Land Use Forecasting Techniques For Use In Small Urban Areas

Volume 1

DRAFT

ACTIVITY WEIGHTED TECHNIQUE	MULTIPLE LINEAR REGRESSION TECHNIQUE	DENSITY SATURATION GRADIENT METHOD
ACCESSIBILITY MODEL	STOUFFER'S INTERVENING OPPORTUNITIES MODEL	SCHNEIDER'S INTERVENING OPPORTUNITY MODEL
DELPHI TECHNIQUE	LAND USE ALLOCATION MODEL	OPPORTUNITY ACCESSIBILITY MODEL

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
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DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

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LAND USE FORECASTING TECHNIQUES FOR USE IN SMALL URBAN AREAS

Volume 1

Prepared by

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August 1977

U.S. Department of Transportation
Federal Highway Administration
Office of Planning
Urban Planning Division

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PREFACE

This report consists of two volumes and is intended to provide information on simple land use forecasting techniques that are considered most practical for use in transportation planning for smaller urban areas of less than 200,000 population. These simpler forecasting techniques are considered more practical for areas of this size due to their lesser staff, time, cost, and data requirements. Volume 1 consists of the main report and Volume 2 contains the appendices.

Chapter I presents a brief discussion of land use forecasting in the urban transportation planning process. Several selected forecasting techniques that can be applied without the use of a computer are described and evaluated in Chapter II. Also, the models are applied to the UTOWN urban area. UTOWN is a hypothetical area used in the Federal Highway Administration and Urban Mass Transportation Administration transportation planning courses. Chapter III compares the characteristics of selected non-computerized models and their forecasting performance.

Chapter IV describes and evaluates selected forecasting techniques that are appropriate for small areas which are specifically designed for use on a computer. The descriptions touch on the background, theory, capabilities, input and output requirements, calibration, application considerations, and software of each model. The evaluations include a discussion of the potential usefulness of each technique in urban transportation studies.

Appendix A describes a comparative test of two intervening opportunity - accessibility land use models using Boston, Massachusetts data. Appendix B describes a comparative test of five simple land use models using data from Greensboro, North Carolina. Appendix C presents a methodology for developing activity distribution models by linear regression analysis. Appendix D contains detailed information on UTOWN including a geographical description of the area, socio-economic, travel, transit network, and highway network data.

This report is not to be interpreted as an endorsement of any particular procedure described as opposed to any other procedure not included in this report.

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CHAPTER I

INTRODUCTION

The location of activities determines where within an urban area travel demand is imposed on various parts of the transportation network. The type and magnitude of the activities determines the extent of the impact of travel demand on the transportation network. Therefore, good transportation planning[1] for an urban area requires a forecast of the type, magnitude, and location of the growth in urban activities.

In transportation planning the forecast of the type and magnitude of the activities is done in the demographic and economic forecasting phases[2].

Basically, there are two approaches to determine what the future location of activities will be. One is to plan or design the future activity pattern and the other is to forecast the pattern.

In actual practice, land use forecasting is a combination of planning and forecasting. Planning implies that urban development controls are utilized in order to achieve a desirable future activity pattern (i.e., land use pattern), while forecasting implies an extension of past relationships in development. A balanced mixture of each is required in order to predict a future development pattern that is consistent with trends as influenced by a reasonable expectation of the exercise of various controls.

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[1] Reference 1 contains a good description of the general urban transportation planning process.

[2] References 2 and 3 provide information on demographic and economic forecasting techniques.

In urban transportation planning studies, land use forecasting (or activity allocation) refers to estimating future amounts of development for small areas (usually traffic analysis zones). The development includes socio-economic variables, such as several stratifications of population and employment (which are normally used in trip generation), in addition to land usage.

The general land use forecasting (activity allocation) process consists of taking areawide forecasts of the several socio-economic variables (i.e. demographic and economic forecasts) as control totals and using some type of procedure to allocate them to analysis zones. Land usage is then usually determined by applying activity land consumption rates[3]. Generally, the activities are located in the analysis zones based on the zonal characteristics such as vacant available developable land, zoning, availability of public utilities, accessibility, etc. The procedures used are various types of allocation techniques ranging from traditional techniques to areawide urban development models.

The traditional allocation technique generally consists of gathering and analyzing data and then locating (allocating) activities based on acceptable planning standards and professional judgment. A step further is to use various mathematical formulations such as regression analysis to quantify existing relationships and then use these mathematical formulations along with planning standards and professional judgment. This begins to make the allocation more

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[3] Information on consumption rates for employment activities may be found in Reference 4.

quantitative and requires more explicit assumptions concerning various factors which influence growth. On the other end, urban development models[4] are even more analytic and include explicit relationships and theories of urban growth processes. Planning judgment still plays an important part in the use of these models.

Unfortunately, due to their high staff, time, data, and cost requirements many of the available urban development models are only practical for use by the larger urban area transportation planning studies (i.e., those urban areas over 200,000 population). However, there are several techniques which are representative of the earliest efforts in the development of operational urban development models and which continue to serve (either in their original or modified form) a great number of transportation planning studies. These techniques are quite simple, generally deal with aggregate relationships, are based largely on accessibility indices, and deal primarily with the location of residential activity. In addition, many of these techniques can be applied without the use of a computer, or simple programs can be prepared for use on a computer. These simpler techniques are considered most practical for use in urban areas of less than 200,000 population due to their lesser staff, time, cost, and data requirements. The remainder of this report provides information on simpler techniques for land use forecasting (activity allocation).

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[4] Additional information on urban development models may be found in Reference 5.

CHAPTER II

SELECTED NON-COMPUTERIZED LAND USE FORECASTING TECHNIQUES

A. Activity Weighted Technique

B. Multiple Linear Regression Technique

C. Density Saturation Gradient Method

D. Accessibility Model

E. Stouffer's Intervening Opportunities Model

F. Schneider's Intervening Opportunities Model

G. Delphi Technique

ACTIVITY WEIGHTED TECHNIQUE

Theory

The activity weighted technique allocates activity growth in proportion to the share of the particular activity which already exist in the zone. The formulation is

$$G_i = G_T \frac{A_i}{A_T}$$

where:

G_i = growth (population or employment) allocated to zone i

G_T = total growth to be allocated

A_i = existing activity (population or employment) in zone i

A_T = total existing activity (population or employment) in urban area

Application

See appendix D, Volume 2, for detailed information on UTOWN.

G_T = Pop (2000) - Pop (1977) = 83,930 - 78,840 = 5090

G_1 = 5090 (2920 ÷ 78,840) = 188.5 = 188

G_2 = 5090 (23,360 ÷ 78,840) = 1508.2 = 1508

G_3 = 5090 (23,360 ÷ 78,840) = 1508.2 = 1508

G_4 = 5090 (14,600 ÷ 78,840) = 942.6 = 943

G_5 = 5090 (14,600 ÷ 78,840) = 942.6 = 943

Employment growth would be distributed in a similar manner.

Evaluation

This technique basically assumes that present trends will continue. For short term estimates of land use from 1 to 5 years this technique has some usefulness. However, for the purpose of planning studies with 20 to 30 years planning periods, the concept of present trends continuing in total is not realistic. When using this technique the planner should be aware of the overall holding capacity for a zone based upon its anticipated activity density. It is possible that a zone has reached its saturation activity density limit. In this event the planner would merely eliminate this zone(s) from the allocation process.

MULTIPLE LINEAR REGRESSION TECHNIQUE

Theory

In the multiple linear regression technique the proportion of total regional growth which locates in a particular area is assumed to be related to the magnitude of a number of variables which in some manner are measures of geographic desirability as viewed by those making the locational decision. The procedure is to determine those factors, and their weights, which in linear combination can be related to the amount of growth which has been observed to take place over a past time period. These factors (called independent variables) and their weights (called regression coefficients), in linear combination (called the regression equation) can then be applied to the individual analysis areas to forecast the magnitude of growth (called the dependent variable). Independent variables are chosen which minimize the overall error between the dependent variable and the actual value. The general formulation is:

$$Y = a + b_1X_1 + b_2X_2 + \ldots\ldots + b_nX_n$$

where:

Y = (Dependent variable) = the forecast activity growth in zone i

X = (Independent variable) = Vairables which have a strong influence (positive or negative) on the dependent variable

a = intercept

b = regression coefficient

The following are examples of actual equations that have been developed in planning studies.

(A) $G_j = -2.3 + 0.061\, X_{1j} + 0.00066\, X_{2j}$
$\quad + 1.1\, X_{3j} - 0.11\, X_{4j} - 0.0073\, X_{5j}$

where:

G_j = Growth in D.U.'s/Unit Vacant Land for zone j

X_{1j} = Zoning protection in zone j

X_{2j} = % Total Land Area in Residential use in zone j

X_{3j} = Measure of Accessibility to Employment from zone j

X_{4j} = D.U. Density in zone j

X_{5j} = % Total Land Area in Industrial use in zone j

(B) $G_j = 350\, X_{1j} - 74\, X_{2j} + 23\, X_{3j}$

where:

G_j = Growth in population for zone j

X_{1j} = Accessibility to employment from zone j

X_{2j} = Cost of land in zone j

X_{3j} = Amount of vacant usable land in zone j

These equations are included strictly as examples and should not be taken as recommended models. In actual practice the regression model must be developed for each specific urban area and will thus contain specific dependent and independent variables that have been found to demonstrate causal relationships in that particular urban area. Perhaps the best description of the assumptions, requirements, and procedure for developing land use models by regression analysis is contained in the paper entitled "Methodology for Developing Activity Distribution Models By Linear Regression Analysis" (2) included in Appendix C, Volume 2 of this report. It is strongly recommended that this paper be read prior to developing a regression type model.

Application

See appendix D, Volume 2 for detailed information on UTOWN. Based upon a good knowledge of the political, economic, and social climate and an analysis of the available trend data for UTOWN, and also after reading the paper in Appendix D, it was decided to structure regression type land use models of the following form:

ΔPOP = ΔAvg. Income + ΔAccessibility to EMP.

ΔEMP = ΔAvg. Income + ΔAccessibility to POP.

Normally other independent variables such as % of Vacant land, % Residential land, % Non-Residential land, etc., might be included (See previous examples of typical regression models). To facilitate simplicity only two independent variables are being used for this UTOWN application.

Table 1 contains the basic UTOWN data used to develop the regression models.

Table 1
UTOWN Data Used For Regression Analysis

Activity	zone 1	2	3	4	5	Means $\bar{A} = \frac{A}{n}$
Δ Population (ΔY_1)	-220	-8040	4520	2040	2040	68
Δ Employment (ΔY_2)	7000	800	200	600	400	1800
Δ Average Income (ΔX_1)	1000	1000	3000	2000	3000	2000
Δ Access to Emp. (ΔX_2)	130.0	5.3	1.1	1.7	0.6	27.7
Δ Access to Pop. (ΔX_3)	-7.0	-82.7	51.7	13.9	10.0	-2.82

The following computations will illustrate the general procedure for developing a regression model for ΔY_1 (ΔPop) = a + ΔX_1 (ΔAvg. Income) + ΔX_2 (ΔAccess to Emp.). The Statistical Package for the Social Sciences, SPSS(s) was used to determine the equation for ΔY_2 (ΔEmp) = a + ΔX_1 (ΔAvg. Income) + X_3 (ΔAccess to Pop.).

The general multiple regression equation for two independent variables is as follows:

$$\hat{Y} = a + b_1X_1 + b_2X_2$$

There are three parameters (a, b_1 and b_2) which must be calculated which give the best fit for the data that are available. The following standard normal equations are used for computing these three parameters.

(1) $b_1\Sigma x_1^2 + b_2\Sigma x_1x_2 = \Sigma x_1y_1$

(2) $b_1\Sigma x_1x_2 + b_2\Sigma x_2^2 = \Sigma x_2y_1$

(3) $\bar{Y} = a + b_1\bar{X}_1 + b_2\bar{X}_2$

Table 2 contains the calculations for the values for these normal equations.

Calculations of Values For Normal Equations

Zone	Deviations From Means: ΔPop	ΔAvg. Income	ΔAccess to Emp.	Squares of Deviations		Cross Products of Deviations		
	$y_1=Y_1-\bar{Y}_1$	$x_1=X_1-\bar{X}_1$	$x_2=X_2-\bar{X}_2$	x_1^2	x_2^2	x_1x_2	x_1y_1	x_2y_1
1	-288	-1000	102.3	1,000,000	10,465.29	-102,300	288,000	-29,462.4
2	-8108	-1000	-22.4	1,000,000	501.76	22,400	8,108,000	8,108,000
3	4452	1000	-26.6	1,000,000	707.56	-26,600	[illegible]52,000	-118,423.2
4	1972	0	-26.0	0	676.0	0	0	-51,272
5	1972	1000	-27.1	1,000,000	734.41	-27,100	1,972,000	-1,972,000
Totals				$\Sigma x_1^2 =$ 4,000,000	$\Sigma x_2^2 =$ 13,085.02	$\Sigma x_1x_2 =$ 133,600	$\Sigma x_1y_1 =$ [illegible],820,000	Σx_2y_1 6,055,265.6

Table 2

Substituting the appropriate values into the first two normal equations we obtain:

$$400 \times 10^4 b_1 + 13.36 \times 10^4 b_2 = 1482 \times 10^4$$

$$13.36 \times 10^4 b_1 + 1.308502 \times 10^4 b_2 = 605.52656 \times 10^4$$

There are now two equations containing two unknowns (b_1 and b_2) which must be solved simultaneously. Solution of these gives the values for the two regression coefficients (b_1 and b_2), and the value of the intercept "a" can now be obtained from the third normal equation.

$$b_1 = 5.347381 \qquad b_2 = 49.17310$$

$$a = \bar{Y} - b_1\bar{X}_1 - b_2\bar{X}_2$$

$$= 68 - 5.347(2000) - 49.173(27.7) = -11990.82$$

These results are substituted into the general multiple regression equation to obtain the final form:

$$\Delta\hat{Y}_1 = a + b_1\Delta X_1 + b_2\Delta X_2 =$$

$$= -11990.82 + 5.347\ \Delta X_1 + 49.173\ \Delta X_2$$

In order to have a way of measuring the reliability of the equation it is necessary to calculate measures of accuracy. The following formulas are used to compute the three most common measures of accuracy for the multiple regression equation.

$$R^2 = \text{Coefficient of Determination} = \frac{\Sigma(Y_1 - \bar{Y}_1)^2 - \Sigma(Y_1 - \hat{Y}_1)^2}{\Sigma(Y_1 - \bar{Y})^2}$$

$$= 1 - \frac{\Sigma(Y_1 - \hat{Y}_1)^2}{\Sigma y_1^2}$$

R = Coefficient of Correlation = $\sqrt{R^2}$

$S_{y_1 \cdot x_1 \cdot x_4}$ = Standard Error of Estimate = $\sqrt{\dfrac{\Sigma(Y_1 - \hat{Y}_1)^2}{N - (n + 1)}}$

The formula for the coefficient of determination (R^2) is stated in the form that is closest to the way it is most commonly defined: it is the percentage of variance that is "explained" by using the regression equation to estimate the dependent variable ($\hat{Y}_1$) instead of using the mean ($\hat{Y}_1$). To obtain the value for the numerator of the formula it is necessary to estimate the change in population (ΔPOP or $\Delta\hat{Y}_1$) for each zone from the multiple regression equation by substituting in the values of the independent variables (ΔX_1 and ΔX_2) for each zone as follows:

$$\Delta\dot{Y}_1 = -11990.82 + 5.347\ \Delta X_1 + 49.173\ \Delta X_2$$

$$\Delta\hat{Y}_1 = -11990.82 + 5.347\ (1000) + 49.173(130) = -251.33$$

$$\Delta\hat{Y}_2 = -11990.82 + 5.347(1000) + 49.173(5.3) = -6383.20$$

$$\Delta\hat{Y}_3 = -11990.82 + 5.347(3000) + 49.173(1.1) = 4104.27$$

$$\Delta\hat{Y}_4 = -11990.82 + 5.347(2000) + 49.173(1.7) = -1213.23$$

$$\Delta\hat{Y}_5 = -11990.82 + 5.347(3000) + 49.173(0.6) = 4079.68$$

The results are listed under column head "computed $\hat{Y}_1$" in table 3 which shows the preliminary computations for the measures of accuracy:

Table 3
Preliminary Computations For Measures of Accuracy

Zone	Deviation From Mean $y_1 = Y_1 - \bar{Y}_1$	y_1^2	ΔPOP. Actual Y_1	ΔPOP. Computed $\hat{Y}_1$	Deviation From Regression $Y_1 - \hat{Y}_1$	$(Y_1 - \hat{Y}_1)^2$
1	-288	82,944	-288	-251	-37	1369
2	-8108	65,739,664	-8108	-6383	-1725	2,975,625
3	4452	19,820,304	4452	4104	348	121,104
4	1972	3,888,784	1972	-1213	3185	10,144,225
5	1972	3,888,784	1972	4080	-2108	4,443,664
Totals		$\Sigma y_1^2 =$ 93,420,480				$\Sigma (Y_1 - \hat{Y}_1)^2 =$ 17,685,987

The actual ΔY_1 values are computed from the original UTOWN data. The rest of the steps in obtaining the sums of the squares of deviations from regression, $\Sigma(Y_1 - \hat{Y})^2$, are shown in the last column. These values are then substituted into the R^2 formula to obtain the value for the coefficient of determination.

$$R^2 = 1 - \frac{\Sigma(Y_1 - \hat{Y}_1)^2}{\Sigma y_1^2} = 1 - \frac{17,685,987}{93,420,480}$$

$$= 1 - 0.18907 \qquad = -0.81093$$

The coefficient of correlation (R) is then readily computed as the square root of the coefficient of determination.

$$\sqrt{R^2} = \sqrt{0.81093} = 0.90052$$

Finally, the standard error of estimate is calculated directly since each of the values in this formula are now known (N is the number of observations, i.e., the number of zones, 5; and n is the number of independent variables, in this case two).

$$S_{y_1 \cdot x_1 \cdot x_2} = \sqrt{\frac{\Sigma (Y_1-\hat{Y}_1)^2}{N - (n+1)}} = \sqrt{\frac{17,685,987}{5 - (2 + 1)}}$$

$$= \sqrt{\frac{17,685,987}{5-3}} = \sqrt{8,842,993.5}$$

$$= 2973.717118$$

Table 4 contains the equations to be used in forecasting Δpop. and ΔEmp. along with their measures of accuracy.

Table 4

Final Regression Models And Their Measures of Accuracy

Equation	Coefficient of Correlation (R)	Coefficient of Determination (R^2)	Standard Error of Estimate
$\Delta Y_1 = -11990.82 + 5.347 \Delta X_1 + 49.173\ \Delta X_2$	0.90052	0.81093	2973.717
$\Delta Y_2 = 9349.32 - 3.704\ \Delta X_1 + 50.297\ \Delta X_3$	0.82768	0.68506	-

In order to apply these equations to forecast ΔPop and ΔEmp in UTOWN for the Year 2000, values for the independent variables (ΔX_1, ΔX_2, ΔX_3) must be estimated. In this example only ΔPop. will be estimated since ΔEmp. would be computed in a similar manner.

Assuming the following values for ΔX_1 and ΔX_2 :

Zone	ΔX_1	ΔX_2
1	3300	130
2	3286	15
3	9857	10
4	6571	8
5	9857	5

We can determine the change in population ($\Delta POP_{77-2000}$) from 1977 to 2000 as follows:

$$\Delta Y_1 = -11990.82 + 5.347\Delta X_1 + 49.173\Delta X_2$$

$$\Delta Y_{11} = -11990.82 + 5.347(3300) + 49.173(130) = 6047$$

$$\Delta Y_{12} = -11990.82 + 5.347(3286) + 49.173(15) = 6317$$

$$\Delta Y_{13} = -11990.82 + 5.347(9857) + 49.173(10) = 41206$$

$$\Delta Y_{14} = -11990.82 + 5.347(6571) + 49.173(8) = 23538$$

$$\Delta Y_{15} = -11990.82 + 5.347(9857) + 49.173(5) = 40960$$

Since we know from an independent population forecast which was made using the cohort survival population forecasting procedure, that the population growth is estimated to be 5090 we must scale down the forecasts from the regression model. This is done as follows:

$$\Delta Y_{11} + \Delta Y_{12} + \Delta Y_{13} + \Delta Y_{14} + \Delta Y_{15} = 118{,}068$$

$$\Delta Y_{11} = 5090\ (6047 \div 118{,}068) = 261$$

$$\Delta Y_{12} = 5090\ (6317 \div 118{,}068) = 272$$

$$\Delta Y_{13} = 5090\ (41206 \div 118{,}068) = 1776$$

$$\Delta Y_{14} = 5090\ (23{,}538 \div 118{,}068) = 1015$$

$$\Delta Y_{15} = 5090\ (40{,}960 \div 118{,}068) = 1766$$

Evaluation

The multiple linear regression technique is a popular approach because of its operational simplicity and capability to handle many, rather than one or two independent variables. There are several points that should be considered when using this technique. Some of these points are as follows:

1. During calibration and forecasting there is no built-in provision, as there is for other models, to assure that the accumulated zonal estimates obtained from the regression equation solution will equal the actual or forecast total regional growth. This means that the zonal forecasts will have to be factored up or down to make it sum to the actual or forecast regional growth.

