ACCESSIBILITY AS A DETERMINANT OF RETAIL SALES

by

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Subject Headings ______ Accessibility Formulae ACCESSIBILITY FORMUALE

______ Retail Competition RETAIL COMPETITION

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ABSTRACT

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Submitted to the Department of City and Regional Planning on May 18, 1962, in partial fulfillment of the requirements for the degree of Master of City Planning.

The relationship between accessibility and the spatial distribution of urban activities and their interactions has received widespread interest from urban planners, but few attempts have been made to quantify and evaluate this relationship in the field of retail activity. The object of this thesis is: 1) to develop a number of measures of retail accessibility; 2) to evaluate the importance of accessibility as a determinant of the volume of retail sales; and 3) to consider the significance of a sales potential concept based on retail accessibility.

Accessibility is measured by four methods which differ in the manner and extent to which they include the effects of competition and the effects of separation. In an empirical test of these methods, accessibility ratings are derived for a set of new car dealers in the Boston area and those ratings are correlated with their annual sales. Results indicate that accessibility, by any method of measurement, is not the major determinant of the volume of sales. Limitations of the test case preclude a precise judgment of any particular method.

The characteristics of sales potential maps based on these methods are then considered; the nature of competitive accessibility ratings makes such sales potentials inherently unstable. Further research into the relationship between retail development and sales potential is required before the significance of a sales potential concept can be evaluated for planning purposes. In the field of market analysis, potential ratings may be of specific value.

Thesis Supervisor: Aaron Fleisher

Title: Associate Professor of Urban and Regional Studies

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This thesis would not have been possible without the generous assistance of the managers of several new car distribution agencies in Boston, who released confidential sales data to the author. Because of the nature of this information, no reference can be made to the names of those companies nor to the true locations of the salesrooms. Automobile registrations were made available by Mr. Donald J. Laing of the Boston Record-American and Advertiser, and are gratefully acknowledged.

TABLE OF CONTENTS

PART ONE

INTRODUCTION

The subject of accessibility has received wide consideration because of its presumed relationship to the spatial distribution of urban activities and to their interactions. Theoretical studies have focussed attention on the factors that underlie accessibility and on their influence on locational decisions. For example, Mitchell and Rapkin have explored the interactions that characterize urban activities, and noted that each activity will attempt to maximize accessibility to the other activities to which it is linked.[1]

Although its influence on urban development is considered significant, there have been few attempts to define accessibility for the purpose of quantifying these relationships and assessing their true significance. The work of Hansen, in defining accessibility and measuring its relation to residential growth, is of particular interest and will be referred to later.[2] In the field of retail

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1. Robert B. Mitchell and Chester Rapkin, Urban Traffic. A Function of Land Use (Columbia University Press, New York, 1954), Chapter VII.

2. Walter G. Hansen, "How Accessibility Shapes Land Use," Journal of the American Institute of Planners, Vol. XXV, No. 2, May 1959, p. 73.

activity, although accessibility has long been an acknowledged factor, there are few methods available to quantify it and compare its influence with other factors.

The subject of this thesis is accessibility and its relation to retail sales. The investigation has three objectives: 1) to develop a number of measures of accessibility at urban sites; 2) to evaluate the importance of accessibility in determining the volume of retail sales compared to other factors; and 3) to consider the significance of a sales potential concept for urban planning.

Potential Models

The concept that a location possesses a certain potential for interaction due to the spatial distribution of potential interactors has been explored and developed by a number of social scientists. Stewart defined the possibility of interaction with respect to an individual i generated by population at j as:

$$ {}_iV_j = k \frac{Pj}{dij} $$

Where Pj is the population at j, dij is the distance between i and j, and k is a constant of proportionality.[3] The

3. A number of potential models are compared and discussed in Gerald A. P. Carrothers, "An Historical Review of the Gravity and Potential Concepts of Human Interaction," Journal of the American Institute of Planners, Vol. XXII, No. 2 (Spring 1956), p. 94.

total possibility of interaction of an individual at i is the population potential at i, and is:

$$ {}_iV = k \left[\frac{P_1}{d_{i1}} + \frac{P_2}{d_{i2}} + \cdots \frac{P_n}{d_{in}} \right] $$

Carrothers reports correlations between measures of potential based on variations of this formula, and a number of phenomena such as migration, telephone calls, and traffic.[4]

In the field of retail activity, the major work along these lines was the development of a retail "gravitation" formula for inter-city trade. Reilly's "Law of Retail Gravitation" measures the attraction of two competing retail centers for the trade of an individual somewhere in between them. According to this formulation, the distributions of purchases is given by:[5]

$$ \frac{Ba}{Bb} = \left(\frac{Pa}{Pb}\right) \left(\frac{Db}{Da}\right)^2 $$

Where Ba and Bb are the proportions of an individual's trade attracted by two cities, a and b, respectively, Pa and Pb are the populations of the cities; and Da and Db are the distances from the individual to the cities. For intra-urban retail trade, there is no similar quantitative method to relate the accessibility of retail sites with the level of activity at them.

4. Ibid., p. 98.

5. This formula was given extensive testing and the results are reported in P. D. Converse, "New Laws of Retail Gravitation," Journal of Marketing (October, 1949), pp. 379-384.

Retail Structure and Accessibility

Accessibility has long been recognized as a factor in the organization of retail land use. According to the theory of retail location, retail sites are allocated to various uses by the market process according to the competitive bids of merchants. The maximum rent bid of each merchant is determined by his estimate of income and operating costs at each site. The most important variables among the determinants of the maximum rent which any merchant can afford to pay for a site are the volume of sales and the markup. Both of these items, particularly the volume of sales, are functions of location.[6]

For any site certain types of retail activity possess an inherent capacity to pay higher rents. Ratcliff states that this hierarchy of uses is not fixed, but depends on the location of the site:[7]

> Correctly defined, the hierarchy is not one of retail uses alone but of retail uses on appropriate sites.... It should be further stated that for each site there exists a hierarchy of uses based on their rent-paying ability on that site, and that there is a hierarchy of sites based on differential productivities under the appropriate uses.

The advantage that location gives one site over another

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6. Richard U. Ratcliff, The Problem of Retail Site Selection (University of Michigan, Ann Arbor, 1939), p. 61.

7. Ibid., p. 73. (Italics his.)

is the source of what Chamberlin terms the "monopoly income" of the landlord:[8] "Two sites have different rents to the degree that they are in different markets..." The accessibility differences between sites and their effect on sales would appear largely responsible for the pattern and distribution of retail activity.

Factors Determining Sales Volume

A number of factors as well as accessibility will influence the decision of a shopper when he chooses between alternative retail stores. The factors that determine sales volume can be considered in three groups: accessibility, merchandising and agglommeration.

Accessibility: Buyers desire, among other things, to minimize the time and effort of shopping and a store will be at an advantage, the closer it is to large volumes of shoppers. In addition, for each particular kind of store the purchasing habits of shoppers in the surrounding area are significant; a store selling expensive jewelry will require well-to-do clientele.

The number and location of competitors will also affect the volume of sales; this will be considered in detail later. In general these factors refer to the location

8. Edward H. Chamberlin, The Theory of Monopolistic Competition (Cambridge, Harvard University Press, 1958), p. 268.

of the site with regard to the location of purchasers and competing dealers and will be called, here, <u>accessibility characteristics</u> of the site.

<u>Merchandising</u>: In addition to the accessibility of the site, there are a number of characteristics of the particular store that will affect its volume of sales. The quality of the merchandise or service offered and the prices charged are extremely important. In addition, a number of intangibles will influence a potential customer's choice: the variety and selection available, the atmosphere of the store, the courtesy of the employees, the advertising image, as well as the dealer's reputation for reliability and honesty. These factors are subject to the policies and abilities of management and are called here <u>merchandising characteristics</u> of the store.

<u>Agglomeration</u>: Sales at a particular store are also influenced by the presence of nearby retail activities. If there are, in the immediate area, other stores offering a variety of merchandise and services, the shopper is offered an opportunity to make many purchases at the same time, and to combine several trips into one.

Similarly, if there are in proximity, a number of stores that sell similar products, the buyer has the opportunity to compare before making his purchase and to shop for the best buy. The advantages of agglomeration vary not only with the nature and value of the product but also with the frequency of the purchase.

PART TWO

MEASURES OF ACCESSIBILITY

Definition of Accessibility

As commonly used, the term accessibility does not have a precise meaning; it is usually thought of as a characteristic of a site which is based on the amount and location of potential interactors. This characteristic is often considered a determinant of the location of different activities and of the level of activity occurring at these locations. In this thesis only similar retail uses will be considered; consequently accessibility should be reflected in the level of activity - the volume of sales - at different sites.

Accessibility is defined, for this thesis, as the relative volume of sales, at similar retail sites, due to the spatial distribution of potential interactors. For some types of products the volume of purchases of an area may be influenced by the abundance or lack of stores in the vicinity; the nature of the product and its substitutability are important. In the more usual case the effect of accessibility is largely in the distribution of trade. In the formulae derived below, the zonal volume of purchases is assumed independent of accessibility.

Accessibility formulae can be based on the potential model; the measurement of accessibility for residential areas by Hansen is an example.[9] By this method, accessiblity rating

9. Walter G. Hansen, "Accessibility and Residential Growth," unpublished M.C.P. thesis, M.I.T., 1959. A brief descrip-

is the sum of "contributions" from zones, where each "contribution" represents the purchases of a zone at a certain site;

$${}_JI_i = kV_i\ F({}_Jd_i)$$

where, ${}_JI_i$ is the volume of purchases of zone i at site J, Vi is the size of zone i, $F({}_Jd_i)$ is some function of the distance between zone i and site J, and k is a constant of proportionality.

In the usual potential model, the same k is assumed for all the zones and since ${}_JI_i$ is taken as a relative value, the k which is implied in each rating is simply left out. This accessibility rating only reflects the location of purchasers; the number and location of other sites does not affect it. To vary the accessibility contribution and reflect competition the factor k must be evaluated.

It is also possible to defferentiate between accessibility formulae according to how they include the effect of separation. In the simpler types a boundary is drawn around the site and the summation of all interactors within the boundary weighted equally, is the basis for all accessibility rating of that site. The second type is similar to the potential models discussed, where many more zones are included, the interactors weighted for separation according to some inverse power relationship.

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tion of Hansen's method is given in Appendix F.

Accessibility Formulae

The different concepts of retail site accessibility will be the basis for four methods of measurement that vary in their complexity and in the factors they include. They are: Method A is based on the distribution interactors around a site and weights all within a boundary equally; Method B also weights interactors within a boundary equally but reflects the location of competitors in drawing the boundary; Method C weights interactors according to their distance, but does not reflect other competing sites; Method D weights interactors according to their distance and accounts for the location of competing sites.

To formulate these methods, imagine a region divided into zones a, b,....n, where Vi represents the size or volume of a zone. Sites A, B, ...M are the locations of dealers; $_JI$ is the accessibility rating of site J and is the sum of accessibility "contributions" from the zones;

$$_JI = {_JI_a} + {_JI_b} + \dots {_JI_n}$$

Method A: This is the simplest method; it sums up the volume of all zones within a specified radius of a site. All included zones are weighted equally, whether near the site or the boundary; consequently the boundary is always somewhat arbitrary. The accessibility rating is:

$$_JI = Va + \dots Vk$$

(including all zones within the radius)

Method B: In order to reflect competition in this method, boundaries are drawn equidistant from each site. Each interactor is counted only once and assigned to the closest site. As in Method A, the weight of each zone is equal whether near boundary or adjacent to the site. The accessibility rating is:

$${}_{J}I = Va + Vb + \ldots\ Vk$$

(including all zones within the boundary)

Method C: The accessibility "contribution" is weighted for distance, and the rating of a site is the sum of these weighted "contributions":

$${}_{J}I = Va\ F({}_{J}d_{a}) + Vb\ F({}_{J}d_{b}) + \ldots\ Vn\ F({}_{J}d_{n})$$

where $F({}_{J}d_{i})$ is some inverse function of the separation between site J and zone i. Since the weight of a zone's "contribution" to site J declines as the separation increases, the boundary problem should not be significant. In Method C, as in all potential models, the factor k, which should appear in each "contribution," is left out, because it is tacitly assumed to be the same for all zones. A rating derived in this manner is not in units of sales; it is really, ${}_{J}I$ / k whose units are those of VF(d). Since all k's are assumed equal, these ratings can be used to proportion the total regional sales, without directly evaluating the factor k.

