district level forecasts, a different allocation procedure must be followed below the district level. Although none of the methods provides forecasts by zone, those that can produce forecasts for a larger number of geographical units are preferred. A method that produces forecasts for smaller spatial units is less likely to produce aggregation error in variables. Both DRAM/EMPAL and POLIS can handle large numbers of spatial units for land use allocation. For instance, the number of spatial units used for the POLIS application in San Francisco (*17*), DRAM/EMPAL in Dallas/Fort Worth (*5*), and the Delphi method used by the Metropolitan Washington Council of Governments (*41*) are 107, 166, and 11, respectively. In other DRAM/EMPAL applications in Houston, Washington, and Los Angeles there were 199, 182, and 772 units used. Other analytical methods, using microcomputers, can be applied to larger numbers of spatial units. In this respect, both DRAM/EMPAL and POLIS are considered superior, in some degree, to all other methods.

*Interaction With Travel Demand Models*

An interface between the land use allocation process and travel demand estimation is often emphasized and considered essential to produce a consistent set of forecasts by spatial unit. Conceptually, this interface is based on the fact that the complement to land use affecting transportation is transportation affecting land use according to Averous (*42*). The location of activities (population and employment) depends on the prior distribution of these activities, the attributes of potential locations, the characteristics of the individual activity (socioeconomic status of population groups, or type of economic activities), and the cost of overcoming their spatial separations. The cost of overcoming the spatial separation is determined by the existing transportation facilities and their attributes (speed of travel, or travel times and travel costs). As the traffic generated from a particular land use allocation affects the characteristics (or attributes) of the network, a feedback link between the location of land use and transportation can be established.

An allocation process ignoring such interactions with the travel demand models is prone to producing errors in its activity allocations. In the absence of any feedback mechanism, the long-term locational impacts of major transportation policies and investment decisions on the location of population and employment, on the characteristics of population served by transportation, and on the resulting travel demand remain intractable. It is well established that variations in regionwide transportation costs have a direct impact on metropolitan sprawl, compactness, or clustering. Similarly, any subarea level variations or link-specific changes in the transportation system may also produce spatial effects, though they may be localized in nature. Conceptually, a feedback mechanism integrates the demand estimation and land use allocation processes and, thus, permits replication of the behavior that leads to long-run equilibrium between the transportation supply and the spatial distribution of socioeconomic activities. Recognizing this, the interaction criterion emerges as an extremely important consideration while evaluating different allocation methods.

The design of urban development models has been linked to the transportation planning process that focused on comprehensive planning and long-range capital investments. As a result, in addition to a consideration of location theory, most of these models, including DRAM/EMPAL and POLIS, incorporate a measure of spatial separation (or accessibility) in terms of travel time and/or costs. The DRAM/EMPAL models use travel impedance that reflects peak-hour congested network conditions assuming that work-trip travel impedance influences long-term residential choice decision. The zone-to-zone impedance matrices, a key input to these models, are an output of the travel demand model chain. The impedance measure thus permits the desired linkage between an allocation model and the travel demand models. However, the revised allocation of land use is rarely used in practice as input in travel demand models to generate a new set of travel impedances. The entire process is rarely iterated several times in the hope of attaining an equilibrium. In other words, travel demand and allocation models are seldom calibrated together, and the forecasts are seldom made in a simultaneous framework. As a result, individual models' coefficients do not reflect the behavior of joint choices made by a household pertaining to its residential location, mode choice, and mobility level (number of trips).

In large metropolitan areas where the share of transit and high occupancy vehicle users (carpoolers and vanpoolers) are substantial, choice of mode for work trips and shopping trips is affected by the relative accessibility of drive-alone compared to other modal options. This, in turn, influences auto ownership and residential choices of various income categories. In particular, transit captive riders coming from no-car and/or low income categories are commonly observed to live and work in an area served by transit. In their current form, neither DRAM/EMPAL nor POLIS are directly sensitive to mode choice behavior and its effects on residential location. However, with minor modifications, these models can incorporate the effects of mode switching, particularly in response to significant changes in auto travel time/costs or improved transit services (e.g., changes in gasoline price, parking fees, transit fares, tolls, level of congestion, and transit service). One simple way is to use a composite impedance measure, reflecting the impedances of all modes and the socioeconomic status of travelers rather than highway impedance. The log sum method, under which the natural logarithm of the denominator of the modal-choice logit equation is used as the impedance, is commonly applied in practice (see COMSIS (*43*) and Allen (*44*) to link trip distribution models with mode-choice models. Use of a similar approach can provide the required link between land use allocation and mode-choice models.

Small urban areas that have insufficient congestion to affect their trip maker and residential location decisions may find the inclusion of the above kind of interaction unnecessary in their forecasting procedures. Similarly, areas with very low transit ridership need not account for mode shift effects on residential location.

Both DRAM/EMPAL and POLIS allow for these interactions (although infrequently implemented) and, therefore, rank at the top in comparison with other allocation methods according to this criterion. Moreover, because these models are operated on computers, integrated land use and transportation policy analyses can be easily undertaken by directly linking the allocation and demand models. UTPS, a travel demand estimation software package distributed by the U.S. Department of Transportation, includes early versions of the DRAM/EMPAL models to undertake this kind of analysis. Similarly, the Integrated Transportation Land Use Package (ITLUP), developed by Putman (*8*), contains both location (DRAM and EMPAL) models and transportation (MSPLIT for mode split calculation and NETWRK for trip assignment) models especially formulated for treating the interaction between demand estimation and land use allocation in a simultaneous framework.

Under the Delphi method, panel members exercise their personal judgment while allocating land uses based on the accessibility related information provided to them. In this case, experts are expected to account for the long-run interrelationship between transport and land use, but there is no feedback process to replicate the cyclical nature of this relationship. On the other hand, analytical methods, such as the cohort-survival model and the shift-share method, completely ignore the notion of interaction with the travel demand estimation process.

### *Sensitivity to Transportation Policy*

A technique is responsive to transportation policies only if it includes transportation variables. Nonetheless, inclusion of a transportation variable does not, in and of itself, make a technique sensitive to a full range of policy issues. Actually, sensitivity to a policy option is dependent mainly on whether the method includes variables related to that particular policy and the relationship between these variables. Policy questions generally cover a wide spectrum of issues ranging from the provision of facilities and services to regulation and funding.

At state and federal levels policy actions are usually tariff and regulation oriented. Fuel tax variance and regulation of common carriers are prime examples. At the urban area level, policies are often related to services, such as road construction, highways, fixed guideway transit, and changes in transit services. In recent years, localities have been concerned with financing of transportation systems by levying some kind of a user fee (e.g., pricing road use, parking, and transit services) and by local taxes (e.g., tax on income, sales, property, fuel and business, development fees).

Most of the aforementioned policies influence the long-run locational decisions of residents and economic activities. Therefore, a land use allocation method should be responsive to such policies. Those transportation policies that neither affect residential location nor generate major spatial effects are generally considered irrelevant for long-term strategic planning. These may include such policy implementation techniques as ridesharing and subarea specific traffic management actions.

Impedance, a measure of the spatial separation of zones, is the key variable reflecting the transportation supply side in most of the land use allocation methods and, in particular, in urban simulation models. Hence, a method's sensitivity to transportation policies greatly depends on the way impedance is defined. For instance, if it represents the composite impedance, which includes all attributes of both transit (e.g., waiting time, access time, in-vehicle time, and fare) and highway (e.g., terminal times, parking cost, in-vehicle time, and travel cost) facilities, a method becomes sensitive to a wide variety of transportation policies affecting a specific, or set, of attributes. Adversely, if the impedance definition represents only highway travel time, any policy influencing the fuel cost, tolls, parking cost, and/or transit service characteristics (changes in feeder services to transit stations, fare, and provision of parking at transit stations) cannot be evaluated.

Relative to this criterion, both DRAM/EMPAL and POLIS rank higher than the other methods because their allocation mechanisms account for the measure of impedance between worker's residences, their employment sites, and shopping locations. These methods are flexible enough to accept any definition of impedance. Moreover, they generate forecasts for smaller geographical areas and, hence, to a degree display sensitivity to area-specific changes (e.g., decrease in congestion, effect of new highway or transit links, effect of mode switching).

Under the Delphi method, panel members take into account major regionwide effects of certain transportation policies (e.g., extension or opening of a new fixed guideway or highway system) on land use. For this purpose the Delphi panel is given a set of rules/assumptions that explain those transportation policies affecting land use. Because this method of forecasting is often repeated at a regular interval of 3 to 5 years, it allows forecast updates based on feedback from the effects of earlier transportation policies.

## The Projection Method

### *Theoretical Basis*

A method to disaggregate regional population and employment totals among smaller spatial units should reflect a consistent and integrated view of the functioning of an urban area. Therefore, the process should recognize a cyclical relationship between land use and transportation. Moreover, the locational decisions pertaining to residential and economic activities utilized by a method must be based on the well-established locational theories of consumer and producer behavior. In this respect, the modeling approaches, such as DRAM/EMPAL and POLIS, are clearly superior to other analytical methods (e.g., shift-share) and nonquantitative approaches including the Delphi technique.

Both the DRAM/EMPAL and POLIS model structures are built upon the knowledge gained over 25 years of experimentation with urban spatial simulation. Although these methods are macrodescriptive (spatial interaction) in nature, they are based on the utility maximization principals at the microlevel. Residential choice in both cases is determined by travel-to-work behavior and attractiveness of a residential area. Retail activities are located in proximity to consumers to maximize sales revenue. The profit maximization and cost minimization objective of different economic activities influencing their location is depicted by the accessibility to labor supply and the existence of agglomeration economies.

These models do not fully and accurately replicate reality nor are they totally accurate. For instance, they neither capture the dynamic behavior of urban spatial phenomenon nor explicitly consider supply side factors influencing locational decisions pertaining to various activities. These models are calibrated to replicate the reality of a cross-sectional data set for a given time, and do not incorporate dynamic properties of urban development. POLIS also lacks a proper procedure for estimating land consumption and for responding to land constraints. Moreover, as these models were developed for the allocation of growth, they may not be able to directly examine the effects of decline. These limitations are a subset of the many inherent weaknesses in the current state of the art of urban location modeling and, therefore, need to be addressed by future research.