2. The method of regression requires a large amount of data since it is assumed that relationships between the dependent and independent variables remains constant over time.

3. A linear equation assumes that relationships are linear. If they are not linear, the technique will fit a straight line to the data anyway.

4. Just because X and Y are correlated does not necessarily mean a cause and effect relationship exists between them. They may both be the effect of Z.

5. A basic assumption in using multiple regression analysis is that the independent variables are not correlated to each other. If correlation exists, the validity of the relationship noted in the equation is questionable. However, some econometricians contend that this is only a problem if the correlation will not exist at the end of the forecast period (4).

6. The number of independent variables should be kept to a minimum, since for each forecast interval and each zone the independent variables will need to be determined. This in itself allows for the introduction of forecasting errors. Also, generally the sum of squares of error tends to decrease rapidly for the first four independent variables, but very small for the addition of each independent variable after four.

DENSITY SATURATION GRADIENT METHOD

Theory

The Density Saturation Gradient Method (DSGM) is based upon the axiom that there are regularities in activity distribution about the central place (1, 2, 3, 5). The DSGM can be used as a tool for the analysis of existing land use structure and as a tool for use in forecasting land use structure. The forecast is basically a trend projection of the existing land use and density structure in the region. Specifically, the regularity of the decline from the central business district is analyzed and a forecast is made of the change in decline in density and percent saturation based upon the stability of these relationships through time.

The DSGM general allocation procedure requires the following steps.

1. Structure the study area into analysis districts.

   (a) On a traffic zone map of the study area locate the "high value corner (HVC)," which is a point representative of the hypothetical activity center of the Central Business District (CBD).

   (b) Draw a series of concentric rings using the HVC as the vertex, with the radius of the first ring normally being 1/2 mile and each succeeding ring being at 1 mile increments. The radius of the rings may be varied in 1/2 mile increments if a more logical analysis of the data would result.

(c) Draw four to eight straight lines outward from the HVC to divide the study area into "sectors." The location and number of these straight lines are based on the judgment of the planner with regard to dividing the study area into the most homogeneous sectors possible. The boundaries of the rings and sectors form what is termed "analysis districts."

(d) Establish the geographical centroid of each traffic zone. Whichever analysis district the centroid falls within is the analysis district that traffic zone is considered to be a part of in the analysis.

2. Calculate (1) average district residential and nonresidential density, (2) district residential and nonresidential capacity, and (3) percent district residential and nonresidential capacity.

3. Plot and analyze average district residential and non-residential density versus distance from the CBD for the total study area and for individual sectors.

4. Plot and analyze percent district residential and non-residential capacity versus distance from the CBD for the total study area and for individual sectors.

5. Forecast what the plots (curves) of percent district residential and non-residential capacity versus distance from the CBD for the total study area and for individual sectors will look like in the forecast year.

   (a) The future shape of the curves should be resultant from the analysis of the existing urban structure, the analysis of all trend data which exist, the judgment and analytic findings of the planner, and finally the analysis of planning goals and policy decisions which are likely to effect future residential and non-residential location.

   (b) Experience has shown that the general shape of the forecast curve remains about the same as the existing curve except for a rotation upward in the outlying areas.

6. Determine the forecast resident population and employment by district.

   (a) Multiply the residential and non-residential capacity of the district by the forecast percent capacity for each, respectively.

   (b) Check these district forecasts with the population and employment forecasts from techniques such as the Cohort Survival Technique and the Economic Base Multiplier Technique and adjust the DSGM district forecasts if necessary to make them compatible with the external forecast totals.

7. Distribute the forecast residential and non-residential growth for the district to the individual analysis zones.

8. Convert the zonal population and employment forecasts into residential and non-residential land consumption.

   (a) This will require estimating the future density of development.

Application

See appendix D, Volume 2 for detailed information on UTOWN. This application is in many respects a gross over-simplification of the actual procedures followed in using the DSGM in an actual planning situation. The DSGM entails a great deal of analysis and experimentation with the land use data and searching for regularities in the land development patterns and growth trends thereof. This kind of activity is in many ways "behind the scenes" in nature and is only hinted at in the following problem. However, this analytic work is a most valuable and rewarding feature of the use of this method in that it is during this phase that the planner gathers an understanding of the structure of the study region and the forces at work which contribute to change in this structure.

This problem will treat the use of the DSGM first as a tool for the analysis of existing land use structure and secondly as a tool for use in forecasting land use structure. Regardless of the decision as to the method to be used in the forecasting of land use, the DSGM remains as a valuable analytic device.

analysis of urban structure

This application will be limited to the analysis of residential land use only. Residential land accounts for the greatest portion of all urban land in use and residential patterns are typically most regular in nature and thereby most suited to analysis by the DSGM. However, the method is not limited to the analysis of residential land only.

The DSGM is concerned with the search for underlying regularities in the pattern of land use in the urban area and in developing an understanding of the factors, and the extent of their influence, which appear to significantly effect the direction and intensity of growth.

Figure 1 illustrates a hypothetical urban area subdivided into a number of traffic analysis zones. Superimposed upon this are the familiar ring - sector boundaries which, in this case, divide the total study area into four quadrents and three concentric circles emanating from the approximate center of the area. The simultaneous consideration of the sectors and rings structures the study area into the basic unit of analysis for the DSGM, the analysis district.

Figure 2 is a magnification of the structure of a typical analysis district. The particular district illustrated is bounded by the 3½ and 4½ mile radii, and by the sector boundary lines which determine the south-east analysis quandrent. Most land use information is collected and recorded to the traffic analysis zone rather than to the analysis district. For this reason it is most convenient to approximate the analysis district as being composed of a number of whole zones. In the UTOWN DSGM application

Hypothetical Urban Area Structured Into DSGM Analysis Districts

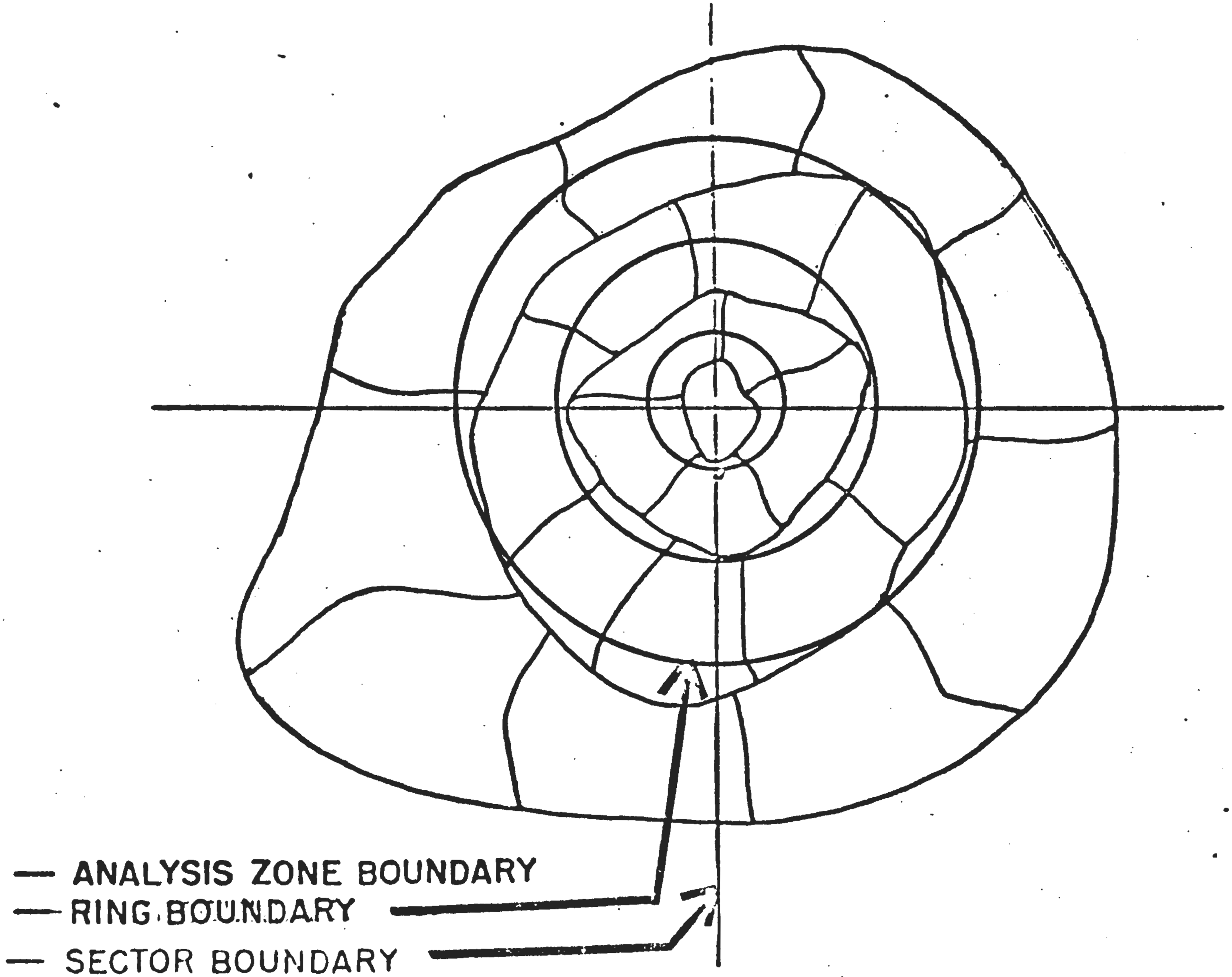
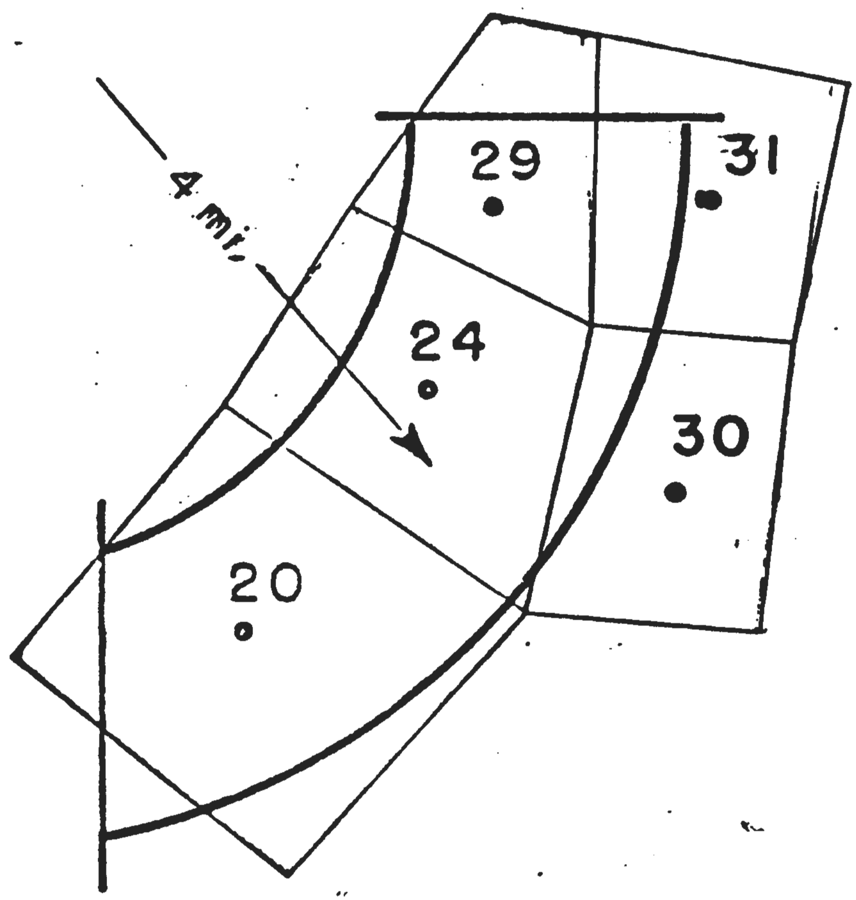


Figure 2



ZONE STRUCTURE OF A TRAFFIC ANALYSIS DISTRICT

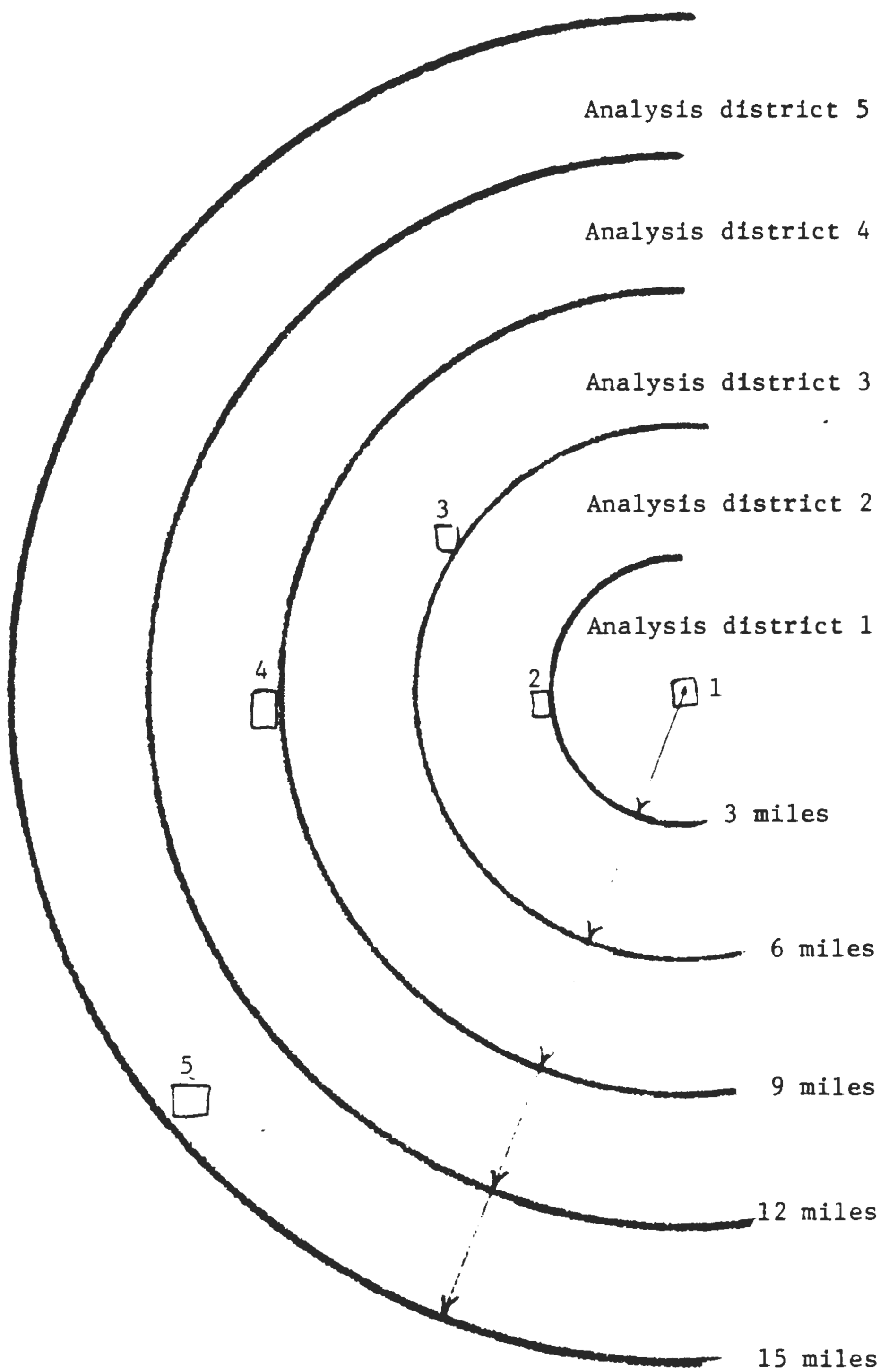
it was arbitrarily decided that those zones whose centroids fall within the boundaries of the district will be considered as part of the analysis district. Using this convention in figure 2 it is seen that the analysis district will actually be composed of analysis zones 20, 24, and 29. Zones 30 and 40 are not part of the district as their centroids fall beyond the boundaries of the theoretical district.

Figure 3 illustrates the analysis structure of the UTOWN study area. Three mile concentric circles from the CBD (zone 1) were used and due to the small number of zones it was decided not to divide the area into quadrents. In this instance only one zonal centroid fell into each district.

The analysis of the existing pattern of residential development will depend predominantly upon the type of data illustrated in Tables 5 thru 9. The calculations in these tables are for all five districts.
Column 2 contains the gross
area, in acres, for each analysis zone in the district (in this case one zone). The total resident population at the time of the analysis (1977) is shown in column 3. Column 4 contains the area of each zone which is currently in residential use. Column 5 shows the maximum amount of additional land in each zone which could ever conceivably be put into residential use. The determination of the values in column 5 are by no means straight-forward or obvious. From the total amount of land available for development in each zone must be substracted those proportions which are or are likely to be reserved for other than residential use. This would include areas devoted to industrial parks,

Figure 3

UTOWN Zonal Centroids
and Znalysis Districts



ANALYSIS OF EXISTING LAND USE PATTERNS USING DENSITY-SATURATION GRADIENT METHOD

(Analysis District 1)

(1) Zone	(2) Total Area (Acres)	(3) Existing Resident Population	(4) Existing Land In Residential Use	(5) Maximum Additional Amount of Land Available for Residential Use
1	67.4	2920	14.4	6.0
Totals (District)	67.4	2920	14.4	6.0

1. Average District Residential Density DEN_{AVG} $= \frac{\Sigma \text{Col. } 3}{\Sigma \text{Col. } 4} = \frac{2920}{14.4} = 202.8 = 203$

2. District Residential Capacity $= \Sigma \text{Col. } 3 + DEN_{AVG} \times \Sigma \text{Col. } 5$
$= 2920 + (203 \times 6.0)$
$= 4138$

3. % Residential Capacity (District) $= \frac{\Sigma \text{Col. } 3}{\text{Capacity}} = \frac{2920}{4138} = 70.6\ \%$

Table 5

ANALYSIS OF EXISTING LAND USE PATTERNS
USING
DENSITY-SATURATION GRADIENT METHOD
(Analysis District 2)

(1) Zone	(2) Total Area (Acres)	(3) Existing Resident Population	(4) Existing Land In Residential Use	(5) Maximum Additional Amount of Land Available for Residential Use
2	318.0	23,360	193.3	27.3
Totals (District)	318.0	23,360	193.3	27.3

1. Average District Residential Density $DEN_{AVG} = \frac{\Sigma \text{Col. } 3}{\Sigma \text{Col. } 4} = \frac{23,360}{193.3} = 120.8 = 121$

2. District Residential Capacity $= \Sigma \text{Col. } 3 + DEN_{AVG} \times \Sigma \text{Col. } 5$
$= 23,360 + (121 \times 27.3)$
$= 26,663$

3. % Residential Capacity (District) $= \frac{\Sigma \text{Col. } 3}{\text{Capacity}} = \frac{23,360}{26,663} = 87.6\ \%$

Table 6

ANALYSIS OF EXISTING LAND USE PATTERNS USING DENSITY-SATURATION GRADIENT METHOD

(Analysis District 3)

(1) Zone	(2) Total Area (Acres)	(3) Existing Resident Population	(4) Existing Land In Residential Use	(5) Maximum Additional Amount of Land Available for Residential Use
3	253.2	23,360	171.2	34.0
Totals (District)	253.2	23,360	171.2	34.0

1. Average District Residential Density DEN_{AVG} $= \frac{\Sigma \text{Col. } 3}{\Sigma \text{Col. } 4} = \frac{23,360}{171.2} = 136.5 = 137$

2. District Residential Capacity $= \Sigma \text{Col. } 3 + DEN_{AVG} \times \Sigma \text{Col. } 5$
$= 23,360 + (137 \times 34.0)$
$= 28,018$

3. % Residential Capacity (District) $= \frac{\Sigma \text{Col. } 3}{\text{Capacity}} = \frac{23,360}{28,018} = 83.4\ \%$

Table 7

ANALYSIS OF EXISTING LAND USE PATTERNS
USING
DENSITY-SATURATION GRADIENT METHOD

(Analysis District 4)

