ACCESSIBILITY

AND

RESIDENTIAL GROWTH

by

WALTER G. HANSEN

B.S.C.E.   South Dakota   School of Mines and   Technology

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF

CITY PLANNING

at the

MASSACHUSETTS INSTITUTE OF

TECHNOLOGY

June , 1959

Signature of Author:. . . . .
              Department of City and Regional Planning
                                        May 6, 1959

Certified by : . . . .
              Thesis Supervisor

Accepted by : . . . .
              Chairman: Departmental Committee on Graduate
                        Students

ABSTRACT

ACCESSIBILITY AND RESIDENTIAL GROWTH

by

WALTER G. HANSEN

Submitted to the department of City and Regional Planning on May 6, 1959 in partial fulfillment of the requirements for the degree of Master of City Planning.

The objective of this thesis is to quantify the general hypothesis of the existence of a relationship between the accessibility of an area and the potential rate and intensity of residential growth in that area; and further, to illustrate how this relationship, once quantified, can provide a basis for a residential land use model-- an estimating process of distributing total metropolitan growth to small areas within the metropolitan region.

Accessibility is defined in this thesis as the potential of opportunities for interaction and is a measure of the intensity of the possibility of interaction. The formula developed to measure accessibility is a variation of the gravitational principle and states that the accessibility to an activity is directly proportional to the size of the activity and inversely proportional to the distance to the location of the activity.

An empirical examination was conducted to determine the relationship between accessibility to employment, shopping, and social opportunities and the residential growth which occured in the Washington, D.C. metropolitan area during the seven year period from 1948 to 1955. Through statistical analyses the association between these variables was established and an estimating formula-- a residential land use model-- based on accessibility and the availability of vacant land, was developed. Tests of this model show that these two factors alone do not produce estimates of sufficient reliability for practical use ; however, methods of refining this basic model through the inclusion of other major variables; such as, land costs, zoning, and taxes, are outlined.

The models applicability to the metropolitan planning process is illustrated through the use of hypothetical examples. These illustrations show that the concept and approach developed in this thesis provide a potentially valuable tool for metropolitan planning purposes.

Thesis Supervisor :. . John.T. Howard.

Title : Head, Department of City and Regional Planning

ACKNOWLEDGMENTS

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

LIST OF TABLES

LIST OF FIGURES

ACCESSIBILITY AND RESIDENTIAL GROWTH

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. One need only to glance at a master plan to observe the intuitive acceptance of this hypothesis by the planning profession.

Although there has been close to universal acceptance of this general proposition, there have been surprisingly few attempts to quantify this hypothetical relationship between accessibility and urban development. Therefore, this thesis is not an attempt to develop and propose a new theory concerning urban development; but rather, has as its purpose the narrower objective of measuring accessibility and examining the relationships which exist between it and the growth and structure of residential development.

Specifically, this study has four major objectives:

(1) To develop a definition and methodology for the measurement of accessibility.

(2) To determine empirically the relationships between residential growth and accessibility to employment, shopping, and social opportunities.

(3) To illustrate how accessibility can provide the planner with a clearer understanding of the dynamics of metropolitan growth and how the above relationships can provide a basis for a residential land use model--a process of distributing metro-

politan growth to small areas within the metropolitan region.

(4) To indicate, in light of the results of this study, avenues

of potentially productive additional research.

A MEASUREMENT OF ACCESSIBILITY

Various indices of accessibility have been developed and used to describe

metropolitan structure. 1/ Distance to the center of the city, concentric

circles or ischronal zones, and the ring sector measures are some of the

simpler attempts to measure the effects of accessibility. The deficiencies

of such indices as measurements of accessibility are too apparent to require

elaboration.

More complex indices have been developed which attempt to measure the

relative accessibility to a spatially dispersed activity rather than to

a point in space. One such index is aggregate travel. Aggregate travel

is defined as the accumulated distance that would be required to . con-

centrate that activity to which accessibility is being measured at any

particular zone.

1/ Most of the work done at this time afford valuable insight into the
structure of the metropolitan community but do not yield quantitative
forecasts or insight into the process of growth; the problem towards
which this paper is focused. This is because these studies reflect
correlations at a specific time rather than trends through time. For
an excellent study of this type see Don J. Bogue, The Structure of the
Metropolitan Community: Ann Arbor, 1949.

For one attempt to quantify the process of growth see Hans Blumenfeld,
"The Total Wave of Metropolitan Expansion, "Journal of the AIP, Winter,
1954. Also see Creighton and Hamburg, "A Method of Land Use Forecasting
Based Upon Historical Trends," (To be released) Journal of the AIP,
Spring, 1959. All of these studies use distance to the CBD as an index
of accessibility.

For example, aggregate travel to population from a zone would be the summation of the individual distances traveled if all persons were to get to that zone. The zone with the lowest number of " person miles " would be the most accessible to the population. This index could of course be refined to include aggregate travel to all work opportunities or shopping establishments.

The reciprocal of aggregate travel is in effect an index which indicates the proximity of any zone to the residential population of the city or to some specialized part of the city such as work places. The index is a relative measure of the ease of contact.

Another measurement of the relative accessibility of an area is the population divided by distance or " potential of population " concept developed by Stewart. 2/ In general terms the concept states that the possibility of having contact with a group of people is directly proportional to the size of the group (activity level) and inversely proportional to the distance or separation from that group. 3/

2/ J. Q. Stewart, " Demographic Gravitation : Evidence and Application "
Sociometry , 11: 1-2 , Jan. 5, 1948, 31 - 58

3/ This concept is expressed in the equation :

$$_1V_2 = \frac{P_2}{D_{1-2}}$$

where:

$_1V_2$ equals the potential of population at point 1 created by the population at area 2.

P_2 equals the number of people at area 2 ; sometimes adjusted for varying capacities for interaction.

D_{1-2} equals the distance of separation between point 1 and area 2; expressed in terms of miles, cost, or time.

As set forth by Stewart the concept of " potential measurements " may
be thought of as a macroscopic measurement indicating the relative in-
tensity of the possibility of interacting with a spatially dispersed
activity.

Stewart's original formulation has been extended to measurements of
" income potential ", " market potential ", and a variety of other
indices describing the effect of an activity over space. More recently,
this concept has formed the basis of the so-called " gravity models"
being used for traffic estimation. The various applications of this
concept have been well documented and need not be examined in detail
at this time. 4/

In general, these investigations have shown that the intensity of a
variety of phenomena; i.e., traffic flow, population density, price
of a commodity, all vary directly with various potential measurements.

Accessibility Defined : Consistent with the potential concept, access-
ibility 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.

In general terms, accessibility is a measurement of the spatial distri-

---

4/   For a summary discussion and extensive bibliography on the various
applications of the potential and gravitational concepts of interaction:
Gerald Carrothers, " An Historical Review of the Gravity and Potential
Concepts of Human Interaction, " Journal of the AIP, Spring. 1956

bution of an activity (opportunities for interaction) adjusted for the ability and desire of people or firms to overcome spatial separation. More specifically, the formulation states that the accessibility at zone 1 to a particular type of activity at zone 2 (say employment) is directly proportional to the size of the activity in zone 2 (number of opportunities for employment) and inversely proportional to some function of the distance separating zones 1 and 2. Therefore, as more opportunities for employment are offered at zone 2, or as the distance separating zones 1 and 2 is decreased, the accessibility to employment at zone 1 will increase. The total accessibility to employment at zone 1 can be expressed as the summation of the accessibility to each of the individual employment areas. 5/

5/ More formally this concept can be expressed by the following formula:

$$_1A_2 = \frac{S_2}{T_{1-2}^x}$$

where:

$_1A_2$ is a relative measure of the accessibility in zone 1 of an activity in zone 2.

S_2 equals the size of the activity in zone 2; i.e., the number of opportunities for interaction

T_{1-2} equals the separation between zones 1 and 2, expressed in terms of miles, time, or costs.

x is an exponent describing the effect of the separation T on the possibility of an interaction occurring.

Although the size of the activity S and the separation T are denoted by a single symbol; their actual calculation may take a more complex form.

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

$$A_1 = \frac{S_1}{T_{1-1}^x} + \frac{S_2}{T_{1-2}^x} + \cdots \cdot \frac{S_n}{T_{1-n}^x}$$

There are of course many technical problems in the application of this concept. Most of these problems will be discussed briefly in the empirical examination section of this study; however, one aspect of the proposed accessibility model deserves special consideration and that is the meaning and function of distance in the denominator of the model.

Exponent of Distance: It is generally agreed and empirical examinations indicate, that an exponential function of distance should be used; that is, the measurement of distance separating the various areas should be raised to some power. It is the particular value that this exponent should assume that has been the source of most of the debate concerning gravity or potential models. Stewart contends that this exponent must be unity. He bases this contention on an intriguing but unconvincing analogy to Newton's Law of Gravity. 6/ Of more interest are the results of the various studies which have empirically determined the value of this exponent. These examinations have resulted in exponents that range from 0.5 to 3.0. This variation would at first glance seem to challenge the validity of the concept; however, re-examination of the concept of accessibility will make apparent the reasons for most of this variation.

Accessibility was defined as the potential of opportunities for interaction. Stated in another manner, accessibility may be thought of as a measure of the effective opportunities at any zone 1 created by the actual opportunities offered at any zone 2 . The difference between these two quantities, actual opportunities minus effective opportunities

---

6/ Stewart and Warntz, " Physics of Population Distribution, " Journal of Regional Science, Vol. 1, No. 1, Summer, 1958 pp. 116-118

would be the opportunity reduction from area 2 to point 1. If this reduction is expressed as a percentage of the actual opportunities offered at area 2 and further divided by the distance separating area 2 and point 1 the resultant would be the rate of opportunity reduction per unit distance.