The basic premise of the Delphi method is that development patterns and forces can reasonably and consistently be comprehended by a panel of informed experts. If this assumption is correct, a confluence of opinion among a panel of experts would produce an estimate of the most probable development patterns. The prediction process typically relies on the wealth of information reflected in the institutions, opinions, and judgment of people (experts) living in the study area. The allocation process is based entirely on the judgment of the panelists rather than on any consistent theory. It is possible for two groups of experts to produce two different sets of spatial allocations for the same regional totals.

Other analytical methods, such as shift-share and structural change models, are mostly based on individual small areas' change over time, in terms of its share of regional growth or its structural evolution (e.g., neighborhood). These allocation methods do not have any sound theoretical foundation.

### *Methods' Track Record*

Without proper information, it is extremely difficult to evaluate an individual method's track record of making accurate predictions of the variables. Almost no "before and after" or ex-post evaluation results are available pertaining to the accuracy and quality of various forecasting and spatial allocation methods. The validity of a method can only be checked against reality and only in light of the differences between the forecast and the actual events. To reflect the comparative accuracy of various procedures in a statistical sense, it would be desirable to apply all alternative methods in a particular study area. For this kind of evaluation, census and actual estimates of variables for many years following the base data are needed. Because most of the methods under consideration were initiated during the 1970s, the census data needed for tracking the accuracy and quality of forecasts are not yet sufficient. Moreover, because the methods change and improve over time, any effort to evaluate an old methodology becomes irrelevant. Methods based on land use and transportation modeling based methods, such as DRAM/EMPAL and POLIS, were first used in the mid 1970s and 1983, respectively. Putman, the creator of DRAM and EMPAL, has examined the forecast accuracy of both models singly and in combination for several metropolitan areas. According to Putman (*8*), the forecast accuracy, measured in terms of the goodness of fit and R-square, ranges from just under 0.8 to above 0.9, with most of the verifiable forecasts just at or above 0.9. A reasonable and systematic procedure capable of forecasting the spatial distribution of population and employment in a metropolitan area with this degree of reliability can be considered to possess high potential for application. The current users of DRAM/EMPAL are primarily from large metropolitan areas, including Atlanta, Dallas/Ft. Worth, Houston, Los Angeles, Kansas City, Seattle, and Washington D.C., although smaller areas, such as Colorado Springs, have found it useful as well.

POLIS has been in use since 1983 at ABAG in San Francisco. It has not been used in any other agency. Prastacos (*17*) examined the fit of the model by comparing the forecasts with the actual 1975–1980 change within the San Francisco Bay Area region. The R-square, a statistical measure of association between observed and model estimated results, was 0.74 and 0.78 for housing and employment, respectively. The results of the San Francisco application are considered satisfactory. POLIS was developed as a tool that could be used in strategic planning of the Bay area and replaced the PLUM model, which was considered less sensitive to the structural changes occurring in the region's economy.

Delphi techniques are used to produce "most likely" forecasts based on the panelists' judgment and cannot be evaluated statistically in terms of how well they can replicate the base-year cross-sectional data. Moreover, because forecasts are modified on a regular interval based on feedback and experience, it is difficult to track their accuracy and reliability. For instance, the Washington Council of Governments has been through four rounds of forecasts. Updates to the Round III forecasts (*41*) were approved in 1985 when regional population and employment trends began showing signs of higher growth than had been expected during the 1970s and early 1980s. Usually, criticism of the forecasts establishes the need for an update.

No documentation on the performance of other analytical methods, such as shift-share and extrapolation methods, are available. These methods are popular in small-size and medium-size areas. For modestly growing, small areas, these methods may yield sufficiently accurate forecasts for short range planning purposes. The inherent assumption is that present trends will continue in the future. This may hold true in the short term under stable growth conditions, but may not prove realistic in the long run.

*Comprehensibility of the Method*

Comprehensibility, in terms of the ease with which an average planner can understand a technique and related assumptions and limitations, is generally inversely related to the sophistication of a method. Urban modeling methods like DRAM/EMPAL and POLIS process large volumes of data to simulate complex interrelationships among variables in an orderly and efficient manner. Their operation and calibration require large computers and well-trained analysts familiar with modeling and programming. The mathematical programming-based structure of POLIS makes it actually less comprehensible as compared with DRAM/EMPAL. Most mathematical programming models produce an optimal solution without being very explicit about how that solution is achieved. A user without training in operations research will have difficulty understanding how various components of an urban system are integrated, and function together, in the POLIS model structure. The DRAM/EMPAL model structure is relatively simple and easy to understand because of its similarity to the spatial interaction model structures that are popular among planners.

At the other end of the spectrum, the Delphi method is most readily understood by planners and local elected officials. The method produces outputs through an open process. Most of the data and computation are commonly handled by a calculator or a spreadsheet. However, because of the subjective nature of this allocation method and lack of a very sound theoretical underpinning, all assumptions driving the allocation process are not explicit. On the other hand, model-based approaches provide a framework for formulating explicit and documented assumptions on which forecasts are to be based. Once the allocation mechanism of a model structure is understood, the user becomes aware of its capabilities and limitations and, thus, uses the method more effectively.

*Inherent Limitations and Biases*

Sophisticated modeling approaches, such as DRAM/EMPAL and POLIS, are the results of a scientific endeavor that has yet to overcome several known limitations. These limitations can be categorized into four broad areas: comprehensiveness in terms of the number of components of the urban system represented, technique used, dealing with urban decline, and treatment of time.

Since extraneous factors hold great control over urban affairs, the predictive capabilities of an urban spatial model that is principally dependent on intra-urban factors will, to a considerable extent, be conditioned by exogenous events or factors. It is essential to be aware of the limitations of DRAM/EMPAL and POLIS in terms of their ability to respond to the effects of major external events as well as to the location, decision specific factors. Although both models are reasonably comprehensive in incorporating transportation, agglomeration economy and site suitability related factors, they are less sensitive to various social and technological factors. For instance, these models do not incorporate the demographic effects of family life cycle stage and the corresponding housing need on residential locational choice. Similarly, societal changes such as increasing rates of household formation, increasing female participation in the labor force, and greater flexibility of working hours are among the emerging issues influencing residential choices. Trends in technological change include telecommunications growth and its falling costs, new computing technology, and the shift from the manufacturing sector to the information and personal service sector. In large metropolitan areas, impacts of these changes are well manifested in the employment suburbanization trend. Neither DRAM/EMPAL nor POLIS is capable of explicitly portraying these phenomena. To overcome these limitations, several sets of forecasts are usually produced by varying input variables related to the assumptions of future scenarios. Of course, none of the other methods is capable of explicit representation of these phenomena either.

Most of the models are designed to allocate growth; therefore, they may be inadequate for examining the effects of regionwide economic and/or demographic decline, according to Mackett (*45*). Although, empirically, DRAM/EMPAL permits negative growth allocation, it may prove inaccurate in forecasting the spatial distributions of a regionwide decline. No research findings are currently available that provide a comprehensive explanation of the economic decline phenomenon and its effect on urban structure.

Simpler analytical methods, such as shift-share and ratio-trend techniques, are biased toward continuation of past history and the assumption of linear growth. There are many phenomena that result from the nonlinearity of the interacting components of an urban system. Most location decisions respond nonlinearly to changes in the density of land uses as well as to changes in the characteristics of transportation system (e.g., congestion effects on link times and costs of travel). DRAM/EMPAL, and POLIS to some degree, capture these relationships.

In a mathematical programming-based technique, all modeled components of an urban system must be represented within an objective function. This feature restricts inclusion of more components without adding mathematical complexities and is considered to be a major constraint in the development of a comprehensive mathematical programming formulation of an urban model. Although POLIS adequately incorporates all major components, it faces the above problem if considered for modification. In mathematical programming-based methods like POLIS, an objective function is optimized under a specified set of constraints. This means that specific numerical values for each constraint (by spatial units) must be provided as exogenous inputs. Through these constraints, information on the availability of land area for various uses and holding capacity, in terms of number of new jobs and residents in each zone, are specified. In other words, a user has to, in effect, allocate all variables by zone for future years prior to running the model. In this respect the DRAM/EMPAL model structure is relatively simple and does not require future distribution of population or employment as input. Given the regional forecasts, EMPAL allocates employment and DRAM distributes households among zones. Furthermore, in its current form, POLIS treats households (or housing) in an aggregate fashion and, hence, the residential distribution process completely ignores effects of household income or any other socioeconomic characteristic on residential location.

DRAM/EMPAL can work over time, typically in 5-year periods, with lag mechanisms to link various land use and transport elements at different points in time. Being a static-equilibrium model, it implicitly assumes that an urban system attains equilibrium at the end of each period. On the other hand, POLIS produces an optimal solution at the point in time for which forecasting inputs are provided. Because of this, it is considered suitable for identifying feasible solutions, but not as a forecasting tool.

The Delphi method has been severely criticized by the believers of the scientific approach to understanding a phenomenon. Sackman, in Linstone (*22*), mentions: "The future is far too important for the human species to be left to fortune tellers using new versions of old crystal balls. It is time for the oracles to move out and science to move in."

However, Delphi is a widely accepted method for dealing with extremely complex problems for which there are no fully adequate models. Delphi is also useful in cases where hard data are unavailable or too costly to obtain. The method has been successfully applied to elicit value judgments and not to search individual data. The Delphi method can be used for developing a broad scenario of the most likely future, but has very limited capability for producing socioeconomic data for smaller geographic units.

A designer who applies the Delphi technique must be aware of its boundaries and pitfalls. Linstone (*22*) points out eight major pitfalls in the method. He identifies a few biases that are found to be inherent in human judgment, such as a tendency towards applying a discount rate to the future, and an attitude of overpessimism in long-range forecasts and overoptimism in short-run forecasts. Some assert that expert opinion is nearly always unconsciously biased. It could be worse if the execution of the Delphi method is sloppy, in terms of poor selection of participants, lack of imagination in examining various facets of the problem, and collection of hastily given responses. Furthermore, a panel consisting of experts on various subsystems does not necessarily constitute expertise on overall urban system behavior and dynamics.