(1) Zone	(2) Total Area (Acres)	(3) Existing Resident Population	(4) Existing Land In Residential Use	(5) Maximum Additional Amount of Land Available for Residential Use
4	367.4	14,600	231.4	85.7
Totals (District)	367.4	14,600	231.4	85.7

1. Average District Residential Density DEN_{AVG} $= \frac{\Sigma \text{Col. } 3}{\Sigma \text{Col. } 4} = \frac{14,600}{231.4} = 63.1 = 63$

2. District Residential Capacity $= \Sigma \text{Col. } 3 + DEN_{AVG} \times \Sigma \text{Col. } 5$
$= 14,600 + (63 \times 85.7)$
$= 20,000$

3. % Residential Capacity (District) $= \frac{\Sigma \text{Col. } 3}{\text{Capacity}} = \frac{14,600}{20,000} = 73.0\ \%$

Table 8

ANALYSIS OF EXISTING LAND USE PATTERNS USING DENSITY-SATURATION GRADIENT METHOD

(Analysis District 5)

(1) Zone	(2) Total Area (Acres)	(3) Existing Resident Population	(4) Existing Land In Residential Use	(5) Maximum Additional Amount of Land Available for Residential Use
5	893,4	14,600	510.4	335.6
Totals (District)	893.4	14,600	510.4	335.6

1. Average District Residential Density DEN_{AVG} $= \frac{\Sigma \text{Col. } 3}{\Sigma \text{Col. } 4} = \frac{14{,}600}{510.4} = 28.6 = 29.0$

2. District Residential Capacity $= \Sigma \text{Col. } 3 + DEN_{AVG} \times \Sigma \text{Col. } 5$
   $= 14{,}600 + (29 \times 335.6)$
   $= 24{,}333$

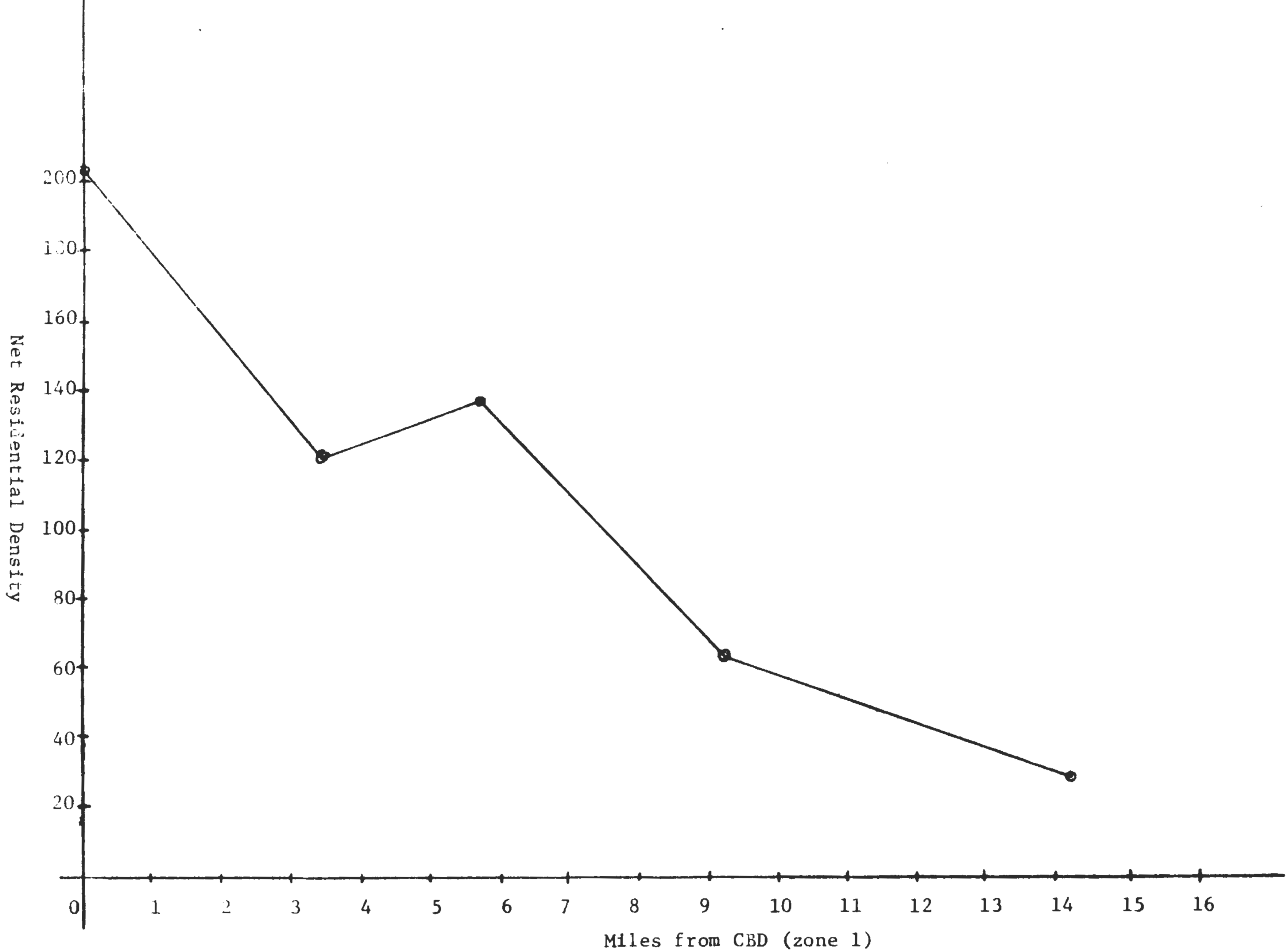
3. % Residential Capacity (District) $= \frac{\Sigma \text{Col. } 3}{\text{Capacity}} = \frac{14{,}600}{24{,}333} = 60.0\ \%$

Table 9

land planned for public uses, such as park land, streets and highways, public buildings, and other areas, which by virtue of land use control, are restricted to other than residential development. In addition to considerations of this nature, the values in column 5 must be sensitive to accepted planning policy decisions. It is at this point that the analyst is called upon to translate the decisions reached with regard to the desired patterns of future residential location into land availability values. If the accepted residential plan restricts growth in a given area, then this should be reflected in the amount of additional land available for residential development for the appropriate zone.

The next step in using the DSGM as an analysis technique to plot curves of residential density versus distance from the CBD (zone 1). Curves can be drawn for the total study area and for individual analysis sectors. The values used in the plotting are net residential density for each analysis district plotted against the distance of the district from the CBD. Equation 1 in tables 5 thru 9 shows the calculation of net district residential density as the quotient obtained by dividing total land in current residential use into total existing resident population. Figure 4 shows the plot of residential density vs distance from CBD for the UTOWN urban area. The plots of residential density can then be studied for underlying regularities and for variances among sectors (if any). It is through this kind of analysis that the planner would gain greater understanding of the existing structure of the study area.

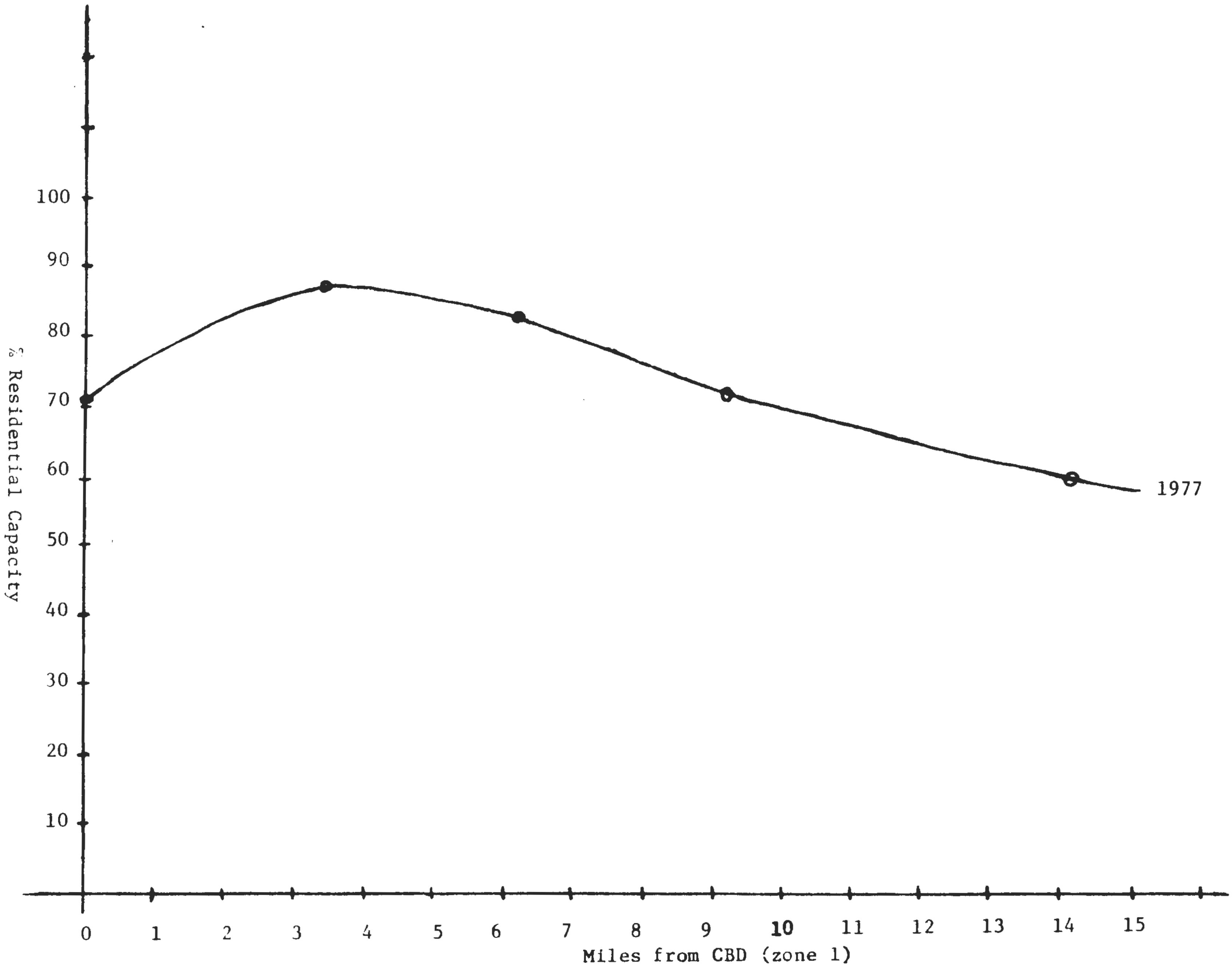
Figure 4
Residential Density VS Distance from CBD for UTOWN Urban Area



Another useful plot is percent district residential capacity versus distance from the CBD. The calculation of UTOWN district residential capacity is shown in equation 2 of tables 5 thru 9. The holding capacity of a district is equal to the current resident population plus the product of expected future residential density and the maximum amount of land available for residential use. The resulting figure then is an approximation of the population of the district under the assumption that all the land available for residential development is consumed. The assumption in Tables 5 thru 9 is that all future residential development took place at the same density as currently exists. Exactly what value to use for future residential density in computing capacity must result from the analysis of existing density patterns, the judgment of the analyst, zoning policy, and future trends.

The final calculation shown in Tables 5 thru 9 is the computation of percent saturation of capacity currently existing in each analysis district. It is determined, as shown in equation 3, by dividing residential capacity (calculated in equation 2) into total district resident population (total of column 3). The individual district percent capacity values are then plotted against distance from the CBD. Figure 5 shows the percent saturation of capacity curve for UTOWN. Plots similar to that in figure 5 can also be prepared on a sector basis (if any). The analysis of these curves should provide a great deal of insight into the residential structure of the area and into the differences existing in the historic growth patterns between sectors.

Figure 5
Percent Saturation of Capacity Curve For UTOWN Urban Area (1977)



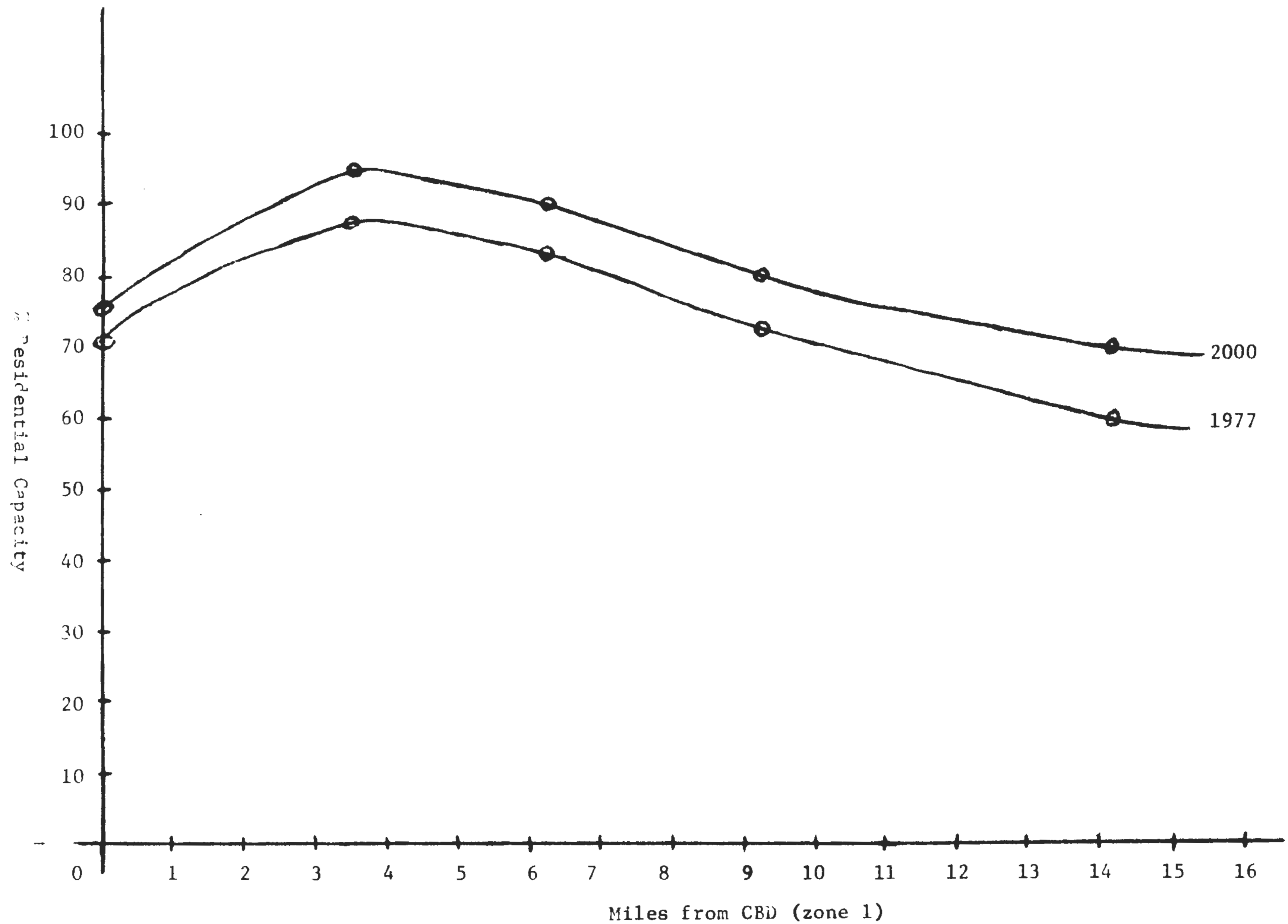
This completes the discussion of the use of the DSGM as a land use analysis device. The remaining portion of this discussion is devoted to the use of the method as a land use forecasting tool. Please note that even if the DSGM is not used in the forecasting of land development, it is a worthwhile procedure for use in the analysis of existing urban structure and often adds significantly to the planner's overall understanding of the existing land patterns.

forecasting of future land use

The DSGM will be used to determine the resident population of each analysis district in the forecast year (2000), and to further distribute this population to the individual analysis zones comprising each district (in the UTOWN case there is only one zone per analysis district). Another step, if desired, would be to convert the zonal resident population estimates into land consumption.

Using the previously prepared plot of percent residential capacity for the whole area (or for each sector, if any) for the existing period, the next step is to forecast what these curves will look like in the forecast year (2000). The upper curve in figure 6 represents this estimation for the UTOWN area. The development of the forecast percent capacity curves is the most significant step in the forecasting procedure. There are no simple rules which can be followed in its derivation. It is likely that a single precise procedure will probably never be found to apply to all areas . It must be resultant from: the analysis of the existing urban structure, the analysis of all trend data which exists, the judgment and analytic findings of the analyst,

Figure 6
Percent Saturation of Capacity Curve For UTOWN Urban Area (2000)



and finally the analysis of planning goals and policy decisions which are likely to effect future residential location. However, experience has shown that the general shape of the forecast curve remains about the same as the existing curve except for a rotation upward in the outer areas.

Once this curve has been agreed upon, the determination of forecast resident population by district is a simple matter. The calculation of forecast district population consists of multiplying the residential capacity of the district by the forecast percent capacity (determined from the upper curve in figure 6) as follows:

Forecast District Population	=	District Pop. Capacity	X	Forecast % Capacity		
Pop.(Dist. 1)	=	4138	X	75.0	=	3104
Pop.(Dist. 2)	=	26,663	X	95.0	=	25,330
Pop.(Dist. 3)	=	28,018	X	90.0	=	25,216
Pop.(Dist. 4)	=	20,000	X	80.0	=	16,000
Pop.(Dist. 5)	=	24,333	X	70.0	=	17,033
						86,683

Since we know from an independent population forecast from a forecasting procedure such as the Cohort Survival Technique, that the population growth is estimated to be 5090, we must scale the DSGM forecast downward. This is done as follows:

Pop.(Dist. 1) =	5090 (3104 ÷ 86,683)	=	85
Pop.(Dist. 2) =	5090 (25,330 ÷ 86,683)	=	1166
Pop.(Dist. 3) =	5090 (25,216 ÷ 86,683)	=	1055
Pop.(Dist. 4) =	5090 (16,000 ÷ 86,683)	=	892
Pop.(Dist. 5) =	5090 (17,033 ÷ 86,683)	=	1892

The final step in the forecast is to distribute the forecast residential growth for the district to the individual analysis zones. Since there is only one UTOWN zone in each district the forecast zonal population equals the forecast district population. However, if any district contained more than one zone the district population growth would have to be allocated between the zones which comprise the district.

One simple procedure for making this district to zone allocation is to distribute the incremental district growth (forecast district population minus existing resident population) to the individual zones in proportion to the amount of land available for residential development. There are many ways in which this distribution can be made. Suffice it to say, it will require the study and evaluation of the growth potential and density patterns of the individual zones. To illustrate the simple procedure described above assume that district 1 contained zones 1 and 2. District 1 existing population would then equal 26,280 (2920 + 23,360). District 1 forecast population would equal 27,531 (3005 + 24,526). Therefore the forecast incremental population growth in district 1 equals 1251 (27,531 - 26,280). The calculations are shown in Table 10.

Table 10

HYPOTHETICAL ILLUSTRATION OF METHOD FOR

ALLOCATING DISTRICT POPULATION TO ZONES USING DENSITY-SATURATION GRADIENT METHOD

Allocation Of Forecast Population To Individual Zones*

(1) Zone	(2) Additional Land Available For Residential Use	(3) Factor Col. 2/ ΣCol. 2	(4) Incremental Growth In Zone	(5) Existing Pop.	(6) Forecast Pop. (Col. 4+Col. 5)
1	6.0	0.18	0.18 X 1251	2920	3145
2	27.3	0.82	0.82 X 1251	23,360	24,386
Total	33.3		1251	26,280	27,531

* Method used will be determined from intensive analysis of data

This completes the total process of forecasting resident population on a zonal basis. It remains to convert these population forecasts into residential land consumption. This will not be done for the UTOWN application. However, it is clear that this would mean estimating, among other things, density of future development.

Employment activity would be analyzed and forecast in a similar manner.

Evaluation

The realibility of the DSGM depends greatly on the strength and stability of the regularity in residential and non-residential densities with distance from the CBD. This method depends equally upon the relationship between distance and percent saturation.

While the DSGM is complete in itself, many planning studies may wish to further modify the results since this technique allows only for a cursory and limited consideration of policy and other planning decisions. The planner is encouraged to expose the results of the forecast, which is essentially a trend forecast, to the further consideration of factors necessary for a realistic and comprehensive end result .

A strong point about the DSGM is that the planner is required to become intimately familiar with the study area and this should contribute to more realistic forecasts.

ACCESSIBILITY MODEL

Theory

The accessibility model is based on the theory that the more accessible an area is to various activities and the more vacant land an area has, the greater its growth potential. Thus, growth in a particular area is hypothesized to be related to two factors, the accessibility of the area to some regional activity distribution, and the amount of land available in the area for development. The accessibility of an area is an index representing the closeness of the area to all other activity in the region. All areas compete for the aggregate growth and share in proportion to their comparative accessibility positions weighted by their capability to accommodate development as measured by vacant, usable land (1, 2).