Now, if a single exponent of distance is to be used in the accessibility model, it means that this rate of opportunity reduction must remain constant for all types of interactions. This in turn means that all types of opportunities must be equally valued by the interacting party because the unit costs of travel, however measured, should remain relatively constant regardless of the destination or the purpose for which the trip is made. However, this latter statement does not appear to be reasonable. For example, it would not be expected that in choosing between two alternatives of work a person would be equally influenced by (place the same value on) differences of travel as he would in choosing between alternate places to buy aspirin or some other type of convenience good.

The empirical examinations conducted within urban areas seem to support this expectation. These studies show that the exponent decrease in the following manner; school trips 2.0+, shopping trips 2.0, social trips 1.1, and work trips 0.9. In short, the variation in the exponent above means that people are willing to travel farther to work than they are for any other trip purpose. 7/

7/ J. Douglas Carroll and H. W. Bevin, "Predicting Local Travel in Urban Areas," <u>Papers and Proceedings of the Regional Science Associations</u>, Vol. 3, 1957. See also Alan M. Voorhees, <u>A General Theory</u>

It is when the results of these intraurban studies are compared to
the findings of interurban examinations that a variation in the value
of the exponent appears, which is not explainable by reference to trip
purpose. The analyses carried out on interurban travel, reveal exponents
of between 2.5 and 3.0. 8/

One reason for this apparent variation in the results of the intra and
interurban investigations, is that these studies did not include ter-
minal time or terminal effect in the measurement of separation. In
interurban travel, since most of the trips are relatively long, the
effect of omitting 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 the percentage increase on the measurement of separation.

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. The details of this study, along with an explanation of the

---

7/ continued:
of Traffic Movement. Past Presidents Award Paper, Institute of Traffic
Engineers.

These exponent values should be considered tentative. Additional research
is being done by the Bureau of Public Roads to determine and statistically
evaluate these exponents for the Washington D. C., area.

8/ J. Douglas Carroll, "Spacial Interaction and the Metropolitan Des-
cription," Papers and Proceedings of the Regional Science Association.
Vol. 1, 1955.

procedure for determining exponents in gravity models are given in Appendix A.

Briefly, this examination showed that, if driving times alone were used as a measure of distance, the exponent of distance did not remain constant but increased as the time of separation increased. By incorporating 5 to 6 minutes of terminal time into this measurement of separation, the variation in the exponent for any particular type or purpose of trip was greatly reduced.

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

EMPIRICAL INVESTIGATION--WASHINGTON METROPOLITAN AREA

Data for the Washington, D. C., metropolitan area were used for

empirical examinations of the relationships between residential develop-

ment and accessibility. 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. 9/

Because a majority (80 percent) of all personal travel originating in

residential areas is for work, shopping, and social purposes, this

study has limited its investigation to the examination of the relation-

ships between residential growth and accessibility to employment,

shopping, and social opportunities.

Table I gives the data used to calculate the various measurements of

accessibility. Using the formulas developed in the preceding section,

the accessibility to employment, shopping, and social opportunities were

calculated for 70 areas in the Washington metropolitan area. A brief

discussion of the components and calculations used to determine the

measurements of accessibility can be found in Appendix B.

9/ The travel data used in the study were collected in 1948 and 1955
in two origin and destination 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, and 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 Planning Regional Planning Council.

TABLE I

Data for Accessibility Calculations

Accessibility to	Units used to Express Activity Level of Size	Exponent of distance (minutes) *
Employment Opportunities	Number of Jobs	2.20
Shopping Opportunities	Annual Retail Sales	3.00
Social Opportunities	Population	2.35

* Distance is expressed in minutes of offpeak driving time plus 5 to 8 minutes of terminal time.

Since accessibility is a spatially continuous measurement, it can be mapped in much the same way as heights are depicted on a topographic map. 10/ The map on Figure 1 shows the lines of equal accessibility to employment for the Washington area in 1955. Figures 2 and 3, are similar maps for accessibility to social and shopping opportunities.

10/ That accessibility is in fact continuous is obvious. Every point in an urban area is accessible, in some manner, to every other point. However, in measuring accessibility, this continuity can only be approximated. This approximation becomes better as the metropolitan area is divided into increasingly smaller segments. The approximation does not materially effect the patterns shown on Figures 1 thru 3. It does however, result in the loss of the smaller localized variations in the pattern of accessibility.

WASHINGTON METROPOLITAN AREA

ACCESSIBILITY INDEX $\frac{1}{100,000} \sum_{1}^{N} \frac{(\text{NUM. OF JOBS})}{(\text{TRAVEL TIME})^{2.0}}$