Method D: In Method D we assign a different value k to each zone. To evaluate k_i consider the competitive situation at each zone. It requires that the sales made to that zone from all sites add up to the total zonal purchases:

$$Vi = k_{i}Vi\ F({}_{A}d_{i}) + k_{i}Vi\ F({}_{B}d_{i}) + \ldots\ k_{i}Vi\ F({}_{M}d_{i})$$

Solving for k_i:

$$k_i = \frac{1}{F({}_Ad_i) + F({}_Bd_i) + \dots F({}_Md_i)}$$

The accessibility contribution is then:

$${}_JI_i = k_i Vi \; F({}_Jd_i) = Vi \; \frac{F({}_Jd_i)}{F({}_Ad_i) + F({}_Bd_i) + \dots F({}_Md_i)}$$

This states that the distribution of purchases from a zone i is based on the relative location of each site compared to the location of all the other sites around zone i. The accessibility rating of a site J, is then:

$${}_JI = k_a Va \; F({}_Jd_a) + k_b Vb \; F({}_Jd_b) + \dots k_n Vn \; F({}_Jd_n)$$

There is now a separate k for each zone. Ratings derived by Method C will be equivalent to those of Method D only for the special case when the factor k actually is the same for each zone.[10]

Sales Potential

In the case of Method D, where k is evaluated (and in Method B, where it is assumed equal to 1) the accessibility rating is in units of V. In Methods A and C, the accessibility ratings are in units of VF(d) and their absolute values depend on the function F(d). Accessibility ratings

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10. The way in which evaluating the factor k will reflect competition can be seen if one imagines a hypothetical situation: in an urban area with sites A,B ... M, a new dealer, Q, opens adjacent to one of the existing dealers. By Method C, which assumes all k's equal, the accessibility rating of a dealer is:

cannot be compared except when similarly derived.

If the merchandising and agglomeration characteristics of all dealers were the same, the accessibility rating would represent the relative level of sales at each site. To derive the sales potential at a site, ${}_{J}S$, based on accessibility:

$$ {}_{J}S = \frac{{}_{J}I}{{}_{A}I + {}_{B}I + \cdot\cdot {}_{M}I} \text{ x (total sales)} $$

<u>The Effect of Separation</u>

The effect of separation on the probability of interaction can be expressed in a number of ways. Potential models usually assume an inverse power relationship:

$$ F({}_{J}d_{i}) = \frac{k}{({}_{J}d_{i})^{x}} $$

where x and k are constants; this type of relationship has been used to distribute urban travel between zones, although

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$$ {}_{J}I = VaF({}_{J}d_{a}) + VbF({}_{J}d_{b}) + \text{---} VnF({}_{J}d_{n}) $$

The existence of dealer Q does not affect any of the terms and therefore, has no effect on the accessibility rating of any site.

In Method D, the accessibility rating is:

$$ {}_{J}I = k_{a}VaF({}_{J}d_{a}) + k_{b}VbF({}_{J}d_{b}) + \dots k_{n}VnF({}_{J}d_{n}) $$

The addition of a dealer Q adds a new term $F({}_{Q}d_{i})$ to the denominator of each k_{i} and decreases its value. This will lower the value of ${}_{J}I$. Some k's will be affected more than others; if these zones which "contribute" most to ${}_{J}I$ are also most affected by the change in k, ${}_{J}I$ will be decreased by a significant amount. An example of the effect of site layout is given in Appendix A.

other types have also been tried.[11] The separation, d, is often approximated by distance or time. Its effect is probably much more complicated, including the cost, comfort, and general effort expended in overcoming distance.

Zone Volume

To develop retail accessibility ratings, the "contributions" of zones have been summed for each site; each "contribution" is a function of the volume of the zone. The volume of a zone can be expressed in several ways. For retail activity, however, the importance of any zone is related directly to its volume of purchases. The units of V should be dollars, or if the purchases under consideration are homogeneous, simply units of that product.

The volume of purchases of a zone may often be approximated by other indices--income, number of households or even the population. These indices do not necessarily express the volume of purchases; buying habits may differ for zones with similar indices. Therefore an accessibility rating based on these indices will approximate the true accessibility only as well as they approximate the volume of purchases.

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11. For example: 1) Alan M. Voorhees, "Forecasting Peak Hours of Travel," Highway Research Board, Bulletin No. 203 (Washington, D. C., 1958); 2) J. Douglass Carroll, Study Director, Chicago Area Transportation Study, Final Report, Vol. II (1960), p. 34.

The volume of purchases, V, has been assigned to a specific zone. In reality, purchasers move about the urban area and relating accessibility to their place of residence will not describe the true potential for interaction. For certain types of sales, accessibility can more reasonably be related to places of employment, recreation, or some other activity.

PART THREE

EMPIRICAL TESTS

Correlation

The statistical test which is used in this thesis to evaluate the significance of accessibility in comparison with the other factors determining sales is the coëfficient of correlation.[12] If accessibility were the only significant difference between stores the methods derived in the previous section would yield ratings that correlate perfectly with the actual sales; the coëfficient of correlation would be one. On the other hand, if accessibility were unimportant, and sales variations were due only to merchandising and agglomerative differences between stores, the correlation would be zero. In reality sales are due to all three factors, and the correlation will probably be of some value other than zero or one. The coëfficient of correlation

12. The coëfficient of correlation is explained in any standard text on statistics. For example, see: 1) Burrington and May, Handbook of Probability and Statistics (Handbook Publishers, Inc., Sandusky, Ohio, 1953), Ch. XII; 2) R. A. Fisher, Statistical Methods for Research Workers (Oliver and Boyd, London, 1934), Ch. VI. Briefly, r^2 is the reduction in variance from the best linear regression line on x and y values:

r = coëfficient of correlation

$$r = \frac{\text{covariance of } x \text{ and } y}{(\text{standard deviation of } x)(\text{standard deviation of } y)}$$

can be used to calculate a factor, r^2, which indicates the reduction in the variation of sales among sites due to the assignment of accessibility ratings.

The Product

The empirical test of these formulae requires the location of a number of similar, competing stores. It is important that the products they sell be similar, so that accessibility will be a valid basis for comparing sales.

The main criterion for choosing a product was a practical one--the availability of information. Sales data is jealously guarded information which merchants are reluctant to divulge. Just as important it was required to know the purchases of the product on a zonal basis. Another requirement was that there be a limited number of competing dealers so that the calculations would be feasible by desk calculator.

One product that met these requirements was new cars; new cars are registered according to the place of residence of the purchaser and annual registrations were available for the Boston metropolitan area, by brand. Most important, the annual sales at Metropolitan Boston dealers were released to the author by the regional distribution agencies of several companies.

Only one brand was used; the cars sold by these dealers are relatively homogeneous, although price, service and advertising differences will affect the level of sales. Some dealers were on "automobile row" while others were not, introducing varying agglomerative effects as well as merchandising factors.

Procedure

The Boston metropolitan area was divided into approximately 100 zones, for which annual registration data was known. New car registrations of the brand under consideration were used as V_i, the volume of zone i. The zones were irregular in shape and coincided with cities and towns, except for the City of Boston, which was subdivided into 11 zones. The locations of 51 dealers were plotted on a map of the region. For 26 of these the annual sales were known, and accessibility ratings were calculated by the four Methods. (Figure 1)

It was assumed that travel time represented the separation as well as any simple index of separation. Distances scaled from the map were converted into travel times by means of a graph (Figure 2) which relates travel time to distance, depending on the type of facility used. The graph was made by the Boston College Seminar Research Bureau, and is based on field surveys in the Boston Area conducted in 1959.[13] The report also noted that for shopping trips,

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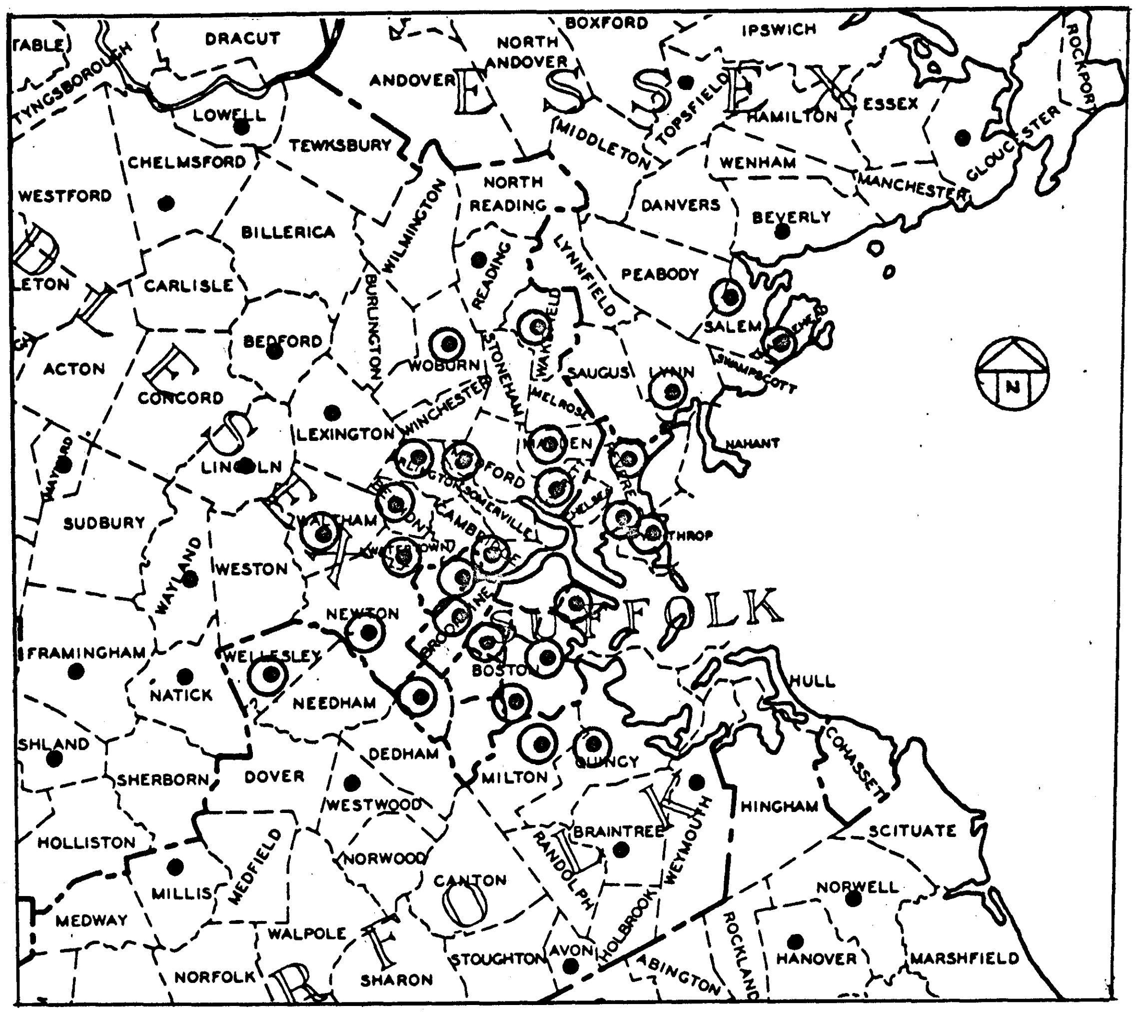
13. Boston College Seminar Research Bureau, Travel in the Boston Region, Vol. II, February 1961, pp. 42-43.

