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How Accessibility Shapes Land Use

An empirical examination of the residential development patterns illustrates that accessibility and the availability of vacant developable land can be used as the basis of a residential land use model. The author presents an operational definition and suggests a method for determining accessibility patterns within metropolitan areas. This is a process of distributing forecasted metropolitan population to small areas within the metropolitan region. Although the model presented is not yet sufficiently well refined for estimating purposes, the concept and the approach may be potentially useful tools for metropolitan planning purposes.

AUTHOR'S NOTE: This article is a preliminary presentation of certain concepts and findings developed while the author was attending the Massachusetts Institute of Technology under Public Law 85–507, which permits employees of the federal government to extend their education in areas closely allied to their work.

This study is part of a broader research project of the Bureau of Public Roads, designed to explore empirical relationships between land use and highway traffic with a view to coordinating and improving urban planning and highway planning.

CITY PLANNERS have continually emphasized the far-reaching effects that accessibility has on the development of land. The more accessible an area is to the various activities in a community, the greater its growth potential.

Consistent with this general concept of a relationship between accessibility and land development, a land use model, based on a realistic measurement of accessibility, can be developed. Such a model would relate the accessibility of an area to the rate and intensity of the land development in that area.

This paper explains the development of a residential land use model—a process of distributing total metropolitan population growth to small areas within the metropolitan region. Similar models, though more complex, are being investigated for commercial and industrial development.

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Because a majority (80 per cent) of total personal travel is for work, shopping, and social purposes, this study has limited its investigations to the examination of the relationships between residential development and accessibility to commercial, industrial, and residential locations. These relationships coupled with the availability of space for development form the basis of the proposed residential land use model.

Measurement of Accessibility

As used in this paper, accessibility is defined as the *potential* of opportunities for interaction. This definition differs from the usual one in that it is a measure of the *intensity of the possibility of interaction* rather than just a measure of the ease of interaction. Defined in this manner, accessibility is a generalization of the population-over-distance relationship or "population potential" concept developed by Stewart.[1]

In general terms, accessibility is a measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome spatial separation. More specifically, the formulation states that the accessibility at point 1 to a particular type of activity at area 2 (say employment) is directly proportional to the size of the activity at area 2 (number of jobs) and inversely proportional to some function of the distance separating point 1 from area 2. The total accessibility to employment at point 1 is the summation of the accessibility to each of the indi-

[1] J. Q. Stewart, "Demographic Gravitation: Evidence and Applications," *Sociometry* 11:1–2 (2/5/48), 31–58.

vidual areas around point 1. Therefore, as more and more jobs are located nearer to point 1, the accessibility to employment at point 1 will increase.[3]

Most of the controversy concerning gravity or potential models has surrounded the question of what the function of distance should be. It is generally agreed, and empirical examination indicates, that an exponential function should be used; that is, the measurement of distance separating the various areas should be raised to some power.

Unlike the contention of Stewart and others that this exponent should be unity, the assumption here is that the value of the exponent in this accessibility or potential model must be the same as that used in the gravity model. However, expirical tests of gravity models have resulted in exponent values that range from 0.5 to almost 3.0. When only those examinations conducted within urban areas are considered, the variation in the exponent for different trip purposes seems reasonable.[3] These studies indicate decreases in the exponent as trips become more important, i.e., school trips 2.0+, shopping trips 2.0, social trips 1.1, work trips 0.9. Inasmuch as distance appears in the denominator of the gravity model, a decrease in the exponent means that distance becomes a less restrictive factor. In short, the variation in the exponent shown above means that people are willing to travel farther to work than they are for any of the other purposes.[4]

It is when the results of these intraurban studies are compared to the findings of interurban examinations that an unexplainable variation in the value of the exponent appears. The analyses carried out in interurban travel reveal exponents of between 2.5 and 3.0.[5]

One reason for this apparent variation in the results of the intra- and inter-urban investigations is that these studies did not include terminal time or terminal effect in the measurement of distance. In interurban travel, since most of the trips are relatively long, the effect of omitting from 5 to 6 minutes of terminal time is probably negligible. In intraurban travel, however, where the median travel time is usually less than 20 minutes, a 5 to 6 minute terminal time would have considerable effect on total trip time.