A comprehensive method such as modeling introduces more opportunities for bias in computation and behavioral assumptions, but the assumptions and relationships are explicit and consistently applied.

### *Usefulness for Other Planning Purposes*

The possibility of making more general use of a technique has two advantages: first, the costs of resources can be spread among planning activities and, second, it provides a single set of forecasts for different planning activities, which permits the development of unified plans for an area. Distribution of population, employment, and certain socioeconomic variables, in particular income, by smaller spatial units are key inputs for several planning activities. These activities include assessment of demand for housing, water and sewer services, electrical power, public school construction and closings, occupational training, and other social service needs. Moreover, these forecasts are frequently used for various kinds of environmental impact studies pertaining to transportation projects, economic development plans, river basin development projects, residential subdivision development, and shopping center location.

Because the estimated demand has a direct bearing on the forecasts for potential revenues and costs linked to the provision of a service, reliable and accurate forecasts remain the critical factor in enhancing usefulness of a forecasting method to other planning activities. The next most important consideration is whether a method provides as outputs, the inputs necessary for a particular planning purpose. In cases where more disaggregate level information on employment, housing and income are required, DRAM/EMPAL appears to be a preferred method. Large urban areas tend to adopt a sophisticated model for land use allocation, as well as for investment analyses pertaining to their major service and infrastructure programs.

## Needed Resources

### *Requirement of Staff and Skills*

Personal skill and resource requirements, in general, are functions of the computational complexity, input data need, and size of the study area. Use of simpler models and the Delphi method for small areas exert minimum demand on manpower resources. The application of sophisticated models requires skilled staff and, often, the assistance of a consultant for the calibration of models for first-time application. Currently, DRAM/EMPAL and POLIS models can be run only on mainframe computers and, hence, trained staff is a prerequisite for their application.

Table 12 displays an approximate estimate of person months and type of persons used for the application of three different methods. These estimates were indicated by the agency staff responsible for the application of the specific technique in each of the three agencies. Since POLIS was developed by the in-house staff of ABAG, the estimate of person months shown in this table is extremely high.

### *Costs Related to Method Set-Up*

Three categories of resources affect the costs of setting up a method: purchase of system and related documentation, hardware and software, and preparation of input data.

System installation related costs are principally incurred when a program for the application of a method is purchased. An old version of DRAM/EMPAL (because it is public domain software) can be obtained from the United States Department of Transportation (DOT) at no cost by public agencies. The program and related documentation are an integral part of the UTPS package currently available from DOT. More recent versions can be obtained from the models' developer, S. H. Putman. POLIS is the property of ABAG and not available for wide circulation. At this stage, no proper documentation for its use, application, and updates is available. Although there is no hardware purchase involved with these methods, they are feasible subject to the availability of a mainframe computer. Computational requirements of the Delphi method and other simple analytical methods can easily be handled by a microcomputer and a spreadsheet program. Documentation on the Delphi procedure and its design is usually prepared by the agency itself or a consultant. No standard documentation is available on the application of the Delphi technique for forecasting land use and socioeconomic variables.

Expenses linked to input data preparation can vary significantly among agencies for the same technique, depending on the size of the study area. Among the cost determining factors will be the number of jurisdictions involved, availability of data, and other site-specific circumstances such as status and nature of the existing data collection mechanisms in an agency (e.g., institutional arrangements to coordinate data collection and availability of an automated information system). According to the staff of the Metropolitan Washington COG, background data preparation for each round of the regional forecasting process based on the Delphi method costs almost $150,000 to $200,000 and takes almost 18 months. Smaller urban areas might accomplish a similar exercise for a substantially lower amount. In this regard, modeling techniques are often considered to be more expensive because of their need for a large amount of input data, which must frequently be assembled from different sources. According to the officials of NCTCOG (Dallas), almost two person years of labor was devoted to preparing the initial data set and calibrating their DRAM/EMPAL models. POLIS required more than two person years for its calibration, data preparation, and initial run. It should be noted, however, that much of the required data will already have been collected for other purposes and, thus, the "cost" of the data will partly depend on the agency's accounting procedures. Another factor affecting the cost of input data preparation and use of a method is the detail required of the predictions. Even a simple method can become computationally overwhelming if more disaggregate level forecasts are made. In general, any effort toward disaggregation (e.g., employment by categories and households by income classes) adds to the complexity of the model calibration.

Table 12. Person skill and resource requirement by allocation method.

| Function | Area | Method | Share of Work: In-House | Share of Work: Consultant | Share of Work: Other | Person Months: Sr. Tech | Person Months: Jr. Tech. | Person Months: Clerical | Person Months: Total | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| Calibration or Development | Albuquerque | Delphi | 75% | 0% | 25% | 1 | 1 | 1 | 3 | Other category included panel members. |
| | MWCOG | Delphi | 75% | 0% | 25% | 1 | 3 | – | 4 | Other included planning staff from local agencies. |
| | ABAG | POLIS | 100% | 0% | 0% | 12 | 12 | 12 | 36 | Model was developed fully by in-house staff. |
| | Dallas | DRAM/ EMPAL | 100% | 0% | 0% | 6 | 6 | – | 12 | |
| Application | Albuquerque | Delphi | 100% | 0% | 0% | 1 | 1 | 1 | 3 | |
| | MWCOG | Delphi | 75% | 0% | 25% | – | – | – | – | Process takes about 18 months. |
| | ABAG | POLIS | 100% | 0% | 0% | 2 | 2 | 2 | 6 | |
| | Dallas | DRAM/ EMPAL | 100% | 0% | 0% | 6 | 6 | – | 12 | |

In summary, DRAM/EMPAL and POLIS are expensive for two reasons: they require sophistication in calibration and use, and they need considerable amounts of data. However, these costs decline significantly for subsequent applications once a calibrated model is installed. In this regard, the Delphi method may cost almost the same for each new round of forecast. Quantitative methods, such as shift-share, extrapolation, and structural change models, may be the least expensive although individual circumstances will influence their cost.

*Turnaround Time*

Turnaround time reflects a measure of the elapsed time between the initiation of a study and the acceptance of its results. For first time users, POLIS and DRAM/EMPAL models can take up to 11 and 24 months, respectively. However, once a model is calibrated, an additional run of DRAM/EMPAL and POLIS would take less than 12 and 5 months, respectively. Additional DRAM/EMPAL runs not requiring major changes in input variables can often be done in a matter of days. Similarly, Delphi-process-based forecasting may be accomplished in less than 18 months. These estimates reflect the upper limit of turnaround time because they represent the experiences of large metropolitan areas. Depending on the availability of needed data and site-specific conditions, these estimates would vary among agencies.

## Transferability Logistics

*Appropriateness to Planning Scale*

Selection of a level of geography for socioeconomic data is a function of the planning scale of a project. Larger spatial units may be appropriate for a regional study, but a local or subarea planning or an impact evaluation project will generally require further disaggregation of data by smaller spatial units comprising the study area. As most of the forecasting and allocation methods distribute the specified regional projections of variables to large districts or zones, they are inappropriate for directly producing inputs for local or subarea level studies. Often, an additional allocation procedure is used to split larger zone or district forecasts into smaller geographical units such as traffic zones. However, a method that produces forecasts for a large number of spatial units offers some flexibility in terms of its usefulness for various scales of planning studies. In addition, it reduces the overall potential for error in the second level allocation.

In general, Delphi-method-based forecasts are highly aggregated in nature. Forecasts are often made for less than ten districts. Hence, only large regional agencies that are interested in developing a set of control values for growth in their local jurisdictions, and, in some instances, even small urban area agencies that are not too large to be concerned about aggregation issues, find this method appropriate. In this respect, most of the analytical methods, in particular, DRAM/EMPAL and POLIS, are preferred. As interzonal accessibility, measured in terms of travel time or cost, is fundamental to the allocation procedures of DRAM/EMPAL, a highly aggregated zone system, the model will actually deteriorate in performance. At the same time, too small a zone system may also affect its performance, because locational externalities in adjacent or nearby zones influence zonal attractiveness.

*Mechanics of Set Up and Modification*

A method easily set up and modified is certainly desirable, all other things being equal. The degree of tediousness in the start up of a procedure is usually tied to the availability of input data and to the difficulties confronted in the initiation of a procedure. On the other hand, if a method is simple and flexible enough to accept some modifications in inclusion of new variables and the selection of certain disaggregation scheme, it can easily be tailored to a situation.

It is extremely difficult to rank methods on the basis of this criterion because of a wide variability in the user's environment. Users of the Delphi method, the most flexible technique, indicate that the level of coordination effort among panel members, ballot processing time, and execution time needed for each Delphi run are functions of the number of Delphi panel members and the jurisdictions within a study area. Smaller urban areas will find this method most suitable with respect to this criterion.

Sophisticated urban development models such as DRAM/EMPAL and POLIS are less onerous in situations where base and lag year land use data and typical household travel survey data are readily available. Large-size and medium-size urban areas usually maintain such data sets and, thus, they can produce all necessary inputs for these models including zone-to-zone travel time matrices with limited effort. Modifications to the program codes of these methods are extremely difficult for someone unfamiliar with these methods and, in fact, such modifications are not recommended for agency staff. Because of a lack of proper software documentation, transferability of POLIS to other sites is currently very limited.

Simpler analytical methods (trend extrapolation method, cohort-survival method, and shift-share models) are found to be extremely popular among smaller agencies, principally because they are simple in concept and easy to set up for a first time user.

**Summary**

A qualitative evaluation of the four most promising land use forecasting methods—DRAM/EMPAL, POLIS, Delphi method, and simple analytical methods (ratio methods and carrying capacity methods)—illustrates a wide disparity in their performance across a set of criteria. Table 13 summarizes, in broad terms, the strength of individual methods under each criterion in a three point scale: high, medium, and low. Recognizing that the selection of a method is dictated by the individual's perception of these criteria and the specific circumstances, no attempt has been made to rank these methods in order of preference.