ZONE EMPLOYMENT

50,000
30,000
20,000
10,000
5,000
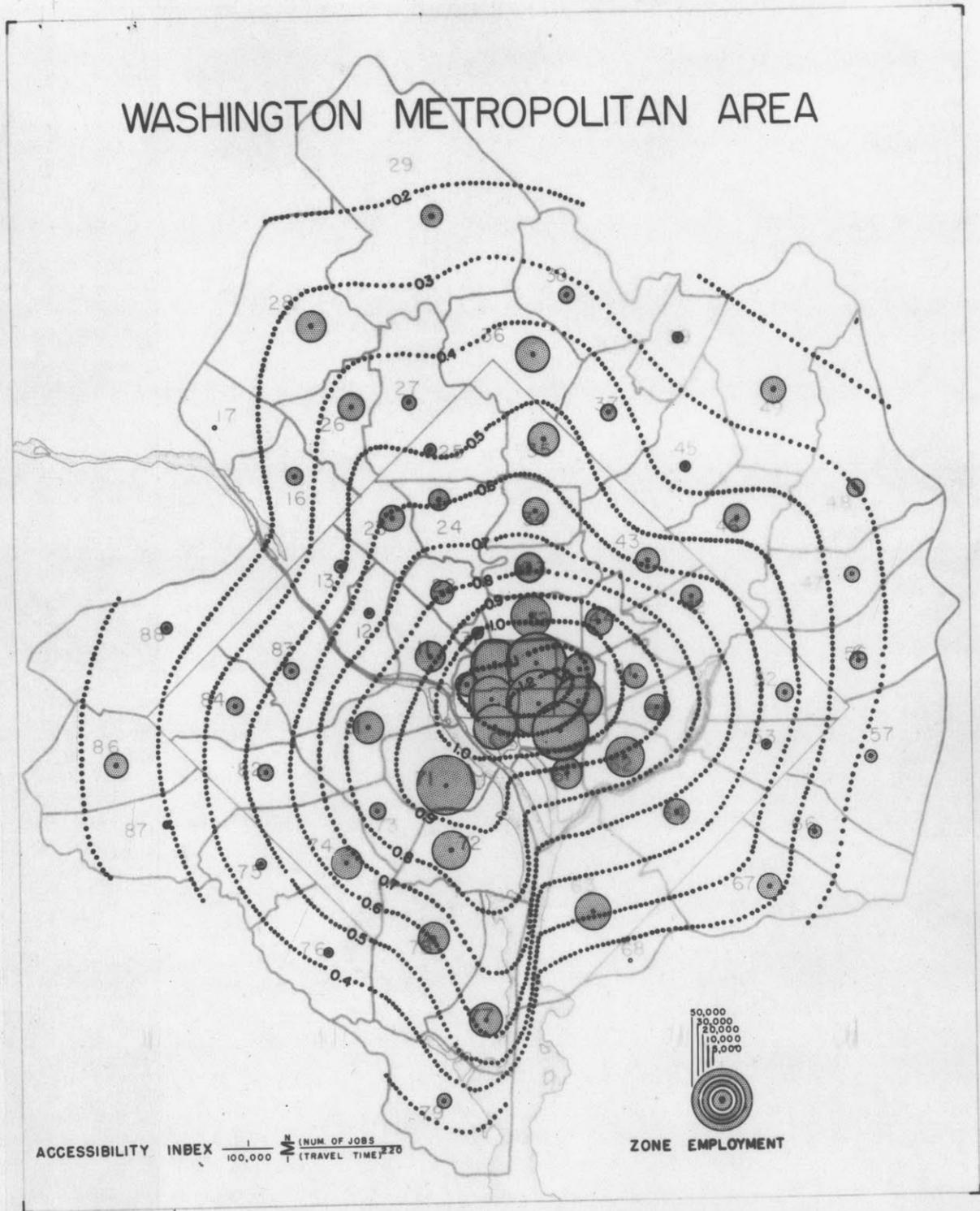
Figure 1   PATTERN OF ACCESSIBILITY TO EMPLOYMENT
WASHINGTON METROPOLITAN AREA, 1955
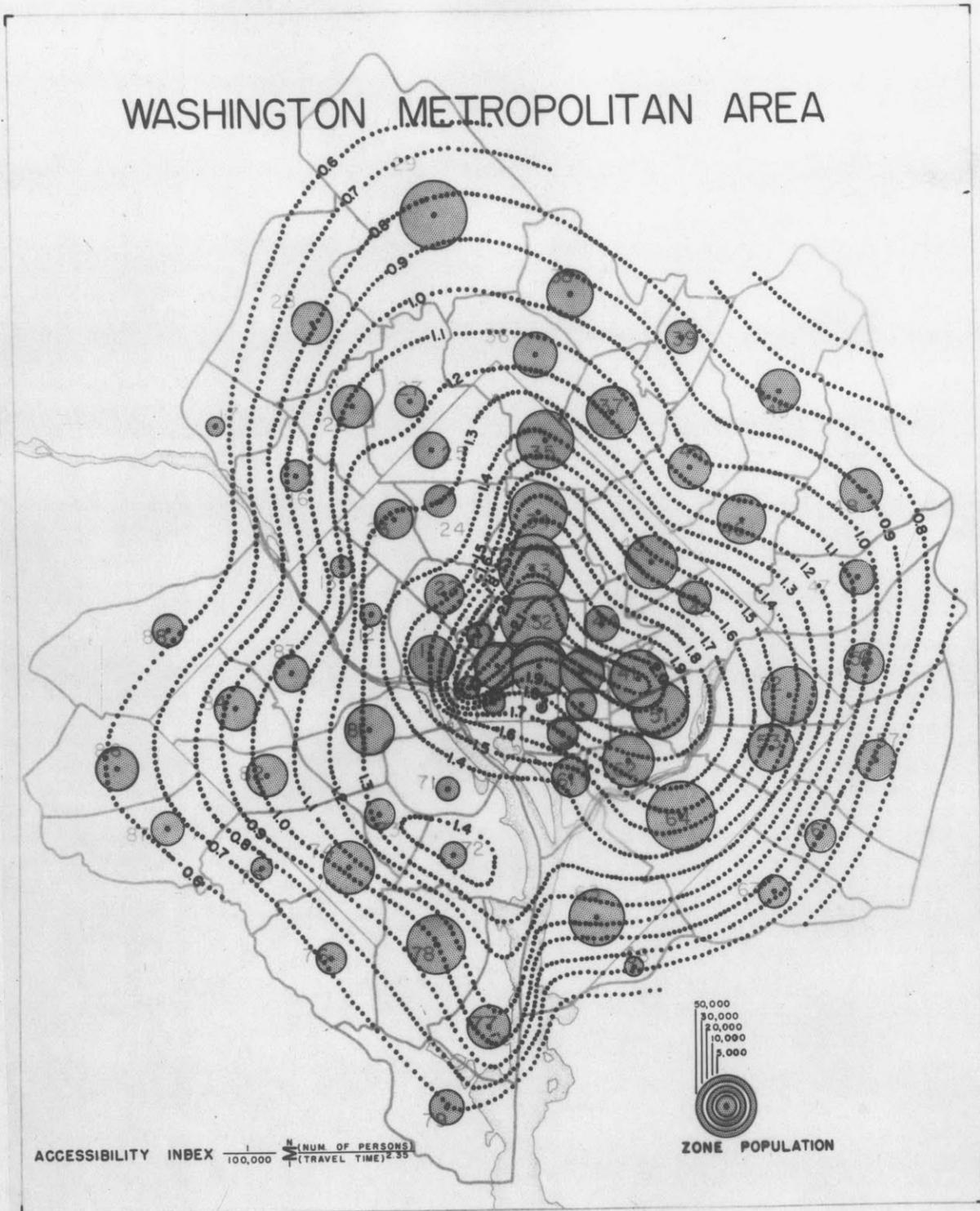
Figure 2   PATTERN   OF   ACCESSIBILITY   TO   POPULATION
WASHINGTON   METROPOLITAN   AREA, 1955
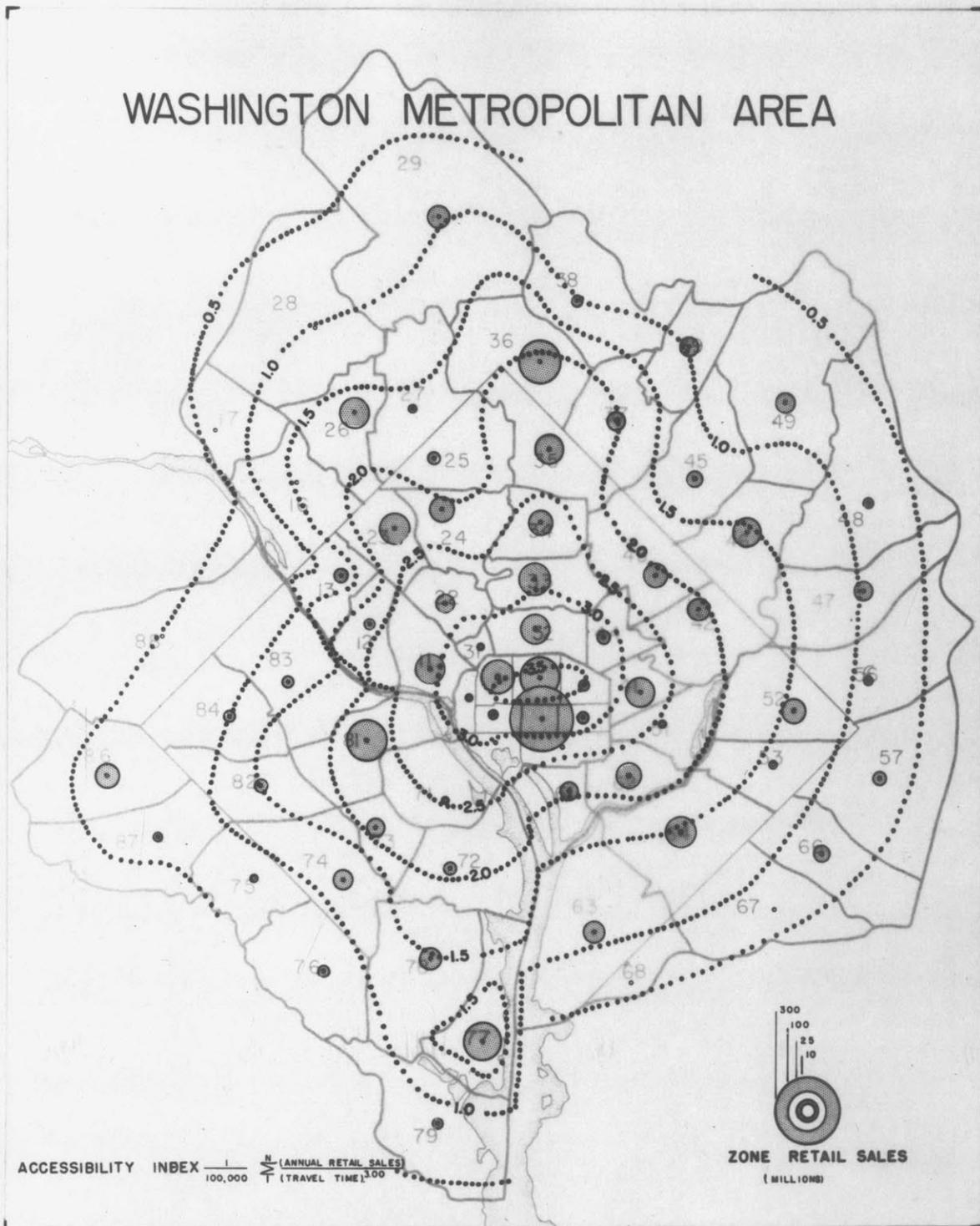
Figure 3   PATTERN OF ACCESSIBILITY TO SHOPPING
WASHINGTON METROPOLITAN AREA, 1955

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 percent of the vacant land in the metropolitan area, 10 percent of the expected growth was assigned to zone A. This proportion of the total metropolitan development assigned to each zone is termed the prorated development.

If there is a difference between this prorated development and the actual development, then some factor or factors other than the availability of land is affecting residential growth. One way of expressing this difference is to divide the actual development by the prorated development. This factor, called the development ratio, is a measure of actual growth per unit of prorated growth.

The residential development ratio was calculated for each of the areas shown in Figure 1. A discussion and summary of these calculations is given in Appendix C. Subsequently, these development ratios were examined to see whether or not they varied systematically with the various measures of accessibility. Observe the results in Figure 4. The relationship between the development ratios and distance to the center of the city is shown for comparative purposes.
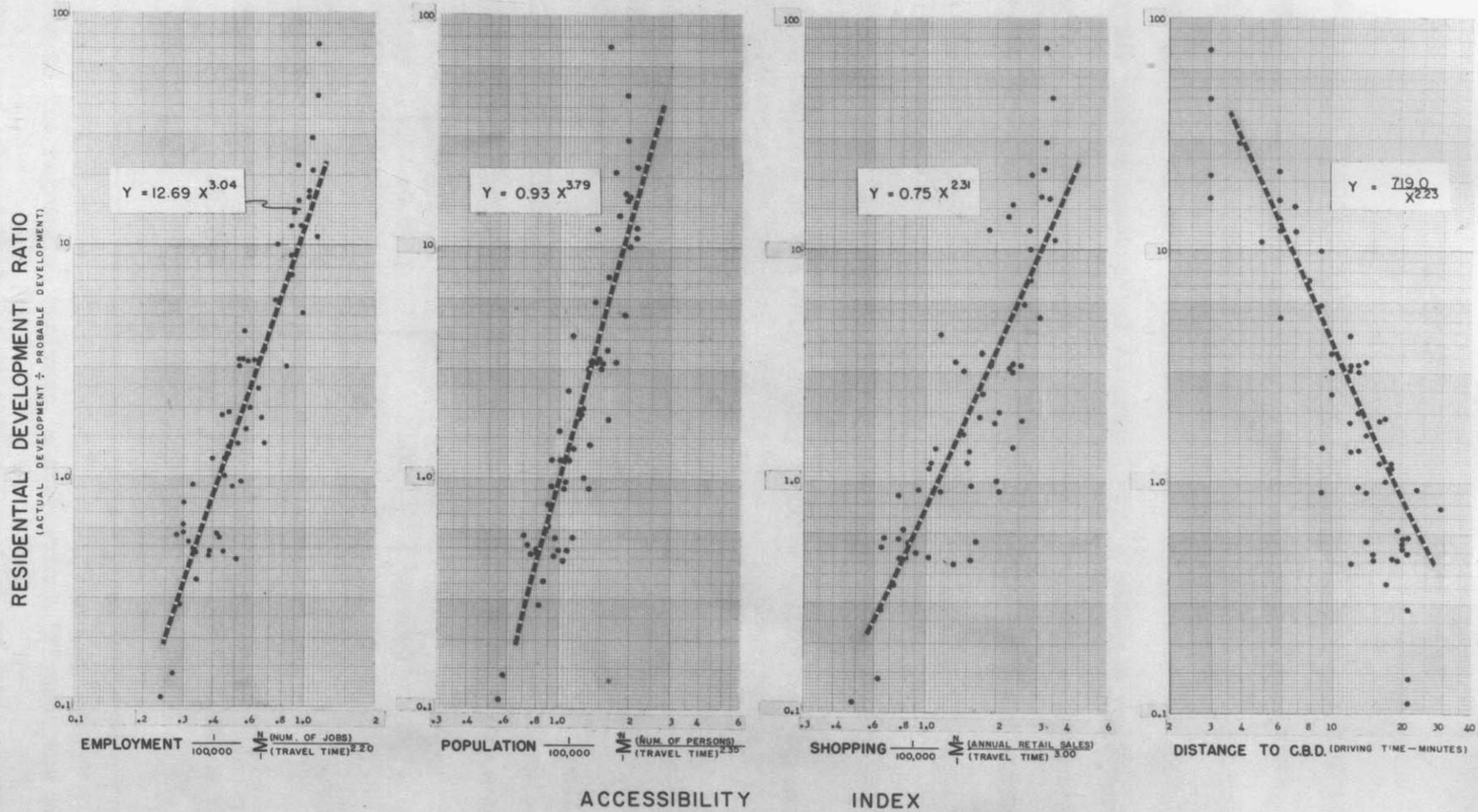
Figure 4   ACCESSIBILITY AND RESIDENTIAL DEVELOPMENT

