Land Use Forecasting for Transportation Planning

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●THIS REPORT is concerned with a recent attempt to develop a land-use forecasting procedure to be incorporated into the urban transportation planning process. The approach taken and the methods used were conditioned to a large extent by the function that such a procedure is required to perform in the larger process of developing urban transportation plans. Therefore, a brief review of this over-all planning process may be helpful in understanding and evaluating the investigations and results reported in this paper.

Figure 1 is a block diagram of the transportation planning process. The approach to transportation planning outlined in this diagram has evolved from the many transportation studies which have been made during the past decade. In particular, credit must be extended to the Detroit and Chicago studies which have contributed so heavily to the development of this process and the various techniques required.

In short, the planning process is composed of policy decisions and a series of estimating techniques, the latter being arranged in such a manner that it is possible to test and evaluate a transportation program in light of (a) anticipated future travel demands and (b) community land-use plans and objectives. Both of these checks must be made if a reasonable transportation program is to be developed (1).

Examination of Figure 1 shows that several conditions must be met by the land-use forecasting procedure if it is to fulfill its function. These conditions and characteristics are:

1. It is a distributive process. Previously developed aggregate forecasts of population and economic activity are to be distributed to transportation planning zones throughout the urban area.
2. It deals with only the net increase of population and economic activity. The existing pattern of land use is assumed to remain stable over the period of the forecast.
3. It must be sufficiently mechanical to be susceptible to machine processing.
4. The transportation network must be made explicit in the forecasting procedure. If this is not done it will be impossible to evaluate a transportation program in light of community land-use plans and objectives.

A RESIDENTIAL LAND-USE MODEL

It was decided that the first investigations of land-use forecasting would be limited to the development of a residential land-use forecasting model. This was done, first, because this type of land use constitutes the bulk of urban development, and second, it was felt that residential growth was more susceptible to systematic prediction because it is the result of numerous individual, relatively minor decisions rather than a few large decisions as is the case with commercial and industrial development.

Among the many factors which could be expected to influence the pattern of residential growth—topography, existing land-use patterns, transportation facilities, public services, and land development regulations, to mention a few—city planners, economists, and urban geographers have long emphasized the importance that accessibility has on the pattern of urban development. The general hypothesis, that the more accessible an area is to the various activities in a community the greater is its growth potential and probable intensity of development, has been expressed in one form or another for some time. This general proposition has received close to universal acceptance despite the complete lack of any attempts to quantify the relationship and test the hypothesis.

Consistent with this intuitive acceptance of a relationship between accessibility and land development, it was felt that a residential land-use model based on a realistic