DRAM/EMPAL and POLIS, the two sophisticated models, are based on sound theories of activity locations and are found to be highly responsive to transportation planning needs such as

**Table 13. Evaluation of land use forecasting methods.**

| METHOD | DRAM/EMPAL MODELS | POLIS MODEL | DELPHI METHOD | ANALYTICAL METHODS |
|---|---|---|---|---|
| **TRANSPORTATION** | | | | |
| - Desired Output | M - H | M | M - L | M - L |
| - Interface with Travel Demand Models | M - H | M - H | L | L |
| - Sensitivity to Transp. Policy | M - H | M - L | M | L |
| **PROJECTION METHOD** | | | | |
| - Theoretical Basis | M - H | M - H | L | L |
| - Track Record | M | M - L | M - L | M - L |
| - Comprehensibility | M - L | L | H | H |
| - Limitations & Biases | M - H | M | L | L |
| - Usefulness to Other Planning | H | M - H | M | M - L |
| **RESOURCES** | | | | |
| - Staff & Skill | M - L | L | H | H |
| - Cost of Setup | M - L | L | M - H | H |
| - Turnaround Time | M - L | M - L | M - H | H |
| **TRANSFERABILITY** | | | | |
| - Planning Site | M - H | M - L | L | M - L |
| - Mechanics of Setup & Modifications | M - L | L | M - H | H |

**LEGEND**
H = High levels of strength under a criteria.
M = Medium levels of strength under a criteria.
L = Low levels of strength under a criteria.

production of desired inputs, interface with travel demand models, and sensitivity to transportation policy variables. The complexity of their structure and set up, however, renders these methods less desirable in terms of their comprehensibility and resource requirement (skill, turnaround time, and cost). On the other hand, an intuitive knowledge-based technique, such as the Delphi method, and simple analytical methods have great appeal for their simplicity, low resource requirement, and ease of set up. However, these methods score low under the criteria of sensitivity to transportation supply related policies and theoretical basis.

In spite of theoretical elegance, urban activity simulation models (DRAM/EMPAL and POLIS) are currently inadequate to capture the contemporary dynamics of urban growth (e.g., rapid suburbanization of service sector jobs), life style and demographic change (e.g., increasing number of multiworker households, use of telecommunication and flexible work schedule). The Delphi method may, to some extent, overcome the impact of these limitations on the forecasts by allowing a collective scrutiny of model outputs by a panel of experts. Small-size and medium-size urban areas that are experiencing stable growth will find simple analytical methods and the Delphi method the most suitable techniques considering the availability of resources and needs.

## APPLICATION EXAMPLES

This section describes six examples of land use forecasting and allocation methods currently used to prepare traffic, zone level input data at metropolitan planning organizations (MPOs). The selected MPOs perform transportation planning activities and have adopted different approaches for preparing inputs to their travel demand models. In survey responses, these MPOs provided information on their methodology and experience using these methods. The cases discussed below are selected because they represent a variety of techniques and provide researchers with well-documented detail on their land use forecasting and allocation procedures.

### Projective Land Use Model (PLUM) and Sophisticated Allocation Process (SOAP)—San Diego Association of Governments

The San Diego Association of Governments (SANDAG) (*46*) produces both short-range and long-range regional growth forecasts based on local public policies of 16 cities and the County of San Diego. The forecasts are updated every 2 years to reflect the changes in public policies and economic conditions affecting population growth and distribution. Series 6 is SANDAG's most recent forecast (adopted in 1984) for the year 2000. These forecasts are based on the 1980 census and adopted land use policies of local jurisdictions between 1983 and 1984. The forecasts are used for the preparation of various elements of the Regional Comprehensive Plan such as the Regional Transportation Plan, Water and Air Quality Strategies and the Housing and Environmental Elements.

The land use allocation process employs three models to distribute the regional forecasts, produced by the Demographic and Economic Forecasting Model (DEFM), to subareas in the county (see Figure 6). The first subregional allocation model is the Basic Employment Allocation Model (BEM). BEM distributes the total regional growth in basic employment (i.e., employment in firms selling products outside the region) to subareas. The industrial basic employment for each SIC group is allocated to six small metropolitan statistical areas (SMSAs) based on several factors including historical capture rates, availability of vacant industrial land, and existing unoccupied industrial floor space. The final basic employment allocation, to 16,000 land-based gridcells, takes into account regional plans and policies and the capacities of land available for industrial use.

Different assumptions are made pertaining to the allocations of nonindustrial basic employment. The nonindustrial basic sector consists of a wide variety of activities, each with its own site-specific conditions. The location of jobs in federal and state governments and the military is mostly in the same areas as in the base year or at specified new sites. The spatial distribution of basic employment derived from BEM becomes one of the inputs for the PLUM and SOAP subregional models.

The Projective Land Use Model (PLUM) is the second model used to allocate regionwide demographic, economic, and land use activities to a subregional zonal system (ZAPs) for a time period between a base year and a target year. There are 143 ZAPs covering the San Diego region. Since PLUM is an "incremental" model, it deals with the increase or decrease over the forecast period. PLUM has three main allocation stages: distribution of households linked with basic employment, service employment linked with households, and households linked with the service sector. It is similar to the Lowry model structure discussed earlier. Zone-to-zone accessibility is determined using travel times by transit and auto, and share of public transit used.

The Sophisticated Allocation Process (SOAP) is the third model in the subregional allocation process. Using the ZAP level information from PLUM, it distributes PLUM's zonal level forecast of activities to 16,000 gridcells (2000 ft × 2000 ft squares). The allocation of activities to gridcells is determined by two primary factors. First, an activity increment is only allocated to a grid that contains vacant land of the appropriate type for that activity. Second, in cases where there is more than enough vacant land, the grids that are more accessible to employment opportunities will be developed first. The grids within each zone are sorted according to accessibility and attractiveness. The allocation mechanism generates in-fill or fringe development instead of leap-frog development.

The preliminary set of forecasts, including approximately 20 variables with six categories of employment, two types of housing, and four categories of population, are reviewed by local jurisdictions. Local jurisdictions reinterpret their general plan, if necessary, and provide new land use policy assumptions. The final forecasts are then adopted by the SANDAG Board of Directors and each of the jurisdictions. The process ensures a coordinated effort in meeting federal and state requirements in air and water quality management. SANDAG has the responsibility to monitor the adequacy of the forecasts.

### DRAM and EMPAL Models—North Central Texas Council of Governments

The North Central Texas Council of Governments (NCTCOG) prepares demographic and land use forecasts for the Dallas-Fort Worth metropolitan area (*5*). The process of land use forecasting begins with the development of regional forecasts for the 9-county Dallas-Fort Worth consolidated metropolitan statistical area (CMSA), followed by allocation to approximately

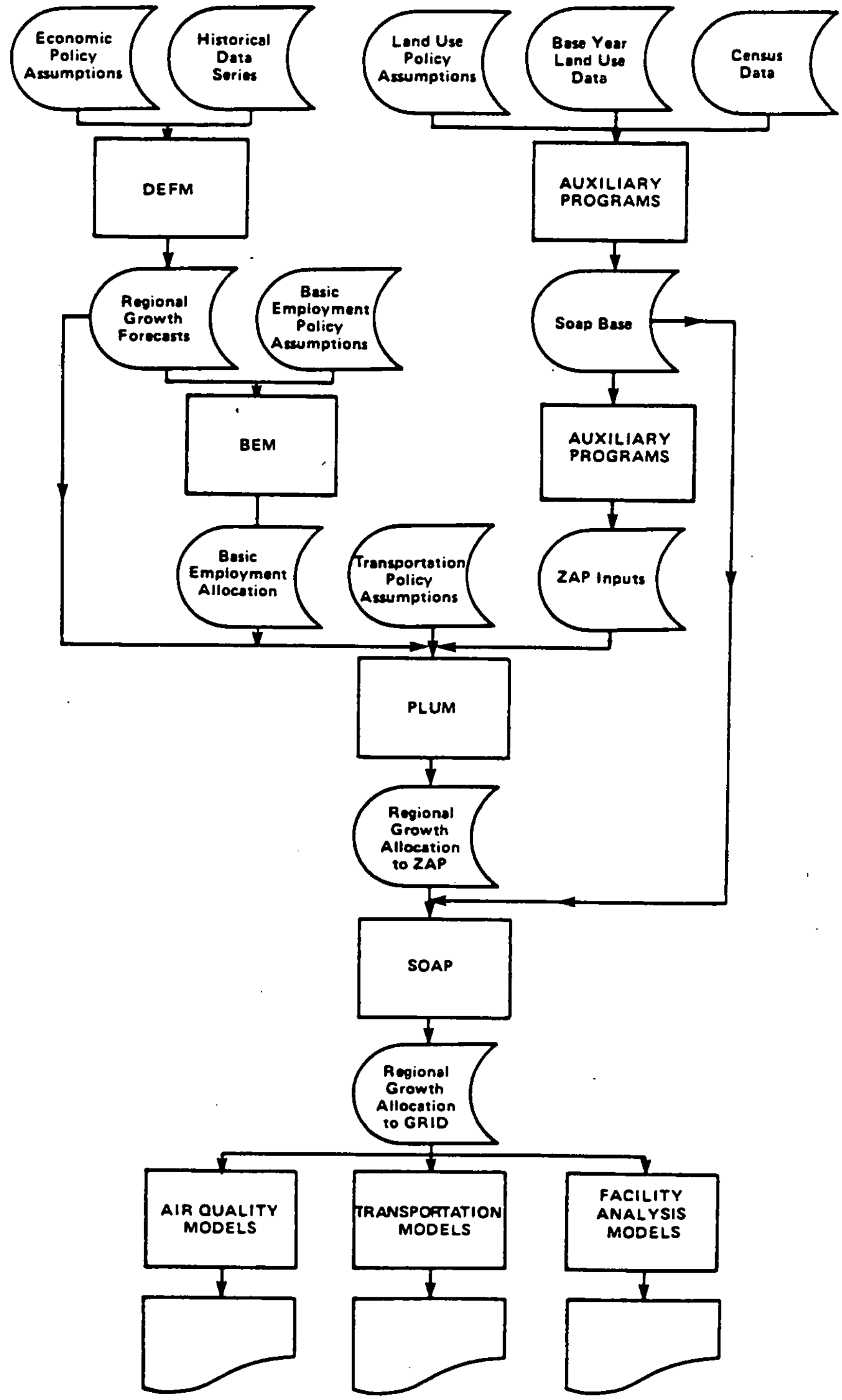



*Figure 6. Land use allocation process at the San Diego Association of Governments.* (Source: Ref. 46)

170 districts, and finally, these district level forecasts are allocated to almost 6,000 traffic survey zones (TSZs). A technical committee with regional representation oversees the development of all three stages. Individual cities of the region review the distribution of forecasts at the TSZ level.