The data shown in Figure 4 substantiate the general hypothesis of the existence of a relationship between accessibility and urban growth, or at least residential growth. To quantify these relationships and to determine the actual degree of association between residential development and the various measures of accessibility, a standard regression analysis (log log) was performed on this data. The results of these analyses are shown by the regression lines on Figure 4 and are summarized in Table 2.

TABLE 2

Statistical Analysis of the Relationship between Residential Development Ratios and Various Measures of Accessibility

INDEPENDENT VARIABLE (A_1)	RESIDENTIAL DEVELOPMENT RATIO (D_1)			ESTIMATING EQUATION
	Coefficient of Correlation	Coefficient of Determination	Standard Error	
Accessibility To Employment	+0.9052	.82	.2690	$D_1 = 12.69\ A_1^{3.04}$
Accessibility To Population	+0.8917	.80	.2899	$D_1 = 0.93\ A_1^{3.79}$
Accessibility To Shopping	+0.8563	.74	.3274	$D_1 = 0.75\ A_1^{2.31}$
Driving Time To C.B.D.	-0.8534	.73	.3293	$D_1 = \dfrac{719.0}{A_1^{2.23}}$

In addition to the regression analyses, a statistical "F" test was undertaken. This test showed that the relationships shown in Table 2 were significant and could not be the result of sampling variability and that the chance of their being random was less than 1 in 1,000.

The summary on Table 2 shows that of the variables tested, accessibility to employment is the best single indicator of residential growth. The correlation coefficient of 0.90 means that accessibility to employment alone explains 81% of the variation found in the residential development ratios. Considering the numerous factors which could influence the rate and intensity of land development, but which have not entered into these calculations, correlation coefficients as high as those shown in Table 2 are somewhat surprising.

One of the reasons for such high correlations is a result of the statistical procedures themselves and should be explained to avoid any misinterpretation of the results. In the type of regression analysis used here, the correlations are not developed on the actual numerical values of the variables themselves, but rather on the basis of the logarithms of these values. Therefore, the correlation coefficients and the resulting coefficients of determination are a measure of the association between the logarithms of the variables. Inasmuch as the variation between the logarithms of two numbers is numerically much less than the numerical variation between the two numbers, the correlation between the logarithms will be higher than a correlation between the actual variables.

To indicate the extent to which accessibility to employment can explain the actual variation in residential development, the equation shown in Table 2 can be used to estimate the distribution of the 1948--1955 residential growth(zonal increase in dwelling units). These estimates can then be compared to the actual growths recorded during this period

and the value of the relationship for estimating purposes may be assessed.

As previously described, the prorated 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 prorated development is multiplied by the development ratio, D_1, which as shown by the formula in Table 2, is equal to 12.9 times the accessibility to employment raised to the 3.04 power. [11]

A comparison of these estimated growths to the actual increases in dwelling units in each zone, showed that 40 percent of the estimates were within 30 percent of the actual figures, and that 70 percent were within 50 percent of the actual growths.

Although these results are quite promising and indicate that accessibility to employment and the availability of land are major factors in residential growth, they do not by themselves produce sufficiently precise results for estimating purposes. Other factors must be included if a usable estimating process is to be developed. The inclusion of the other measures of accessibility, by multiple correlation procedures, would undoubtedly improve the predictive ability of the model. Other factors such as zoning, land costs, and competition for land with other types of land use, must also be considered.

[11] This formula varies from the one previously reported in W. G. Hansen, "How Accessibility Shapes Land Use", Journal of the AIP, (To be released) Spring, 1959. The reason for this variation is that in the present case, the development ratio, D, was based on observed increases in dwelling units, while the previously reported D was based on increases

The inclusion of some of these factors will be briefly discussed in the concluding section of this study. However, it is not the purpose of this paper to develop a usable residential land use model; but rather to outline its development and potential value.

For these reasons, the development of the model in the following section, based solely on accessibility to employment, should not be interpreted as a proposal, but rather as an illustration.

11/ (cont) in population. Inasmuch as there is a fairly regular decrease in persons per dwelling unit as accessibility increases, the relationship between the variables produces a slightly higher exponent when D is based on dwelling unit increase. The previous formula was:

$$D_1 = 13.7 A_1^{2.7}$$

A RESIDENTIAL LAND USE MODEL

Using the relationships determined in the preceding section, it becomes possible to develop a generalized estimating model based on accessibility and vacant or developable land. It was shown that the growth in the area could be determined by multiplying the pro-rated development by the development ratio. More formally:

$$(1) \quad G_1 = Pd_1 D_1$$

where: G_1 equals residential growth of zone 1, in terms of dwelling units

  Pd_1 equals the probable development in zone 1

but:

$$(2) \quad Pd_1 = G_t \frac{O_1}{O_t}$$

  G_t equals total metropolitan growth in terms of dwelling units

  O_1 equals vacant land in zone 1

  O_t equals total vacant land in metropolitan region.

therefore:

$$(3) \quad G_1 = G_t \frac{O_1}{O_t} D_1$$

also:

$$(4) \quad G_t = G_1 + G_2 + G_3 \ldots G_n$$

substituting (3) into (5)

$$(5) \quad G_t = G_t \frac{O_1}{O_t} D_1 + G_t \frac{O_2}{O_t} D_2 \ldots + G_t \frac{O_n}{O_t} D_n$$

reducing to:

$$(6) \quad O_t = O_1 D_1 + O_2 D_2 \ldots O_n D_n$$

Substituting into equation (3)

$$(7) \quad \frac{G_1}{G_t} = \frac{O_1 D_1}{O_1 D_1 + O_2 D_2 \ldots O_n D_n}$$

Substituting $K A_1^{3.04}$ for D_1 and cancelling K's

$$(8) \quad \frac{G_1}{G_t} = \frac{O_1 A_1^{3.04}}{O_1 A_1^{3.04} + O_2 A_2^{3.04} \ldots . O_n A_n^{3.04}}$$

In effect this model or formula states that the proportion of the total metropolitan increase in dwelling units that can be expected in any given zone, is equal to the product of vacant land times the accessibility of that zone divided by the summation of the similar products for all zones. The following illustration is presented to clarify the mechanics of the model and to demonstrate its potential value to the city planning process.

Illustration of Model: Figure 5 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 2000 dwelling units and 1000 jobs. The distribution of residential growth 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 increase in employment takes place in zone 3.

TT = TRAVEL TIME IN MINUTES
(DRIVING PLUS TERMINAL TIME)