The formulation of the accessibility model is:

$$G_i = G_T \frac{A_i^a V_i}{\sum_i A_i^a V_i}$$

where:

G_i = growth (population or employment) allocated to zone i

G_T = total growth to be allocation = $\sum_i G_i$

A_i = accessibility (index) for zone i

V_i = vacant available land in zone i

a = empirically determined exponent

The formulation of the accessibility (index) A_i is:

$$A_i = \sum_j \frac{E_j}{T_{ij}^{\,b}}$$

where:

E_j = a measure of activity in zone j

T_{ij} = traveltime from zone i to zone j

b = empirically determined exponent

Two alternative formulations of the accessibility index are:

$$A_i = \sum_j \frac{E_j}{(T_{hij} + T_{tij})^b}$$

where:

T_{hij} = highway traveltime from zone i to zone j

T_{tij} = transit traveltime from zone i to zone j

and

$$A_i = \sum_j E_j F_{ij}$$

where:

F_{ij} = the traveltime factors or friction factors commonly used in the gravity model trip distribution technique. F_{ij} represents the friction of time separation of zones T_{ij} minutes apart. The F_{ij} values are approximately proportional to the actual number of trips T_{ij} minutes long per trip-end in each pair of zones T_{ij} minutes apart. In practice the calculation of F_{ij} is considerably complicated by a desire to have the F_{ij} values form a smooth monotonic relation to T_{ij} yet maintain approximate equality between the resulting mean trip length and the actual mean trip length (2, 3, 4).

There are two exponents that must be empirically determined or estimated in order to make the forecast. They are "b" and "a". There are three general options available for determining "b" and "a". They are:

1. Select values of "b" and "a" which were found to be best for a study area of similar characteristics as the one under study (1, 2).

2. Determine values of "b" and "a" by examining the A_i and G_i formulations on historic data with various values of "b" and "a".

3. Determine values of "b" and "a" by fitting the values to actual changes in some activity. See the Appendix of Reference 2 for a discussion of this option.

<u>Application</u>

See appendix D, Volume 2 for detailed information on UTOWN. This application of the accessibility model is limited to forecasting zonal population growth, however, the same general procedure is followed when forecasting zonal employment or other urban activity growth.

The total UTOWN forecast growth from 1977 to 2000 (G_T) is 5090 as determined from some technique such as the Cohort Survival Population forecasting technique. The growth in population in a given zone is theorized to be proportional to the product of the zone's accessibility to employment, raised to a power, and amount of vacant available land within the zone. The following shows the employment and amount of vacant available land existing in each of the zones.

Zone	E_i Employment 1977	V_i Vacant Avail. Land 1977
1	25,000	6.0
2	5,800	27.3
3	1,400	34.0
4	1,800	85.7
5	1,000	335.6

The values of vacant available land in 1977(above)has been constrained to reflect the maximum additional amount of vacant land available for residential use. See tables 5 thru 9 in the Density Saturation Gradient Method section of the report.

The calculation of accessibility of each zone to employment is as follows:

$$\text{Access to EMP} = \sum_j \frac{E_j}{(T_{hij} + T_{tij})^b}$$

In order to keep the application simple and easy to follow transit travel-time was not used in the calculation of accessibility. Also for this application it was assumed that "b" is equal to 2.

$$A_i(EMP) = \sum_j \frac{E_j}{T_{hij}^{\,b}} = \frac{E_i}{T_{hi1}^{\,2}} + \frac{E_2}{T_{hi2}^{\,2}} + \frac{E_3}{T_{hi3}^{\,2}} + \frac{E_4}{T_{hi4}^{\,2}} + \frac{E_5}{T_{hi5}^{\,2}}$$

$$A_1(EMP) = \frac{25,000}{(12)^2} + \frac{5,800}{(24)^2} + \frac{1,400}{(39)^2} + \frac{1,800}{(41)^2} + \frac{1,000}{(49)^2} = 186.1$$

$$A_2(EMP) = \frac{25,000}{(24)^2} + \frac{5,800}{(15)^2} + \frac{1,400}{(24)^2} + \frac{1,800}{(26)^2} + \frac{1,000}{(34)^2} = 75.1$$

$$A_3(EMP) = \frac{25,000}{(39)^2} + \frac{5,800}{(24)^2} + \frac{1,400}{(14)^2} + \frac{1,800}{(27)^2} + \frac{1,000}{(39)^2} = 36.8$$

$$A_4(EMP) = \frac{25,000}{(41)^2} + \frac{5,800}{(26)^2} + \frac{1,400}{(27)^2} + \frac{1,800}{(16)^2} + \frac{1,000}{(33)^2} = 33.3$$

$$A_5(EMP) = \frac{25,000}{(50)^2} + \frac{5,800}{(35)^2} + \frac{1,400}{(39)^2} + \frac{1,800}{(33)^2} + \frac{1,000}{(17)^2} = 20.8$$

In Summary

Zone	Accessibility to Employment $-(A_i\ (EMP))$ 1977	Accessibility to Employment $-(A_i\ (EMP))$ 2000
1	186.1	316.1
2	75.1	90.1
3	36.8	46.8
4	33.3	41.3
5	20.8	25.8

Normally the accessibility to employment in 1977 would be used, assuming accessibility to employment in the year 2000 could not be determined. However, since $A_i(EMP)_{2000}$ was estimated for use in the multiple linear regression technique section it will also be used here.

The calculation of zonal growth is illustrated in Table 11. The values in column 5 of the table are the percentage of the total growth forecast for each zone. Column 6 contains the projected growth in number of persons for each zone. The final step, not undertaken in the problem, would be to translate these additional persons into increased residential land consumption for each zone. This would of course depend upon densities of residential development assumed for each zone as a result of the analysis fo existing densities, expected trends in residential densities, the application of land use control affecting development density, and the application of controls on development which are consistent with and complementary to the accepted local and regional planning goals.

Evaluation

The accessibility model is simplistic in many respects, relating growth to essentially two variables. Urban growth dynamics is a very complex and often irrational process. Therefore, it is essential that the results of the accessibility model forecasts be modified (this is also the case with other models)to reflect certain of the complexities which the model cannot treat and which have or are expected to exert profound influence upon urban growth patterns. Some of the factors were mentioned previously with respect to developing future residential densities and possible changes in the land market and or actions of residential developers.

Table 11
USE OF ACCESSIBILITY MODEL FOR

DISTRIBUTION OF TOTAL POPULATION GROWTH TO ZONES

$$G_i = G_T \cdot \frac{A_i \times V_i}{\sum_i A_i \quad V_i}$$

Assume G_T = (Total Growth in Population

(1) Zone	(2) A_i	(3) V_i	(4) $A_i \quad V_i$	(5) $\frac{A_i \times V_i}{\sum_i A_i \quad V_i}$	(6) Gi = (col. 5) Growth in population
1	316.1	6.0	1896.6	.10	509
2	90.1	27.3	2459.7	.14	713
3	46.8	34.0	1591.2	.09	458
4	41.3	85.7	3539.4	.20	1018
5	25.8	335.6	8658.5	.47	2393
Total			18,145.4	1.00	5090

STOUFFER'S INTERVENING OPPORTUNITIES MODEL

Theory

The basic premise of Stouffer's Intervening Opportunities Model (Stouffer's model) is that the number of persons or jobs locating at a given distance (from some central point) is directly proportional to the number of opportunities (units of residential or non-residential capacity) at that distance and inversely proportional to the number of intervening opportunities encountered up to that distance (1, 2, 3). The formulation of the model is:

$$g_p = \frac{k\,O_p}{O}$$

where

g_p = number of activities (population, households, jobs, etc.) forecast to be located in an analysis interval p

O_p = total opportunities (available residences or jobs) in interval p

O = total number of opportunities (sum of all opportunities) from the point of origination through and including interval p

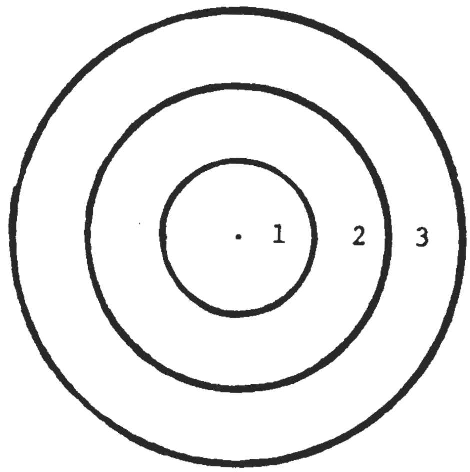
k = proportionality constant to assure that activities allocated (located) equals the actual number of activities (total growth) that is being allocated

One of the first requirements for applying Stouffer's model is to define a central distribution point (CDP) from which the total activity growth is to be distributed. The CDP is normally a point representative of the hypothetical activity center of the CBD or the major employment center.

Obviously the assumption of a single employment center is questionable and would be more questionable as the size of the study are increases. Therefore, an optional technique is to delineate several major centers of employment. The proportion of total activity growth to be distributed from each employment center is directly proportional to the importance of a particular center's magnitude of employment relative to all centers. Each center would then be operated independently distributing it's portion of total activity growth. In the case where more than one CDP is identified, the final zonal activity growth would be determined by summing the portions of activity growth allocated from each CDP to each particular zone. Reference 3 describes an application in which one CDP was used to distribute dwelling units and Appendix A, Volume 2 describes an application which used six CDP's.

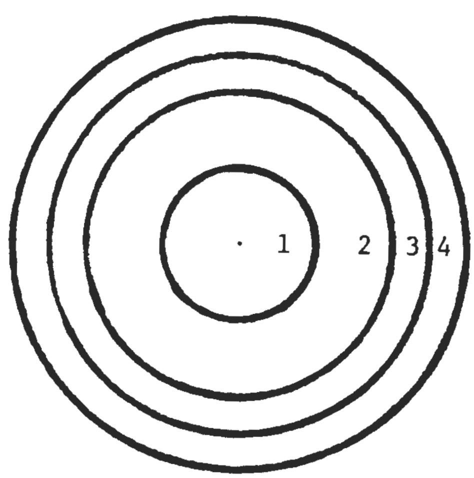
The second requirement is to structure the study area into a number of discrete geographic units which are then ranked from each CDP. One option for structuring or aggregating areas is to form a number of concentric circles of uniformly increasing radii using the CDP(s) as the center. Another option is to form the rings so that there is approximately an equal number of opportunities in each ring. Figures 7 and 8 give an example of these two options. Within ring p, the total possible opportunities are enumerated (O_p). Using the equal opportunities option shown in figure 2 seems to produce better results (2, 3).

Figure 7
Uniform Size Rings Option



Ring	No. of Available Opportunities
1	100
2	100
3	200

Figure 8
Equal Opportunity Rings Option



Ring	No. of Available Opportunities
1	100
2	100
3	100
4	100

The third requirement is to rank the traffic zones according to time from the CDP(s). The fourth requirement is to assign zones to rings according to their ranking (in time) from the CDP(s).

The fifth requirement is to determine the constant "k" which is used to assure that the total number of activities located equals the actual total growth. The value of "k" can be determined two ways. It can be <u>calculated</u> or it can be determined by making a <u>semi-logarithmic plot</u> of total allocated activities versus total accumlated opportunities. The slope of the line would be the value of "k."

<u>Determining "k" by Calculation</u>

Assuming that the activity we wish to allocate is households and that the opportunities are available residences, the value of "k" for the hypothetical area in figure 7 would be calculated as follows:

100 households are to be located. Therefore $G_1 + G_2 + G_3 = 100$

$$g_p = k \frac{O_p}{O}$$

$$g_1 = k \frac{100}{100}$$

$$g_2 = k \frac{100}{100 + 100} = k \frac{100}{200}$$

$$g_3 = k \frac{200}{100 + 100 + 200} = k \frac{200}{200 + 200} = k \frac{200}{400}$$

combining

$$g_1 + g_2 + g_3 = 100 = k\,\frac{100}{100} + k\,\frac{100}{200} + k\,\frac{200}{400}$$

$$100 = k\,\frac{400 + 200 + 200}{400}$$

$$100 = 2k$$

so $$k = 50$$

Thus

$$\left.\begin{aligned} g_1 &= 50\,\frac{100}{100} = 50 \\ g_2 &= 50\,\frac{100}{200} = 25 \\ g_3 &= 50\,\frac{200}{400} = 25 \end{aligned}\right\}\ \text{100 households}$$

It is seen that by knowing the overall household (or activity) change and the location of where the residences (or opportunities) are available, the location of households (or activity) can be forecast.

Determining "k" from semi-logarithmic plot

The assumption is that "k" is constant (1). Therefore, by converting $g_p = k\,\frac{O_p}{O}$ into its continuous differential form we get $d(G_p) = k\,\frac{d(O)}{O}$ and by integrating we obtain:

$$G_p = k \ln O + \text{constant}$$

where

G_p = the total number of activities allocated to all opportunities from the CDP up to and including opportunity interval p

$\ln O$ = log of accumulated available opportunities

By making a semi-lograthmic plot of total allocated activities growth (abscissa - linear scale) versus total accumulated opportunities (ordinate - logarithmic scale) a straight line of slope "k" should occur. In reality, this does not necessarily hold true. Experience has shown that when actual data are used two or more straight lines may occur as in figure 9. In this case, the actual values are approximated by two straight lines with slopes "k_1" and "k_2."

The sixth step is to apply the model using the "k" value(s). When Stouffer's model is applied directly using a calculated value of "k", it is termed an uncalibrated model. When a value(s) of "k" is used as derived from a semi-logarithmic plot of actual data it is termed a calibrated model.

The last step is to determine the zonal forecasts by proportioning the ring forecasts among the constituent zones on the basis of opportunities.

Application

See Appendix D, Volume 2, for detailed information on UTOWN.

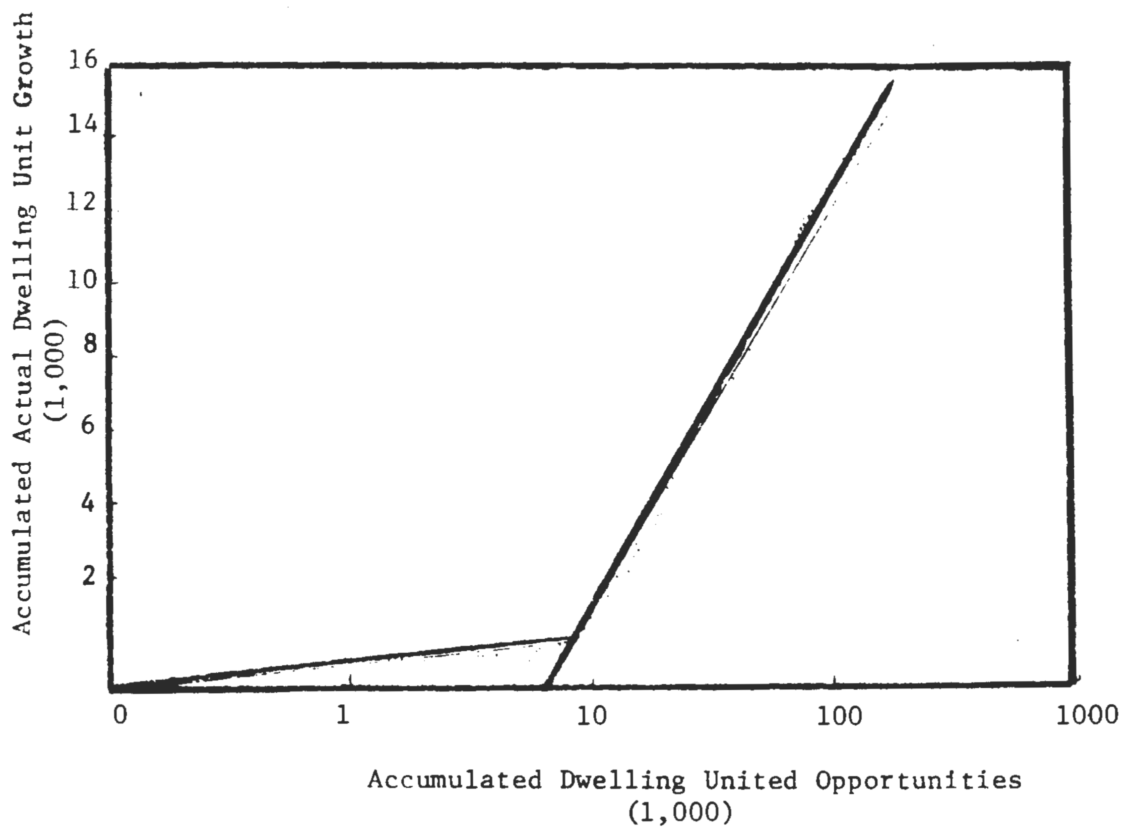
1. Determination of CDP

   Zone 1 is CBD and is designated as CDP

2. Structure area into discrete geographic units

   Figure 10 gives 5 equal size concentric rings from CDP. Future opportunities for population locating in zones is shown in column 4 below.

Figure 9
Example Plot For Derivation of "k" in Calibrated Stouffer's Model



(1) Zone	(2) Max. Zonal POP. Capacity	(3) Exist Zonal Pop. (1977)	(4) Col. (2) - Col. (3) Additional Zonal Pop. Capacity (Opportunities) 1977 - 2000
1	4138	2920	1218
2	26,663	23,360	3303
3	28,018	23,360	4658
4	20,000	14,600	5400
5	24,333	14,600	9733

Column 2 data is from the Density Saturation Gradient Method UTOWN application.

Since there is a small number of zones to begin with the option of forming equal opportunity rings will not be used.

3. Rank zones by time from CDP

As in the application of the assessibility model to UTOWN both highway and transit traveltime could be used to rank zones by time from the CDP. However, as before only highway traveltime will be used in order to keep the application simple and comparable with the other applications. Using the traveltimes from Appendix D, Volume 2, the zones are ranked from zone 1 (CDP).

Zoning Ranking from CDP

1 (12 min.)

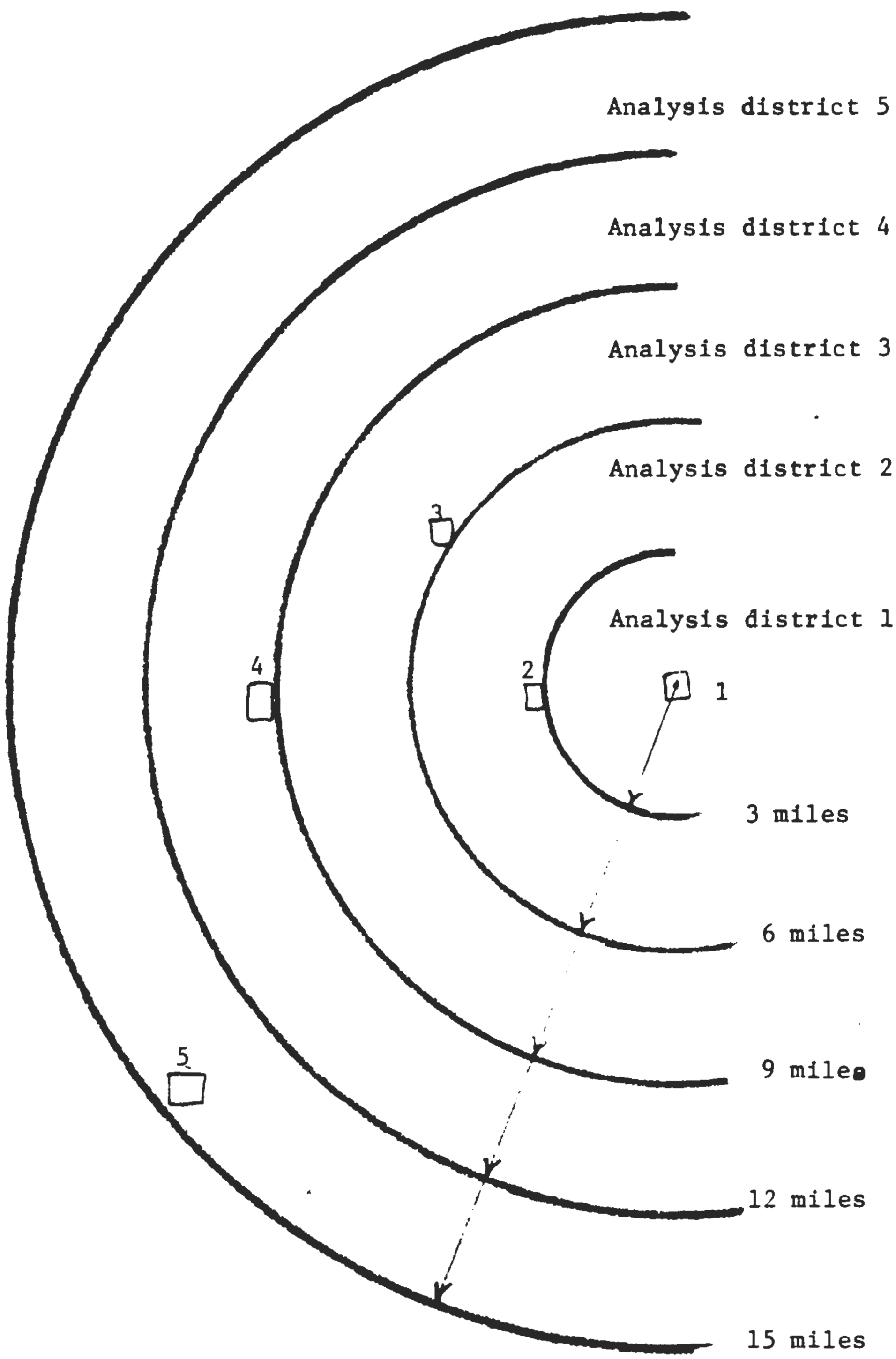
2 (24 min.)