LOCATION OF ZONES AND SITES FIGURE 1

BOSTON METROPOLITAN AREA



KEY

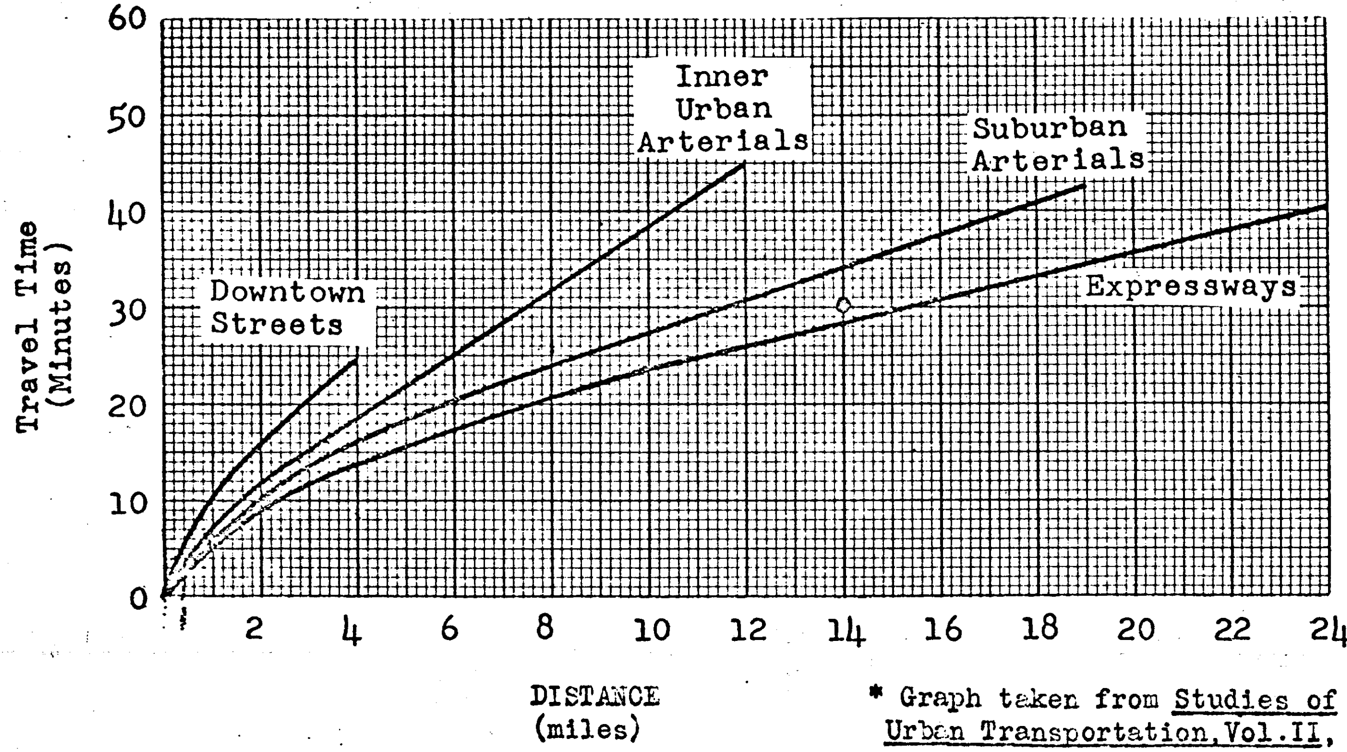
Zone Boundaries - - - - - - - -

Auto Dealer Sites * ●

Auto Dealer Sites for which accessibility ratings were calculated and correlated with sales.* ⊙

*Note: The positions of sites indicated on this map are not those of the Auto Dealers on which the empirical tests were made, but are merely representative of the actual distribution of dealers.

Automobile Trip Travel Time*
(By Type of Highway and Trip Length)



* Graph taken from <u>Studies of Urban Transportation, Vol. II</u>, Seminar Research Bureau, Boston College, (1961) p.42.

TRAVEL TIME

FIGURE 2

3-5 minutes of terminal time is usually involved; consequently, 4 minutes were added to every value of travel time scaled from the graph.

The travel time used in these tests was calculated only for auto travel, with normal driving conditions. This would appear reasonable for new car shopping trips which are probably made by car and in off-peak hours.

Method A: In Method A, the number of registrations within an arbitrary driving time of a site is counted. For this test a travel time of about 20 minutes was used corresponding to three miles. Within this boundary were a few whole zones and portions of several others. Proportions of the registrations of these zones on the boundary were assigned to a site, based on the proportion of the zone within the specified radius. Only rough proportions were possible, so the uniform three mile radius was used without regard to time along routes.

The reduction of variance was----40% (Figure 3).

Method B: For Method B, the region was divided into market areas around each site; boundary lines were drawn perpendicular and equidistant between adjacent sites. Each purchaser is assigned to the closest dealer. In this case, as in Method A, fractions of zones were involved and as they could only be estimated roughly, boundary lines were located by distance rather than travel time along routes.

The reduction in variance was----43% (Figure 4).

Method C: In Method C, zones are weighted according to distance, and the following formula was used to express that relationship:

$$F({}_Jd_i) = \frac{1}{({}_jd_i)^2}$$

Analyses of shopping trips have derived exponents for d ranging from 2.0 to 3.0.[14] The actual exponent is probably different for each product, as the effect of separation is not necessarily the same for every type of purchase. The exponent 2, though arbitrary, should give an indication of accessibility. The formula used was:

$${}_JI = \frac{Va}{({}_Jd_a)^2} + \frac{Vb}{({}_Jd_b)^2} + \ldots . \frac{Vn}{({}_Jd_b)^2}$$

With an inverse power function, the weight of a zone is dependent on its distance from a site. This distance was scaled from the centroid of the zone to the site and converted into travel time by the graph. When sites were within or adjacent to zones, the site-centroid distance is not accurate, and a different method was derived to calculate travel time for these cases.[15]

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14. See: 1) J. Douglass Carroll, "Spatial Interaction and the Metropolitan Description," Papers and Proceedings of the Regional Science Association, Vol. 1, 1955; 2) Boston College Seminar Research Bureau, op. cit.

15. This method gave a "typical" purchaser's driving time to the site based on the size and shape of a zone and

The problem of boundaries, where to stop adding additional zones to the summation, should not be critical; as distance increases, the weight, $\frac{1}{(d)^2}$, of each additional zone decreases. In general, the cut-off point was extended where there were large zones, or where the density of sites was sparse.

The reduction of variance was----46% (Figure 5).

Method D: This method is the most complex. The procedure was to include, as in Method C, as many zones as would contribute substantial amounts to sites under consideration.[16] Then, the relative accessibility of each site around that zone was calculated. The "contribution" from zone i to site J is:

$$ {}_{J}I_{i} = Vi \frac{\frac{1}{({}_{J}d_{i})^2}}{\frac{1}{({}_{A}d_{i})^2} + \frac{1}{({}_{B}d_{i})^2} + \cdots \frac{1}{({}_{M}d_{i})^2}} \quad \text{and} \quad {}_{J}I = {}_{J}I_{a} + {}_{J}I_{b} + \cdots {}_{j}I_{n} $$

The reduction in variance was----32% (Figure 6).

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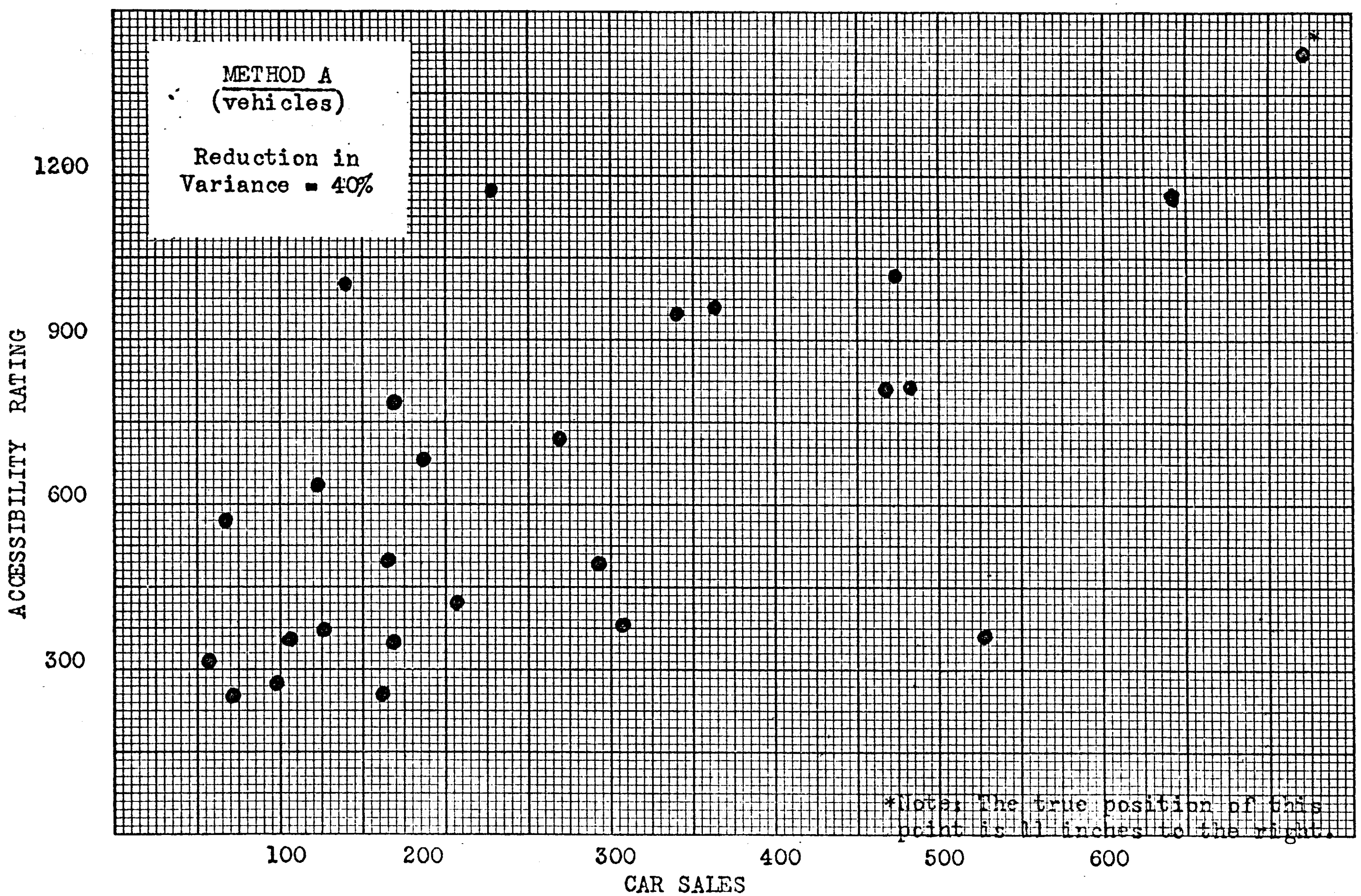
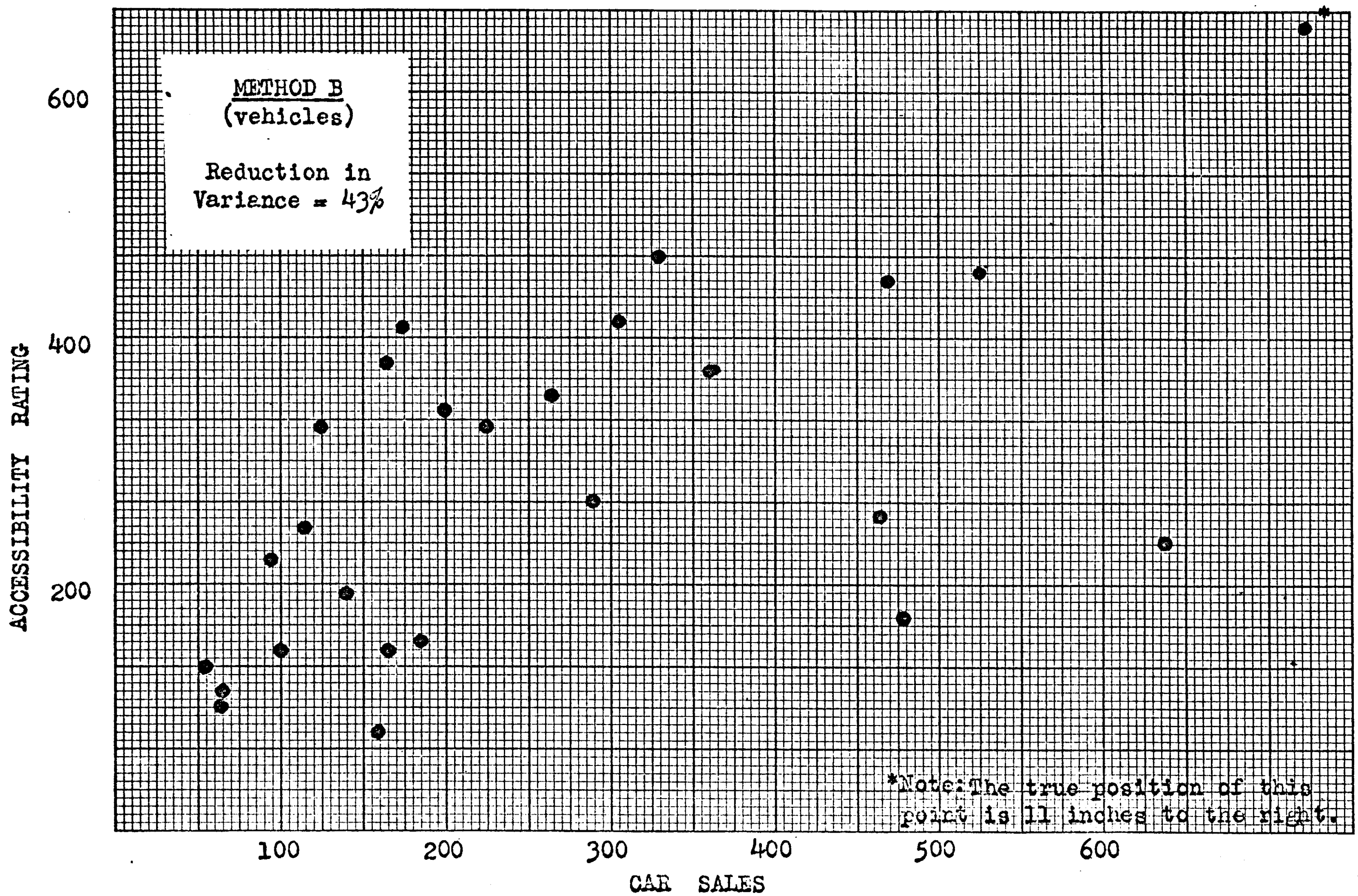
the location of the site. It is explained in Appendix B.