NOTE: INTRAZONE TRAVEL TIME
EQUALS 9 MINUTES

ZONE 3
200 ACRES VACANT

TT = 36   TT = 26   TT = 31

ZONE 1
5000 JOBS
0 ACRES VACANT

ZONE 2
100 ACRES VACANT

TT = 26   TT = 16

ZONE 4
50 ACRES VACANT

TT = 31
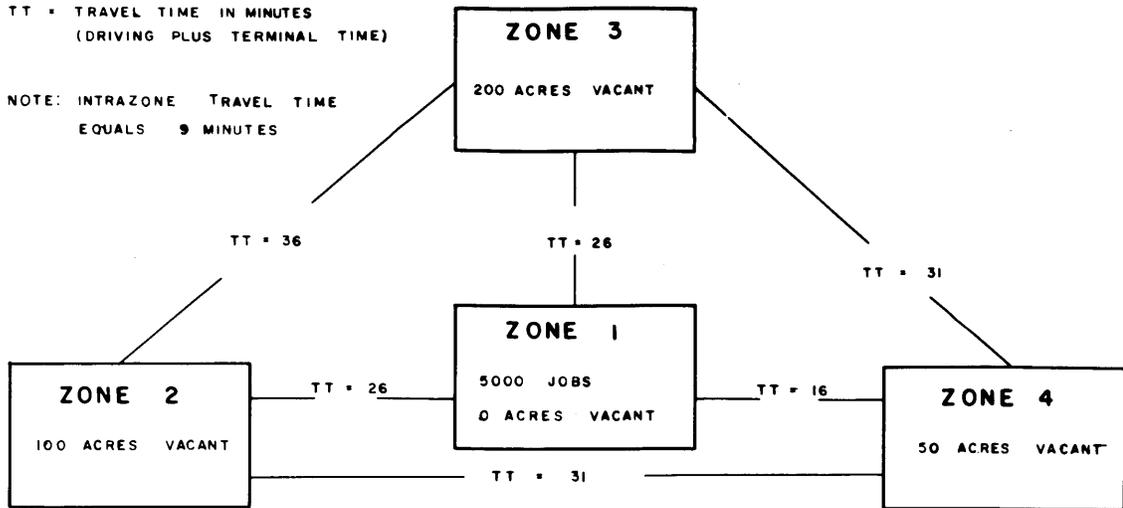
AREA NUM.	ACCESSIBILITY TO EMPLOYMENT $A_i = \sum_1^n \frac{JOBS}{TT^{2.2}}$	DEVELOPMENT RATIO $KD_i = A_i^{3.04}$	$D_i O_i$	% OF TOTAL DEVELOPMENT $\frac{D_i O_i}{\sum_1^n DO}$	RESIDENTIAL GROWTH G_i (D.U.)
CASE I					
2	$\frac{6000}{26^{2.2}} = 4.6$	105	10500	6.5 %	130
3	$\frac{6000}{26^{2.2}} = 4.6$	105	21000	13.0	260
4	$\frac{6000}{16^{2.2}} = 13.3$	2600	130000	80.5	1610
			$\sum_1^n DO =$ 161500	100.0 %	$G_T =$ 2000
CASE II					
2	$\frac{6000}{21^{2.2}} = 7.5$	460	46000	23.4 %	468
3	$\frac{6000}{26^{2.2}} = 4.6$	105	21000	10.6	212
4	$\frac{6000}{16^{2.2}} = 13.3$	2600	130000	66.0	1320
			$\sum_1^n DO =$ 197000	100.0 %	$G_T =$ 2000
CASE III					
2	$\frac{5000}{26^{2.2}} + \frac{1000}{36^{2.2}} = 4.2$	79	7900	1.7 %	34
3	$\frac{5000}{26^{2.2}} + \frac{1000}{9^{2.2}} = 11.9$	1850	370000	80.0	1600
4	$\frac{5000}{16^{2.2}} + \frac{1000}{31^{2.2}} = 11.6$	1700	85000	18.3	366
			$\sum_1^n DO =$ 462900	100.0 %	$G_T =$ 2000

Figure 5   ILLUSTRATION OF LAND USE MODEL

The calculations in Figure 5 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). 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 the 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 a decline in 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.

It should be pointed out that the reliability of this model, or for that matter, any estimating process which attempts to estimate thru time, but does not contain time as a variable, is extremely sensitive to the quantity of development being distributed. The model is only capable of accurately distributing fairly small increments of growth. 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 fore-casts; 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.

The sensitivity of the model and this process of sythesizing growth are shown in Figure 6. These calculations are based on the same assumptions made for Case I in the preceding illustration, the only difference being that the total growth will be distributed with two applications of the model. The growth of 2000 dwelling units and 1000 jobs is assumed to be linear; therefore 1000 dwelling units, based on an increase in employment of 500 jobs, will be distributed with each application of the model. It was assumed that all development would occur at a density of thirty dwelling units per acre.

Figure 6 illustrates quite clearly this sensitivity of the model. Two successive applications of the model produced zone estimates as much as 38 percent different than those estimated with a single application. This example also gives insight into one possible reason for the variation found in the empirical examination. It might be that the comparison between the actual and estimated growths would have been much improved if sufficient data had been available to use two or three applications of the model.

It is this aspect of the illustrated land use model--the ability to synthesize the process of metropolitan growth, which offers the greatest potential value to the planning process. It will allow the planner to assess the accumulated consequences, through time, of a given action taken at a given time. The incorporation of the fourth dimension, time, into the present planning

ZONE NUM.	ACCESSIBILITY TO EMPLOYMENT A_1	DEVELOPMENT RATIO $D_1 = A_1$	VACANT LAND O_1	$D_1 O_1$	% OF TOTAL GROWTH	RESIDENTIAL GROWTH (D.U.)	RESIDENTIAL GROWTH (ACRES)	REMAINING VACANT LAND
FIRST ITERATION : TOTAL GROWTH 1,000 D.U.							at 30 D.U./Acre	
2	$\dfrac{5500}{26^{2.2}}$ = 4.25	82	100	8,200	6.6 %	66	2.2	97.8
3	$\dfrac{5500}{26^{2.2}}$ = 4.25	82	200	16,400	13.2	132	4.4	195.6
4	$\dfrac{5500}{16^{2.2}}$ = 12.20	2000	50	100,000	80.2	802	26.7	23.3
				124,600	100.0 %	1000		
SECOND ITERATION: TOTAL GROWTH 1,000 D.U.								
2	$\dfrac{6000}{26^{2.2}}$ = 4.60	105	97.8	10,250	11.3 %	113		
3	$\dfrac{6000}{26^{2.2}}$ = 4.60	105	195.6	20,500	22.7	227		
4	$\dfrac{6000}{16^{2.2}}$ = 13.30	2600	23.3	59,700	66.0	660		
				90,450	100.0 %	1000		

SUMMARY: DISTRIBUTION OF TOTAL RESIDENTIAL GROWTH 2,000 D.U.

	USING ONE ITERATION (Figure 5)	USING TWO ITERATIONS (Above)	% DIFFERENCE
2	130	179 (66 + 113)	+37.5 %
3	260	359 (132 + 227)	+38.0 %
4	1,610	1,462 (802 + 660)	- 9.2 %

Figure 6   SUCCESSIVE APPLICATIONS OF MODEL SYNTHESIZE RESIDENTIAL GROWTH

process would enable the planner to examine the path thru time by which a given objective or goal may be obtained. For example, it would be possible to determine the timing and sequence of constructing an express- way system which would best promote a desired distribution of metropolitan residential growth.

Thus far, this study has shown the existence of a relationship between accessibility and residential growth and has developed an estimating process or model based on these relationships. The developed model was shown to offer great potential benefits to the planning process. Before these benefits may in fact be realized, however, other factors affecting metropolitan development must be incorporated into the model. The final section of this thesis will briefly indicate how the effect of these other factors on the development of land, may be assessed and further, how this effect may be incorporated into the present model.

CONCLUDING COMMENTS

The immediate value of the relationships and resulting model described in this study is that it makes possible its own improvement or reliability. The use of this model will make it possible to isolate and examine empirically, the effect of other factors on land development; such as, income, zoning, taxes and land costs. The assessment of the effect of such factors can be accomplished by empirically studying the relationship between them and the differences between observed growth and growth estimated on the basis of accessibility alone.

The results of such studies would provide the planner with a clearer understanding of the metropolitan community. It would also enable him to determine the effectiveness of the various types of land controls at the metropolitan scale. In addition, the results of these studies could be incorporated into the present model, thereby, increasing its reliability for estimating purposes.

The effect on residential growth of factors, other than accessibility, can be incorporated into the model in three ways: as modifying factors in the calculation of accessibility; as adjustments in the determination of pro-rated development; and as restraints in the output of the model itself.

Modification of the accessibility calculations can be accomplished by changing the measurement of opportunities from a single quantity, such as people or jobs as was used in this study, to a complex index. For example, population could be modified by some measurement of opportunities for social interaction. Opportunities for employment could probably be better measured by some estimate of the actual opportunities offered during the time period

studied rather than using total employment.

Another method of refining the accessibility index would be to make calculations for more precise types of accessibility. For example, it would be possible to determine the accessibility to employment opportunities for each of the major types of industries or occupations. One such refinement that should be made, but which was not possible in this study because of insufficient data, is to separate accessibility to shopping into the two major categories of shopping goods and convenience goods.

The determination of the prorated development expected in each area offers many opportunities to include the effect of other factors in the estimating process. Instead of determining prorated development on the basis of area of vacant land, these calculations could be based on the ultimate capacity of each zone in terms of dwelling units. 12/ These capacity figures could be based on a combination of many factors i.e., existing density of development, present or planned zoning, subdivision regulations, and taxing policies. These capacity calculations should of course be based on factors which empirical examinations have shown have an effect on residential growth.

12/ Zonal capacity was one of the variables used to estimate future residential growth in Chicago Transportation Study. For an explanation of how these capacities were determined see: Klopprodt, "Allocating Population to Small Areas," Chicago Area Transportation Study Pamphlet June, 1957.

Referring to the calculations in Figure 5 in the preceding section it
would be possible to place restraints on the output of the model. By
not allowing the amount of growth in a particular zone to exceed a pre-
determined amount, any growth which would normally be distributed to the
restrained zone in excess of this amount would automatically be redis-
tributed to the other zones. The effect of zoning might be incorporated into
the model in this manner .

In conclusion, this study has developed a residential land use model--
a process of distributing total metropolitan growth to small areas within
the metropolitan region. The model was shown to have great potential value
to the planning of metropolitan communities. Although considerable
additional research and refinement are required before the model will be suffi-
ciently precise for actual application, the model is sufficiently flexible
to incorporate factors other than accessibility which affect residential
growth.

The additional refinement of this estimating process, although feasible,
would require considerable time and effort. It is the opinion of the
writer that the benefits accruing from such additional study as may be
required would more than justify the expenditure.