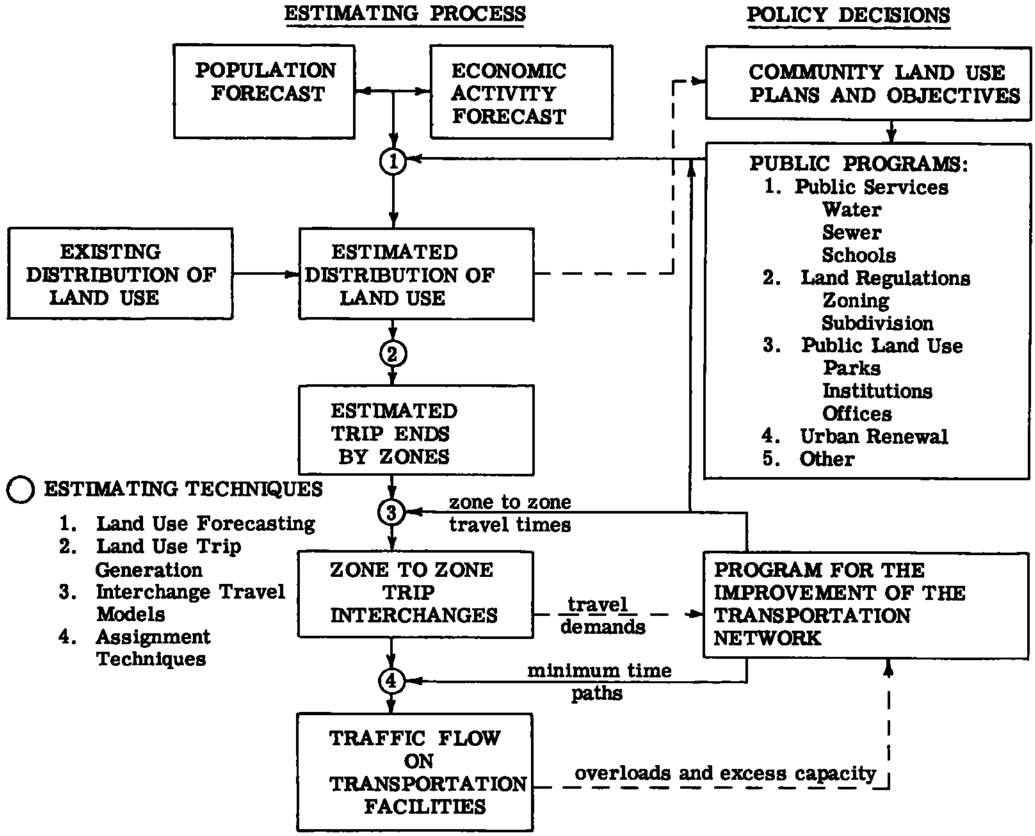


Figure 1. Transportation planning process.

measurement of accessibility along with the availability of vacant developable land could be established. Such a model would take the following form:

$$\frac{G_i}{G_T} = \frac{O_i\, f(A_i)}{O_i f(A_i) + O_j f(A_j) + \ldots\ O_n f(A_n)} \tag{1}$$

in which

G_i is equal to the residential growth in zone i.

G_T is equal to the total residential growth in the urban area.

O_i is the vacant developable land in zone i.

A_i is a measure of the accessibility of zone i.

f is a function.

The model states that the proportion of the total urban area residential growth which can be expected to take place in any zone i is equal to that zone's attractiveness for development relative to the summation of the attractiveness of all zones, where the attractiveness of a zone is equal to the amount of developable land in a zone modified by some function of the accessibility of that zone.

As used in this investigation, accessibility is defined as the potential of opportunities for interaction. Stated in another manner it may be thought of as a measure of the effective opportunities for interaction at any zone i, created by the actual opportunities at any zone j. Stated in this manner it is obvious that the accessibility at zone i to a particular activity at zone j (say employment) varies directly with the size of the activity located at zone j (number of jobs) and varies inversely with some function of the distance separating zones i and j. More formally this concept is expressed in the following formula:

$$ {}_iA_j = \frac{S_j}{f(D_{i-j})} \qquad (2) $$

in which

${}_iA_j$ is a measure of the accessibility at zone i to an activity located in zone j.

S_j is a measure of the size of the activity located in zone j; for example, number of jobs, population, retail sales.

D_{i-j} is a measure of the distance between or separation of zones i and j.

It was assumed that the function of distance in Eq. 2 would be exponential; that is, the measurement of distance would be raised to some power. This assumption was based on results of various examinations which have been made of urban travel patterns. In addition, to meet the condition that the transportation network be made explicit in the land-use forecasting model, the distance separating the various zones must be expressed in terms of travel time. Under these conditions the formula for calculating the total accessibility of a zone becomes:

$$ A_i = \frac{S_i}{T_{i-i}^{\,b}} + \frac{S_j}{T_{i-j}^{\,b}} + \cdots \frac{S_n}{T_{i-n}^{\,b}} = \sum_{i}^{x=n} \frac{S_x}{T_{i-x}^{\,b}} \qquad (3) $$

in which

T_{i-x} equals the travel time between zone i and any zone x.

b is an exponent describing the magnitude of the effect that the separation T_{i-x} has on the possibility of interaction between zones i and x.

This measurement of accessibility contains elements of both the existing pattern of land use and the transportation system. It is a relative measure of the effective distribution of an activity around a zone.

Using Eq. 3 and data for the Washington, D.C., metropolitan area, an empirical examination was made to determine the relationship between this measurement of accessibility and residential growth. O-D studies, conducted in 1948 and repeated in 1955, supplied the bulk of the information required to calculate the accessibility measurements and to determine the pattern of residential growth over the 7-yr period. (The travel data used in the study were collected in 1948 and 1955 in two O-D surveys conducted by the Regional Highway Planning Committee for the Washington Metropolitan Area which was financed jointly by the highway departments of the District of Columbia, Maryland, Virginia, and by the Bureau of Public Roads. Land-use and economic data were obtained from the National Capital Planning Commission and the National Capital Regional Planning Council.)

Because a majority (80 percent) of all personal travel originating in residential areas is for work, shopping, or social purposes, this study was limited to an examination of the relationships between residential growth and accessibility to employment, shopping, and social opportunities.

Table 1 gives the types of data which were used to calculate the various measures of accessibility. The exponents of distance shown in this table were based on information made available by the Baltimore Transportation Study of 1957-58. (The exponent values are tentative. Additional research is being done by the Bureau of Public Roads to develop and statistically evaluate these exponents for the Washington, D.C., area.)