Since 1986 the economic and demographic forecasts for the 9-county Dallas-Fort Worth CMSA have been prepared by Data Resource Incorporated (DRI). The earlier regional model, Interactive Population and Employment Forecasting Model (IPEF), was replaced by DRI forecasts because of the added complexity in the regional forecasting caused by the recent changes in the structure of the economy, overbuilding, oil price change, and overextended savings and loans institutions.

The DRAM and EMPAL models are used to allocate the regional forecasts to 166 districts. The EMPAL model predicts future-year employment by district for each of five industry sectors (construction, manufacturing and mining, wholesale trade-transportation-communications utilities, services, and government and education). The allocation is based on base year (10-year lag of the forecast year) zonal attractiveness characteristics, proximity to employment in surrounding zones, and forecast year zone-to-zone minimum travel times between highway and transit modes produced by the NCTCOG travel demand simulation models. The zonal attractiveness for each employment type is estimated as a function of the base year levels of employment for each type in the zone, the employment density, and the amount of total employment in surrounding zones.

The DRAM model allocates households to districts for each of the four income quartiles based on the peak period travel impedance to all work place zones, and a multivariate attractiveness index of the residence district. The residential attractiveness index combines the lag-year proportion of the zone developed, the proportion of the lag-year households in multifamily category, and a generalized accessibility index which approximates a land rent surface for the region. For each district the lag-year mix of households by income and successive implementation of the model over certain intervals of time reflects the dynamics of urban housing filtering.

The second level allocation of population and employment forecasts from 166 districts to almost 6,000 TSZs is accomplished by a probabilistic allocation program. The allocation begins with existing spaces (empty offices or residential units), and then to vacant land designated for the appropriate land use in five development priority categories. The development priorities are assigned by a process of working with local planners.

To develop an extensive regional data base that served as the foundation for the entire forecasting process, NCTCOG undertook a major initiative in 1985. It was a "bottom-up" approach of data compilation. An inventory of all commercial and residential structures was extracted from master appraisal files and a set of information on each structure was geocoded to TSZ. Geocoding was accomplished primarily through address matching against the census 1980 DIME file, and augmented by manually checking against county tax maps. To circumvent the distortions of employment location and use of space caused by overbuilding, tax law changes in 1981, and the deregulation of savings and loans, NCTCOG developed employment data from Dun and Bradstreet and the Texas Employment Commission. All establishments with 50 and more employees were geocoded. Several checks were made both at the county level and by allocation. The land use plans were coded into multiple records by TSZ, including the type of use, density, acreage, and priority of development within a forecast district.

### Delphi Method

*Metropolitan Washington Council of Governments*

The Cooperative Forecasting Program used by the Metropolitan Washington Council of Governments was established in 1975 as part of the Metropolitan Growth Policy Program to produce forecasts of employment, households, and population in 5-year increments for the region, jurisdictions, and small areas. This approach replaced use of the EMPIRIC model, which did not perform well in representing local projects and development policies.

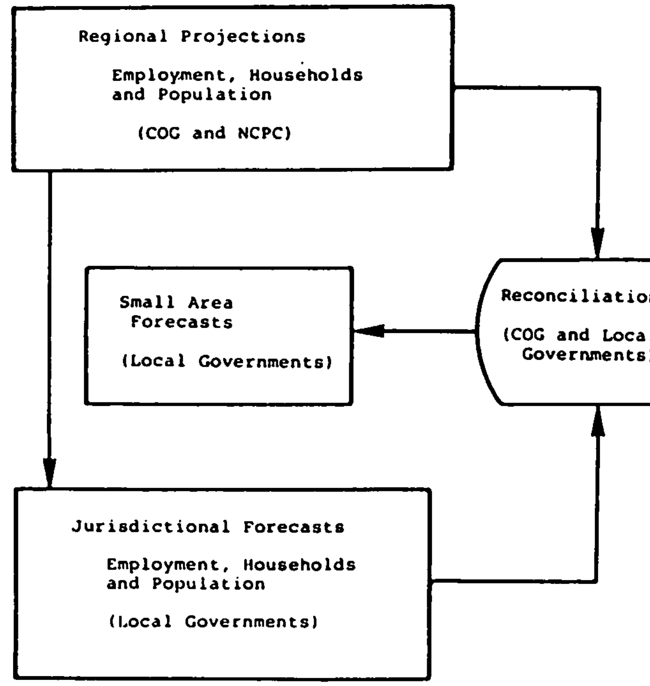



*Figure 7. Delphi process at the Metropolitan Washington Council of Governments.* (Source: Ref. 41)

The program, which is based on both "top down" and "bottom up" approaches, produces forecast inputs to regional functional plans and to the plans and programs of the local governments of the region. The entire process is designed to be repeated at regular intervals, to provide an opportunity for monitoring of forecast accuracy, improvement of projection techniques, and sensitivity to newly developing policies and plans. Since 1975, four rounds of forecasts have been developed.

A schematic chart of the process is shown in Figure 7. The process begins with the development of the statistical, benchmark projections of employment, households, and population for the region. These forecasts are developed using an econometric forecasting model. For Round IV, three scenarios of future growth were developed using different sets of assumptions regarding federal jobs, new jobs held by in-commuting workers, employment rate, multiple job-holding rate, elderly and youth population, and household size.

Each local government prepares for its own jurisdiction forecasts using an agreed-upon set of guidelines regarding methodology and assumptions. The forecasts include "pipeline" development (building permits, approved site plans) for short-range forecasts and trends, and adopted plans for long-term forecasts. Most jurisdictions, particularly larger ones, use statistical projection techniques at the jurisdictional level to determine the pace at which residential and commercial development is likely to occur.

The most important step in the process is to reconcile local government forecasts with each other, and to reconcile the sum of local forecasts with the regional benchmark projections. The Cooperative Forecasting Subcommittee, comprised of MW-COG, local jurisdiction members (eight counties, five cities, and the District of Columbia), and representatives from federal and state government planning agencies, reviews all assumptions and methodologies and, if necessary, modifies the forecasts during

**Table 14. Comparison of Round IV projections of jobs, population, and households. (Source: Ref. 47)**

| | | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|---|
| JOBS | Local Estimate: | 1,947.7 | 2,267.9 | 2,560.6 | 2,822.3 | 3,047.0 | 3,236.5 |
| | Model Output: | 1,988.1 | 2,236.8 | 2,497.2 | 2,753.7 | 2,926.6 | 3,115.1 |
| POPULATION | Local Estimate: | 3,160.6 | 3,475.1 | 3,723.7 | 3,902.1 | 4,028.0 | 84,150.4 |
| | Model Output: | 3,151.2 | 3,449.6 | 3,789.4 | 4,017.1 | 4,116.5 | 4,297.1 |
| HOUSEHOLDS | Local Estimate: | 1,200.1 | 1,351.6 | 1,482.2 | 1,589.7 | 1,676.6 | 1,751.0 |
| | Model Output: | 1,194.3 | 1,329.8 | 1,480.3 | 1,595.6 | 1,668.8 | 1,764.5 |

LOCAL ESTIMATES MINUS MODEL OUTPUT

| | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|---|
| Jobs | -40.4 | 31.1 | 63.4 | 68.6 | 120.4 | 121.4 |
| Population | 9.4 | 25.5 | -65.7 | -115.0 | -87.7 | -146.7 |
| Households | 5.8 | 21.8 | 1.9 | -5.9 | 7.8 | -13.5 |
| Jobs | -2.07% | 1.37% | 2.48% | 2.43% | 3.95% | 3.75% |
| Population | 0.30% | 0.73% | -1.76% | -2.95% | -2.18% | -3.53% |
| Households | 0.48% | 1.61% | 0.13% | -0.37% | 0.47% | -0.77% |

the examination and discussion process. Table 14 illustrates the results of the reconciliation process from Round IV of the cooperative forecasting process completed in 1988 (*41*).

Small area forecasts are developed by each jurisdiction, given the jurisdictional totals. The allocation of the short-range forecasts is based primarily on the "pipeline" development. Local policies and assumptions on market behavior dictate the long-term forecasts. There are eight jurisdictions and 1,353 zones in the region. Small area employment projections are produced into four categories: office, retail, industrial, and other.

### *Middle Rio Grande Council of Governments of New Mexico*

The Middle Rio Grande Council of Governments (MRG-COG) (*24*) provides projections of future land use in the form of a socioeconomic data set which is used to produce travel forecasts for the Albuquerque area. A Socioeconomic Forecast Task Group, created in 1982, is responsible for providing expertise about past development trends and future development policies for the area. The initial group was later expanded to include representatives from the private sector to increase the overall expertise of this group. All decisions made by the task group are conducted through a Delphi method or a straight voting procedure.

For the 2010 land use forecast by zone, the regional control totals were forecasted by extrapolating the year 2000 projections prepared by the Bureau of Business and Economic Research at the University of New Mexico. The task group reviewed, adjusted, and endorsed the regional control totals. Before initiating the subregional allocation process the methodology to allocate the data from regional totals to 22 superzones was also examined by the task group. In order for the task group to make informed decisions about the development potential of each superzone, "Fact Sheets" were prepared for each superzone. These fact sheets contained information on the development trend and the 1980 stage of development within each superzone. Based on the goals and policy statements adopted by the various local governments in the area, MRGCOG staff developed an extensive "shopping list" of future urban form assumptions.