3 (39 min.)

4 (41 min.)

5 (49 min.)

Figure 10
UTOWN Zonal Centroids
and Analysis Districts



4. Assign zones to rings

Using the rings defined in figure 10 zones are assigned to them according to traveltime from the CDP.

Ring	Zones
1	1
2	2
3	3
4	4
5	5

By inspecting the traveltimes of zone 3 (39 min.) and zone 4 (41 min.) it may have been possible to assign them both to ring 3, however, to keep this application comparable with the others the above assignment of zones will be used.

Please note that if the equal opportunities rings were used the zones assigned to rings would be made according to the sum of their opportunities. For instance, if the total opportunities were 100,000 and there are 8 rings then zones would be included whose opportunities sum to approximately 12,500. The zones would be selected in the order of their rank.

5. Determine the Constant "k"

The value of "k" will be determined by calculating it. An attempt to determine the value of "k" was made by fitting Stouffer's model to 1970-77 UTOWN data. A semi-logarithmic plot of accumulated population growth from 1970 to 1977 versus accumulated population capacity from 1970 to 2000 was made (see figure 11). However, when using the values of "k" determined from the plot it was clear that not enough data points (i.e., only 5 UTOWN zones) were available to obtain a sufficient estimate of the "k" values. Columns (3) and (5) in the following data were utilized to make the plot in figure 11.

(1) Zone	(2) Population Growth 1970-77	(3) Accumulated Pop. Growth 1970-77	(4) Max. Pop. Capacity 1970+	(5) Accumulated Max. Pop. Capacity 1970+
1	-220 (0)	0	998	998
2	-8040 (0)	0	-4737 (0)	998
3	4520	4520	9178	10,176
4	2040	6560	7440	17,616
5	2040	8600	11,773	29,389

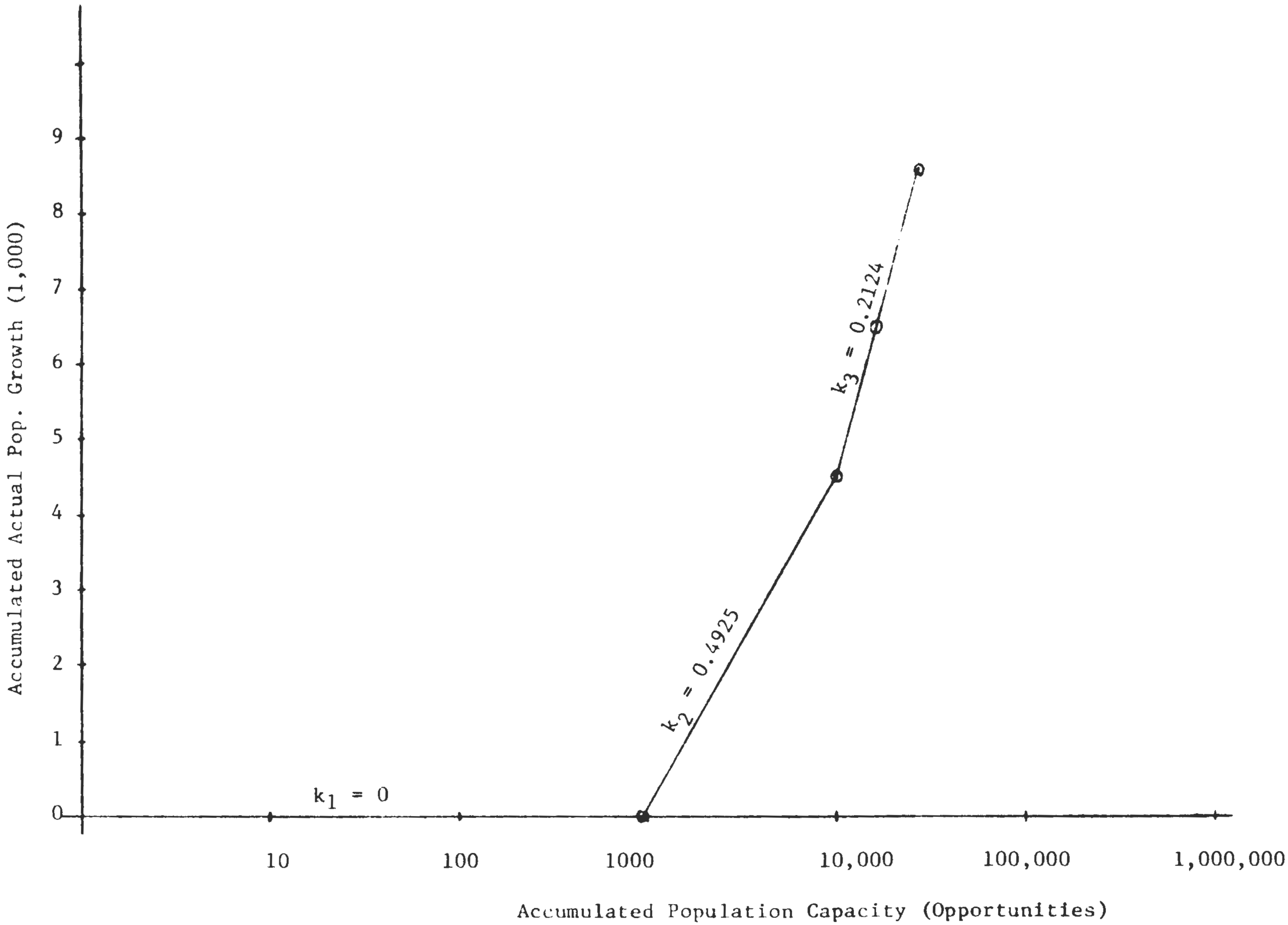
The calculation of the value of "k" follows:

Forecast total population growth (1977-2000) = 5090

Therefore $g_1 + g_2 + g_3 + g_4 + g_5 = 5090$

(1) Ring	(2) Zone	(3) Max. Additional Zonal Pop. Capacity 1977+ (Opportunities)	(4) Accumulated Pop. Opportunities 1977+
1	1	1218	1218
2	2	3303	4521
3	3	4658	9179
4	4	5400	14,579
5	5	9733	24,312

Figure 11
Plot for Derivation of "k" in Calibrated Stouffer's Model for UTOWN Urban Area



$$g_p = k \frac{O_p}{O} \quad \text{where } O = \sum_{i=1}^{p} O_i$$

$$g_1 = k \frac{O_1}{\sum_{i=1}^{1} O_i} \qquad k \frac{1218}{1218}$$

$$g_2 = k \frac{O_2}{\sum_{i=1}^{2} O_i} = k \frac{3303}{1218 + 3303} = k \frac{3303}{4521}$$

$$g_3 = k \frac{O_3}{\sum_{i=1}^{3} O_i} = k \frac{4658}{9179}$$

$$g_4 = k \frac{O_4}{\sum_{i=1}^{4} O_i} = k \frac{5400}{14,579}$$

$$g_5 = k \frac{O_5}{\sum_{i-1}^{5} O_i} = k \frac{9733}{24,312}$$

combining we obtain

$$g_1 + g_2 + g_3 + g_4 + g_5 = 5090 = k \frac{1218}{1218} + k \frac{3303}{4521} + k \frac{4658}{9179} + k \frac{5400}{14,579} + k \frac{9733}{24,312}$$

$$5090 = 1.0k + 0.73k + 0.51k + 0.37k + 0.40k$$

$$5090 = 3.01k$$

$$k = 1691.03$$

6. Apply model using k constant(s)

$$g_p = k \frac{O_p}{O} \quad \text{where } O = \sum_{i=1}^{p} O_i$$

$$g_1 = (1691.03) \frac{1218}{1218} = 1691$$

$$g_2 = (1691.03) \frac{3303}{4521} = 1235$$

$$g_3 = (1691.03) \frac{4658}{9179} = 862$$

$$g_4 = (1691.03) \frac{5400}{14,579} = 626$$

$$g_5 = (1691.03) \frac{9733}{24,312} = 676$$

7. Determine zonal forecasts

Normally the zonal forecasts are determined by proportioning the ring forecasts among the constituent zones on the basis of opportunities. However, in this UTOWN application there was only one zone per ring therefore the zonal forecasts equal the ring forecasts.

$g_1 = 1691$

$g_2 = 1235$

$g_3 = 862$

$g_4 = 626$

$g_5 = 676$

Evaluation

The Stouffer's model compared quite favorably with other models when used to forecast zonal dwelling units (3). A major requirement is the need to estimate the future distribution of opportunities (future activity capacity) for the particular activity being allocated.

Stouffer's model will only forecast a decrease of activities in a zone provided there is a decrease of activity for the entire study area. Then it will proportionally decrease activities within all zones as opposed to decreasing activity in some zones and increasing activity in other zones with a net change still remaining negative. Similarly, the same is true with increase in activity. Stouffer's model will distribute an amount of activity increase throughout the region as opposed to having some zones receive activity growth while others receive a decrease in activity with the net effect for the entire study remaining positive.

SCHNEIDER'S INTERVENING OPPORTUNITIES MODEL

Theory

The basic premise of Schneider's Intervening Opportunities Model (Schneider's model) is that the probability of an activity (person, jobs, etc.) finding a suitable opportunity (a unit of available residential or non-residential capacity) for location at a given distance is hypothesized to be a monotonically decreasing function of the number of intervening opportunities (number of opportunities encountered up to that distance), opportunities being ranked by time from some central distribution point (1, 2, 3, 4). The formulation of the model is:

$$d(G_p) = g_t \left[e^{-\ell O} - e^{-\ell (O+O_p)} \right]$$

where

G_p = total number of locations in opportunity interval from the central distribution point up to interval p

g_t = total growth to be allocated

ℓ = model parameter expressing the probability of an opportunity being accepted for location

O = total number of opportunities ranked from the central distribution point up to interval p

O_p = Opportunities in interval p

e = base of natural logarithms = 2.71828

Schnieder's model has a negative exponential formulation. The formulation produces a number which ranges from zero to one. The logic of this formulation is as follows: g_t represents the total amount of activity which is forecast to take place within the study area within a given time period. If the term $\left[e^{-\ell 0} - e^{-\ell (0+0_p)}\right]$ generates a number that is greater than one, this would imply that more activity is being allocated to "zone one" than has been allocated or predicted for the entire region. The other limit of this term would be zero. Thus, the entire term ranges from zero to one.

One of the first requirements for applying Schneider's model is to define a central distribution point (CDP) from which the total activity growth is to be distributed. The CDP is normally a point representative of the hypothetical activity center of the CBD or the major employment center. Obviously the assumption of a single employment center is questionable and would be more questionable as the size of the study area increases. Therefore, an optional technique is to delineate several major centers of employment. The proportion of total activity growth to be distributed from each employment center is directly proportional to the importance of a particular center's magnitude of employment relative to all centers.

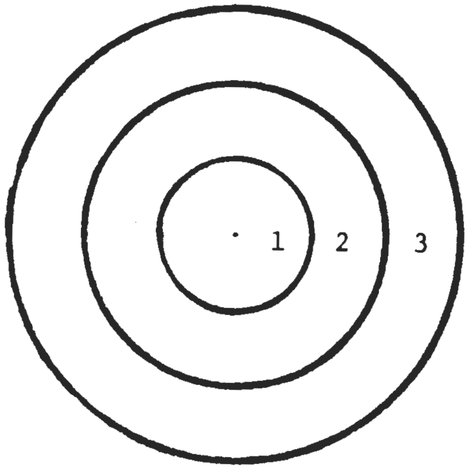
Each center would then be operated independently distributing it's portion of total activity growth. In the case where more than one CDP is identified the final zonal activity growth would be determined by summing the portions of activity growth allocated from each CDP to each particular zone. Reference 1 describes an application in which one CDP was used to distribute dwelling units and Appendix A, Volume 2, describes an application which used six CDP's.

The second requirement is to structure the study area into a number of discrete geographic units which are then ranked from each CDP. One option for structuring or aggregating areas are to form a number of concentric circles of uniformly increasing radii using the CDP's as the center. Another option is to form the rings so that there is approximately an equal number of opportunities in each ring. Figures 12 and 13 give an example of these two options. Within ring p, the total possible opportunities are enumerated (O_p). Using the equal opportunities option shown in figure 13 seems to produce better results (3, 4).

The third requirement is to rank the traffic zones according to time from the CDP(s). The fourth requirement is to assign zones to rings according to their ranking (in time) from the CDP(s).

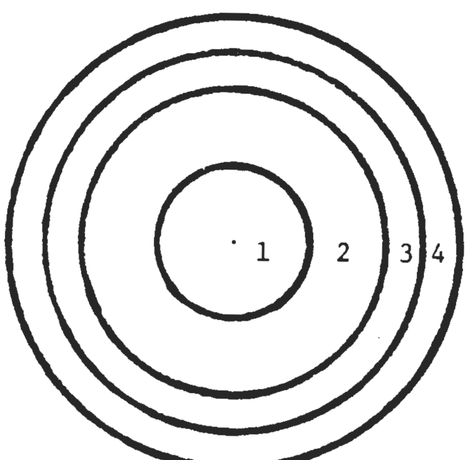
The fifth requirement is to determine the constant "ℓ" (probability of an opportunity being accepted for location). The value of "ℓ" can be determined two ways. It can be calculated or it can be determined by making a semi-logarithmic plot of total activities remaining to be allocated versus total accumulated opportunities. The slope of the line would be the value of "ℓ".

Figure 12
Uniform Size Rings Option



Rings	No. of Available Opportunities
1	100
2	100
3	200

Figure 13
Equal Opportunity Rings Option



Rings	No. of Available Opportunities
1	100
2	100
3	100
4	100

In order to determine the "ℓ" value using either option the model formulation is changed using the assumption that the rings are of infinitesimal width. The original equation becomes:

$$d(G_p) = g_t \left[e^{-\ell O} - e^{-\ell (O + O_p)} \right]$$

With all parameters as before, but the value $d(G_p)$ is the change in activity located in the ring of infinitesimal width. Integration from the CDP centroid through ring p yields

$$G_p = g_t \left[1 - e^{-\ell O} \right]$$

The logrithmic form of this equation is

$$\ln \ (g_t - G_p) = \ln g_t - \ell O$$

The parameter values are defined as always except that G_p is the total activity change allocated through ring p.

The calculation of "ℓ" is as follows:

Assume that the activity we wish to locate is households and that opportunities are available residences, and figure 1 shows the hypothetical area.

The formulation $G_p = g_t \left[1 - e^{-\ell O} \right]$ assumes the area is infinite (i.e., the area is unbounded). As the model considers additional rings, and thus additional opportunities, or equivalently as the area of the region goes to infinity, the negative exponential value ($e^{-\ell O}$) approaches zero. At this time the total activity growth allocated equals the total activity growth. The problem of an infinite or unbounded area is overcome by assuming that within the finite study area a specified percentage, such as 99 percent, of the growth occurs. Thus, the integrated formulation

$$G_p = g_t \left[1 - e^{-\ell 0}\right]$$

equals $0.99 = 1 - e^{-\ell 0}$

or $\ell = \frac{4.60517}{0}$

So $\ell = \frac{4.60517}{400} = 0.0115129$ (or 1.151×10^{-2})

Since only 99% of the total growth is assumed to locate in the area, the total growth should be increased one percent (i.e., $1.01 \times g_t$) in order to make certain that the correct amount of forecast growth is allocated. Thus growth to be allocated is 101 households (1.01 X 100 households).

using $d(G_p) = g_t \left[e^{-\ell 0} - e^{-\ell(0+0_p)}\right]$

$$G_1 = 101 \left[e^{-.01151(0)} - e^{-.01151(100)}\right]$$
$$= 101\ (1 - .3163) = 101\ (0.6837)$$
$$= 69$$

$$G_2 = 101 \left[e^{-.01151(100)} - e^{-.01151(200)}\right]$$
$$= 101\ (.3163 - .1001) = 101\ (0.2162)$$
$$= 22$$

$$G_3 = 101 \left[e^{-.01151(200)} - e^{-.01151(400)}\right]$$
$$= 101\ (.1001 - .0100) = 101\ (.0901)$$
$$= 9$$

Note: $G_1 + G_2 + G_3 =$ 100 Households

The determination of "ℓ" using the graph or plotting option is as follows:

The logarithmic formulation of the model (as previously determined) is $\ln (g_t - G_p) = \ln g_t - \ell O$. This relationship plots as a straight line where the ordinate, $(g_t - G_p)$, is in logarithmic scale and the abscissca, total accumulated opportunities (O) from the CDP, is in linear scale. The slope is "ℓ" and the intercept g_t. If Schneider's model effectively replicates the spatial distribution of residential growth in the particular urban area then the semi-logarithmic plot should yield a straigth line of slope "ℓ". In reality, this does not necessarily hold true. Experience has shown that when actual data are used two or more straight lines may occur as in figure 14. In this case, the actual values are approximated by two straight lines with slopes "ℓ_1" and "ℓ_2."

The sixth step is to apply the model using the "ℓ" value(s). When Schneider's model is applied directly using a calculated value of "ℓ" it is termed an uncalibrated model. When values of "ℓ" are used as derived from a semi-logarithmic plot of actual data it is termed a calibrated model.

The last step is to determine the zonal forecasts by proportioning the ring forecasts among the constituent zones on the basis of opportunities.

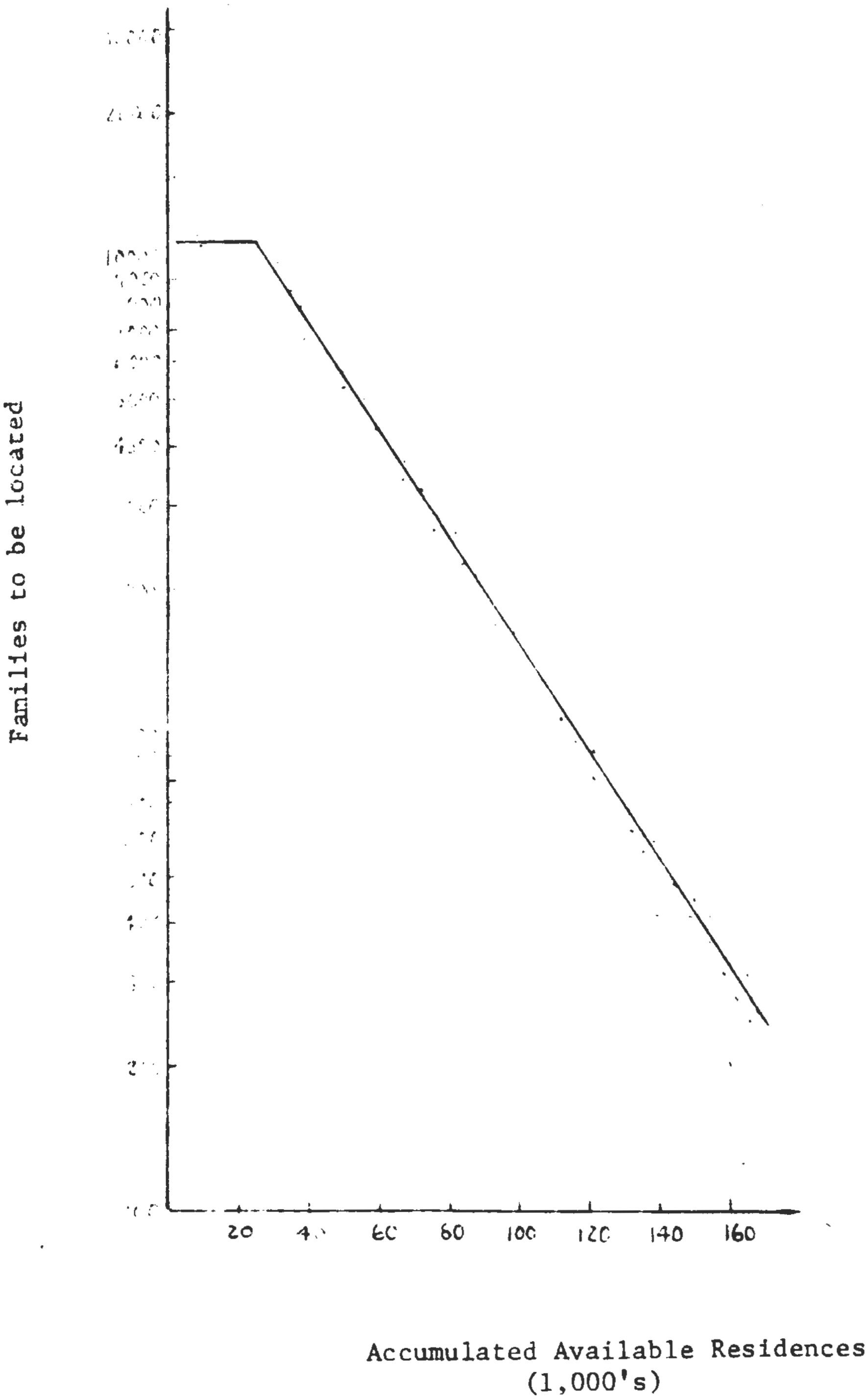
Application

See Appendix D, Volume 2, for detailed information on UTOWN.