APPENDIX A

DETERMINATION OF THE EXPONENT OF DISTANCE

IN GRAVITY MODELS

Before it is possible to empirically determine the effect of distance
or spacial friction on travel, it is necessary to correct or account
for the variation in the size of the zones (in terms of trip generation).
This is done by assuming that it is equally easy to travel between all
zones; i.e., all zonal pairs have equal time, cost and distance frictions.
If this assumption were valid each zone would draw or attract only its
proportion of the trips generated by any of the other zones. For example,
assume that zone 1 attracts a total of 1,000 trips and that there are
10,000 trips made in the entire metropolitan area. Then if all inter-
zonal travel frictions are assumed to be equal, zone 1 could be expected
to attract 1,000 divided by 10,000 or 10% of the trips produced by each
of the other zones. These resultant interzonal volumes, called the
probability interchange are the volumes that could be expected if distance
of separation had no effect on the volume of interchange between zones.

To the extent that the probability interchange differs from the actual or
observed interchange some factor (s) other than zone size are effecting
travel volumes. One way of expressing this difference is to divide the
actual and probability interchange. This ratio will be termed the inter-
change ratio, and is a measure of the actual trips per probable trips.

By comparing the resulting interchange ratio between two zones, to the dis-
tance of separation between those zones, it is possible to assess the effect
of distance, measured in terms of miles, time, or cost; on the interchange
volume.

Several studies, conducted in various cities have been made along the
lines outlined above. These studies have shown that the interchange
ratio varies systematically with the reciprocal of distance to some
power. A summary of the results of these studies is shown in Table A-1.

TABLE A-1

Empirically Determined Exponent of Distance

City	Purpose of Trip			
	Work	Social	Shopping	All Purpose
Detroit *	1.20	1.0	2.60	1.63
Fort Wayne **	.805	-	-	-
Oklahoma **	.745	-	-	-
South Bend **	.703	-	-	-
Wichita **	.680	-	-	-
Baltimore ***	.900	1.0	2.00	1.60

Sources:

* Carroll and Bevis, "Predicting Local Travel," Papers and Proceedings of
the Regional Science Association, Vol. 3, 1957.

** Alan M. Voorhees, "Forecasting Peak Hours of Travel", Highway Research
Board Bulletin. 203, 1958.

*** Unpublished data Baltimore Transportation Study.

Although there is considerable variation in these developed exponents there
is a certain consistency in the variation of exponent for different trip
purposes. The effect of distance seems to become less restrictive i.e.,
the exponent decreases,as purpose of trip becomes more important. 13/

13/ For a good discussion of the logic of the variation in exponent by trip

Effect of Terminal Time   To determine the effect that the inclusion of
terminal time into measurement of separation would have on the exponent
of distance, an analysis was made of travel patterns in Baltimore,
Maryland.

Figure A-1 shows the interchange ratio, actual trips divided by pro-
bable trips, plotted on log-log-co-ordinates. (A straight line on this
type of paper has an equation of the form $Y=KX^a$ where a, the exponent,
is equal to the slope of the line.. As the slope of the line becomes
steeper, the exponent increases. A 45 degree line, has an exponent of
± 1)

The Baltimore data are plotted twice, once using driving time alone as
a measure of separation and again, using driving plus 6 minutes of terminal
time as the measure of separation. The Detroit data is presented to show
the similarity between the two cities and is plotted using driving time
alone as the measure of separation. Observe in Figure A-1 that when the
Baltimore data were plotted using driving time alone the slope of the
line does not remain constant but increases as driving time increases.
However, when separation is expressed in terms of driving time plus ter-
minal time, this variation in slope (and exponent) is greatly decreased.
The resultant pattern of solid points can be approximated with a straight
line.

13/ continued.
purpose see, Carrol and Beuis, "Predicting Local Travel in Urban Areas,"
Papers on Proceedings of the Regional Science Association, Vol. 3, 1957.
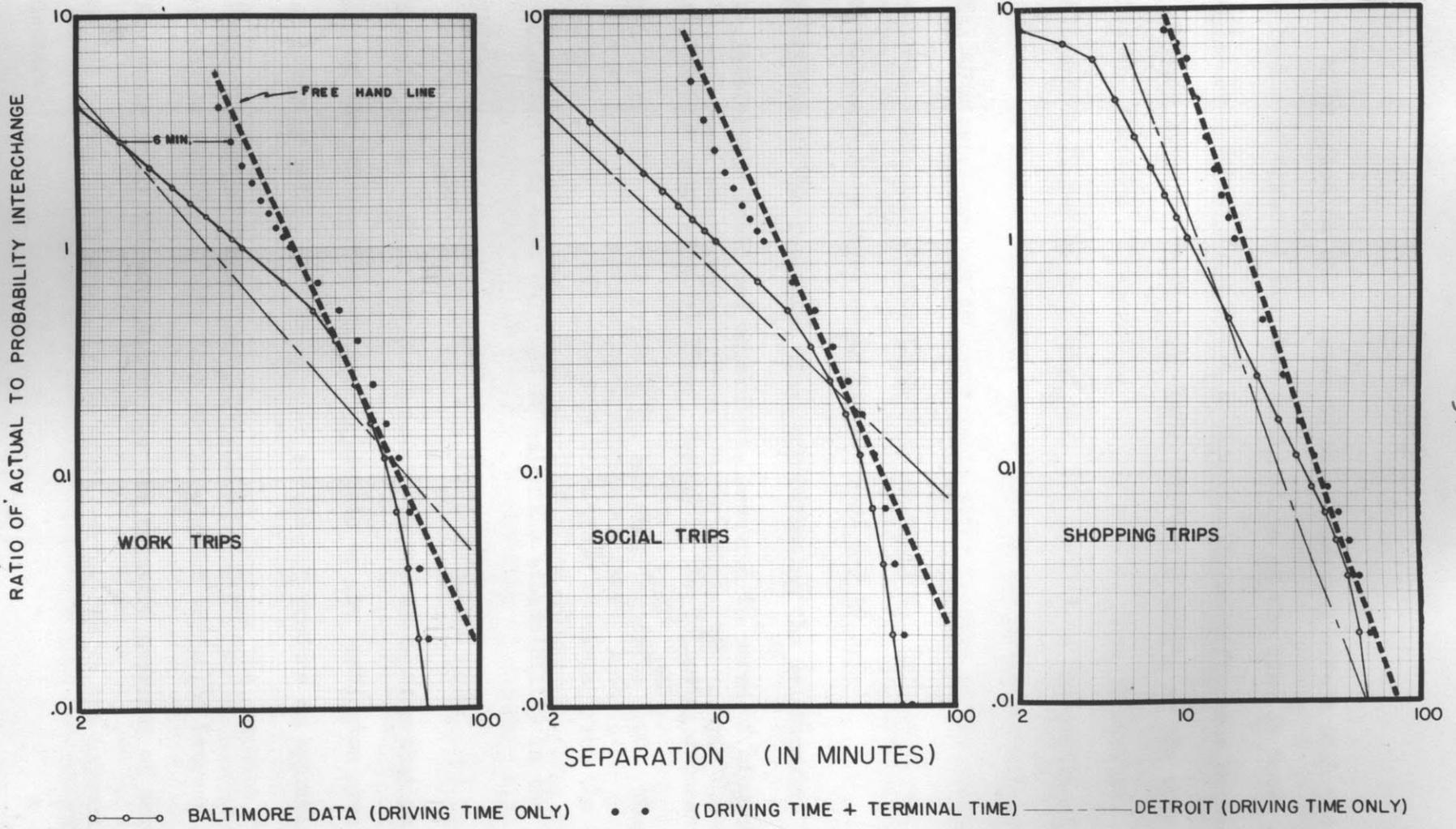
Figure A-1   THE   EXPONENT   OF   DISTANCE   IN   GRAVITY   MODELS

Also to be noted on this figure is the decreasing effect that the inclusion of terminal time has on the slope of the line as total separation increases. There would be practically no difference between the slopes of lines drawn through either the solid points or the open points when the distance of separation becomes greater than 50 minutes. For this reason it may be concluded that the results of the empirical examinations of interurban travel, where most of the trips would be greater than 40 minutes, are not in appreciable error because of the ommission of terminal time in the measurement of separation. Such studies of interurban travel have resulted in exponents of 2.5 to 3.0.

The slopes of the free hand lines approximating the relationship between the interchange ratio and separation, measured in terms of minutes of driving time plus terminal lines, result in the following exponents: Work trips 2.20, Social trips 2.35, and Shopping trips 3.00. These exponents are in general agreement with those resulting from the interurban examinations and were utilized to calculate accessibility in the present study.

Implicit in the use of these exponents, is the assumption that the findings of the Baltimore study are applicable to the Washington area. While not strictly valid, this assumption should not produce an appreciable error in the accessibility calculations. First, because the exponent for any particular purpose of trip does not show great variation between cities (See table A-1); and second, because the relative measures of accessibility are not particularly sensitive to small variations in the exponent of distance.

APPENDIX B

CALCULATION OF ACCESSIBILITY

Prior to applying the accessibility formulas developed in the body of this thesis it is necessary to consider three important aspects of accessibility. These elements can best be expressed in the form of three questions. Accessible to what? Accessible by what means of travel? Accessible at what point in time? In the present examination these questions were for the most part answered or partially answered by the limitations of the available data; however, to assist in possible future empirical tests and to assess the consequences of data limitations in the present analysis it is desirable to discuss briefly each of these aspects of accessibility.

Accessible to what? First it should be explained that this question does not imply a pre-evaluation of the relative importance of accessibility to different types of activities; but rather that it is necessary to determine which of the limitless types of accessibility are going to be calculated and compared to the pattern of growth. Also that it is necessary to determine the units which are to be used to express the size of the activity to which accessibility is being calculated.