16. The method of computation of an accessibility rating by methods C and D is shown, for a typical case, in Appendix C.



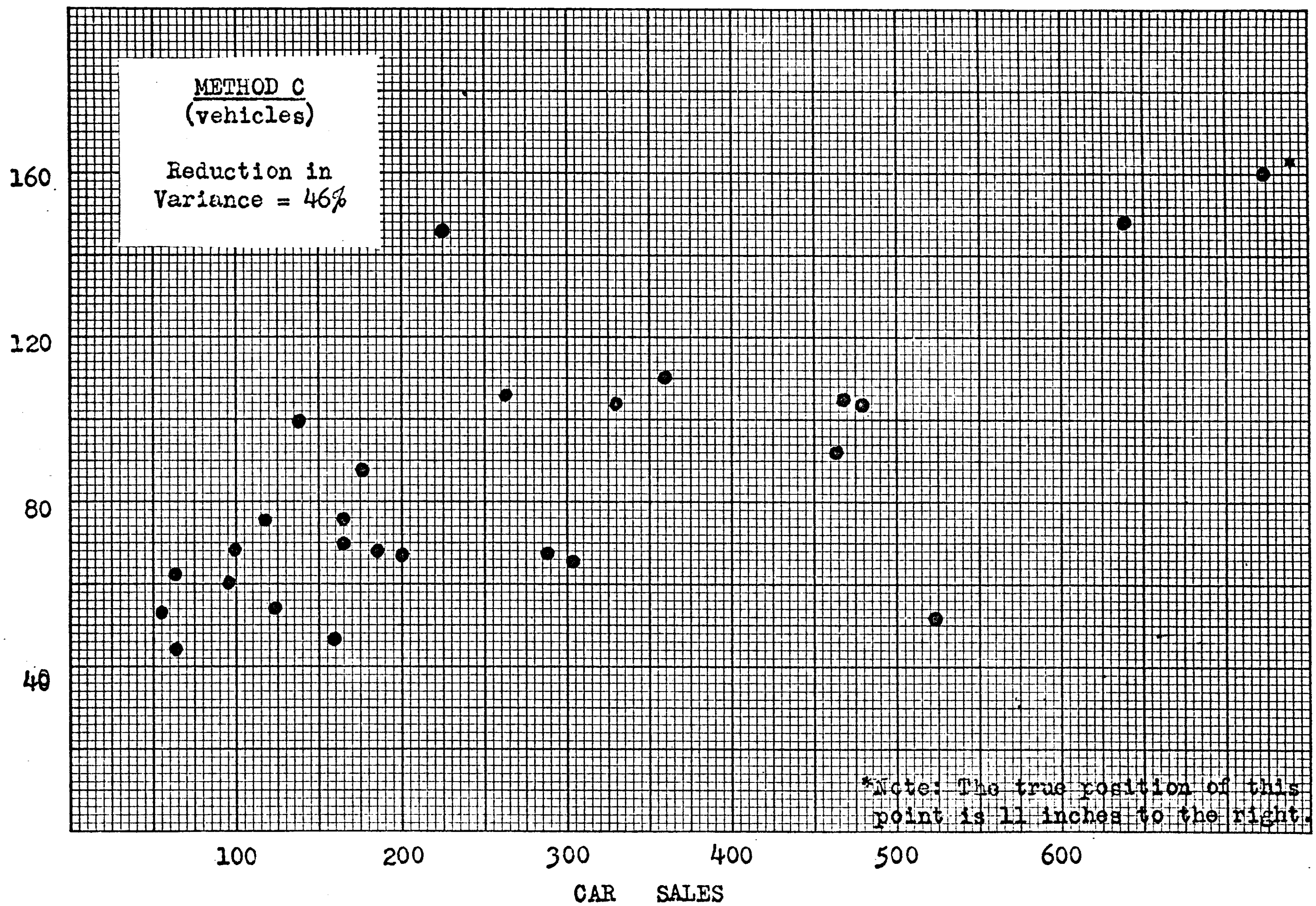
CORRELATION OF ACCESSIBILITY AND SALES

FIGURE 3



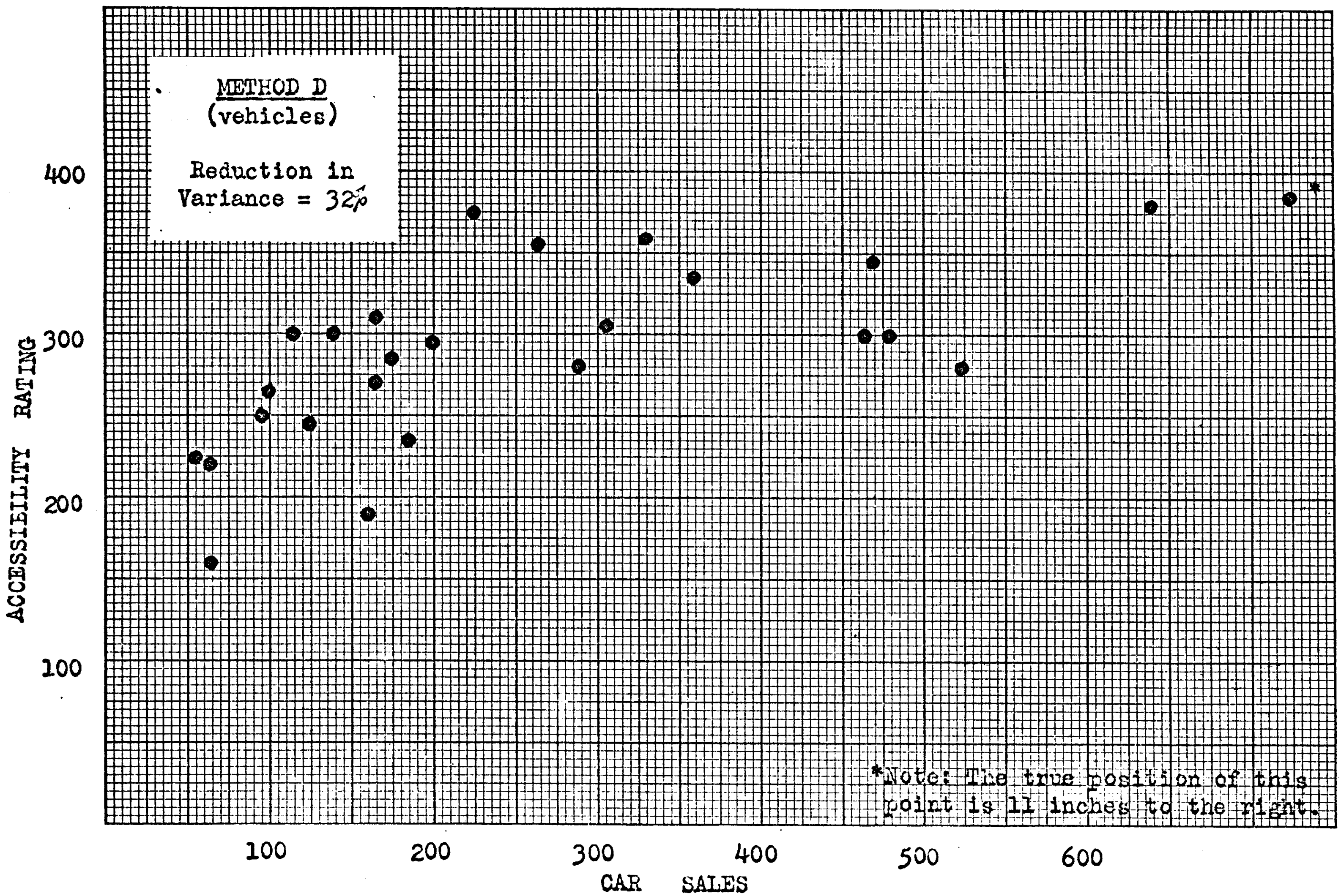
CORRELATION OF ACCESSIBILITY AND SALES

FIGURE 4



CORRELATION OF ACCESSIBILITY AND SALES

FIGURE 5



CORRELATION OF ACCESSIBILITY AND SALES

FIGURE 6

PART FOUR

ANALYSIS OF RESULTS

Significance of Accessibility

The results summarized are:

	A	B	C	D
Reduction in variance-------	40	43	46	32

By any method, accessibility accounted for about 30 to 45% of the variation in new car sales from dealer to dealer. This appears quite high in view of all the merchandising and agglomerative factors that are usually imagined to play such a determining role.

For example, Ratcliff says, in discussing the significance of location in the customer purchasing habits for various articles:[17]

> ...in the purchase of groceries, convenience to home is highly important because of the frequency of purchase, bulk of the articles, relative unimportance of comparison and the relative immediacy of the need.... On the other hand, the high economic value of an automobile, and the infrequency of purchase, result in attaching much less importance to convenience of auto salesrooms...

The fact that auto sales are divided among a large number of dealers in the metropolitan area reflects automobile

17. Richard U. Ratcliff, _op. cit_., p. 66.

companies' belief that accessibility does count significantly in the volume of sales. The existing distribution of auto salesrooms is a matter of company policy; exclusive franchises are given to each dealer for a specified area.

As the size of a salesroom increases, both merchandising advantages and internal economies accrue to the dealer: he can offer a wider selection, his salesmen are more fully utilized, and so forth. These advantages of fewer, larger salesrooms do not increase indefinitely. With fewer dealers, the average customer must travel further to get to a salesroom. At some point the loss in customer convenience is more than the dealer advantage. The optimum number of outlets is dependent on the significance of accessibility as well as internal and merchandising characteristics.[18]

Layout of Dealers

The similarity of values for Methods A, B, and C and especially the low value of Method D, were not expected. As far as this study is concerned, the additional calculation involved in the more complex methods seems hardly justified.

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18. This was pointed out to the author by the head of one of the regional distribution agencies who noted that the number of dealers in the Boston metropolitan area was to be reduced. Consumer demand has made a wider selection of models important for a dealer, he stated, and at the same time, newer highways make each dealer convenient to a larger number of people than before.

The reason for this may lie in the special character of auto dealer locations. The layout of salesrooms is determined by the company to eliminate any competing dealers in proximity. The layout over the region is fairly uniform and the advantage of Method D, reflecting the effects of near-by competitive dealers, does not appear warranted by this situation.[19] In a more typical marketing situation where locations are freely chosen and dealers are sometimes near each other and sometimes far apart, Method D may yield higher correlations.

Accessibility to Population

Data on purchases of specific types of products are not often available on a zone basis. To see the effect of another index of zone volume, new values of accessibility were calculated, substituting the population of a zone, Pi, for new car registrations, Vi, of the particular brand. The results were:

Reduction in Variance (Figures 7-10)		A	B	C	D
	Vi	40	43	46	32
	Pi	40	34	45	39

The results are not very different; in all cases except Method D, the reduction in variance, with population as a measure of zone volume, is less than or about equal to the reduction in variance when vehicles were used. This

19. Appendix A shows how Methods C and D reflect the layout of dealers.

was expected; in the derivation of these methods in Part Two, it was stated that other indices of zone volume will approximate the accessibility based on purchases only as well as these indices approximate the volume of purchases. The results indicate that, at the scale of zones used here, population is a reasonable basis for computing retail accessibility for auto dealers.