1. Determination of CDP

   Zone 1 is CBD and is designated as CDP.

Figure 14
Example Plot for Derivation of "ℓ" in Calibrated Schneider Model



2. <u>Structure area into discrete geographic units</u>

Figure 15 gives 5 equal size concentric rings from CDP. Future opportunities for population locating in zones is shown in column (4) below

(1) Zone	(2) Max. Zonal Pop. Capacity	(3) Exist. Zonal pop. (1977)	(4) Col.(2) - Col.(3) Additional Zonal Pop. Capacity (Opportunities) 1977-2000
1	4138	2,920	1218
2	26,663	23,360	3303
3	28,018	23,360	4658
4	20,000	14,600	5400
5	24,333	14,600	9733

Column 2 data is from the Density Saturation Gradient Method UTOWN application.

Since there is a small number of zones to begin with the option of forming equal opportunity rings will not be used. Opportunity is usually defined as the product of available land for a given activity and the density of the activity (unit activity per unit land).

3. <u>Rank zones by time from CDP</u>

As in the application of the accessibility model to UTOWN, both highway and transit traveltime could be used to rank zones by time from the CDP. However, as before only highway traveltime will be used in order to keep the application simple, and comparable with the other applications. Using the traveltimes from Appendix D, Volume 2, the zones are ranked from zone 1 (CDP) as follows.

Zonal Ranking from CDP

1 (12 min.)

2 (24 min.)

3 (39 min.)

4 (41 min.)

5 (49 min.)

4. Assign zones to rings

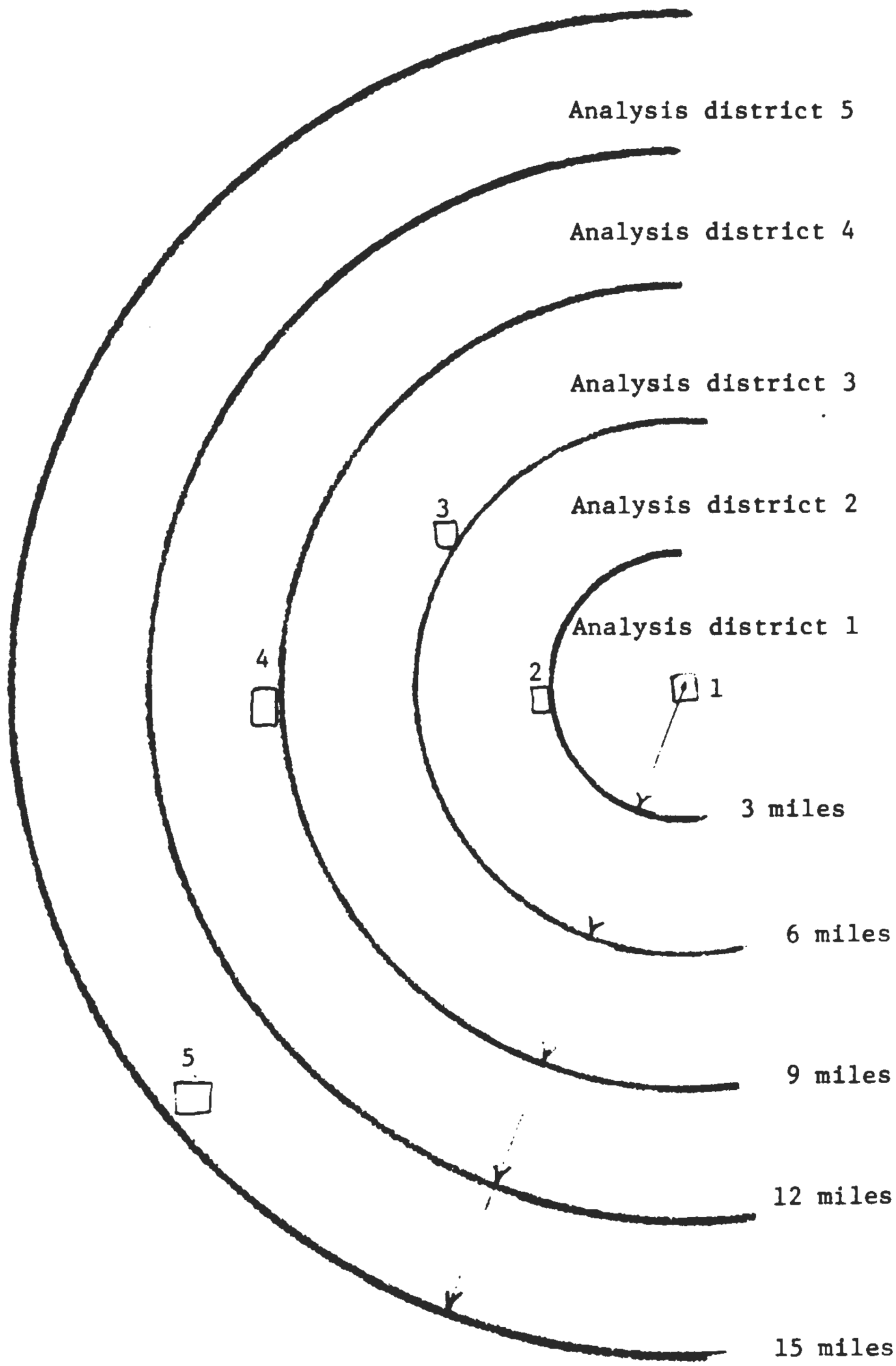
Using the rings defined in figure 15 zones are assinged to them according to traveltime from the CDP.

Ring	Zones
1	1
2	2
3	3
4	4
5	5

By inspecting the traveltimes of zone 3 (39 min.) and zone 4 (41 min.) it may have been possible to assign them both to ring 3, however, to keep this application compariable with the others the above assignment of zones will be used.

Please note that if the equal opportunities rings were used the zonal assignment to rings would be made according to the sum of their opportunities. For instance, if the total opportunities were 100,000 and there are 8 rings the zones would

Figure 15
UTOWN Zonal Centroids
and Analysis Districts



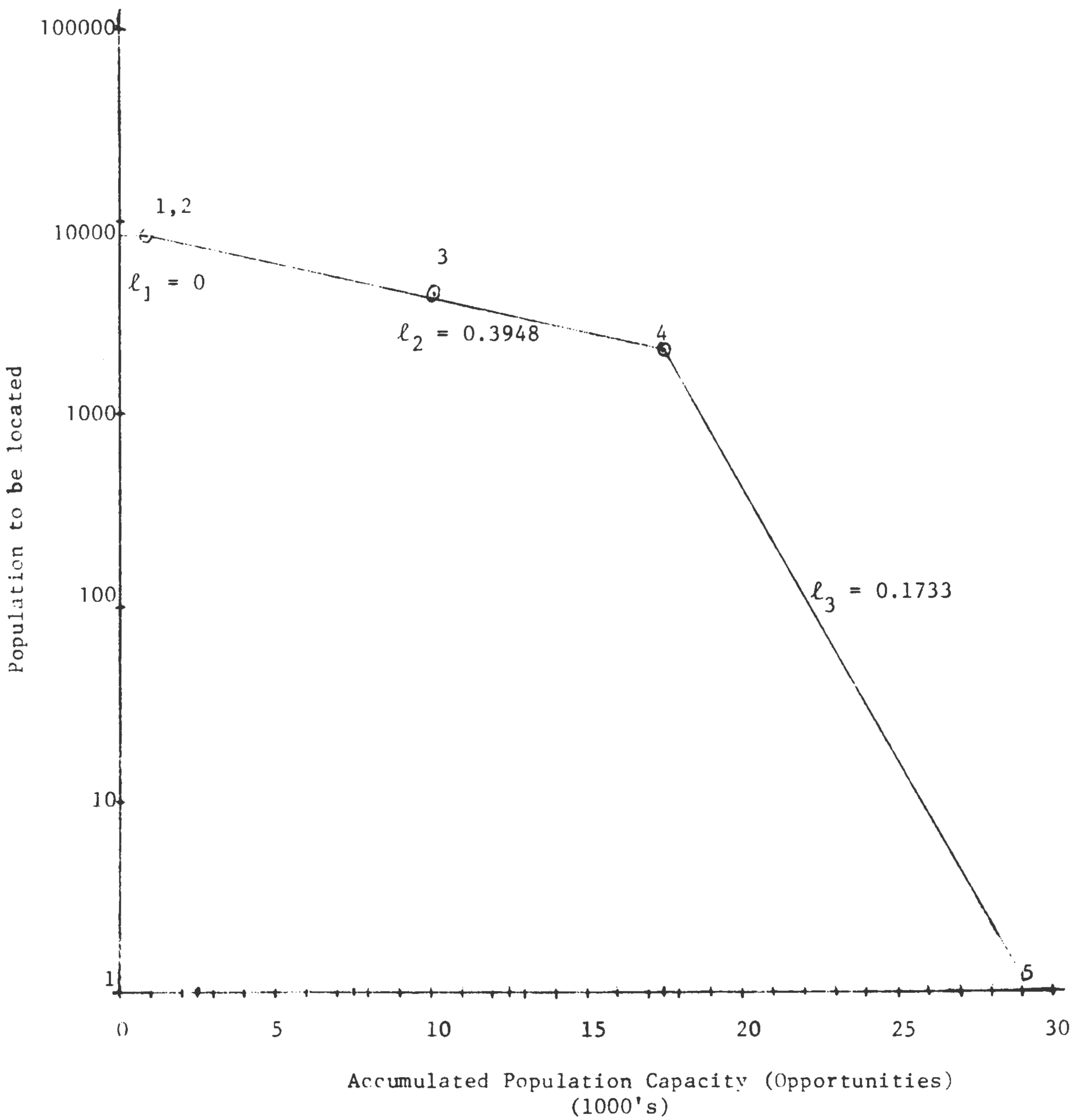
be included whose opportunities sum to approximately 12,500. The zones would be selected in the order of their rank.

5. Determine the Constant "ℓ"

The value of "ℓ" will be determined by calculating it. An attempt to determine the value of "ℓ" was made by fitting Schneider's model to 1970-77 UTOWN data. A semi-logarithmic plot of population to be located from 1970 to 1977 versus accumulated population capacity (opportunities) from 1970 to 2000 was made (see figure 16). However, when using the values of "ℓ" as determined from the plot it was clear that not enough data points (i.e., only 5 UTOWN zones) were available to obtain a sufficient estimate of the "ℓ" values. Columns (3) and (5) in the following data were utilized to make the plot in figure 16.

(1) Zone	(2) Population Growth 1970-77	(3) Pop. Growth remaining to be located 1970-77	(4) Max. Pop. Capacity (Opportunities) 1970+	(5) Accumulated Max. Pop. Capacity (Opportunities) 1970+
		(8600)		
1	-220 (0)	8600	998	998
2	-8040 (0)	8600	-4737 (0)	998
3	4520	4080	9178	10,176
4	2040	2040	7440	17,616
5	2040	0	11,773	29,389

Figure 16
Plot For Derivation of "ℓ" in Calibrated Schneider Model For
UTOWN Urban Area



The calculation of the value of "ℓ" follows:

Forecast total population growth (1977 - 2000) = 5090

(1) Ring	(2) Zone	(3) Max. Additional Zonal Pop. Capacity (Opportunities) 1977+	(4) Accumulated Pop. Opportunities 1977+
1	1	1218	1218
2	2	3303	4521
3	3	4658	9179
4	4	5400	14,579
5	5	9733	24,312

Assume 99 percent of the growth occurs inside the study area. Thus using $G_p = g_t\left[1 - e^{-\ell 0}\right]$ we get $0.99 = 1 - e^{-\ell 0}$

or

$$\ell = \frac{4.60517}{0}$$

$$= \frac{4.60517}{24,312} = 0.0001894 \text{ (or } 1.894 \times 10^{-4})$$

6. Apply model using "ℓ" value

Since only 99% of the total growth is assumed to locate in the area the total growth should be increased one percent (i.e., 1.01 X g_t) in order to make certain that the correct amount of forecast growth is allocated. Therefore the population growth to be allocated is 5141 (1.01 X 5090).

using $d(G_p) = g_t\left[e^{-\ell 0} - e^{-\ell(0+0_p)}\right]$

$$G_1 = 5141\left[e^{-0.0001894\ (0)} - e^{-0.0001894\ (1218)}\right]$$

$$= 5141\ (1 - .7940) = 5141\ (0.2060)$$

$$= 1059$$

$$G_2 = 5141 \left[e^{-0.0001894\ (1218)} - e^{-0.0001894\ (4521)} \right]$$
$$= 5141\ (.7940 - .4247) = 5141\ (.3693)$$
$$= 1898$$

$$G_3 = 5141 \left[e^{-0.0001894\ (4521)} - e^{-0.0001894\ (9179)} \right]$$
$$= 5141\ (.4247 - .1758) = 5141\ (.2489)$$
$$= 1280$$

$$G_4 = 5141 \left[e^{-0.0001894\ (9179)} - e^{-0.0001894\ (14,579)} \right]$$
$$= 5141\ (.1758 - .0632) = 5141\ (.1126)$$
$$= 579$$

$$G_5 = 5141 \left[e^{-0.0001894\ (14,579)} - e^{-0.0001894\ (24,312)} \right]$$
$$= 5141\ (.0632 - .0100) = 5141\ (.0532)$$
$$= 274$$

7. Determine zonal forecasts

Normally the zonal forecasts are determined by proportioning the ring forecasts among the constituent zones on the basis of opportunities. However, in this UTOWN application there was only one zone per ring therefore the zonal forecasts equal the ring forecasts.

$g_1 = 1059$

$g_2 = 1898$

$g_3 = 1280$

$g_4 = 579$

$g_5 = 274$

Evaluation

The Schneider's model compared favorably with other models when used to forecast zonal dwelling units (4). A major requirement is the need to estimate the future distribution of opportunities (future activity capacity) for the particular activity being allocated.

Schneider's model will only forecast a decrease of activities in a zone provided there is a decrease of activity for the entire study area. Then it will proportionally decrease activities within all zones as opposed to decreasing activity in some zones and increasing activity in other zones with a net change still remaining negative. Similarly, the same is true with increase in activity. Schneider's model will distribute an amount of activity increase throughout the region as opposed to having some zones recieve activity growth while others receive a decrease in activity with the net effect for the entire study remaining positive.

For a computerized version of Schneider's model see the writeup on the Opportunity-Accessibility Model in Chapter 4.

DELPHI TECHNIQUE

Theory

The Delphi technique is a methodology for eliciting and refining expert or informed opinion. The Delphi concept was developed at the Rand Corporation for the forecasting of time-related future events (1).

The Delphi technique has only recently been considered for use in land use forecasting (2, 3). This technique has also recently been used in population forecasting (4).

The general Delphi technique involves the repeated consulting with a group of informed individuals as to their best judgement as to when or what type of an event is most likely to occur (i.e., what type or when the event will occur, not when it should occur), and providing them with systematic reports as to the totality of judgments submitted by the group. The responses of all participants are assembled, summarized and returned to the group members, inviting them to reconsider and to offer any defense they may have for an estimate that seems out of line with others made by the group. This information, and revised estimates, may then be circulated to the participants for additional analysis. The procedure varies considerably among specific applications but the primary result is that it produces a consensus of the judgments of a majority of informed individuals while avoiding the bias of leadership influence, face-to-face confrontation, or group dynamics. Group participants are expected to clarify their own thinking, and the final decisions, according to the theory, will tend to converge by narrowing the range of estimates in response to the most convincing arguments.

The following are the typical steps involved in land use forecasting using the Delphi technique.

1. <u>Establish Delphi Panel</u>

   Typical Delphi panels have involved from 10 to 16 members. For land use forecasting the Delphi panel should consist of a wide crosssection of occupation categories as opposed to only one or two major categories. The reason is that some occupations tend to view situations in a similar way while others have a profound divergence in their views. Logically, some occupations tend to enhance the qualifications of Delphi land use forecasting participants, however, the primary consideration must be the total qualifications and experience of the particular individual. Typical panel members might include realtors, planners, city officials, merchants, newspaper publishers, surveyors, appraisers, pharmacists, dentists, bankers, utility employers, county agents, etc. Other significant characteristics of panel members are age, number of years lived in area, and educational level. Depending upon the size of the study area it might be desirable to form more than one panel which covers only a portion of the total area. Reference 3 describes a Delphi land use forecasting application which used three panels.

2. <u>Develop Delphi Questionnaire</u>

   A mail-back questionnaire is typically used and is designed for completion in approximately 1 hour. The questionnaire should be self-explanatory, and should include questions which are designed to obtain the panel member's ideas on the future growth and distribution of various types of urban activities and land uses in the study area. Typical urban activities are population, employment, and housing, and typical land uses have included residential, commercial, industrial, public-semipublic, roads, water, vacant, agricultural, etc.

It is helpful to include information on the existing (and past trends if available) magnitude, and locational pattern of the urban activities and land uses. A typical questionnaire is listed in reference 5.

3. Administer First Round Delphi Questionnaire

This is typically done by mail with a pre-addressed and pre-stamped envelop enclosed. Although the questions are usually designed for completion in 1 hour. It is not unusual for each panel member to devote approximately 3 hours to this initial questionnaire. The extra time is attributed to the conscientiousness and thoughtfulness of the panel members.

4. Summarize First Round Delphi Questionnaire Responses and Prepare Second Round Questionnaire

The first-round questionnaire is revised or re-designed as appropriate to permit the panel members to reconsider their original opinions given the summary of first round panel responses.

5. Administer Second Round Delphi Questionnaire

Again, this is typically done by mail with a pre-addressed and pre-stamped envelope enclosed. Usually each panel member devotes approximately 2 hours to this questionnaire. The panel members are permitted to modify their original opinions based upon the majority opinions or hold to their original ideas.

6. Summarize Second-Round Delphi Questionnaire Responses and Prepare Third Round Questionnaire

Typically the second round summary will be different from the first-round summary and will tend to show a convergence toward a concensus of opinion toward the future land use pattern. The mail-back questionnaire is again revised or re-designed as appropriate to permit the panel members to reconsider their original opinions given the latest summary of second-round panel responses.

7. Administer Third-Round Delphi Questionnaire

Again this is typically done by mail with a pre-addressed and pre-stamped envelope enclosed. Usually each panel member devotes approximately 1 hour to this questionnaire. The panel members are permitted to modify their past opinions based upon the majority opinions or hold to their original ideas given the latest summary of second-round panel responses.

8. Summarize Third-Round (usually final) Delphi Questionnaire Responses and Finalize Forecasts

Experience has shown that the response rate to questionnaires sent in fourth on greater rounds are very low and thus the forecasts are based upon the third-round responses.

Application

See Appendix D, Volume 2, for detailed information on UTOWN. This application is in many respects a gross over-simplification of the actual procedures followed in using the Delphi technique in an actual land use forecasting situation. For instance, the Delphi panel would contain more members; land use categories (none in this UTOWN application) would be used in addition to urban activities; the Delphi questionnaire would be much more detailed and specific.

1. Establish Delphi Panel

UTOWN Delphi Panel members are

a. Mr. Frank Clark, President-UTOWN Power and Utility Company, lived in UTOWN for 15 years.
b. Ms. Bonnie Danel, City Planning Director, lived in UTOWN for 10 years.
c. Ms. Marian Ott, Mayor, lived in UTOWN for 20 years.
d. Mr. George Schoener, President-Banker, lived in UTOWN for 30 years.
e. Mr. Jim Walls, Realtor-Appraiser, lived in UTOWN for 15 years.