To determine the effect of terminal time on the exponent of distance, the results of an analysis of travel patterns in Baltimore, Maryland, were examined.[6] The examination showed that, if driving times alone were used as a measure of distance, the exponent did not remain constant but increased as the time of separation increased. By incorporating from 5 to 6 minutes of terminal time into this measure of separation the variation in the exponent for any particular type of purpose of trip was greatly reduced.

When the separation of areas was expressed in terms of travel time plus terminal time the exponents for the various types of trips were found to be: work trips 2.20; social trips 2.35; shopping trips 3.00. These values are consistent with those determined by the various interurban examinations and were incorporated into the formula for computing accessibility.

Empirical Analysis

Data for the Washington, D.C., metropolitan area were used for empirical examinations of the relationships between residential development and accessibility.[7] Origin and destination studies, conducted in 1948 and repeated in 1955, supplied the bulk of the information necessary to calculate the accessibility measurements and to determine the pattern of residential, commercial, and industrial development over a period of seven years.

Table 1 illustrates the kinds of data used to calculate the various measurements of accessibility. Using the formulas developed in the preceding section, the accessi-

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[3] More formally this concept can be expressed by the following formula:

$$ {}_1A_2 = \frac{S_2}{T^x_{1-2}} $$

where

${}_1A_2$ is a relative measure of the accessibility at Zone 1 to an activity located within Zone 2;

S_2 equals the size of the activity in Zone 2; i.e., number of jobs, people, etc.;

T_{1-2} equals the travel time or distance between Zones 1 and 2;

x is an exponent describing the effect of the travel time between the zones.

If there are more than two zones involved, the formula becomes:

$$ A_1 = \frac{S_2}{T^x_{1-2}} + \frac{S_3}{T^x_{1-3}} \cdots + \frac{S_n}{T^x_{1-n}} $$

This is the formula which was used to calculate the variation in the accessibility between areas.

[3] J. Douglas Carroll, Jr., and H. W. Bevis, "Predicting Local Travel in Urban Areas," *Papers and Proceedings of the Regional Science Association*, Vol. 3, 1957. See also Alan M. Voorhees, *A General Theory of Traffic Movement*, (the 1955 Past Presidents Award Paper, Institute of Traffic Engineers).

[4] These 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.

[5] J. Douglas Carroll, Jr., "Spatial Interaction and the Metropolitan Description," *Papers and Proceedings of the Regional Science Association*, Vol. 1, 1955.

[6] For an explanation of the mechanics of this type of analysis, see *Detroit Metropolitan Area Study*, July 1955, Vol. 1, pp. 92–93.

[7] The travel data used in the study were collected in 1948 and in 1955 in two origin-and-destination surveys conducted by the Regional Highway Planning Committee for the Washington Metropolitan Area, 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.

bility to employment, population, and shopping opportunities were calculated for 70 areas in the Washington metropolitan area. Since accessibility is a spatially continuous measurement, it can be mapped in much the same way as heights are depicted on a topographic map.

TABLE 1

DATA FOR ACCESSIBILITY CALCULATIONS

Accessibility to	Units used to Express Activity Level or Size	Exponent of Distance*
Employment...............	Number of jobs	2.20
Shopping opportunities.....	Annual retail sales	3.00
Residential activity........	Population	2.35

* Distance is expressed in minutes of off-peak driving time plus 5 to 8 minutes of terminal time.

The map in Figure 1 on page 72 shows the lines of equal accessibility to employment for the Washington area in 1955. Similar maps may be conceived for accessibility to population and to shopping opportunities.