The Parameters

The parameters used in Methods A, B, C and D were chosen arbitrarily. To test the possibility of increasing the correlation with different parameters, new accessibility ratings were computed for one case, Method D, using a closer cut-off point to cease adding zones. This is not the same as increasing the exponent but has a somewhat similar effect by increasing the weight of closer zones.

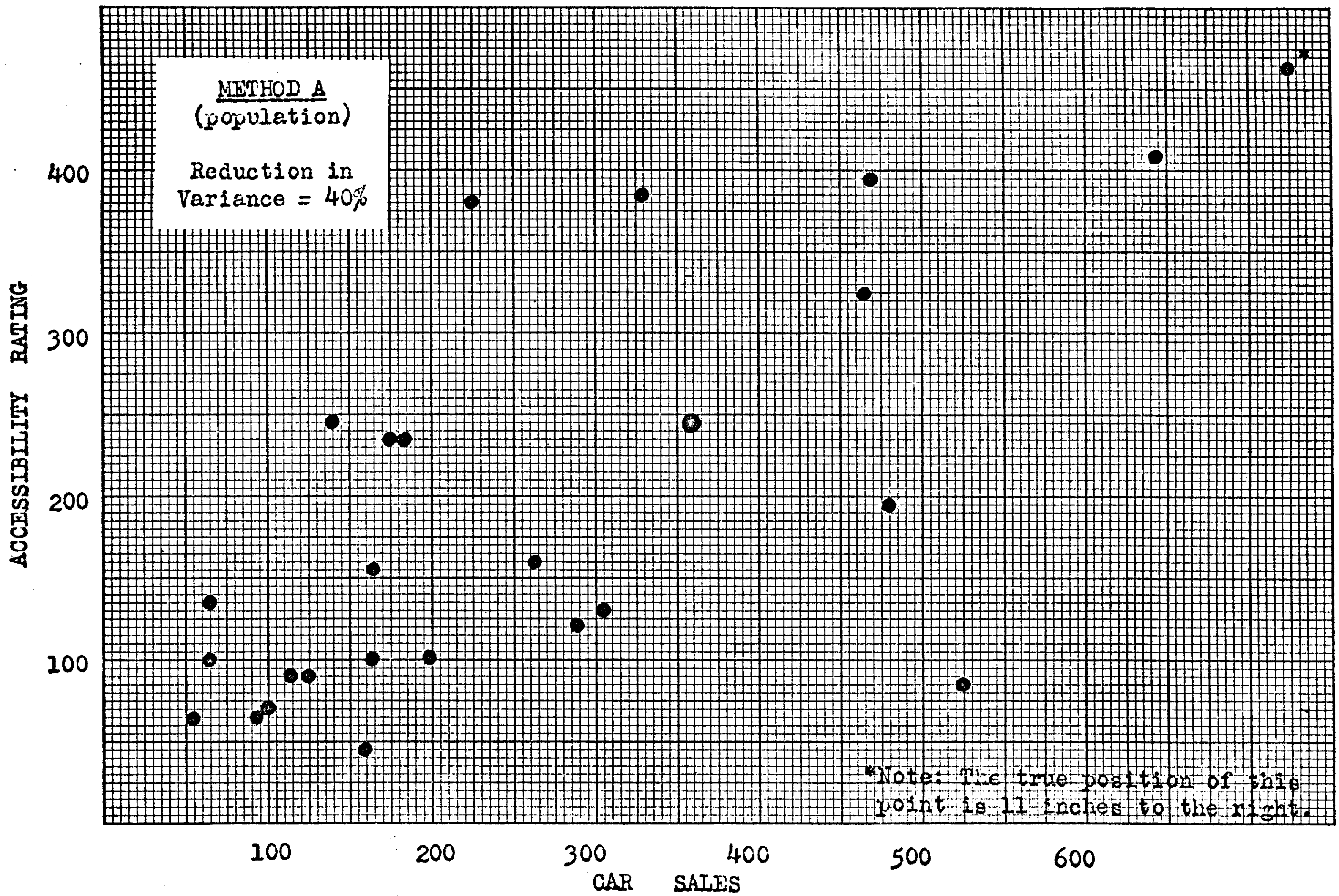
The results were--------

	D	D'
V	32	58
P	39	39

There is a marked improvement for Method D with vehicles, while with population, none at all. This test was not sufficiently clear to tell the effect of a different exponent.

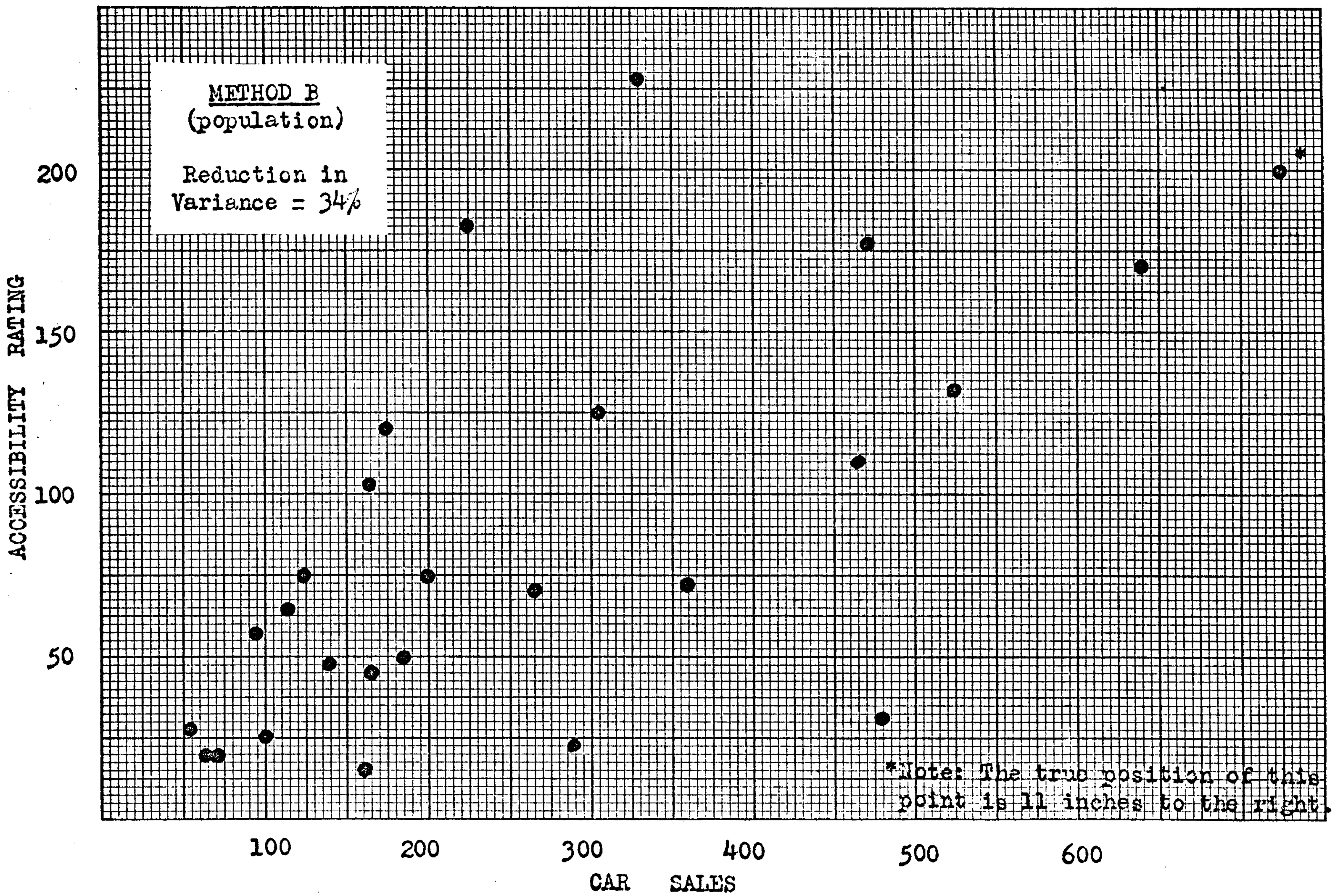
Accuracy of the Results

Errors that are introduced by inaccuracies in measurement are difficult to estimate. In Methods C and D, distance