2. Develop Delphi Questionnaire

For simplicity purposes only one question will be asked:

a. Given

a total population growth of 5090 from 1977 to 2000, the UTOWN case study zone map, and the UTOWN socio-economic and land use data shown in Volume 2, Appendix D.

What (based upon your best judgment) will be the distribution of this growth among the 5 UTOWN zones?

3. Administer First-Round Delphi Questionnaire

4. Summarize First-Round Delphi Questionnaire Responses and Prepare Second-Round Questionnaire

panel members	Zones				
	1	2	3	4	5
1 (planner)	255	1272	1272	1018	1273
2 (Realtor-Appraiser)	-280	-7560	-3360	2000	14290
3 (Mayor)	518	200	1518	1018	1836
4 (Power-Utility)	-150	-1700	1950	3400	1590
5 (Banker)	764	127	2036	127	2036
mean	(221.4)	(-1532.2)	(683.2)	(1512.6)	(4205)
median	(255)	(127)	(1518)	(1018)	(1836)
standard deviation	(358.9)	(2886.2)	(1863.1)	(1017.3)	(4609.0)

The revised questionnaire states: Given the summary of panel responses and previous data,do you wish to change your opinion on the future population distribution? Please indicate your new population distribution, if any.

5. Administer Second-Round Delphi Questionnaire

6. Summarize Second-Round Delphi Questionnaire Responses and Prepare Third-Round Questionnaire

panel members	Zones				
	1	2	3	4	5
1	255	509	1527	1018	1782
2	-280	-7000	-2000	2000	13,370
3	518	200	1518	1018	1836
4	-150	-1100	1950	2800	1590
5	509	51	1781	713	2036
mean	(170.4)	(-1468)	(955.2)	(1509.8)	(4122.8)
median	(255)	(51)	(1527)	(1018)	(1836)
Standard deviation	(302.3)	(2573.5)	(1357.0)	(709.9)	(4222.7)

The revised final questionnaire states: This is the final round questionnaire. Given the summary of panel responses and previous data,do you wish to change your opinion on the future population distribution? Please indicate your new population distribution, if any.

7. Administer Third-Round Delphi Questionnaire

8. Summarize Third-Round (final) Delphi Questionnaire Responses and Finalize Forecast

panel members	Zones				
	1	2	3	4	5
1	255	509	1527	1018	1782
2	-280	-5000	-1500	2000	10,000
3	300	200	1518	1018	2044
4	-150	-800	1950	2500	1590
5	509	51	1781	713	2036
mean	(126.8)	(-1008)	(1055.2)	(1449.8)	(3490.4)
median	(255)	(51)	(1527)	(1018)	(2036)
standard deviation	(269.1)	(1864.6)	(1175.7)	(622.0)	(2975.2)

There are numerous options for determining or deciding upon the final values which will be used for the UTOWN zonal forecasts of population growth. The median values will be used in this UTOWN application. The procedure is as follows:

Zone	Median Value (Final round)
1	255
2	51
3	1527
4	1018
5	2036
(Total)	(4887)

Zonal Population Forecast

zone 1	=	5090 (255 ÷ 4887)	=	266	
zone 2	=	5090 (51 ÷ 4887)	=	53	
zone 3	=	5090 (1527 ÷ 4887)	=	1590	5090
zone 4	=	5090 (1018 ÷ 4887)	=	1060	
zone 5	=	5090 (2036 ÷ 4887)	=	2121	

Evaluation

The Delphi technique depends upon the cooperation and contribution of many individuals. The success of any Delphi application depends upon this cooperation, in addition to the convergence of the forecasts in a minimum number of questionnaire rounds (three or less is preferred), along with the acceptability of the forecasting methodology and results to the several decisionmakers and users.

Past Delphi applications, whether they were related to forecasting land use, population, etc., required considerable time and expense. Although a large portion of this was attributable to research and development, it is likely that any Delphi application is likely to involve more time and expense than the conventional methods of forecasting. Therefore, it is likely that the Delphi land use forecast would be cost effective only in special situations where conventional methods are not available or are inappropriate.

CHAPTER III

COMPARISON OF THE CHARACTERISTICS OF SELECTED NON-COMPUTERIZED MODELS AND THEIR FORECASTING RESULTS

Table 12 lists seven noncomputerized land use models along with the variables they employ (i.e., those zonal characteristics which each model considers when determining how much growth to allocate to a zone). Table 13 contains (1) the year 2000 UTOWN forecast zonal population growth, (2) the percentage of total population growth which each zone received, and (3) the deviation of each zonal forecast from the median of all model forecasts. This table also contains a modified trend forecast.

Since the values in Table 13 are for the year 2000 there is no way of checking the absolute accuracy of the forecasts. If the purpose of the UTOWN model applications had been to compare the forecasting accuracy, the models could have been applied using 1970 as the base year and 1977 as the forecast year where the future zonal growth is already known. This approach was taken in the comparison tests in reference 1.

The purpose of this report and the various model applications using UTOWN is to demonstrate the use of the models in a forecasting vein. Therefore, in order to compare the model forecasting performance the model forecasts will be compared against a slightly modified trend forecast which is developed in the following:

TABLE 12

LIST OF MODEL VARIABLES USED IN

UTOWN APPLICATION

A. Activity Weighted Technique

(1) Existing Amt. of population

B. Multiple Linear Regression Technique

(1) change in average income

(2) change in access to emp.

C. Density Saturation Gradient Method

(1) Existing pop.

(2) Existing land-residential use

(3) Max. additional amt. land available for residential use

(4) Existing average district residential density

(5) Future average district residential density

(6) district residential capacity

(7) Existing percent residential capacity (District)

(8) Future percent residential capacity (District)

TABLE 12(Continued)

LIST OF MODEL VARIABLES USED IN

UTOWN APPLICATION

D. Accessibility Model

(1) Zonal Employment

(2) Zone to zone traveltime

(3) Access. to emp.

(4) Vacant available residential land

E. Stouffer's Intervening Opportunities Model

(1) Exist population

(2) Max. available residential land

(3) Future population density

(4) Avail. population capacity (opportunities)-ring

(5) zone to zone traveltime

TABLE 12(Continued)

LIST OF MODEL VARIABLES USED IN

UTOWN APPLICATION

F. Schneider's Intervening Opportunities Model

(1) Existing pop.

(2) Max. avail. Residential land

(3) Future population density

(4) Avail. population capacity (opportunities)-ring

(5) zone to zone traveltime

G. Delphi Technique

(1) Historic Pop. Data

(2) Other data as avail.

(3) Total forecast population growth

(4) Subjective opinions

TABLE 13
YEAR 2000 UTOWN ZONAL POPULATION GROWTH FORECASTS

Forecasting Technique	UTOWN Zonal Population Growth Forecast					Average Deviation from Median
	1	2	3	4	5	
A. Activity Weighted Technique	188[a] (3.8%)[b] [-78] [c]	1508 (29.6%) [-342]	1508 (29.6%) [228]	943 (18.5%) [0]	943 (18.5%) [823]	[294.2]
B. Multiple Linear Regression Technique	261 (5.1%) [-5]	272 (5.4%) [-894]	1776 (34.9%) [496]	1015 (19.9%) [72]	1766 (34.7%) [0]	[293.4]
C. Density Saturation Gradient Method	85 (1.7%) [-181]	1166 (22.9%) [0]	1055 (20.7%) [-225]	892 (17.5%) [-51]	1892 (37.2%) [126]	[116.6]
D. Accessibility Model	509 (10%) [243]	713 (14%) [-453]	458 (9%) [-822]	1018 (20%) [75]	2393 (47%) [627]	[444]

TABLE 13 (Continued)
YEAR 2000 UTOWN ZONAL POPULATION GROWTH FORECASTS

Forecasting Technique	UTOWN Zonal Population Growth Forecast					Average Deviation from Median
	1	2	3	4	5	
E. Stouffer's Intervening Opportunities Model	1691 (33.2%) [1425]	1235 (24.3%) [69]	862 (16.9%) [-418]	626 (12.3%) [-317]	676 (13.3%) [-1090]	[663.8]
F. Schnedier's Intervening Opportunities Model	1059 (20.8%) [793]	1898 (37.3%) [732]	1280 (25.2%) [0]	579 (11.4%) [-364]	274 (5.3%) [-1492]	[676.4]
G. Delphi Technique	266 (5.2%) [0]	53 (1.1%) [-1113]	1590 (31.2%) [310]	1060 (20.8%) [117]	2121 (41.7%) [355]	[379]

TABLE 13 (Continued)
YEAR 2000 UTOWN ZONAL POPULATION GROWTH FORECASTS

Forecasting Technique	UTOWN Zonal Population Growth Forecast 1	2	3	4	5	Average Deviation from Median
mean	579.9 (11.4%)	977.8 (19.2%)	1218.4 (23.9%)	876.1 (17.2%)	1437.8 (28.3)	
median	266 (4.9%)	1166 (21.5%)	1280 (23.6%)	943 (17.4%)	1766 (32.6%)	
standard deviation (mean)	508.4	575.9	398.2	169.1	695.8	
H. Trend Forecast	-284 (-5.5%)	-2713 (-53.3%)	4001 (78.6%)	2043 (40.1%)	2043 (40.1%)	

[a] Forecast zonal pop.

[b] (Percent of total pop. growth)

[c] Deviation from the Median

UTOWN Trend Forecast

(1) Zones	(2) 1970 Pop. (1970 % Share of Pop.)	(3) 1977 Pop. (1977 % Share of Pop.)	(4) Δ % Share of Pop. 1970 - 1977
1	3140	2920	
	(4%)	(3.8%)	-.2%
2	31,400	23,360	
	(40%)	(29.6%)	-10.4%
3	18,840	23,360	
	(24%)	(29.6%)	5.6%
4	12,560	14,600	
	(16%)	(18.5%)	2.5%
5	12,560	14,600	
	(16%)	(18.5%)	2.5%
Total	78,500	78,840	

In order to determine what the percent change of shares will be from 1977 to 2000 on a strictly trend basis the following calculations are made.

Zone

1 $\frac{-.2\%}{7\text{yrs}} = \frac{x\%}{23\text{ yrs}}$ $x = \frac{23\ (-.2)}{7} = -0.66\%$

2 $\frac{-10.4}{7} = \frac{x}{23}$ $x = \frac{23\ (-10.4)}{7} = -34.16\%$

3 $\frac{5.6}{7} = \frac{x}{23}$ $x = \frac{23\ (5.6)}{7} = 18.4\%$

4 $\frac{2.5}{7} = \frac{x}{23}$ $x = \frac{23\ (2.5)}{7} = 8.21\%$

5 $\frac{2.5}{7} = \frac{x}{23}$ $x = \frac{23(2.5)}{7} = 8.21\%$

If zone 2 continued to lose population at it former rate by the year 2000 there would be no one residing there. Therefore, it was assumed zone 2 would decline only 5% more, then a stable growth would be reached. Similarly the percentage changes in zones 3, 4, and 5 were revised downward. The revised percentage change of share values from 1977 to 2000 are:

Zone	Revised % Share 1977 to 2000
1	-0.66
2	-5.00
3	3.00
4	1.33
5	1.33

Therefore, the year 2000 percent share of population is determined by adding the above values to the 1977 percent of population values as follows:

(1) Zone	(2) 1977 % Share of Pop.	(3) Δ % Share of Pop. 1977-2000	(4) 2000 % Share of Population
1	3.8	-0.66	3.14
2	29.6	-5.00	24.60
3	29.6	3.00	32.60
4	18.5	1.33	19.83
5	18.5	1.33	19.83

To determine the zonal population for the year 2000 the above values in column (4) are multiplied by the year 2000 forecast population.

pop. zone 1 = .0314 (83,930) = 2636

pop. zone 2 = .2460 (83,930) = 20,647

pop. zone 3 = .3260 (83,930) = 27,361

pop. zone 4 = .1983 (83,930 = 16,643

pop. zone 5 = .1983 (83,930) = 16,643

Finally, the calculation of the zonal growth is as follows:

(1) Zone	(2) 1977 Pop.	(3) 2000 Forecast Pop.	(4) Col.(3) - Col.(2)
1	2920	2636	-284
2	23,360	20,647	-2713
3	23,360	27,361	4001
4	14,600	16,643	2043
5	14,600	16,643	2043

End of Trend Forecast

Table 14 indicates the deviation of the model forecasts from the trend forecasts. The numbers in parentheses are the model forecasts normalized by the trend forecasts (i.e., normalized zonal trend forecasts are 1.0).

Using the average deviation from the median shown in Table 13, the following lists the models as ranked by nearest to the median forecast.

1. Density Saturation Gradient Method (DSGM)
2. Multiple Linear Regression Technique (MLRT)
3. Activity Weigthed Technique (AWT)
4. Delphi Technique (DT)
5. Accessibility Model (AM)
6. Stouffer's Intervening Opportunities Model (SIOM)
7. Schneider's Intervening Opportunities Model (SnIOM)

Similarly by using the average normalized value of Table 14, the following ranks the models which performed in an overall manner closet to the trend forecast.

1. SnIOM
2. AM
3. MLRT
4. DT
5. SIOM
6. AWT
7. DSGM

TABLE 14
COMPARISON OF MODEL FORECAST WITH TREND FORECAST

Forecasting Technique	UTOWN Zonal Population Growth Forecast 1	2	3	4	5	Average Normalized Value
A. Activity Weighted Technique	472[a]	4221	-2493	-1100	-1100	
	(0.7)[b]	(0.6)	(0.4)	(0.5)	(0.5)	(0.54)
B. Multiple Linear Regression Technique	545	2985	-2225	-1028	-277	
	(0.9)	(0.1)	(0.4)	(0.5)	(0.9)	(0.56)
C. Density Saturation Gradient Method	369	3879	-2946	-1151	-151	
	(0.3)	(0.4)	(0.3)	(0.4)	(0.9)	(0.46)
D. Accessibility Model	793	3426	-3543	-1025	350	
	(1.8)	(0.3)	(0.1)	(0.5)	(1.2)	(0.78)
E. Stouffer's Intervening Opportunities Model	1975	3948	-3139	-1417	-1367	
	(6.0)	(0.5)	(0.2)	(0.3)	(0.3)	(1.46)

TABLE 14(Continued)
COMPARISON OF MODEL FORECAST WITH TREND FORECAST

Forecasting Technique	UTOWN Zonal Population Growth Forecast					Average Normalized Value
	1	2	3	4	5	
F. Schneider's Intervening	1343	4611	-2721	-1464	-1769	
Opportunities Model	(3.7)	(0.7)	(0.3)	(0.3)	(0.1)	(1.02)
G. Delphi Technique	550	2766	-2411	-983	78	
	(0.9)	(0.0)	(0.4)	(0.5)	(1.0)	(0.56)
mean	918.6	3695.9	-2807.6	-1149.1	-657.6	
	(2.2)	(0.4)	(0.3)	(0.4)	(0.7)	(0.80)
median	671.5	3805.0	-2833.5	-1064.0	-651.0	
	(1.4)	(0.4)	(0.3)	(0.5)	(0.7)	(0.66)
H. Trend Forecast	0	0	0	0	0	
	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)

[a] Deviation from the Trend forecast

[b] (zonal pop. forecast normalized with trend forecast)

Ranking the models according to the number of locational characteristics considered when allocating growth, the following list is obtained:

1. DSGM
2. SIOM
3. SnIOM
4. AM
5. DT
6. MLRT
7. AWT

The following model ranking is made by considering the range of the forecasts, from smallest range to largest.

1.	SIOM	(R-1065)
2.	AWT	(R-1320)
3.	MLRT	(R-1515)
4.	SnIOM	(R-1624)
5.	DSGM	(R-1807)
6.	AM	(R-1935)
7.	DT	(R-2068)
	Trend Forecast	(R-6714)

Finally ranking the models from most to least subjective, the following list is obtained:

1. DT
2. DSGM
3. SnIOM
4. SIOM
5. MLRT
6. AM
7. AWT

Table 15 provides a summary ranking of the seven models. The first column gives a numerical ranking of the models based upon how near the model forecast was to the median of all model forecasts. Similarly, the second column indicates the order in which each model's forecast was nearest to the trend forecast. Column 3 ranks models by the number of variables they employ. Column 4 ranks the models by the magnitude of the range in forecasts. Column 5 ranks models according to their overall subjectiveness.

There appears to be a relationship between the number of model variables (i.e., location characteristics) and the variation of zonal forecasts. Specifically, as the model's locational characteristics increase the greater will be the variation in zonal forecasts. Logically this might be expected since zones with similar characteristics might tend to develop in a like manner while those that exhibit different characteristics tend to develop rather differently. The point is

TABLE 15
SUMMARY OF MODEL RANKINGS ACCORDING TO FIVE CRITERIA

Forecasting Technique	Ranking				
	Near to Median Forecast	Close to Trend Forecast	Greatest No. of locational Charac.	Smallest Forecast Range	Most Subject-ive
A. Activity Weighted Technique	3	6	7	2	7
B. Multiple Linear Regression Technique	2	3	6	3	5
C. Density Saturation Gradient Method	1	7	1	5	2
D. Accessibility Model	5	2	4	6	6
E. Stouffer's Intervening Opportunities Model	6	5	2	1	4
F. Schneider's Intervening Opportunities Model	7	1	3	4	3
G. Delphi Technique	4	4	5	7	1

that as more locational characteristics are considered more zones will tend to be different and thus receive varying amounts of growth, thus, the increased variation in zonal forecasts.

A less obvious relationship is found between subjective and less-subjective (more analytical) models and the number of locational characteristics. The more subjective models tend to have a slightly larger number of locational characteristics. The more subjective models also tend to have a wider range in the zonal forecasts. This can be traced directly to the earlier identified relationship between the number of locational characteristics and the variability in zonal forecasts (i.e., since subjective models tend to have more variables it is logical that their range (variability) of zonal forecasts will be larger).

It is interesting to note that although zones 1 and 2 had been losing population, none of the models accounted for this trend. All zones were forecast to receive an increase in population. This is an operational characteristic of the simpler land use models. These models will forecast a decrease of activities in a zone only if there is a decrease for the entire study area in which case they will proportionally decrease activities within all zones. These models merely distribute areawide growth or areawide decline. They are not structured to forecast growth in some zones and decline in others.

One possible exception is the Delphi Technique. However, the majority of panel participants would have to identify the possibility of opposite trends in certain zones and reach a concensus.

The two intervening opportunity models tended to allocate a larger percentage of total population growth to the zones nearest to the central distribution point (CDP). This is perhaps related to the operational nature of these models where the zones are ranked by traveltime from the CDP and then the nearer zone is considered first. The other zones are then considered in-turn as to their ranking and their ability (i.e., opportunities for receiving activity growth) to satisfy growth desires.

It was surprising to find that the multiple linear regression technique did not come closer to the trend forecast since this is basically a trend type technique (i.e., the regression equation is fitted to past data in a least squares fit).

The Activity Weighted Technique is the least recommended technique due to the lack of any significant theoretical foundation.

Each of the seven models appear logical enough for use in small area land use forecasting (i.e., activity allocation). This is particularly true since the land use model, whether they be relatively simple or complex are tools that can be used to cut down on some of the tedious, repetitive and time consuming tasks that are encountered in activity allocation, and most evident in alternative policy testing. None of the existing models completely describe the very complex and ill-structured urban development process, since in any model development exercise there is continual compromise between operation and descriptiveness. Thus, the model output (zonal activity forecasts) must be tempered with the professional judgement of the planner (3).

CHAPTER IV

SELECTED COMPUTERIZED LAND USE FORECASTING TECHNIQUES

A. Land Use Allocation Model

B. Opportunity - Accessibility Model

LAND USE ALLOCATION MODEL

Background and Description

The Land Use Allocation Model (LUAM) is a computerized urban planning tool which was developed as part of the continuing comprehensive transportation planning study for the Mahoning and Trumbull Counties area in Ohio (now the Eastgate Development and Transportation Agency--EDATA).

The development of LUAM has as its basic objective the provision of a planning tool to speed the land use evaluation process. "The model has been designed to combine the analysis of existing land use characteristics, population and economic projections, physiographic conditions, present and potential public utility service, transportation system characteristics which affect land usage, public policies which affect master planning and urban renewal, development control activities, and established social and community factors" (1). Using a variety of data, LUAM predicts and identifies the amounts of industrial, commercial, public and semi-public, and residential use in future years.

A basic input to LUAM are population and economic projections for the forecast year (1990 for the EDATA application) which the model combines and interprets as requirements for the construction of homes, factories, shopping centers, offices, schools and other major land uses.

Theory and Operation

In LUAM, the allocation of land for specific uses (11 major categories) is determined on the basis of indices called desirabilities and suitabilities. These are factors synthesized from a number of specifically defined parameters each characterizing subdivisions of the planning area. In the sense that LUAM utilizes explicit mathematical relationships between these parameters, LUAM is an analytic model. The analytical relationships which define these indices are fixed in the model, however, the user has control over their interaction. This control is exercised by changing various weighting coefficients which control the contribution of each input factor.