The method used in the present examination to determine the types of accessibility to be calculated, was to observe the types of activities with which people had repeated contact. Using the results of various origin-destination surveys it was found that on the average 80 percent of all the trips made in an urban area had either their origin or destina-

tion at home; 40 percent had their origin or destination at work;
20 percent at shopping or commercial recreation areas; 20 percent
at residential areas for social purposes; and the remaining 40 per-
cent at a variety of places for purposes such as medical, dental,
change travel mode, etc. (Note: each trip has both an origin and
destination hence the 200 percent.) With the majority of trips, other
than "home", concentrated in the work, social, and shopping catagories
these were the types of accessibility which were calculated. It could
be argued that frequency of contact is but one aspect of indicating the
importance of accessibility; however, lacking any other criteria,
the determination was based solely on this factor. Other types of
accessibility should be evaluated in light of residential growth in
future examinations.

Once the types of activities to which accessibility is to be calcu-
lated have been determined, the units to measure the relative size of
the activity areas must be developed. In the present analysis, total
employment (number of jobs) was used to indicate the number of em-
ployment opportunities in an area. Total population (number of people)
was used to indicate the number of opportunities for social interaction
offered by an area. Annual retail sales (dollars) were used to in-
dicate the activity level or opportunities for shopping interaction
offered by an area. It is possible that these measures could be modified
so that they would indicate better the actual opportunities for inter-
action offered by each zone or area. For example, instead of total em-
ployment, the average annual number of job openings would probably be
a better measure of employment opportunities. Opportunities for social

interaction could be measured by some combined index of number of people, average income, and social status. Numerous other modifying factors could be developed; however, only through empirical analysis will the desirability of their inclusion into the accessibility calculations be assessed.

It should be remembered that absolute figures are unimportant in expressing the size or activity level of an area. The model only considers the size of one area relative to the size of other areas, whether this relationship is expressed as 1 to 2 or 1,000 to 2,000 makes no difference.

Accessible by what means of travel ? It will be noted that in the formula for calculating accessibility the distance between any given pair of zones can only assume one value at any particular point in time. However, the actual distance between any pair of zones can have a variety of values depending upon the mode of travel used. This weakness is present in all locational analysis proceedures and as yet no adequate solution has been offered. One method which has been used is to express interzone distance in terms of average costs or average time; however, this is at best an approximation, an in addition, before these average values can be computed it is necessary to know what proportion of each interzone movement utilizes each mode of travel, which in some cases is the intended output of the model.

In this analysis distance is expressed in terms of off-peak driving time plus 5 to 8 minutes of terminal time. No attempt was made to adjust for mass transit. In this particular case this omission does not introduce

an appreciable error into the accessibility calculations because the
Washington,D.C. area has only surface transit (streetcars and buses)
and the interzone travel time by transit does not vary from that by
car. If a similar examination were going to be made for a city such
as Boston, some method would have to be devised to account for transit
or the relative accessibility of the central area would be much too low.

Accessible at what point in time ? One of the major problems encountered
in this study was to determine which pattern of accessibility should
be compared to the observed distribution of residential growth. Theoret-
ically,the accessibility which existed at the exact time the land devel-
opment occured should have been used; however, the process of growth is
continuous and the pattern of accessibility is constantly changing. In
Washington only the total growth over a seven year period was available.
Data was not available to break this into smaller increments. Also, the
only travel time data available was for the end point of this seven year
interval. For these reasons the growth which occured from 1948 to 1955
was compared to the pattern of accessibility in 1955. It is now felt
that this proceedure possibly introduced an appreciable unknown into the
analysis and attempts are now being made to estimate travel times for
1948 and 1952 and also to divide the total growth into two increments.

When these data become available the residential growth which occured
between 1948 and 1952 will be compared to the average accessibilty during
this period. The remaining residential growth will be compared to the
1952 - 1955 average accessibility values. It is hoped that this proceedure
will improve the general findings of this thesis.

ACCESSIBILITY CALCULATIONS FOR ZONE____37____

TO ZONE	TOTAL POPULATION	TOTAL EMPLOYMENT	RETAIL SALES (000) $	TRAVEL TIME* (min.)	FRICTION FACTORS**			ACCESSIBILITY TO***		
					F_1	F_2	F_3	POPULATION A_1	EMPLOYMENT A_2	SALES A_3
01	12,218	45,355	-	24	.39	.41	.30	4,770	18,550	-
02	-	25,696	-	27	.30	.32	.21	-	8,230	-
03	11,999	35,482	5,684	23	,43	,45	.35	5,150	16,000	1,990
04	27,360	11,257	5,684	21	.53	.55	..45	14,500	6,200	2,550
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
88	13,764	1,602	400	34	.17	.19	.11	2,330	300	40
							TOTAL	1,211,800	440,180	2585,100

*Actual off - peak driving time plus terminal time.

** Inverse of travel time : $F_1 = \dfrac{1}{tt^{2.35}}$ $F_2 = \dfrac{1}{tt^{2.20}}$ $F_3 = \dfrac{1}{tt^{3.00}}$

*** $A_1 = F_1$ times population ; $A_2 = F_2$ times employment ; $A_3 = F_3$ times Retail sales

Figure B - 1   SAMPLE CALCULATIONS OF ACCESSIBILITY

APPENDIX C

CALCULATION OF RESIDENTIAL DEVELOPMENT RATIOS

The residential development ratio is defined as the ratio of actual
growth to the prorated growth, where the prorated growth of any area
i is equal to the total metropolitan growth divided by the total vacant
land in the metropolitan area and multiplied by the vacant land in area
i . In other words, the proportion of the total prorated growth in area i
is equal to area i's proportion of the total vacant land in the metro-
politan region.

In Washington, the amount of vacant land in each zone was not directly avail-
able; therefore, to estimate this item the following proceedure was used.
First, the amount of vacant land, residential land , and total number of
dwelling units in each zone was known. for 1955 , The change in the
number of dwelling units in each zone between 1948 and 1955 was known. The
following equation was used to estimate the vacant land in each zone in
1948.

$$1948 \text{ Vacant Land} = 1955 \text{ Vacant Land} + 1955 \text{ Residential Land} \times \frac{1955\text{-}48 \text{ D.U.}}{1955 \text{ D.U.}}$$

The results of these calculations were adjusted in specific cases where
it was known that the density of development which occured between 1948
and 1955 was significantly different than that which occured prior to
1948. These adjustments were for the most part quite minor. Table C - 1
gives a summary of these calculations along with the 1955 accessibility
index for each zone.

Table C-1   CALCULATION OF RESIDENTIAL DEVELOPMENT RATIO & SUMMARY OF ACCESSIBILITY VALUES

ZONE NUMBER	DWELLING UNITS 1955	DWELLING UNITS 1948	DWELLING UNITS 1955-1948	RESIDENTIAL LAND (ACRES) 1955	VACANT LAND 1955-1948 [1]	VACANT LAND 1955	VACANT LAND 1948 (EST.)	PROBABLE DEVELOP. % OF TOTAL	ACTUAL DEVELOP. % OF TOTAL	RESIDENTIAL DEVELOPMENT RATIO	ACCESSIBILITY INDEX EMPLOYMENT	POPULATION	SHOPPING	TRAVEL TIME TO C.B.D.	RESIDENTIAL DENSITY 1955 (D.U./ACRE)
1	130	65	65	2	1	⌄	1	2	43	2100	108	173	284	11	650
2	⌄	⌄	⌄	⌄	⌄	⌄	⌄	⌄	⌄	⌄	110	160	280	11	⌄
3	9562	7315	2247	176	41	3	44	90	1500	1690	105	192	311	11	540
4	3040	3032	8	56	⌄	⌄	⌄	⌄	5	⌄	117	203	346	11	540
5	564	566	2-	1	⌄	⌄	⌄	⌄	⌄	⌄	121	177	316	11	5640
6	9202	8129	1073	72	8	⌄	8	16	716	4480	114	197	350	11	1280
7	7377	5292	2085	32	9	⌄	9	19	1390	7300	114	164	326	11	2300
8	4387	3778	609	50	7	⌄	7	14	406	2900	107	197	329	12	880
9	2594	1991	603	47	11	7	18	37	402	1080	114	215	354	13	550
11	11037	8367	2670	401	97	20	117	240	1780	740	88	162	282	16	280
12	2212	1507	705	522	166	⌄	166	341	470	140	67	134	236	17	42
13	1802	1020	782	474	205	77	282	580	521	90	49	104	115	21	38
16	3207	1832	1375	785	337	633	970	2000	916	46	39	95	153	26	41
17	1058	479	579	498	273	1127	1400	2680	386	14	27	57	61	29	21
22	8541	6375	2166	394	100	20	120	250	1445	580	75	142	263	17	220
23	6575	5198	1377	562	118	22	140	290	916	320	61	138	236	20	117
24	3869	2895	974	468	117	41	158	330	650	200	58	126	204	21	83
25	4120	3126	994	522	126	42	168	350	662	190	47	125	169	25	79
26	6199	3553	2646	936	398	312	710	1460	1760	120	45	110	150	26	66
27	3521	2442	1079	861	264	326	590	1210	672	55	43	115	164	28	41
28	3727	2725	1002	919	246	422	668	1370	667	49	33	79	91	29	41
29	6754	2066	4688	1439	1000	970	1970	4050	3120	77	30	88	76	37	47
31	6510	4632	1878	110	52	6	58	76	1255	1650	105	198	340	14	590
32	43723	37402	6321	602	87	6	93	191	4220	4210	94	214	322	14	730
33	18536	14639	3897	442	93	33	126	259	2600	1000	76	199	277	17	420
34	12395	12092	303	596	15	16	31	64	204	320	63	178	255	20	206
35	11400	6048	5352	865	253	89	342	704	2240	320	54	141	231	21	132
36	7332	4983	2349	1170	375	388	763	1560	1570	100	45	128	200	25	63
37	13744	4337	9407	1344	920	709	1629	3350	6260	185	44	121	209	24	100
38	7330	3561	3769	1154	595	743	1338	2740	2520	92	33	92	93	31	63
41	8164	7156	1008	181	22	5	27	55	667	1210	97	212	282	14	450
42	3484	3221	263	297	22	25	47	97	176	180	65	161	197	20	116
43	9883	6043	3840	686	267	124	391	805	2560	320	56	151	190	19	144
44	4358	3806	552	193	11	10	21	43	221	510	98	191	312	14	310
45	6664	1165	5499	665	548	928	1476	3030	3670	120	40	101	104	26	100
46	9272	7033	2239	998	242	300	542	1110	1495	135	47	117	153	20	93
47	3894	2016	1878	834	258	1047	1305	2680	1255	47	39	109	103	23	73

Table C-I Con't.