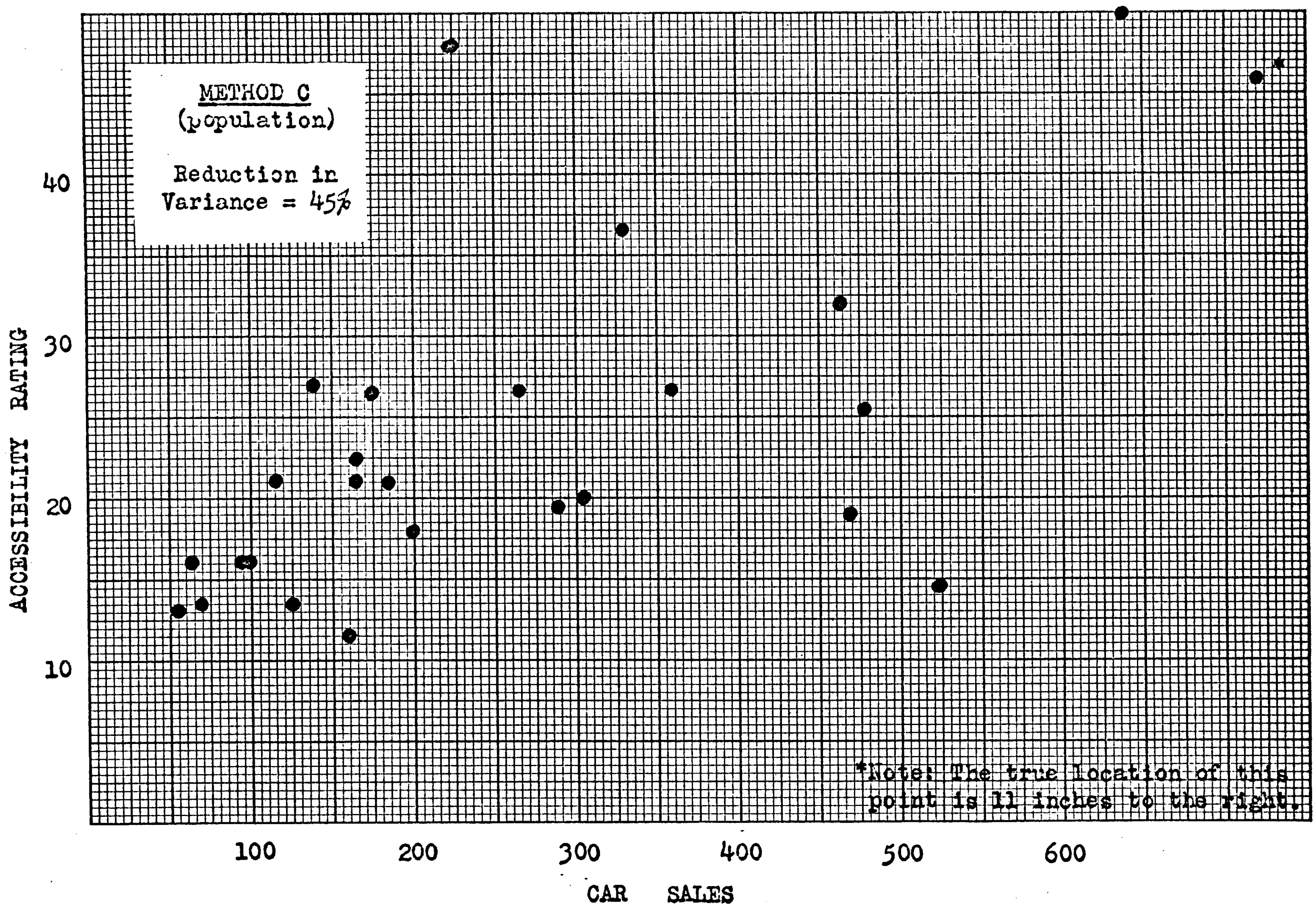
CORRELATION OF ACCESSIBILITY AND SALES

FIGURE 7



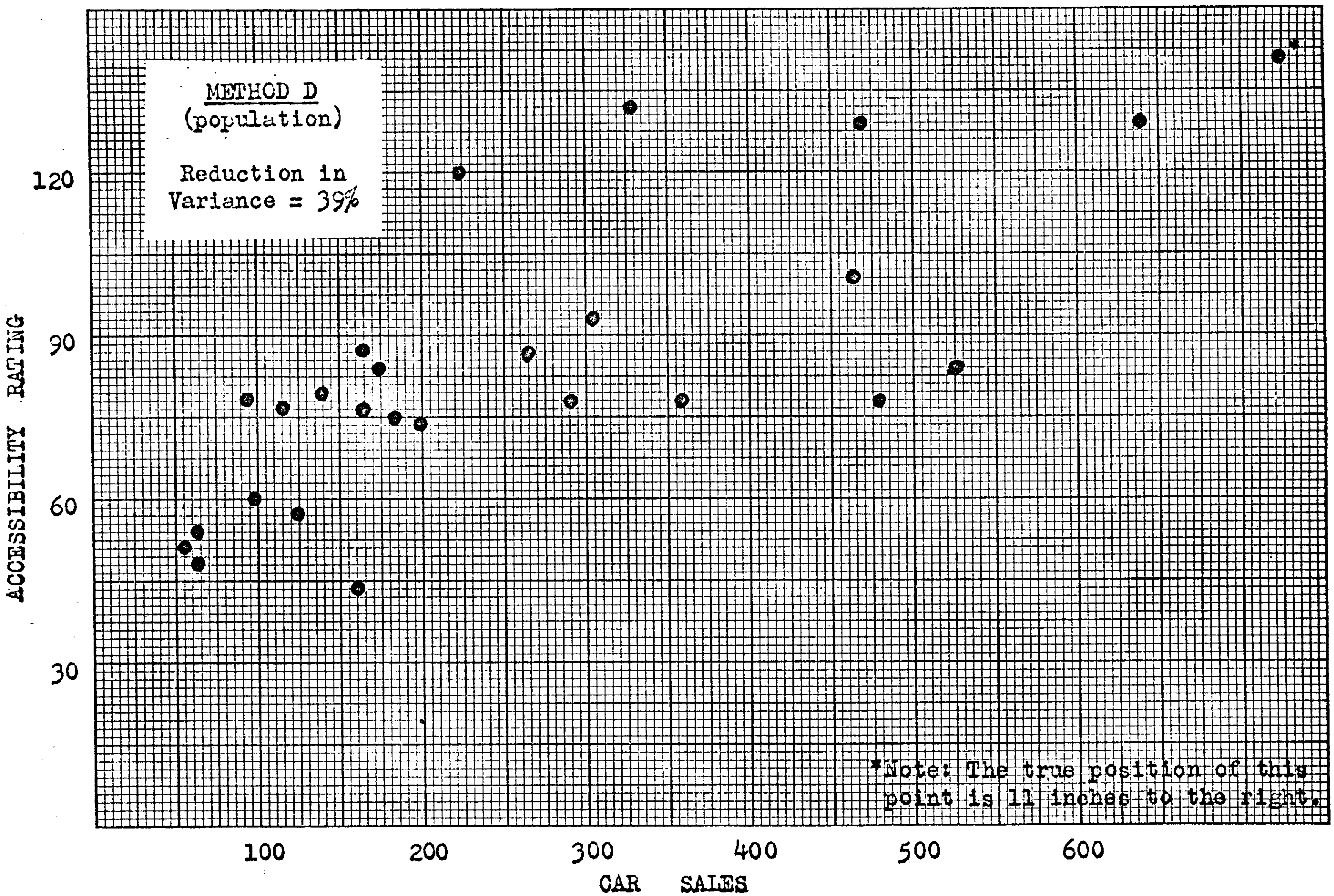
CORRELATION OF ACCESSIBILITY AND SALES

FIGURE 8



CORRELATION OF ACCESSIBILITY AND SALES

FIGURE 9



CORRELATION OF ACCESSIBILITY AND SALES FIGURE 10 was scaled along mapped routes, using the shortest route observable. Where routes turned corners or curved a modification was attempted. In many cases, however, errors in reading and estimation accumulate and will yield inaccurate values of d. The problem of designating a route for travel time computation is also a source of error. The four curves in Figure 1 diverge sharply at large distances. As most routes involved portions of urban, suburban, expressway and occasionally downtown routes, visual estimation of correct position between the lines introduces error. At large distances, where the curves are far apart, the error will be minimized because travel time enters the formula as an inverse square; large absolute errors yield small differences in the weighting factor.

When the separation is small, however, errors are more significant and are likely to arise from the irregular shape of zones and non-uniformity within them. The size of zones is therefore a limit to the sensitivity of the formulae. Where zones are large, as in these tests, the methods of measurement may not give correct values for zones with nearby sites.[20]

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20. An indication of this came when it was discovered that one site had been located on the map about 1/2 miles from its true location. A recalculation was made (by Method D) for the corrected location and the change in accessibility rating was only about 10%.

RETAIL ZONES

In this investigation, retail accessibility has been measured for sites and correlated with the sales volume at these sites. It is also possible to derive measures of retail accessibility for zones and to correlate accessibility ratings with the average level of sales at zones.

A correlation of this type, however, may tend to exaggerate the influence of accessibility; individual site differences within each zone may balance out and their true significance will not be evident. For example, if retail sites are aggregated into zones, each zone will include some stores that, because of merchandising or agglomerative superiority, sell more than other, equally accessible stores in the same zone. In averaging sales of that zone, the specific differences between stores may be lost. The average sales per zone will not reflect fully merchandising and agglomerative factors; it will emphasize, rather, the common characteristic of sites within that zone--their general location. If average zone sales are correlated with the zone accessibility, the degree of correlation may not be the same as with a similar analysis for sites.

This is true of residential development as well. Each parcel has, in addition to its accessibility, other characteristics that influence its potential for development; environment, shape, building costs, and so on. The factor of accessibility may not be the major influence in development of sites. When large numbers of parcels are aggregated into zones, the difference between the average development potential of two zones, for reasons <u>other</u> than their location, will probably diminish.

It should be understood that the extent of correlation observed is dependent on the size of zones under consideration as well as on the influence of accessibility. As spatial aggregations include more individuals, the non-spatial characteristics of the individuals figure less in the zone's average potential. Only when zones are reduced in size to where they contain no more than one site, will the true importance of accessibility be evident.[21]

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21. A hypothetical demonstration of the effect of aggregation is shown in Appendix D.

PART FIVE

CONCLUSION

Sales Potential

The construction of potential maps to indicate the potential for manufacturing, distribution and other activities raises the possibility of sales potential maps--contours showing the retail accessibility to purchasers at any point.[22] To estimate anticipated sales of a hypothetical store would require further consideration of other factors that affect sales--merchandising and agglomeration--both for the hypothetical and existing stores; the potential map would give the spatial factor.

A potential map, based on competitive accessibility, however, would not be stable. Potential contours on such a map will show accessibility ratings at any point in the area for a hypothetical store. Since accessibility, according to this definition, is based on the location of other dealers as well as purchasers, the appearance of a new competing store will affect the accessibility of other locations. If retail accessibility were defined in a more

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22. For examples of potential maps, see:
    1) Beverly Duncan and Otis Dudley Duncan, "The Measurement of Intra-City Locational and Residential Patterns,"

limited way, as in Method C, the accessibility rating at any point would not be dependent on the location of dealers, and retail development at any location would have no effect on the potential contours.

It should be noted that with the appearance of a new store the sales potential changes in either case. With Method C, however, the accessibility ratings do not change and the effect is a uniform percentage decrease in the sales potential at every site.[23] If the number of dealers in the area is large, this decrease may not be significant. In any case, the shape of the sales potential contours will not be changed, and comparative locational advantages will remain stable through time, as far as dealer changes are concerned.

In Method D, the shape of accessibility contours will be affected by each case of retail development. In this

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. Journal of Regional Science, Vol. 2, No. 2, 1960;

2) Edgar S. Dunn,, "The Market Potential Concept and the Analysis of Location," Papers and Proceedings of the Regional Science Association, Vol. 2 (1956), p. 183.

23. From page 13:

$$ {}_{J}S = \frac{{}_{J}I}{{}_{A}I + {}_{B}I + \cdots {}_{N}I} \times \text{(total sales)} $$

The addition of a new term, ${}_{Q}I$, to the denominator of each site will decrease each ${}_{J}S$ by a factor of:

$$ \frac{A^{I} + B^{I} + \cdots\cdots N^{I}}{A^{I} + B^{I} + \cdots\cdots N^{I} + Q^{I}} $$

method, the decrease in sales potential with the opening of a new store is assigned to different locations according to their spatial relationship with the new store.[24] Over time, relative accessibility advantages of locations will not remain stable with retail development.

Planning Significance

This thesis has not dealt directly with either the process or the pattern of retail development, but rather with what is felt to be an underlying cause--the relationship between accessibility and the volume of sales. The idea of guiding urban growth by the selective development of transportation facilities is only feasible where accessibility is a major determinant of land use. This investigation has shown that accessibility is not the major factor in determining the volume of sales at new car dealers, and that wide variations in the sales and therefore rent paying ability are possible at any location.

Future research may establish certain categories of retail activity which are more dependent on accessibility. The development of these stores, however, would not necessarily tend towards any predictable pattern. With sales potential maps for particular types of retail activity, a hierarchy of uses might be established for a set of sites, and thereby a hierarchy of sites for each use, all based

24. A hypothetical demonstratioh of the instability of a retail potential map based on Method D is shown in Appendix E.

on the relationship between rent-paying ability and anticipated sales.

If the distribution of sales is actually determined by competitive principles (similar to those of Method D), the sales potential pattern would be subject to unpredictable change, and the hierarchies based on these potentials might not be stable. For example, if a dealer opens at some location other than the optimum (by whatever criteria), he will not necessarily fail; he will merely earn less than he might have at some other location. His presence, however, will alter the sales potential at other locations, and the optimum may now be in some other location. There may no longer be any point with sufficient sales potential to support the entry of an additional store.

Just how significant this instability is over the long run, is quite important. If the decisions of private developers have a predictable relationship to sales potential, then measurements of accessibility may be of some value in anticipating developmental trends. Further research is needed in this area.

In any case, accessibility ratings may offer some means of quantitatively evaluating alternative plans by which private development is guided through land use controls. The problems of differentiating between retail uses for zoning purposes, as well as the criteria for such an evaluation, will require further study.

Marketing

Although the planning possibilities of retail potential maps appear limited, it may be of specific value in marketing decisions, where the sales potential at a particular time and place is of interest. The usual method of estimating the sales of a proposed store is largely intuitive.[25] The market analyst establishes a trading area from which the store is expected to draw its customers and then, based on the location of competing stores and the relative attraction of the proposed store, he assigns a percentage of the area's trade to the proposed store. All the factors that influence sales are weighted on the basis of the analyst's experience and judgment.

With the use of accessibility formulae, it should be possible to derive a rating for the spatial component of sales and allow the analyst to concentrate on rating the merchandising and agglomerative factors which require subjective weighting.[26] Additional investigation along these

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25. For examples, see: 1) Richard L. Nelson, The Selection of Retail Locations (F. W. Dodge Corp., New York, 1958), p. 191; 2) Homer Hoyt, "Market Analysis of Shopping Centers," Urban Land Institute, Technical Bulletin No. 12, October 1949.

26. In Method D, for example, trade is distributed from a zone according to relative attraction of each site around it. If a rating, M, were assigned to each site which reflected its relative merchandising and agglomerative attraction, the formula could be modified to include its influence. Instead of basing the relative attraction on location, $F({}_Jd_i)$, as before:

lines should be undertaken before the practical value of any accessibility formula can be evaluated.

$$_J I_i = Vi \frac{F(_J d_i)}{F(_A d_i) + F(_B d_i) + \dots F(_M d_i)}$$

The relative attraction of each site would depend on both the spatial attraction, $F(_J d_i)$, and the non-spatial attraction, $_J M$:

$$_J I_i = Vi \frac{_J MF(_J d_i)}{_A MF(_A d_i) + {_B MF}(_B d_i) + \dots {_M MF}(_M d_i)}$$

APPENDICES

Appendix A

COMPETITIVE ACCESSIBILITY

Accessibility ratings will be calculated for two types of abstract dealer distributions by Methods C and D to illustrate the difference between a rating based solely on the location of purchasers and one which is based on the location of purchasers and competing dealers.