TABLE 1

DATA FOR ACCESSIBILITY CALCULATIONS

Accessibility to	Units Used to Express Activity Level of Zone S_i	Exponent of Distance[1] b
Employment opportunities	Number of jobs	2.20
Shopping opportunities	Annual retail sales	3.00
Social opportunities	Population	2.35

[1] Distance is expressed in minutes of off-peak driving time plus 5 to 8 min of terminal time.

Travel time was expressed in minutes of driving time plus 5 to 8 min of terminal time, depending on the location and density of the zone.

These examinations led to the development of the following residential land-use model:

$$\frac{G_i}{G_T} = \frac{O_i \text{ A-E}_i^{3.04}}{O_i \text{ A-E}_i^{3.04} + O_j \text{ A-E}_j^{3.04} + \ldots O_n \text{ A-E}_n^{3.04}} \qquad (4)$$

in which

G_i and G_T are increases in the number of dwelling units.

A-E_i equals the accessibility to employment at zone i.

Other models could have been developed based on accessibility to retail activity or population or some combination of all three accessibility indexes; however, accessibility to employment was found to be most closely correlated to residential growth and it was not felt that the inclusion of the other measures of accessibility would result in any substantial improvement of the estimating accuracy of the model. This formula varies from one previously reported (2).

The model (Eq. 4) was used to estimate the distribution of the 1948-1955 residential growth (zonal increase in dwelling units) for the Washington, D.C., area. Comparison of these estimated growths to the actual increase of dwelling units in each zone showed that approximately three-quarters of the estimates were within 50 percent of the actual growths.

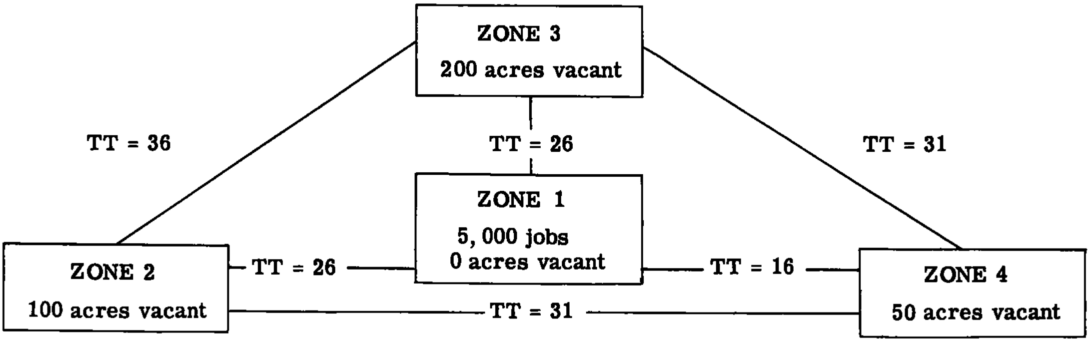
Although these results are quite promising and indicate that accessibility and the availability of land are major determinants in the pattern of residential growth, they do not in themselves produce sufficiently accurate estimates for planning purposes. Other factors must be examined and included in the model if a usable estimating process is to be developed.

The immediate value of the described model is that it makes it possible to examine empirically the effects that other factors such as zoning, taxes, and land costs have on the pattern of residential growth. The effect of such factors can be determined by studying their relationship to the differences between the actual distribution of growth and the estimated distribution of growth based on accessibility. In brief, the model can be used to establish a common reference base.

These examinations would provide both the city planner and the transportation planner with a deeper insight into the process of urban development.

An examination of this type is now being made in the Hartford, Conn., area. Several factors which seem to exert a substantial influence on residential growth have been identified: land costs, cost of providing utilities, zoning policies, land holding, and prestige. When these and other related factors with their relationship to residential growth have been quantified, it should be possible to develop a sufficiently accurate residential land-use model.

The following example is presented to help clarify the mechanics of the model and to demonstrate its potential value to transportation planning. The model used in this example is based solely on accessibility to employment and vacant land, and should not therefore be interpreted as a proposal, but rather as an illustration.