To determine the relationship between residential development and accessibility, it is first necessary to account for the zonal variation in land available for residential development. This was done by distributing total metropolitan growth to the individual zones on the basis of vacant developable land; i.e., if Zone A contained 10 per cent of the vacant land in the metropolitan area, 10 per cent of the expected growth was assigned to Zone A. This proportion of the total metropolitan development assigned to each zone is termed the *probable development.*

If there is a difference between the probable and actual development, it is assumed that the variance is related to accessibility. One way of expressing this difference is to divide the actual development by the probable development. This factor is termed the development ratio.

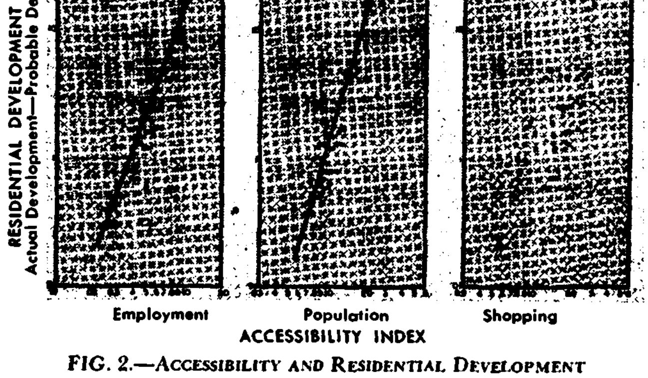


FIG. 2.—ACCESSIBILITY AND RESIDENTIAL DEVELOPMENT

The residential development ratio was calculated for each of the areas displayed in Figure 1. Subsequently, these development ratios were examined to reveal whether they varied systematically with the various measures of accessibility. Observe the results in Figure 2. Visual examination suggests that the correlations between the development ratio and the measures of accessibility to employment and population are quite high.

The free-hand line in Figure 2, approximating the relationship between the development ratio and accessibility to employment can be expressed by the following formula:

$$D_1 = KA_1^{2.7}$$

where

D_1 is the development ratio for Zone 1;

A_1 is the accessibility to employment at Zone 1;

K is a constant of proportionality.

Using this relationship it becomes possible to estimate the residential growth in any zone if the accessibility to employment and the amount of developable land of the zone are known. As previously described, the probable development in any zone is determined on the basis of the proportion of the developable land in that zone. To estimate the actual development, the probable development is multiplied by the development ratio (D_1) (which in Washington is equal to 13.7 times the accessibility to employment raised to the 2.7 power).[8]

This method was used to estimate the residential growth from 1948 to 1955 for each of the zones in the Washington metropolitan area. A comparison of the estimated growths to the actual growths showed that 40 per cent of the zonal estimates were within 30 per cent of the actual growths and 70 per cent of the zonal estimates were within 60 per cent of the actual figures. When it is remembered that these estimates are based on only two independent variables, accessibility to employment and vacant land, the results are quite promising. The inclusion of the other measures of acces-

[8] A more generalized estimating model is shown by the following formula:

$$\frac{P_1}{P_t} = \frac{D_1O_1}{D_1O_1 + D_2O_2 + \cdots D_nO_n}$$

substituting $KA^{2.7}$ for D, and cancelling the K:

$$= \frac{A_1^{2.7}O_1}{A_1^{2.7}O_1 + A_2^{2.7}O_2 + \cdots A_n^{2.7}O_n}$$

where

P_1 equals the increase in residential population in Zone 1;

P_t equals the total increase in residential population for; the entire metropolitan area

O_1 equals the developable land in Zone 1.

sibility through multiple correlation will undoubtedly improve the predictive ability of the model.

The following example is presented to help clarify the mechanics of the model and to demonstrate its potential value to the planner.

Illustration of Model

Figure 3 is a diagram of a four-area hypothetical metropolitan region showing the existing population, employment, vacant developable land, and the travel times between areas. Estimated growth for the region by 1965 is 2,000 more people and 1,000 more jobs. The distribution of residential development will be determined 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.