A final list of urban form assumptions was prepared through an iterative process. The general content of these assumptions was land use distribution and density, demographic characteristics, travel characteristics, and identification of sites for unique activity centers. Conceptually, a regional scenario of polycentric urbanization was envisioned. Subsequently, each task group member assigned development probabilities for each superzone in terms of an attractiveness index for each of the three land uses (residential, industrial, and other). The attractiveness index is a dimensionless variable intended to embody all the factors influencing the development in a superzone. The value of the attractiveness index varies between zero and ten. An index value of zero indicates almost no development potential, while a value of ten reflects almost certain development probability.

In applying the Delphi method, three votes of task group members were taken to establish a convergence for their decision. Convergence was defined as the average of all votes within a range of plus-or-minus 2.0. For instance, if the votes ranged from 1 to 5 with an average of 3, convergence was achieved. Once convergence was achieved, the average of all numbers became the attractiveness index. The next step was to allocate the increment of regional population and employment among superzones. Population and employment were converted to acreage and allocated first to activity centers. The remaining land acreage was distributed among superzones in proportion to the amount of developable land within a superzone and its attractiveness. A spreadsheet package was used for the above computation. Several adjustments to the development capacity of superzones were made to restrain growth in certain areas. A factoring procedure was adopted to eliminate land that was not anticipated to develop before the year 2010 and to compensate for areas that were not likely to conform to the average density ratios used in the model.

The superzone forecasts approved by the task group were disaggregated to traffic zones based on a set of equations. The equation used for the allocation of population considers zonal characteristics including residential developable vacant land, the expected density of development, the current mean number of persons per dwelling unit, and the proximity of the zone to an activity center. This equation was calibrated at the zonal level on the development trend in a superzone from 1970 to 1980 and validated on 1970–1980 population change for two superzones. Employed residents are estimated directly from the population. Employment was disaggregated from superzones by allocating land available for employment and attractiveness of a zone for business and industry. Retail employment was forecast the same way as population, using an equation that relates retail employment to location and magnitude of population, the location and magnitude of employment, the location of major streets, and areas identified as being traditional retailing centers.

#### Analytical Method—The Council of Fresno County Governments

The Council of Fresno County Governments (COFCG) (*48*) developed, in early 1986, the COFCG Socio-Economic Database Allocation Model using dBASE (a microcomputer database management program). The model facilitates easy and quick allocation of socioeconomic data over 700 TAZs located within the Fresno-Clovis Metropolitan Area and Madeira County. Most of the assumptions concerning the location of growth are made outside the model by the affected jurisdictions. The model permits efficient management of the socioeconomic database files and estimation of the TAZ level information that assist any manual allocation decisions such as "developed capacity" and "vacant or remaining capacity." In other words, it is a tool for quicker allocation to each TAZ compared to manual assignment given regional or subarea controls and allocation rules.

The allocation process followed by COFCG and the City of Fresno staff can be described in six steps:

*Step 1*—Create vacant/developed land inventory using aerial photographs, building permit information, and existing land use surveys.

*Step 2*—Calculate the acreage of vacant/developed land by planned land use type for each TAZ using the CADVANCE (a computer graphic program).

*Step 3*—Manually input the acreages (calculated in step 2) and land use factors into the Allocation Model. The factors are derived jointly by affected agency staff for each land use category (e.g., single family residential, multiple family residential, commercial, industrial, public facility, and open space land use densities). Persons per household and occupancy rate factors are also identified.

*Step 4*—The model automatically assigns the socioeconomic data to each TAZ for the base year and "build-out" of the General Plan. By multiplying the land use factors by the remaining capacity and developed land for each land use category in a TAZ base year and "build-out," data are derived respectively.

*Step 5*—Input allocation controls and manually adjust the base year and "build-out" files. For the districts, community planning areas and census tracts, estimates of allocation controls for the base year and future years are input. Census and building permit information provide base-year population and housing units estimates. The State of California Employment Development Department annually furnishes employment estimates for Fresno County. To estimate employment by sector and census tract, a linear regression analysis is undertaken and applied to the base-year estimate.

At this stage, the inconsistencies between the base-year data by TAZ developed under step 4 and actual or existing development are manually adjusted. Future year estimates of population, person per household and occupancy rates, and employment (using regression analysis) for each of the areas are determined by affected agency staff and reaffirmed by their respective governing bodies.

The user now adjusts the vacant or remaining "capacity" to reflect future-year projections by TAZ while maintaining the area controls. Because areas within the central city are usually "built-out" or close to capacity, most of the adjustments are made to TAZs located within growth areas.

*Step 6*—Output the base year, future year, and/or "build-out" socioeconomic files for the MINUTP transportation model. The model automatically adds the base year and the adjusted "vacant capacity" data for each TAZ to produce future year data files.

CHAPTER FOUR

# CONCLUSIONS AND FUTURE RESEARCH

This chapter presents project conclusions and recommended areas for future research. The conclusions are presented in two areas of the research: sensitivity between socioeconomic variables forecasting/allocation and travel demand, and the descriptive review of land use forecasting/allocation methods.

## CONCLUSIONS

#### Sensitivity of Travel Forecasts to Errors in Socioeconomic Variables

The final output of the urban transportation planning process (UTPP), link volumes, is sensitive to errors in the district level forecasting/allocation of socioeconomic variables. The degree of sensitivity varies across types of facilities and the overall magnitude of error. Transportation facilities serving interdistrict travel, such as major and minor arterials, are most responsive to the district level allocation errors, due primarily to the accumulation of link volume error from lower level facilities (e.g., collectors) to higher level facilities. However, freeways that principally facilitate major regional and interregional movements are least impacted by the district level input errors. The most affected transportation facilities are likely to be concentrated in the vicinity of areas with large allocation errors. Planners undertaking corridor level studies should be most concerned about the reliability and accuracy of district level forecasts, particularly for those districts directly served by the corridor under study. Suburban districts deserve special attention because most of the future growth is likely to be concentrated in them.

Minor errors (less than 20 percent) in the allocation of district level socioeconomic variables to traffic zones do not influence link volumes or transportation facilities serving regional and interdistrict travel such as freeways, major arterials, and minor arterials. However, because of the sensitivity of travel demand on local collector roads to traffic zone inputs, errors in subdistrict level forecasting/allocation can severely impact site-specific or local network planning and design. Generally, the likelihood of introducing large errors in the disaggregation of district forecasts to traffic zones is high for undeveloped areas, hence, greater precaution must be taken while developing traffic zone level data for such areas. Large errors (above 20 percent) in subdistrict allocation can significantly affect the prediction of link volumes and lead to resource misallocation in road construction.

Travel demand models must be applied at the traffic zone level using zone specific inputs. The practice of applying demand models at the district level, and then stratifying the estimated tables of district-to-district trips into tables of zone-to-zone trips, can produce large errors in the UTPP outputs. Because of the exclusion of accessibility variations between zones, the trip-table expansion process generally increases the share of longer trips, thus leading to overprediction of link volumes and vehicle-miles of travel for each class of facility.

### Forecasting/Allocation Methods for Preparing Zone Level Inputs to UTPP

Most agencies, regardless of their land use forecast/allocation method, develop traffic level socioeconomic inputs in two steps: from region to district (or jurisdiction), then from district to traffic zone. Because district level forecasts do not generally produce all the required inputs for UTPP, some form of postprocessing procedure is commonly applied to calculate the required inputs. The input variables frequently used, but usually not produced by allocation methods, are household income, car ownership, households by car ownership and income or household size, and households by size.

There is no single suitable method for preparing district level forecasts of inputs under all situations and circumstances. However, combining an intuitive, knowledge-based technique, such as the Delphi method, with a formal, analytical method(s), seems to be the most desirable approach to developing district or zone level inputs. The Delphi method can be applied to produce subregional or district constraints applicable to analytical methods of forecasting or analysis. Similarly, a well-tested analytical method can furnish useful information for the Delphi panel members who exercise collective expert judgment. Only large urban agencies with time, funding, and skilled personnel should consider sophisticated models such as DRAM and EMPAL for district level prediction of population and employment by category. Although the DRAM and EMPAL models are based on sound theories of activity location, there remain several limitations. Most models, including DRAM, EMPAL and POLIS, are inadequate to capture the dynamics of urban growth and the effects of changes in population characteristics on residential location decisions. The Delphi method may highlight, and to some degree overcome, the impact of these limitations on the forecasts. Small-size and medium-size urban agencies will find simple analytical methods (ratio techniques, shift-share analysis, and carrying capacity methods) and the Delphi method to be the most suitable techniques, considering the availability of resources and needs.

There are no formal methods of subdistrict forecasting/allocation. Most agencies develop their own procedures. Generally, these forecasting/allocation procedures are driven by the zone-specific supply side factors such as development proposals "in pipeline," zoning, past trends, and the availability of developable land. Frequently, these procedures are similar to the simple analytical methods used for district level allocation. For partially developed districts, the likelihood of introducing large errors in zonal allocations is low because of the common practice of distributing only incremental change in the district level input variables and a good understanding of the prevailing market conditions. It is recommended that greater attention be paid to undeveloped areas (especially those in suburban districts) when preparing zone level inputs.

## RECOMMENDED RESEARCH

A formal comparison of subregional forecasts produced by the most promising methods (the Delphi method, the DRAM and EMPAL models, and simple analytical techniques) against 1990 census data should be undertaken. This comparison should include the participation of agencies representing various sizes of urban areas.

Techniques for projection of automobile ownership, household income, and household size from the primary outputs of the socioeconomic forecasting/allocation methods (spatial distribution of population and employment) must be researched, and a manual for their application should be prepared. Because most of the travel demand models, particularly the trip generation and mode choice models, are sensitive to the foregoing variables, the reliability of overall trips and trips by travel mode (transit, shared ride and single occupancy vehicles) are, to a great extent, conditioned by the accuracy of the above variable (e.g., automobile ownership, household income and household size) forecasts at the zone level. Commonly used methods for preparing these variables are based on the areawide relationships or ratios established from the 1980 census data. The forecasts and the relationships developed on the basis of 1980 census data should be compared with the 1990 census data to check the validity of the most widely used techniques. The research effort should focus on establishing simple, but behaviorally sound, relationships to predict socioeconomic characteristics of population at the subdistrict level.