Area Num.	Accessibility to Employment $A_i = \sum_1^n \frac{\text{jobs}}{TT^{2.2}}$	Development Ratio $KD_i = A_i^{3.04}$	D_iO_i	% of Total Development $\frac{D_iO_i}{\sum_1^n DO}$	Residential Growth G_i (D.U.)
<u>Case I</u>					
2	$\frac{6,000}{26^{2.2}} = 4.6$	105	10,500	6.5	130
3	$\frac{6,000}{26^{2.2}} = 4.6$	105	21,000	13.0	260
4	$\frac{6,000}{16^{2.2}} = 13.3$	2,600	130,000	80.5	1,610
		$\sum_1^n DO =$	161,500	100.0	$G_T = 2,000$
<u>Case II</u>					
2	$\frac{6,000}{21^{2.2}} = 7.5$	460	46,000	23.4	468
3	$\frac{6,000}{26^{2.2}} = 4.6$	105	21,000	10.6	212
4	$\frac{6,000}{16^{2.2}} = 13.3$	2,600	130,000	66.0	1,320
		$\sum_1^n DO =$	197,000	100.0	$G_T = 2,000$
<u>Case III</u>					
2	$\frac{5,000}{26^{2.2}} + \frac{1,000}{36^{2.2}} = 4.2$	79	7,900	1.7	34
3	$\frac{5,000}{26^{2.2}} + \frac{1,000}{9^{2.2}} = 11.9$	1,850	370,000	80.0	1,600
4	$\frac{5,000}{16^{2.2}} + \frac{1,000}{31^{2.2}} = 11.6$	1,700	85,000	18.3	366
		$\sum_1^n DO =$	462,900	100.0	$G_T = 2,000$

TT = Travel time in minutes (driving plus terminal time).
Note: Intrazone travel time equals 9 min.

Figure 2. Illustration of land-use model.

Illustration of Model

Figure 2 is a diagram of a four-area hypothetical metropolitan region, showing the existing employment, vacant developable land, and the travel times between areas. Estimated growth for the entire metropolitan region, by some future point in time, is 2,000 dwelling units and 1,000 jobs. The distribution of residential growth will be forecast for each of the following cases:

Case I. The travel times between areas are the same in 1965 as at present and the increase in employment takes place in zone 1.

Case II. By 1965 an express highway is built between zones 1 and 2 reducing the travel time from 26 min to 21 min. The increase in employment takes place in zone 1.

Case III. The travel times between zones are the same in 1965 as at present and the increase in employment takes place in zone 3.

The calculations in Figure 2 demonstrate the potential value of this and similar land-use models to city and transportation planning. The model can assist the planner in assessing the probable effects of a given action; for example, the construction of an express highway (Case II) or a policy of decentralizing employment (Case III). Of particular importance is the fact that this determination of consequences need not be limited to some predetermined area of "influence," but can be assessed for all areas within the metropolitan region. For example, comparing Case II to Case I in the preceding illustration, the fact that zones 3 and 4 will experience less than expected growth due to the construction of the expressway may be more important than the increased growth in zone 2. Present estimating procedures would be unable to make such assessments.

By incorporating this land-use forecasting model into the transportation planning process (Fig. 1), it would be possible to determine the impact that these changes would have on the transportation system.

It should be pointed out that the reliability of this model for forecasting purposes is sensitive to the quantity of residential growth being distributed. The model distributes an increment of growth according to a constant set of factors. In reality, however, growth is a continuous process and the factors affecting its distribution, accessibility, vacant land, and other elements, are constantly changing. If a large increment of growth expected to occur over a fairly long period of time (20 yr) is distributed in a single application of the model, the resulting errors are likely to be quite large.

This does not mean that the model cannot be used for long-range forecasts; quite the contrary. When combined with estimates of the probable density of development in each zone, successive applications of the model can be used to synthesize urban growth up to any point in time. It is this aspect of the illustrated residential land-use model which offers the greatest potential value to the transportation planning process. When coupled with the traffic estimating procedures, it will be possible to examine the reasonableness of a transportation program in light of travel demands at several points in time. Such an examination would prove invaluable in determining priorities. It would also be possible to determine the timing and sequence of constructing segments of an expressway system which would best promote a desired distribution of metropolitan residential growth.

As other factors are examined and incorporated into the model—in particular these factors which are subject to change by conscious public action, such as zoning and the provision of public services—the model should become increasingly valuable for planning purposes. For example, it would be possible to coordinate a program of zoning regulations with a transportation program so that the transportation system will operate with maximum efficiency.

In conclusion, it is felt that a prototype of the land-use forecasting procedure required for transportation planning purposes has been developed. However, much hard work remains to be done before the potential value of this procedure can be realized. It is hoped that this paper will stimulate others to investigate this potentially productive area of research.

REFERENCES

1. Carroll, J.D., Jr., and Creighton, R.L., "Planning and Urban Area Transportation Studies." HRB Proc. 36:1-7 (1957).
2. Hansen, W.G., "How Accessibility Shapes Land Use." Jour. Amer. Inst. of Planners (May 1959).