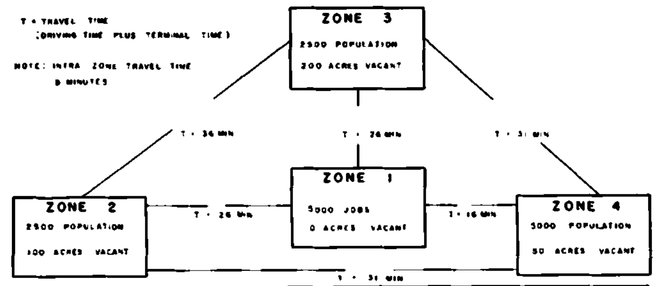
Case II. By 1965 an express highway is built between Zones 1 and 2 reducing the travel time from 26 minutes to 21 minutes. The increase in employment takes place in Zone 1.

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

The calculations in Figure 3 demonstrate the potential value of this and similar land use models to the city planner. The model can assist the planner in assessing the probable effects of a given action; such as the construction of an express highway (Case II) or a policy of decentralizing employment (Case III). This determination of consequences need not be limited to some predetermined area of "influence," but can easily be assessed for the entire metropolitan region.

It should be pointed out that the reliability of this model for estimating purposes is very sensitive to the quantity of development being distributed. The model is only capable of distributing fairly small increments of growth in a single application. The reasons for this limitation are quite apparent when it is remembered that the pattern of accessibility is constantly changing through time, and, furthermore, that the accessibility and the availability of developable land at any point in time is in part dependent upon the distribution of growth during the immediately preceding period.

This does not mean that the model cannot be used for long range forecasts; quite the contrary. When combined with knowledge concerning the probable density of development in each area, successive applications of the model can integrate time or synthesize metropolitan growth up to any point in time. It is for this purpose that the model when sufficiently refined, offers its greatest potential value. It will allow the planner to assess



Area number	Accessibility to employment (A_1)	Dev't ratio*	$D_1 C_1$	% of total Dev't†	Res. pop. increase (P_1)
CASE I					
2	$\frac{6000}{26^{2.2}} = 6.3$	145	14,500	14.7	294
3	$\frac{6000}{26^{2.2}} = 6.3$	145	29,000	29.5	590
4	$\frac{6000}{16^{2.2}} = 13.3$	1100	55,000	55.8	1116
Total			98,500	100.0	2000
CASE II					
2	$\frac{6000}{21^{2.2}} = 7.5$	230	23,000	21.5	430
3	$\frac{6000}{26^{2.2}} = 6.3$	145	29,000	27.1	542
4	$\frac{6000}{16^{2.2}} = 13.3$	1100	55,000	51.4	1028
Total			107,000	100.0	2000
CASE III					
2	$\frac{5000}{26^{2.2}} + \frac{1000}{36^{2.2}} = 5.7$	110	11,000	4.1	82
3	$\frac{5000}{26^{2.2}} + \frac{1000}{9^{2.2}} = 13.3$	1100	220,000	82.0	1640
4	$\frac{5000}{16^{2.2}} + \frac{1000}{31^{2.2}} = 11.6$	750	37,500	13.9	278
Total			268,500	100.0	2000

* $(D_1 = A_1^{2.7})$ † $(D_1 O_1 / \Sigma_1^N DO)$.

FIG. 3.—Hypothetical Example: Application of the Accessibility Model

the accumulated consequences through time of a given action taken at a given time. For example, it would be possible to determine the timing and sequence of constructing an expressway system which would best promote a desired distribution of metropolitan population.

The immediate value of the relationships described in this paper is that it will be possible to isolate and examine empirically the effect of other factors on land development, such as income, zoning, taxes, and land costs. The results of such studies would provide the planner with a clearer understanding of the metropolitan community and of the effectiveness of land controls. The results of these studies could also be incorporated into the present model.

Although additional research and refinement are required, the approach described here can provide the city and transportation planner with a valuable tool.