Assume a homogeneous plane of purchasers, who are in zones aa, ab.......nn; the volume of each zone is $Vi = 1$. In the first layout, the dealers are located uniformly, one in each zone. (Figure 11a) It is assumed that all merchandising and agglomerative characteristics are equal, and that sales will vary with accessibility. All transportation routes are at right angles so the separation from any site to any zone is simply the sum of their horizontal and vertical separation. The inverse square relationship which weights each zone according to its distance from the site is:

Distance	$F({}_J d_i)$
0	4
1	1
2	.25
3	.11
4	0

(For a site within a zone, intra-zonal distance is assumed 1/2 unit.)

where $F({}_J d_i) = \frac{1}{(\text{distance})}-2$, and the cut-off point at which zones are no longer added is 4.

COMPETITIVE ACCESSIBILITY FIGURE 11

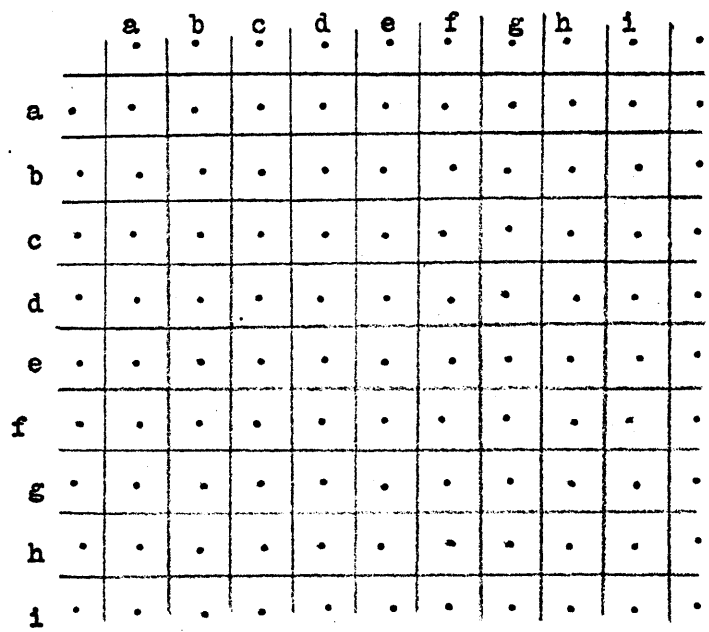


FIGURE 11a

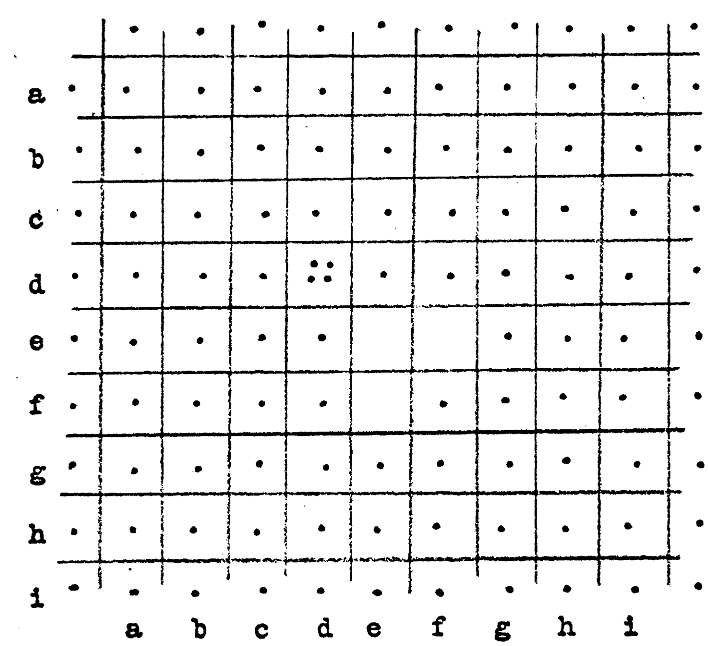


FIGURE 11b

Accessibility ratings will be calculated for the sites in two zones, dd and ff, by Methods C and D. (By inspection it is obvious that the ratings should be equal.)

Method C: For the site in aa:

$$_{aa}I = \sum_{ii=aa}^{nn} Vii\ F(_{aa}d_{ii})$$

$$_{aa}I = (1)4 + (4)1 + (8).25 + (12).11$$

$$_{aa}I = 11.32; \quad \text{Similarly, } _{ff}I = 11.32.$$

Method D: For the site in aa:

$$_{aa}I = \sum_{ii=aa}^{nn} Vii \frac{F(_{aa}d_{ii})}{\sum_{aa=aa}^{nn} F(_{aa}d_{ii})}$$

$$_{aa}I = (1)\frac{4}{11.32} + (4)\frac{1}{11.32} + (8)\frac{.25}{11.32} + (12)\frac{.11}{11.32}$$

$$_{aa}I = \frac{11.32}{11.32} = 1$$

Similarly, $_{ff}I = 1.$

For the second layout, we again have a homogeneous plane of purchasers, but in this case, three of the stores have been moved out of zones ee, ef and fe, and are now located in zone dd, along with the original site in dd. Now accessibility ratings will be calculated for the store in ff and the original store in dd.

Method C: The accessibility rating in Method C is dependent upon only the location of purchasers, which has not changed. Therefore, the accessibility rating of the site in dd is the same as it was before and is equal to the rating of ff.

Method D: For this case we will again consider any zone that is accessible to the site in ff or in dd, and distribute their "contributions". For example, the "contributions" of zone ed to the sites in dd and ff are:

$$dd^{I}ed = \frac{1}{(1)4 + (6)1 + (6).25 + (12).11} = \frac{1}{12.82} = .078$$

$$ff^{I}ed = \frac{.11}{12.82} = .009$$

Similarly, accessibility contributions are calculated for all zones that are accessible to dd or to ff. The new ratings of the sites in dd and ff are:

$$dd^{I} = \sum_{ii=aa}^{nn} dd^{I}ii = .802$$

$$ff^{I} = \sum_{ii=aa}^{nn} ff^{I}ii = 1.249$$

Since the total number of stores has not changed from the first layout, these accessibility ratings are directly comparable to sales potentials. The new accessibility rating for the site in zone dd indicates that its sales potential has been reduced by 20% because of the increased competition. On the other hand, the site in zone ff has increased its sales potential by about 25% because of fewer competitors in the vicinity.

Appendix B

ZONE CENTROIDS

In Methods C and D, zonal "contributions" are weighted according to an inverse square function, $\frac{1}{({}_J d_i)^2}$, which varies with the travel time between Site J and zone i. In general, separation is measured from the site to the centroid of a zone. This method, whereby the center of gravity is used to represent a "typical" individual, is reasonable for large travel times, where the travel time from the site to any point in the zone is not very different than the travel time to the center of gravity.

When a site is adjacent to or within a zone, the travel time from the site to the center of gravity will not be an accurate measure. This is most obvious when the site is at the center and travel time to the center of gravity is zero; this is clearly less than the travel time to a "typical" individual.

What is required is a new travel time, $\bar{d}$, such that:

$$Vi\ F(\bar{d}) = \sum_{j=1}^{n} V_j F(d_j)$$

the zone volume, Vi, times the inverse square function of $\bar{d}$ is equal to the summation of each individual times the function of his travel time, d_j, to the site. In the case of Methods C and D, the function is $\frac{1}{d^2}$, so it is required to find a $\bar{d}$ such that:

$$\frac{Vi}{\bar{d}^2} = \sum_{j=1}^{n} V_j \frac{1}{d_j^2}$$

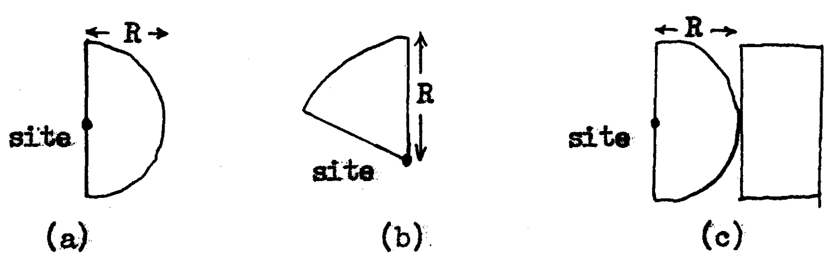
First assume a circular zone of radius R, with a uniform density; the site is located in the center of the zone. In this case Vi is πR^2 and the travel time from any small circular element of length $2\pi r$ and width dr is equal to r + 4 (including terminal time); the equation is then:

$$\pi R^2 \frac{1}{(\bar{r} + 4)^2} = \int_0^R 2\pi r \, dr \frac{1}{(r + 4)^2}$$

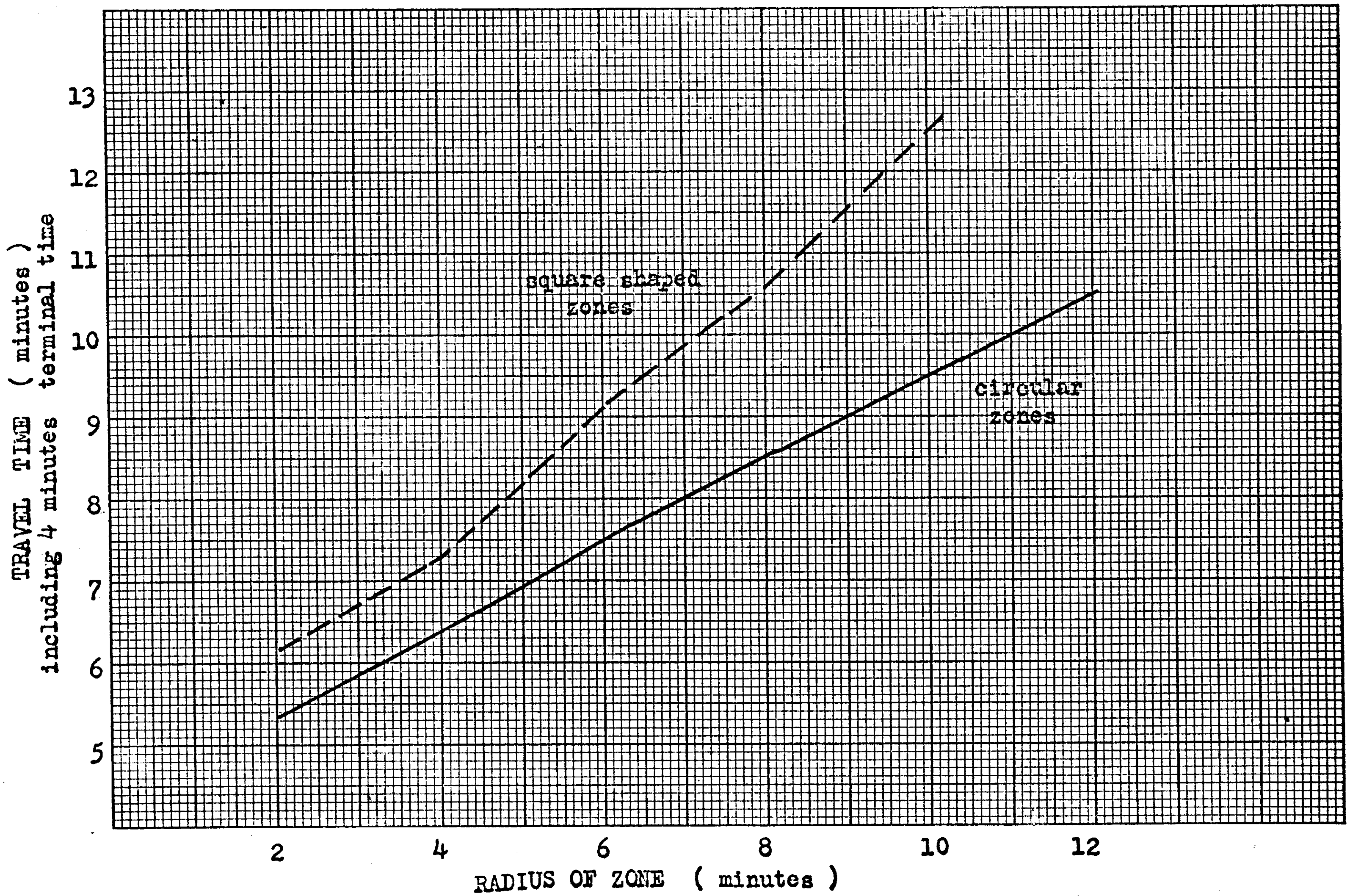
Integrating the expression and solving for $(\bar{r} + 4)$:

$$(\bar{r} + 4) = \frac{R}{\sqrt{\left(\text{Log}\frac{R+4}{4} + \frac{4}{R+4} - 1\right)}}$$

This expression has been evaluated and is plotted against values of R as a solid line. (Figure 12) With the same graph, zones which approximate semi-circles, (a), or sectors, (b), can be handled.