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## APPENDIX A

## APPLICATION EXAMPLES OF DRAM/EMPAL MODELS

The following example illustrates the estimation of retail employment (R) location at time t+1 using the data shown in Tables A-1 through A-5. For each employment sector (i.e. service employment S) the same procedure is repeated using sector specific parameters.

**<u>Step 1:</u> Normalize Base Year Employment and Worker Residence Data**

Both $V_i^t$, workers living in district i at time t, and $R_i^t$, retail workers in zone i at time t, are first normalized to the regional retail employment forecast (R at time t+1 = 8000).

To normalize the base year data, the following equations are used. The results are displayed in Table A-5.

$$V_i^{t'} = \frac{V_i^t}{\Sigma_i V_i^t} * \Sigma_i R_i^{t+1} \qquad \text{(A-1)}$$

$$R_i^{t'} = \frac{R_i^t}{\Sigma_i R_i^t} * \Sigma_i R_i^{t+1} \qquad \text{(A-2)}$$

## Table A-1. Model Data Requirements

**Regional Forecasts**

| | |
|---|---|
| Retail employment | 8000 |
| Service employment | 8000 |
| Total employment | 16000 |
| % unemployment-retail | 2% |
| % unemployment-service | 3% |
| Employees per household low income | 1.8 |
| Employees per household middle income | 2.0 |
| Employees per household upper income | 1.5 |

**District Level Data**

| | Districts | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | SUM |
| Retail employment ($R_j^t$) | 1500 | 1000 | 3000 | 1500 | 7000 |
| Service employment ($S_j^t$) | 500 | 1500 | 3000 | 1000 | 6000 |
| Workers living in district i($V_i^t$) | 1500 | 3000 | 5000 | 3500 | 13000 |
| Low Income Workers living (PP1) | 1000 | 500 | 1000 | 1000 | 3500 |
| Medium Income Workers living (PP2) | 200 | 2000 | 3000 | 1500 | 6700 |
| Upper Income Workers living (PP3) | 300 | 500 | 1000 | 1000 | 2800 |
| Residential land time t ($L^t_R$) | 150 | 200 | 500 | 200 | 1050 |
| Commercial land time t ($L^t_C$) | 400 | 150 | 300 | 100 | 950 |
| Service land time t ($L^t_S$) | 100 | 150 | 450 | 200 | 900 |
| Vacant land time t ($L^t_V$) | 100 | 100 | 250 | 100 | 550 |
| Total land (L) | 750 | 600 | 1500 | 600 | 4400 |



## Table A-2. Travel Time Matrix ($C_{ij}$)

| Employment District | Residential District | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | 5 | 10 | 15 | 20 |
| 2 | 10 | 5 | 10 | 15 |
| 3 | 15 | 10 | 5 | 10 |
| 4 | 20 | 15 | 10 | 5 |

Table A-3. Conversion Matrix: Employment Type to Income Group

| Income Group | Retail | Service |
|---|---|---|
| Low | 0.400 | 0.300 |
| Middle | 0.350 | 0.350 |
| Upper | 0.250 | 0.350 |



Table A-4. CALIB MODEL COEFFICIENTS

| EMPLOYMENT TYPE | PARAMETERS | | | | |
|---|---|---|---|---|---|
| | $W_1$ | $W_2$ | a | b | c |
| Retail Employment | 0.3 | 0.7 | 2 | 0.5 | 0.6 |
| Service Employment | 0.4 | 0.6 | 2 | 0.4 | 0.7 |

| | K-FACTOR BY DISTRICT | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Retail Employment | 1.0 | 0.8 | 1.1 | 1.0 |
| Service Employment | 1.0 | 1.3 | 0.8 | 1.1 |

DRAM

| INCOME GROUP | PARAMETERS | | | | | |
|---|---|---|---|---|---|---|
| | d | e | f | g | h | a |
| Low Income | 0.8 | 1.0 | 0.5 | 0.15 | 0.5 | 2 |
| Middle Income | 0.7 | 0.5 | 0.5 | 0.10 | 1.0 | 2 |
| Upper Income | 0.9 | 0.5 | 1.0 | 0.13 | 0.5 | 2 |

| INCOME GROUP | K-FACTOR BY DISTRICT | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Low Income | 1.0 | 0.8 | 1.2 | 1.0 |
| Middle Income | 1.0 | 1.0 | 0.9 | 1.3 |
| Upper Income | 1.0 | 1.1 | 1.0 | 1.1 |

Table A-5. Normalized Base Year Data

| | Base Year Data Retail | | Normalized Future Data Retail | |
|---|---|---|---|---|
| | Workers | Employment | Workers | Employment |
| District | $V_i^t$ | $R_i^t$ | $V_i^{t'}$ | $R_i^{t'}$ |
| 1 | 1500 | 1500 | 923 | 1714 |
| 2 | 3000 | 1000 | 1846 | 1143 |
| 3 | 5000 | 3000 | 3077 | 3429 |
| 4 | 3500 | 1500 | 2154 | 1714 |
| Total | 13000 | 7000 | 8000 | 8000 |



**Step 2: Calculate Other Input Variables**

In this step $L_i^b$, $R_i^c$, and $c_{ij}^{-a}$ are calculated for the retail employment sector. The results are shown in Tables A-6 and A-7.

**Step 3: Estimate Probability of Employment Location in a Given District**

The probability of employment locating in district j due to the population in district i is expressed as:

$$P_{ij} = \frac{L_j^b * R_j^c * c_{ij}^{-a}}{\Sigma_k L_k^b * R_k^c * c_{ik}^{-a}} \qquad \text{(A-3)}$$

The numerator of the above equation reflects the attractiveness of employment in district j to workers living in district i. The denominator $\Sigma_k (L^b_k * R_k^c * c^{-a}_{ik})$, represents the total regional attraction as perceived from district i. The employment in each district resulting from workers living in district 1 is illustrated in Table A-8.

The calculation described above is repeated for all districts, and the results are shown in Table A-9.

**Step 4: Allocate Workers to Employment Sites**

The next step is to multiply the normalized number of workers living in district i ($V_{i'}$) times the probability of working in j and living in i.

$$A_{ij} = V_{i'} * P_{ij} \qquad \text{(A-4)}$$

For example, $A_{21}$ (III in Table A-8) is the retail employment which would locate in district 2 due to the population in district 1. The final column of Table A-8 shows the estimated value of $A^{t+1}_j$ for district i. The calculation continues for districts 2 through 4. Table A-10 displays the final results for all the districts.

Table A-6. Model Variables

| Retail | | | | |
|---|---|---|---|---|
| | Land Area | | Retail Employment | |
| District | $L_i$ | $L_i^b$ | $R_{i'}$ | $R_i^c$ |
| 1 | 750 | 27.39 | 1714 | 87.18 |
| 2 | 600 | 24.50 | 1143 | 68.36 |
| 3 | 1500 | 38.73 | 3429 | 132.16 |
| 4 | 600 | 24.50 | 1714 | 87.18 |

| Service | | | | |
|---|---|---|---|---|
| | Land Area | | Service Employment | |
| District | $L_i$ | $L_i^b$ | $S_{i'}$ | $S_i^{c'}$ |
| 1 | 750 | 27.39 | 667 | 94.82 |
| 2 | 600 | 24.50 | 2000 | 204.51 |
| 3 | 1500 | 38.73 | 4000 | 332.23 |
| 4 | 600 | 24.50 | 1333 | 153.95 |



Table A-7. Calculation Of Impedance Function $c_{ij}^{-a}$

| Employment District | Residential District 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 0.0400 | .0100 | .0040 | .0025 |
| 2 | .0100 | .0400 | .0100 | .0040 |
| 3 | .0040 | .0100 | .0400 | .0100 |
| 4 | .0025 | .0040 | .0100 | .0400 |

Table A-8. Calculating $A_i$ Values For District 1 - Retail

| Employment District | Attractiveness Function $(L_j^b * R_j^c * c^{-a}_{ij})$ | $P_{ij}$ (Equ. A-3) | Employment for Living in Dist. 1 (Equ. A-4) |
|---|---|---|---|
| 1 | 95.50 | 0.69 | 637 |
| 2 | 16.75 | 0.12 | 111 |
| 3 | 20.45 | 0.15 | 138 |
| 4 | 5.34 | 0.04 | 37 |
| TOTAL | 138.04 | 1.00 | 923 |



Table A-9: Attraction Between Districts - Retail

| Employment District | Residential District 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 95.50 | 23.88 | 9.55 | 6.00 |
| 2 | 16.75 | 67.00 | 16.75 | 6.70 |
| 3 | 20.45 | 51.12 | 204.50 | 51.12 |
| 4 | 5.34 | 8.54 | 21.36 | 85.44 |
| $\Sigma_k$ | 138.04 | 150.54 | 252.16 | 149.26 |

Table A-10. Retail Employment-Relation Place of Residence to Place of Work - Retail

| Employment District | Residential District 1 | 2 | 3 | 4 | Total |
|---|---|---|---|---|---|
| 1 | 637 | 923 | 117 | 87 | 1135 |
| 2 | 111 | 822 | 204 | 97 | 1235 |
| 3 | 138 | 627 | 2495 | 737 | 3996 |
| 4 | 37 | 104 | 261 | 1233 | 1634 |
| Total | 923 | 1846 | 3077 | 2154 | 8000 |



**Step 5: Calculate Final $E_j^{t+1}$**

Total retail employment forecast for a district is estimated using the following equation:

$$E_j^{t+1} = W_1 * A_j + W_2 * R_j \qquad \text{(A-5)}$$

Tables A-11 and A-12 show the results of using the above procedure to allocate retail and service employment respectively to the district level.

**Step 6: Apply K-Factors**

At this stage, the employment forecasts (by type) are adjusted by multiplying with the K-factors developed in CALIB, see Ducca (14).

This operation will change the total number of employees and, hence, the district forecast will no longer equal the regional forecast. To overcome this, the district employment numbers are once again normalized to the regional forecast, in a manner similar to that explained in Step 1. This operation will be repeated for each employment type.