ZONE NUMBER	DWELLING UNITS 1955	DWELLING UNITS 1948	DWELLING UNITS 1955 – 1948	RESIDENTIAL LAND (ACRES) 1955	VACANT LAND 1/ 1955 – 1948	VACANT LAND 1955	VACANT LAND 1948 (EST.)	PROBABLE DEVELOP. % OF TOTAL	ACTUAL DEVELOP. % OF TOTAL	RESIDENTIAL DEVELOPMENT RATIO	ACCESSIBILITY INDEX EMPLOYMENT	POPULATION	SHOPPING	TRAVEL TIME T) C.B.D.	RESIDENTIAL DENSITY 1955 (D.U. / ACRE)
48	5300	1857	3443	819	533	1270	1803	3700	2300	62	30	90	80	27	65
49	2667	1643	1024	473	181	416	597	1225	684	56	28	79	76	28	56
51	13510	11030	2480	281	52	v	52	107	1655	1550	94	198	234	15	480
52	11399	8326	3073	714	192	146	338	695	2050	300	52	151	145	15	480
53	7677	4888	2789	461	168	105	273	562	1860	330	52	147	133	22	165
56	5102	1472	3630	671	478	2030	2508	5160	2420	47	34	99	82	26	76
57	5204	1984	3220	707	436	3258	3694	7580	2150	28	29	82	64	29	74
61	7155	6596	559	193	15	v	15	31	374	1210	87	146	185	15	370
62	12397	9830	2567	297	61	v	61	125	1715	1370	90	180	226	14	420
63	12494	7601	4893	573	224	143	367	754	3260	430	55	115	115	20	220
64	19715	11236	8479	1097	471	302	773	1590	5660	360	67	161	173	18	180
66	5218	2309	2909	658	367	2252	2619	5380	1940	36	34	86	73	25	80
67	3912	437	3475	428	380	1675	2055	4220	2310	55	43	96	84	22	91
71	111	111	v	10	v	v	v	v	v	v	92	130	249	17	110
72	2972	3640	668-	409	v	295	295	605	446-	v	87	141	220	17	73
73	3874	3401	473	371	45	126	171	352	315	90	88	134	210	17	104
74	11004	7703	3301	1208	361	415	776	1590	2200	138	52	98	110	21	91
75	5615	411	5204	1097	1020	2551	3571	7350	3470	47	45	77	77	23	51
77	8579	7021	1558	350	63	145	208	428	1040	240	63	109	176	18	250
78	13551	9615	3936	1789	520	287	807	1660	2630	160	56	100	145	22	76
81	12881	9292	3589	945	264	123	387	795	2390	300	83	134	233	18	136
82	6524	4985	1539	904	213	313	526	1080	1030	95	53	107	155	21	72
83	4533	2922	1611	1280	455	730	1185	2440	1075	44	51	105	132	20	35
84	6165	2482	3683	1267	755	261	1016	2090	2450	120	47	93	103	24	49
86	6390	2418	3972	1432	891	1373	2264	4660	2650	57	30	70	66	29	45
87	4002	362	3640	1175	1070	1198	2268	4660	2430	52	33	73	64	28	34
88	1881	380	1501	1899	1510	2854	4364	8970	1000	11	24	55	48	29	10
TOTALS	465779	315839	149940	40502	17989	30719	48708	100102	99952						

SELECTED BIBLIOGRAPHY

1. Anderson, Theodore R., "Intermetropolitan Migration: A Correlation Analysis," American Journal of Sociology, 61:5   March, 1956 459-62

2. Anderson, Theodore R., "Potential Models and Spatial Distribution of Population," Papers and Proceedings of The Regional Science Association, Vol. 2, 1956

3. Barr, R. McDonald, "Accessibility Values in Metropolitan Location Patterns," unpublished M.C.P. thesis, M.I.T., 1957

4. Bevis, Howard W., "Forecasting Zonal Traffic Volumes," Traffic Quarterly, 10:2, April, 1956, 207-22

5. Blumenfeld, Hans, "The Tidal Wave of Metropolitan Expansion," Journal of the American Institute of Planners, Winter, 1954

6. Bogue, Donald J. "The Structure of the Metropolitan Community: A Study of Dominance and Subdominance. Ann Arbor: University of Michigan, 1949

7. Carrol, J. Douglas, " Spatial Interaction and the Urban-metropolitan Description," Papers and Proceedings of the Regional Science Association, Vol. 1, 1955 (also Traffic Quarterly, 9:2 April, 1955 149-61)

8. Carrol, J. Douglas, and Bevis, Howard W., "Predicting Local Travel in Urban Areas," Papers and Proceedings of the Regional Science Association, Vol. 3, 1957

9. Carrothers, Gerald A.P., " An Historical Review of the Gravity and Potential Concepts of Human Interactance," Journal of The American Institute of Planners , Spring, 1956

10. Casey, Harry J., "The Law of Retail Gravitation Applied to Traffic Engineering," Traffic Quarterly, July, 1955

11. Cavanaugh, Joseph A., " Formulation, Analysis, and Testing of the Interactance Hypothesis," American Sociological Review, 15:6 Dec., 1950   763-66

12. Chicago Area Transportation Study, Allocating Population to Small Areas, Chicago, 1957

13. Creighton, Roger and Hamburg, John, "A Method of Land Use Forecasting Based Upon Historical Trends," Journal of the American Institute of Planners, Special issue, Spring, 1959

14. Detroit Metropolitan Area Traffic Study, Part:Data Summary and Interpretation, Detroit: July, 1955   90-101

15. Dodd, Stuart C., "The Interactance Hypothesis: A gravity Model Fitting Physical Masses and Human Groups," _American Sociological Review_, 15:2 April, 1950   245-56

16. Dodd, Stuart C., " Diffusion is Predictable: Testing Probability Models for Laws of Interaction," _American Sociological Review_, 20:4 July, 1955   393-401

17. Dunn, Edgar S., " The Market Potential Concept and The Analysis of Location," _Papers and Proceedings of the Regional Science Association,_ Vol. 2, 1956

18. Ikle, Fred C., " Sociological Relationship of Traffic to Population and Distance," _Traffic Quarterly_, 8:2 April, 1954   123-36

19. Isard, Walter, _Location and Space-Economy_, Cambridge: Technology Press, M.I.T., 1956

20. Mitchell, Robert B. and Rapkin, Chester A., _Urban Traffic: A Function of Land Use_, New York: Columbia University Press, 1954

21. Reilly, W. J., _The Law of Retail Gravitation_, New York: W.J. Reilly Co. 1931

22. Roether, Richard W., _Population Potential in Metropolitan Areas_, Unpublished M.C.P. thesis, M.I.T.;1949

23. Schmidt,R. E. and Campbell, M. E., _Highway Traffic Estimation_, Connecticut: Eno Foundation, 1956   40-104

24. Stewart, J. Q., " An Inverse Distance Variation for Certain Social Influences," _Science_ , 93:2404 Jan., 1941 89-90

25. Stewart, J. Q., " Demographic Gravitation: Evidence and Application," _Sociometry_, 11:1-2 , Feb. and June, 1948   31-58

26. Stewart, J. Q., "Physics of Population Distribution," _Journal of Regional Science_, 1:1 Summer, 1958

27, Stouffer, Samuel A., " Intervening Opportunities: A Theory Relating Mobility and Distance," _American Sociological Review_, 5:6 Dec., 1940 845-57

28. Voorhees, Alan M., _A General Theory of Traffic Movements_, The 1955 Past Presidents' Award Paper, Institute of Traffic Engineers, New Haven, Conn.

29. Voorhees, Alan M., " Forecasting Peak Hours of Travel," Washington: _Highway Research Board, Bulletin 203_, 1958

30. Voorhees, Alan M., Sharpe, Gordon B., and Stegmair, J. T., " Shopping Habits and Travel Patters," Washington: Highway Research Board; Special Bulletin 11-B, 1955

31. Wynn, F. H., " Intracity Traffic Movements," Factors Influencing Travel Patterns, Washington: Highway Research Bulletin 119, 1956

32. Zipf, G. K., " The Unity of Nature: Least Action and Natural Social Science," Sociometry, 5:1 Feb., 1942 48-62

33. Zipf, G. K., " The P P / D Hypothesis: On the Intercity Movement of Persons," American Sociological Review, 11:6 Dec., 1946 677-86

34. Zipf, G. K., " The Hypothesis of The Minimum Equation as a Unifying Social Principle," American Sociological Review, 12:6 Dec., 1947 627-50

35. Zipf, G. K., Human Behavior and The Principle of Least Effort, Cambridge: Addison-Wesley Press, 1949