LUAM is a macromodel. The land it allocates is identified only by the eleven land use categories, the amounts of land to be allocated, and the specific sub-area[1] in which the allocation is to be made. It does not specify where the various land uses are to be located within each subarea.

LUAM may be executed in either a static or dynamic mode. The model is presently designed to operate in a static mode, that is, the desirability and suitability indices remain constant for the given iteration step, which in this instance is 23 years (1967-1990). At the cost of increased running time, LUAM can be easily changed to operate in a dynamic mode, by

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1 The EDATA Planning Area is subdivided into 669 traffic zones and areas outside the cordon line.

recomputing the desirability and suitability indices after each of two or more given iteration steps.

LUAM is also deterministic. All relationships are defined with specific analytical expressions. Evaluation of probabilistic studies can be done by creating a family of population and economic projections corresponding to several probabilistic futures. The deterministic solutions of LUAM for each input would then define the probabilistic solution for the area.

Finally, LUAM is a sequential model. Land is first allocated for manufacturing uses. The homes for the new manufacturing employees are subsequently allocated. Next, land is assigned for population dependent services - schools, government, shopping centers, etc. and finally residential land is allocated for new employees of the population dependent services.

The chart in Figure 17 illustrates the flow of the overall LUAM program as conducted by the EDATA.

The initial tasks are involved with the manipulation of input data to provide land area summaries, develop the input data base, and formulate output tables.

The process, after data manipulation, could be described in the following steps:

1. Output the base year summaries for later comparison with the projection year output.
2. Formulate the employment tables by employment categories, and formulate certain employment ratios which are used in a later evaluation of the employment parameters.
3. Reorganize output from the population projection model.
4. Reorganize output from the economic prediction submodel.
5. Distribute employment by assigning people to available employment according to each of the eleven major employment categories.
6. Associate types of housing with households to whom such housing is desirable. Additional residential land is then allocated according to the needs of new housing to be constructed.
7. Determine the need to allocate land for population-dependent services such as trade, services, transportation, communication and utilities as well as cultural, entertainment and recreational activities. Subsequently, land is allocated according to the housing needs of the additional population that will be employed in the above mentioned services.
8. Formulate the projection year output for user evaluation. This information can also be used as basic input data for any future time increment projection.
9. Ready the population and economic prediction model output data for any future projections.

PROGRAM FLOW CHART

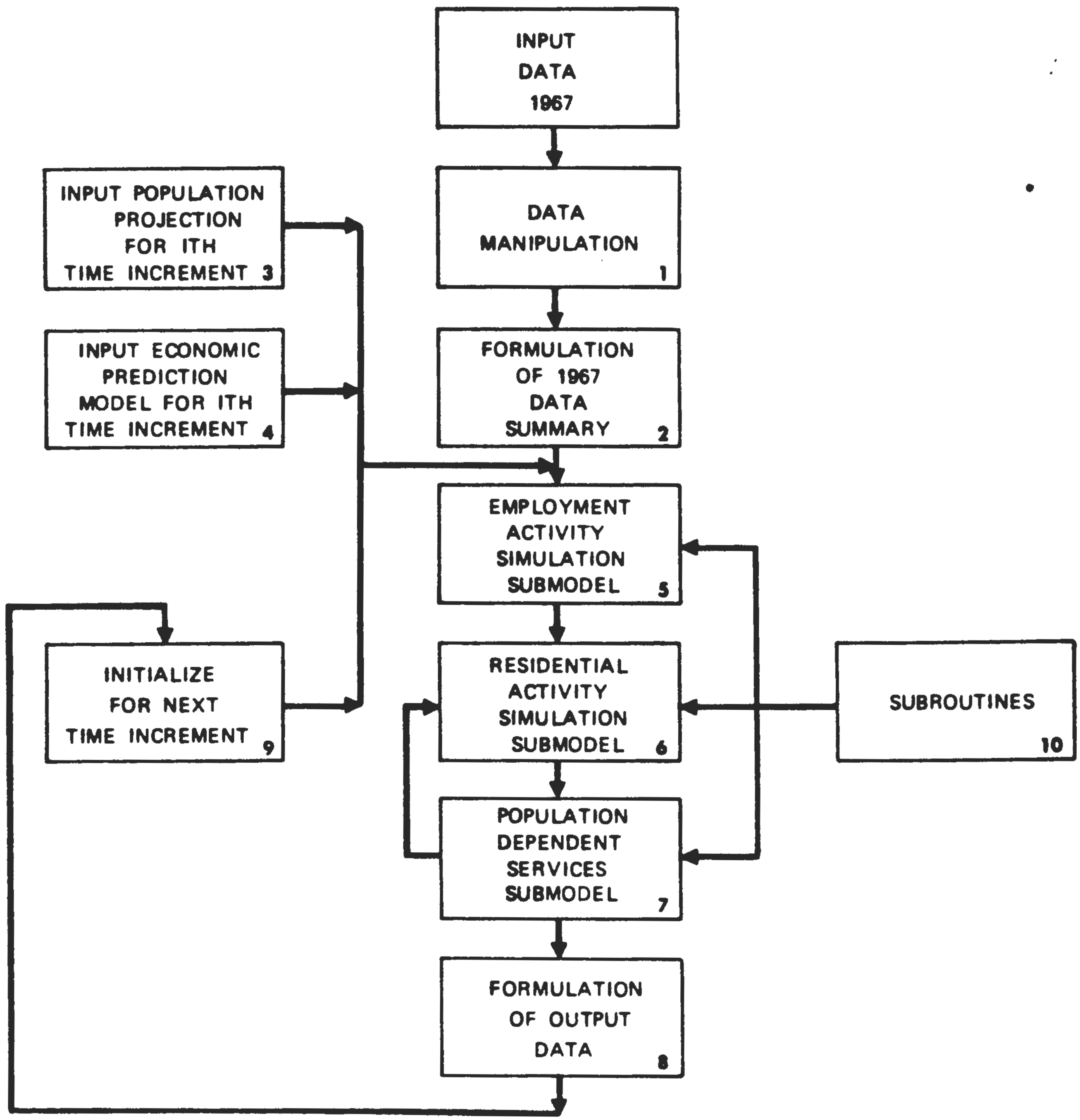

FIGURE 17

(Extracted From Reference 3)

In brief terms, the land allocation process in LUAM proceeds in these steps:

1. From the input new basic employment data (by 11 categories of manufacturing) the number of employees is converted to an amount of land consumed for new manufacturing by means of a land-per-employee factor.
2. Manufacturing land is allocated to analysis zones according to suitability indices.
3. Land is allocated for residential use by the families of the new manufacturing employees. The major influence in this process is the "relative desirability" indices which are computed for each zone. Zones are ranked in a high-to-low desirability sequence and the allocations follow that sequence. Allocations also follow an income heirarchy - highest income families are allocated first and the lowest income families last. A "housing preference matrix" is also used to define the exact number of families to be housed in each type of housing.
4. Land is allocated for population dependent services (e.g., schools, government, wholesale and retail trade, etc.) and the remaining residential uses. Land consumption for the service uses is derived from the adjusted employment projections. Land is first allocated to zones without constraints by use of the suitability indices. The excess allocations are then redistributed according to service category. The categories with the lowest suitability in each zone retain or gain the lowest allocations.

The allocation of land for "population dependent services" is repeated for six zoning classifications. Of the eight zoning classifications considered by the model, three are residential and are combined into one category for allocation purposes. The residential allocation is then subdivided in proportion to the areas of the three residential classifications.

Inputs and Outputs

LUAM has rather extensive input data requirements as shown in Figure 18. These data have been subdivided into three general types:

1. The "data base" (28 items), which is composed of factual information describing existing conditions that are not subjected to the planner's control.
2. The "population and economic projections" (5 items) contain data from independent models, which data may be modified by the user, but exogenous to the model.
3. The "control variables" (31 items) include all the quantities the planner can directly manipulate to affect the results of the model--e.g., zoning classifications, accessibility, desirability and suitability indices, utility availability, etc.

Important members of the control variables are the suitability indices which are used in the allocation of land for nonresidential uses. A

Figure 18

LAND USE ALLOCATION MODEL INPUTS

DATA BASE

1. Land area allotted to highways in each traffic zone
2. Total area of each traffic zone
3. Travel time between each zone and the nearest employment center
4. Number of families in each type of housing in each traffic zone
5. Existence of Manufacturing Employment Center in each zone (yes/no)
6. The number of cars driven to work from or in each traffic zone
7. The number of off-street parking spaces for all employed working in the zone
8. Amount of existing vacant manufacturing floor space in each zone
9. Total land area of each zone
10. Total occupied land area in each zone
11. Number of people employed in each of the 10 non-residential categories in each traffic zone
12. Number of people and families in each income group
13. Amount of land occupied by the residences for each income group
14. Number of dwellings in each income group
15. Number of cars owned by each income group
16. Average number of cars/dwelling unit
17. Number of students - elementary, junior high, senior high
18. Identification of base year associated with the data base information
19. Definition of the traffic zones in each zonal group
20. Area-wide averages for % of land occupied by each service category
21. Area-wide total vacant floor space for manufacturing
22. Actual manufacturing unemployment
23. Employment Participation rate for each income category
24. Percent of manufacturing employees in each of the 4 income classes
25. Average number of autos owned in each income category (per family)
26. Average number of families in each income category
27. Number of families living in each of the 5 types of housing
28. Percentage of each income category living in sparsely populated areas.

ECONOMIC AND POPULATION PROJECTIONS

1. Number of employees in each population dependent service category
2. Projected employment changes in each of the eleven service group categories
3. Shortage or excess of employees
4. Projected employees and unemployed from Population Model
5. Manufacturing employees from Economic Model

CONTROL VARIABLES

1. Weighing factors and coefficients for computing suitabilities and desirabilities
2. Minimum land requirements to support each land use category ("Must" Code Matrix)
3. Scale of values for land attributes in Suitability Index
4. The maximum percentage of the land in each of the eleven land use categories that may be assigned to each of the eight zoning classifications

Figure 18 (cont.)

The following information is specified for each zone:

5. Aesthetic rating
6. Amount of land zoned for each type of housing
7. Suitability of ground for construction
8. Availability of public water and sewer
9. Zoning classification of the zone
10. Residential holding capacity
11. Distance to nearest population center
12. Accessibility to transportation systems - highway, rail, bus, air, rapid rail
13. Population density
14. Income profile
15. Degree of need for each of 11 land use categories
16. Iteration step increments to be used for the Model analyses
17. Land per employee in each service group category
18. For each of the 11 land use categories, the land requirement for parking and highways
19. Percentage of governmental service land used for elementary, junior high and senior high schools
20. Pupils per acre for elementary, junior and senior high schools
21. Percent of the population dependent service employees in each of four income categories
22. Land and floor area required per manufacturing employee
23. Average number of autos driven to work and average number of parking places per employee
24. Option (yes/1)(no/0) should available jobs be filled with existing unemployed in the study area
25. People per acre ratios which define manufacturing and employment centers
26. Population densities for densely, moderately and sparsely populated areas
27. Housing preference matrix. The elements of which identify the percentages of each income category which prefer each of 5 housing types.
28. Average travel time between home and work for each income category
29. Population density preferred by each income group for its housing
30. Maximum allowable fraction of land to be occupied by highways and roads
31. Household unit factor - average number of persons per household.

suitability index is derived for each of the ten nonresidential uses from various parameters and weighting factors. The system has the form of a pyramid of parameters. On the lowest level are the most objective parameters which describe conditions in fine detail. Numerical values are assigned at this level, and the suitability index is completed from a weighted average of the major components which are scaled 0 to 10.

The output of LUAM is printed in tabular form for each traffic zone. The output is as follows:

(1) Total land use (in tenths of acres) for the 11 major land use categories.
(2) Vacant land by major zoning calssification.
(3) Maximum holding capacity of vacant residential land.
(4) The presence of public water supply.
(5) The presence of sewers.
(6) Employment by major non-residential land use categories.
(7) Proposed number of dwelling units.
(8) Estimated automobile ownership.
(9) Average number of automobiles per dwelling.
(10) Land suitability for development based on ground water characteristics, bedrock, slope and soil condition.
(11) Estimated population.
(12) Estimated number of families.
(13) School enrollment (elementary, junior high, and senior high), (1).

LUAM operates on two levels of aggregation--the zonal group (e.g., 20 traffic zones) and the traffic zone. Allocation by the submodels is first on a zonal group basis, and then on a traffic zone basis.

Capabilities

The LUAM can be used for allocating land use, population and employment for some future point in time. It can also be used to evaluate land development patterns and the effects of certain development-related conditions or policies.

LUAM can respond to policies that are reflected in items such as: zoning classifications; accessibility to transportation; availability of public water and sewerage; land use constraints; and school standards. The policy factors reflect their influence through the normal desirability and suitability indices which may also be modified by weighting factors.

Calibration

The calibration process for LUAM consists essentially of determining weighting coefficients. In order to calculate these coefficients, it is necessary to gather a substantial amount of data; enough to develop a socio-economic profile that properly characterizes the area. If the model is to be properly calibrated, it is necessary that data from three or four time frames (e.g., 1960, 1965, 1970, 1975) be available.

The LUAM developers indicate that the values for the weighting coefficients may be determined by a sensitivity study, or values may be a-priori, based on real world experiences. The EDATA developed weighting coefficients using data from a single base year. The weighting coefficients were developed based upon local evaluation of the characteristics influencing the value of the coefficients. The coefficients can be refined as more information becomes available.

Computer Software

The software package for LUAM is operational on the Burroughs B5500 computer and the IBM 360 computer. Reference 2 provides documentation on the Burroughs version. The computer program for both versions including documentation is available from the Eastgate Development and Transportation Agency, 1616 Covington Street, Youngstown, Ohio 44510.

Evaluation

The LUAM appears to be a sound and logical model for providing transportation planning inputs. LUAM operates in a sequential manner in its allocation of land, similar to that used in a Lowry-type model.

Since LUAM has been, to date, used exclusively in the EDATA area, it has not been subjected to those universal adaptations which normally occur when a model is applied to different study applications. The specific structure of the LUAM data inputs may be found to be a constraint on the transferability of the model to another study area. However, the EDATA feels that that the availability and reliability of some of the data necessary for LUAM input should not be a constraint to transferability. The new study area would be in the same position as EDATA when their model application was undertaken. Certain data would be readily available and other data would have to be collected. All of the data should be available from some source. Therefore, the reliability of the model should not differ significantly. Application of the model could not be immediate, as there are a great amount of data necessary for input.

Similarly, in its present form, LUAM is tailored to the EDATA application and is limited in the number and kind of immediately available options which it offers. However, if one is prepared to make changes to the body of the programs, there are many more options that are feasible.

The EDATA application of LUAM identified two major deficiencies in the model. One of these is the inability of LUAM to subtract. If new growth is being allocated to all zones the model performs well. However, if some zones experience a loss of growth the model cannot account for this, and the amount of existing zonal activity remains unchanged. The other concerns the strict requirement that all LUAM allocation areas must be zoned. In the EDATA study area there were several rural townships that had not developed zoning plans and values had to be assumed by the study in order to undertake the LUAM application. Since it is not likely that some of these townships will develop zoning plans by the next LUAM application in 1977 the EDATA study plans to modify LUAM to relax this strict requirement. In addition, LUAM will be modified to incorporate a subtraction capability in the model.

The EDATA intends to validate LUAM as part of their major review process. Following the validation process, the EDATA will use LUAM to forecast data to the year 2000.

OPPORTUNITY - ACCESSIBILITY MODEL

Background

The Opportunity - Accessibility model was developed for use by the Upstate New York Transportation studies. This model is a tool for allocating various urban activity forecasts to small analysis areas.

Model Description

The model is called an Opportunity - Accessibility model where opportunity is defined as the product of available land for a given activity multiplied by the density of the activity (unit activity per unit land). The basic premise of the model is that the probability of an activity (person, jobs, etc.) finding a suitable opportunity (a unit of available residential or nonresidential capacity) for location at a given distance is hypothesized to be a monotonically decreasing functions of the number of intervening opportunities (number of opportunities encountered up to that distance). Opportunites being ranked by time from some central distribution point such as the central business district. The formulation of the model is:

$$d(Gp) = g_t \left[e^{-\ell O} - e^{-\ell (O+O_p)} \right]$$

Where:

Gp = total number of locations in Opportunity interval from the central distribution point up to interval p

g_t = total growth to be allocated

ℓ = model parameter expressing the probability of an opportunity being accepted for location

O = total number of Opportunities ranked from the central distribution point up to interval p

Op = Opportunities in interval p

e = base of natural logarithm = 2.71828

The model has a negative exponential formulation which produces a number which ranges from zero to one. The logic of this formulation is as follows: g_t represents the total amount of activity which is forecast to take place within the study area within a given time period. If the term $[e^{-\ell O} - e^{-\ell (O+Op)}]$ generates a number that is greater than one, this would imply that more activity is being allocated to zone one than has been allocated or predicted for the entire study area. The other limit of this term would be zero. Thus, the entire term ranges from zero to one.

The zones within the study area are sequenced or ranked in ascending order of traveltime from one or more central distribution points. Based upon this order, activities are placed or allocated in each of the zones depending on the opportunities available within each zone.

The activities are allocated in the following sequence when one central distribution point is used:

1. Allocate nonresidential trips
2. Adjust available land supply
3. Allocate residential trips
4. Adjust available land supply
5. Allocate population
6. Adjust population land supply

If recursive forecasting is used the above six phases are repeated for each period of time through the forecast target year.

In the event more than one central distribution point is used, phases 1 and 2 are repeated for each of the centers, then phases 3 and 4 are repeated for each of the centers, and finally phases 5 and 6 are repeated. The amount of activity to be allocated from each center is some portion of the total activity which has been exogenously forecast.

At the end of a run for a given target year, the original inventory files for each of the activities (that are being allocated) by zone are then updated and a new accounting is provided of available land for development which may then be used for the next forecast period.

Input Requirements

The model requires two exogenous inputs: the forecast change of the activity to be allocated to the various zones, and the ranking of zones in ascending order based on the traveltime from the central distribution point to the centroid of the zones. These times are determined by using traffic network programs.

The model also requires a complete inventory of each analysis zone of the type of activity that is to be allocated. Seven types of activities can be allocated. They are:

1. Population
2. Vacant land
3. Residential land
4. Nonresidential land
5. Nongenerating land
6. Residential trips
7. Nonresidential trips

Vacant land is stratified into two categories: that being available for development, and that which is permanently withheld from development.

The following variables are needed to calculate zonal opportunities: (1) the availability of land for a particular type of activity within each zone, and (2) the density of this activity for that particular zone. In order to rank the zones the traveltime from the central distribution point to the centroid of each zone is needed. It should be realized that for each activity to be allocated the data base within each zone for each activity must be determined by zone.

Model Outputs

The model produces zonal level forecasts of the following activities:

1. Population
2. Vacant land
3. Residential land
4. Nonresidential land
5. Nongenerating land
6. Residential trips
7. Nonresidential trips

Capabilities

The Opportunity - Accessibility Model can be used as a straight forward tool to forecast the future small area distribution of several activities within an urban area. In addition it allows the analysis and evaluation of the impacts of various public and private policies regarding transportation and land development.

Calibration

The model is calibrated by determining the "ℓ" values using data from two time periods. For an explanation of the fitting of the model to actual data, the formula can be restated after integration as $Gp = G_t\,(1 - e^{-\ell O})$ substracting G_t from both sides and rearranging,

$$G_t - Gp = G_t\, e^{-\ell O}$$

or

$$\ln\,(G_t - Gp) = \ln G_t - \ell O$$

In theory this relationship plots as a straight line where the ordinate $(G_t - Gp)$ is in logarithmic scale and the abscissca (total accumulated opportunities from the central distribution point (O)) is in linear scale, the zones being ranked by traveltime to the central distribution point. The slope is "ℓ" and the intercept G_t. Experience has shown that when actual data are used two or more straight lines may occur. In this case, the actual values are approximated by two straight lines with slopes "ℓ_1" and "$\ell 2$".

Computer Software

The model is operational on the IBM 7094 and Burroughs 5500 Computers. The model is programmed in FORTRAN. The model and user's documentation may be requested from the New York State Department of Transportation, 1220 Washington Avenue, State Campus, Bldg. 5, Albany, New York 12232.

Evaluation

The Opportunity - Accessibility Model compares favorably with other models when used to forecast zonal activity growth. The major requirement of the model is the need to estimate the future distribution of opportunities (future activity capacity for the particular activity being allocated). Opportunity is usually defined as the product of available land for a given activity and the density of the activity (unit activity per unit land).

For a discussion of a noncomputerized version of this model see the writeup on Schneider's Model in Chapter 2.

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