**Step 7: Apply Constraints**

The next step is to constrain the employment forecast to a prescribed limit for each district. This may be necessary to reflect the zoning conditions, topographic or other natural constraints, or even the judgment of land use planners familiar with the district.

The constraints are applied by adjusting the district value to match either the maximum or minimum value which has been specified. The surplus employment of a district is reallocated to the remaining districts. This is an iterative procedure

Table A-11. Final Retail Employment By District

| District | $A_j$ | $W_1*A_j$ | $R_j$ | $W_2*R_j$ | $E_j^{t+1}$ |
|---|---|---|---|---|---|
| 1 | 1135 | 340 | 1714 | 1200 | 1540 |
| 2 | 1235 | 370 | 1143 | 800 | 1170 |
| 3 | 3996 | 1199 | 3429 | 2400 | 3599 |
| 4 | 1634 | 491 | 1714 | 1200 | 1691 |
| Total | 8000 | 2400 | 8000 | 5600 | 8000 |



Table A-12. Final Service Employment By District

| District | $A_j$ | $W_1*A_j$ | $S_j$ | $W_2*S_j$ | $E_j^{t+1}$ |
|---|---|---|---|---|---|
| 1 | 686 | 274 | 667 | 400 | 674 |
| 2 | 1672 | 669 | 2000 | 1200 | 1869 |
| 3 | 4216 | 1687 | 4000 | 2400 | 4087 |
| 4 | 1426 | 570 | 1333 | 800 | 1370 |
| Total | 8000 | 3200 | 8000 | 4800 | 8000 |

The mathematical formulation of the DRAM model for each household category can be expressed as follows:

$$N_j = \Sigma_i\, n_{ij} * \frac{c_{ij}^{-a} * L_{Rj}^{d} * D_j^{c} * P1_j^{d} * P2_j^{c} * P3_j^{g}}{\Sigma_k c_{ik}^{-a} * L_{Rk}^{d} * D_k^{c} * P1_k^{d} * P2_k^{c} * P3_k^{g}} \qquad \text{(A-6)}$$

where:

$N_j$ = total number of workers living in district j

$n_{ij}$ = workers employed in district i living in district j

$c_{ij}$ = impedance between district i and j at time t

$L_{Rj}$ = residential land in district j

$$D_j = \frac{L_{Rj} + L_{Cj} + L_{Sj}}{L_{Rj} + L_{Cj} + L_{Sj} + L_{Vj}} + 1 \qquad \text{(A-7)}$$

where:

$D_j$ = the developability index of district j

$L_{Cj}$ = commercial land in district j

$L_{Sj}$ = service land in district j

$L_{Vj}$ = vacant land in district j

$$P1_j = \frac{PP1_j}{PP1_j + PP2_j + PP3_j} + 1 = \text{percent of low income workers living in district } j + 1 \qquad \text{(A-8)}$$

$$P2_j = \frac{PP2_j}{PP1_j + PP2_j + PP3_j} + 1 = \text{percent of middle income workers living in district } j + 1 \qquad \text{(A-9)}$$

$$P3_j = \frac{PP3_j}{PP1_j + PP2_j + PP3_j} + 1 = \text{percent of upper income workers living in district } j + 1 \qquad \text{(A-10)}$$



$PP1_j$ = number of low income workers living in district j

$PP2_j$ = number of middle income workers living in district j

$PP3_j$ = number of upper income workers living in district j

**<u>Step 1:</u> Calculate Total Potential Work Force**

The employment forecast in EMPAL does not include the unemployed workers; however, their residential location should be included. This can be accomplished using the unemployment rates shown in Table A-1 with the following equations:

$$R_i = \frac{R_i}{\text{(1 - Retail unemployment rate)}} \qquad \text{(A-11)}$$

$$S_i = \frac{S_i}{\text{(1 - Service unemployment rate)}} \qquad \text{(A-12)}$$

Table A-13 shows the potential work force by type and district.

**<u>Step 2:</u> Convert Employment by Type to Income Group**

DRAM allocates workers to residential location by income group and EMPAL allocates employment by type. To convert the employment data from type to income group a conversion matrix (Table A-13) is used. Table A-14 shows the results of this conversion for both retail and service employment.

**<u>Step 3:</u> Calculate the Remaining Variables**

The remaining variables to be calculated are D (developability index), P1, P2, and P3 (the percent of population in each of the three income groups). These will be calculated using the equations A-7, A-8, A-9, A-10. The computation results are shown in Table A-15.

Table A-13. Calculation of Total Potential Work Force

| District | POTENTIAL Retail Employment | POTENTIAL Retail Employment (equ. A-11) | POTENTIAL Service Employment | POTENTIAL Service Employment (equ. A-12) |
|---|---|---|---|---|
| 1 | 1540 | 1571 | 674 | 695 |
| 2 | 1170 | 1194 | 1869 | 1927 |
| 3 | 3599 | 3672 | 4087 | 4213 |
| 4 | 1691 | 1726 | 1370 | 1412 |



Table A-14. Conversion From Employment Type To Income Group

| | Employment | | Income Group | | |
|---|---|---|---|---|---|
| District | Retail | Service | Low | Middle | Upper |
| 1 | 1571 | 695 | 837 | 793 | 636 |
| 2 | 1194 | 1927 | 1056 | 1092 | 974 |
| 3 | 3672 | 4213 | 2733 | 2760 | 2393 |
| 4 | 1726 | 1412 | 1114 | 1098 | 926 |

Table A-15. DRAM Variables

| Variables | Districts 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $D_j$ | 1.87 | 1.83 | 1.83 | 1.83 |
| $P1_j$ | 1.29 | 1.43 | 1.28 | 1.28 |
| $P2_j$ | 1.03 | 1.29 | 1.45 | 1.22 |
| $P3_j$ | 1.11 | 1.18 | 1.36 | 1.36 |
| $D_j^e$ | 1.65 | 1.62 | 1.62 | 1.62 |
| $L_{Rj}^d$ | 150.00 | 200.00 | 500.00 | 200.00 |
| $P1_j^f$ | 1.14 | 1.19 | 1.13 | 1.13 |
| $P2_j^g$ | 1.00 | 1.038 | 1.06 | 1.03 |
| $P3_j^h$ | 1.05 | 1.09 | 1.17 | 1.17 |
| $A_j$ | 179.55 | 269.79 | 700.71 | 272.35 |



$A_j$, the attractiveness of district j for residential location, is estimated as follows:

$$A_j = L_{Rj}^d * D_j^e * P1_j^f * P2_j^g * P3_j^h \qquad \text{(A-13)}$$

The estimated values of $A_j$ are displayed in the last row of Table A-15.

**Step 4: Calculate the Attractiveness of Each District**

The measure of attractiveness of district j as perceived from district i is calculated as follows:

$$c_{ij}^{-a} * A_j \qquad \text{(A-14)}$$

The impedance $c_{ij}^{-a}$ has already been estimated in the EMPAL section (see Table A-7). The attractiveness of the districts to workers working in district 1 is illustrated in Table A-16.

These calculations are then completed for the remaining districts as shown in Table A-17.

**Step 5: Apply Final DRAM Equation**

Finally the DRAM equation (equ.3) is applied. Table A-18 illustrates the final results.

In the DRAM model, the K-Factors and constraints to district growth are included in the probability equation. The K-factors developed with the CALIB model and shown in Table A-4 would be applied by altering the standard DRAM equation in the following manner:

$$N_j = \Sigma_i n_{ij} * \frac{c_{ij}^{-a} * A_j}{\Sigma_k c_{ik}^{-a} * A_j} - * \frac{K_j}{\Sigma_i(K_i)} \qquad \text{(A-15)}$$

Table A-16. Attractiveness Of All Districts To Workers Working in District 1

| Residential District | $c_{ij}^{-2}$ | $A_j$ | $c_{ij}^{-2} * A_j$ |
|---|---|---|---|
| 1 | .0400 | 179.55 | 7.18 |
| 2 | .0100 | 269.79 | 2.69 |
| 3 | .0040 | 700.71 | 2.80 |
| 4 | .0025 | 272.35 | 0.68 |





Table A-17. Attraction Between Districts

Low Income

Attractiveness ($C_{ij}^{-a} * A_j$)

| Residential | Employment District | | | |
|---|---|---|---|---|
| District | 1 | 2 | 3 | 4 |
| 1 | 7.18 | 2.69 | 2.80 | 0.68 |
| 2 | 2.69 | 10.82 | 7.00 | 1.09 |
| 3 | 2.80 | 2.69 | 28.03 | 2.72 |
| 4 | 0.68 | 1.08 | 7.01 | 10.89 |
| $Sum_k$ | 13.35 | 17.28 | 44.84 | 15.38 |

Table A-18. Relation of Place of Work To Place of Residence of Low Income Group

| Residential District | Employment District 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 450 | 164 | 170 | 49 |
| 2 | 168 | 661 | 428 | 79 |
| 3 | 176 | 165 | 1708 | 197 |
| 4 | 43 | 66 | 427 | 789 |
| Total | 837 | 1056 | 2733 | 1114 |



Upon the application of the K-factors, no further scaling needs to be done, unlike the EMPAL model.

The use of constraints necessitates modification of the probability equation and additional runs for the model. As mentioned before, the DRAM probability equation is:

$$N_j = \Sigma_i \, n_{ij} * \frac{c_{ij}^{-a} * A_j}{\Sigma_k c_{ik}^{-a} * A_j} \qquad \text{(A-16)}$$

To constrain the number of workers living in zone j ($N_j$), the $ATR_j$ (attraction of zone j ) is adjusted after each DRAM model run using the following equation:

$$A_j' = A_j * \frac{C_j}{N_j} \qquad \text{(A-17)}$$

Where:

$A_j'$ = the new attraction of zone j

$C_j$ = maximum number of workers allowed to live in zone j

This new $ATR_j'$ is used in the DRAM equation and a new $N_j'$ is derived. This process continues until the new forecast of number of workers living in zone j is equal to the previous forecast. Putman's most recent version of DRAM incorporates the constraints into the locational probability calculation, thus making these model iterations unnecessary.

# APPENDIX B

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