For the common situation where a site is on or near the edge of a square-shaped zone, a combination of two figures, (c) was assumed and ($\bar{r}$ + 4) evaluated for the combination; this relationship is plotted as a dashed line on the graph. (Figure 12) All zones were assumed to be one or another of these shapes when a site was in or adjacent to them.



TRAVEL TIME TO SITES IN OR ADJACENT TO ZONES

FIGURE 12

ZONE 26

to site	distance (miles)	travel time (minutes)	$F(_Jd_i)$	ACCESSIBILITY CONTRIBUTION $_JI_i$			
				vehicles $V_i = 141$		population $P_i = 26,379$	
				Method C	Method D	Method C	Method D
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
						(000)	
20	2*	7	139	19,600	72	3,665	13,520
21	2.5	18	31	4,370	16	818	3,020
22	4.1	23	19	2,680	10	501	1,850
28	6.5	24	17	2,390	9	448	1,660
29	6.5	25	16	2,260	8	422	1,560
16	3.8	23	19	2,680	10	501	1,850
6	5.0	23	19	2,680	10	501	1,850
18	6.5	30	11	1,550	6	290	1,070
		total	271 (9)	total	141	total	26,380

* diameter of zone (site within zone 26)

$(4) = \frac{1}{(3)^2} \times 10^5$

$(5) = (4) \times V_i$

$(6) = \frac{(4)}{(9)} \times V_i$

$(7) = (4) \times P_i$

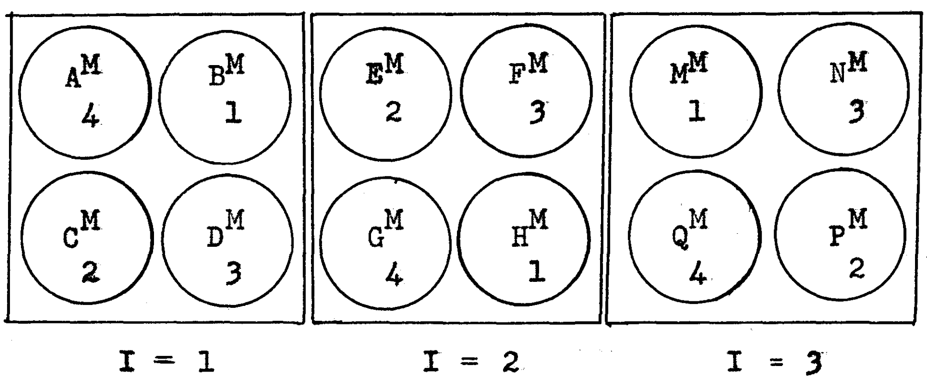
$(8) = \frac{(4)}{(9)} \times P_i$

Appendix C SAMPLE CALCULATION OF ACCESSIBILITY CONTRIBUTION; Method C and Method D

Appendix D

EFFECT OF AGGREGATIONS

To evaluate effect of aggregation, the coëfficient of correlation between accessibility and sales will be calculated for a hypothetical set of sites, first, as individuals, and second, when aggregated into zones.



Consider a hypothetical portion of an urban area with twelve sites, A, B, ...Q; these sites have different merchandising and agglomerative attractions which effect their level of sales. The numbers at each site, ($_JM$), indicate the relative non-spatial attraction of each site due to these factors. The accessibility of each site is dependent on the layout of sites and purchasers (or just purchasers, if Method C is used). Assume that, because of their similar location, the accessibility of sites A, B, C, and D is the same and equal to 1 (a relative value), the accessibility of the sites E, F, G, and H is equal to 2 (they may be closer to a dense area), and the accessibility of sites M, N, Q and P is equal to 3.

The sales at each site is a function of both accessibility of the site and the agglomeration and merchandising characteristics of the store, and is equal to the product of the accessibility rating and the merchandising-agglomeration rating:

$$_JS = {_JM} \times {_JI}$$

The sales at each site are then:

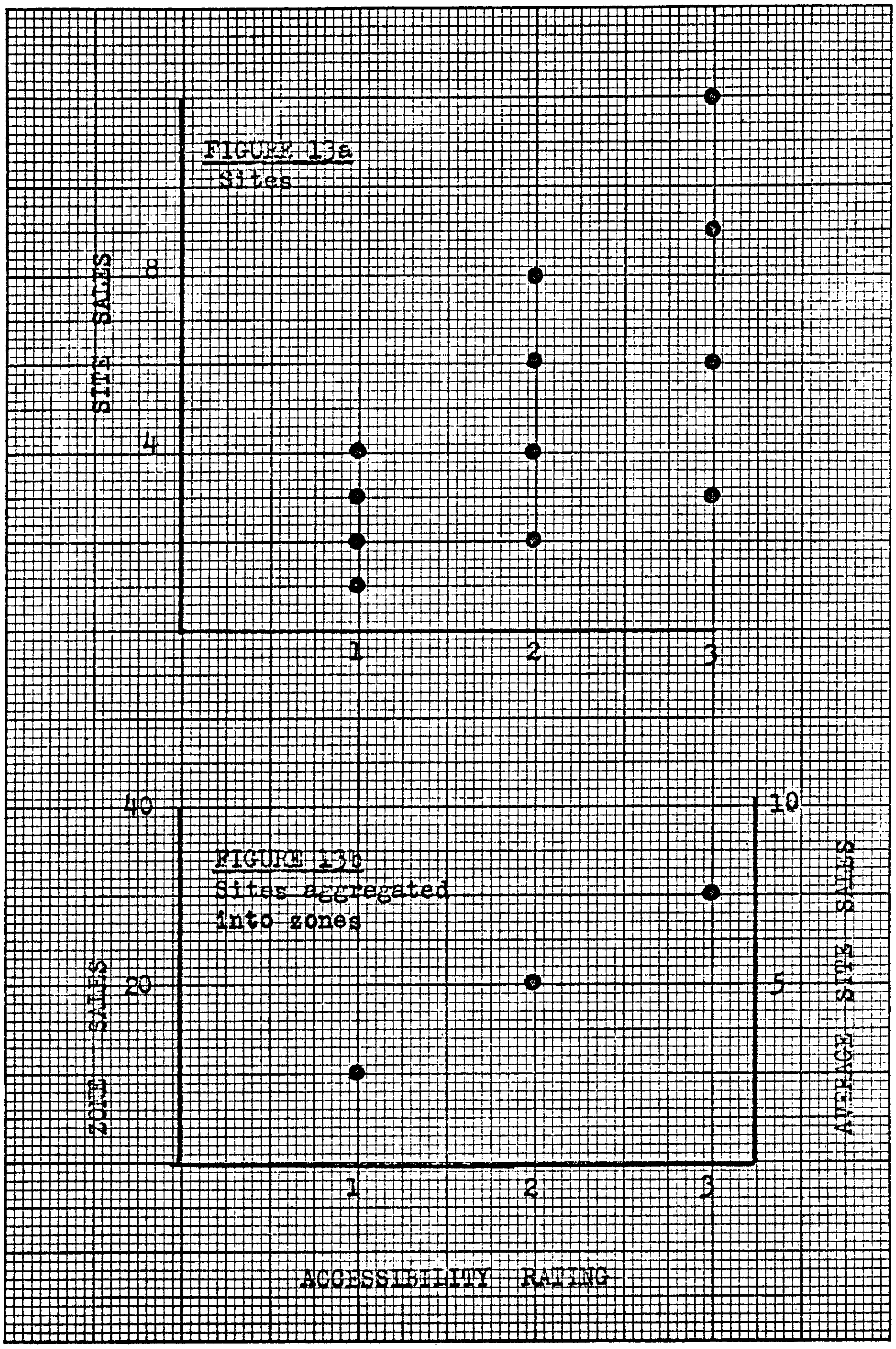
A	B	C	D
(4)(1) = 4	(1)(1) = 1	(2)(1) = 2	(3)(1) = 3
E	**F**	**G**	**H**
(2)(2) = 4	(3)(2) = 6	(4)(2) = 8	(1)(2) = 2
M	**N**	**Q**	**P**
(1)(3) = 3	(3)(3) = 9	(4)(3) = 12	(2)(3) = 6

The sales of each site, plotted against accessibility, are shown in Figure 13a.

The coefficient of correlation in this distribution is equal to .5, indicating that 25% of the variation in sales is explained by the accessibility rating. If the sales of each site are aggregated into zones, and the zonal accessibility plotted against zonal sales, the results are shown on the graph (Figure 13b). These points lie on a straight line and the coëfficient of correlation for such a distribution is equal to 1.0, indicating that all the variation in sales is explained by the accessibility rating.

If the zones had been drawn a different way, the coëfficient of correlation would have probably had some other value. Thus the size of the zone (the number of individuals in it) is a factor in the degree of correlation that will be observed.

EFFECT OF AGGREGATION FIGURE 13



Appendix E

UNSTABLE SALES POTENTIAL

The sales potential at any location, according to Method D, is a function of the location of buyers and sellers. In this appendix the sales potential will be calculated for a hypothetical situation. The effect of a new retail store on the sales potential map will then be investigated.

It is assumed that 16 homogeneous, square zones form a bounded urban area and that dealers are located in zones aa, ad and da. (Figure 14a) The dealers are exactly alike in merchandising and agglomeration characteristics, so sales volume should vary with accessibility.

If an accessibility rating is computed for a new, hypothetical store located in each zone, the sales potential of each zone can be calculated. The values in each square show the sales potential, based on accessibility ratings computed as in Appendix A, by Method D. (Figure 14b)

These values can be used to construct a potential map; the contours show the approximate locations of equal levels of sales potential. (Figure 14c) The point of maximum sales potential is in zone cc, where a new store would have a sales potential of 5.80.

Suppose, however, a new store opens in zone cd. The new distribution of sales is shown in Figure 14d. The potentials have changed because there are four stores. The sales potential of a new store located in each zone is shown in Figure 14e.

If a potential map is constructed from these values, the contours will be in different locations and in different shapes. (Figure 14f) Note the highest potential is now 4.14. If 4.15 were the minimum necessary for entry into this market, no new store could enter.

* indicates a site in that zone

	a	b	c	d
a	*			*
b				
c				
d	*			

FIGURE 14a

* 2.61	3.73	4.24	* 3.40
3.73	5.25	5.68	4.79
4.24	5.68	5.80	4.89
* 3.40	4.79	4.89	4.00

FIGURE 14b

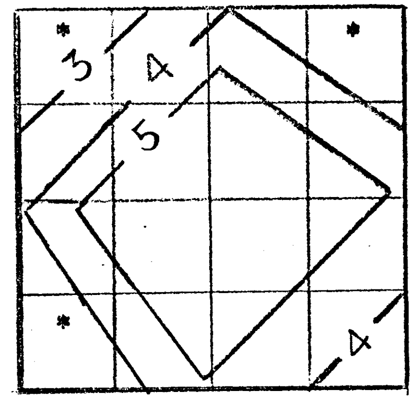


FIGURE 14c

* 3.77			* 3.23
			* 4.89
* 4.12			

FIGURE 14d

* 2.36	3.11	3.10	* 1.97
3.12	4.09	4.04	2.98
3.17	4.14	4.14	* 3.10
* 2.55	3.40	2.99	2.47

FIGURE 14e

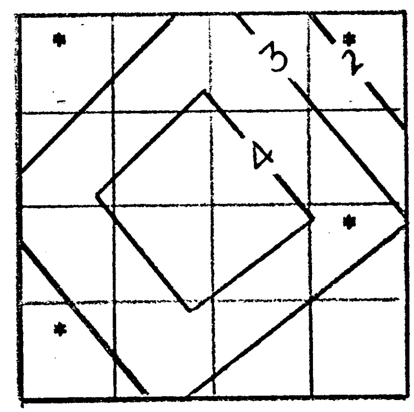


FIGURE 14f

UNSTABLE SALES POTENTIAL

FIGURE 14

Appendix F

ACCESSIBILITY AND GROWTH

The computation of accessibility ratings, which were correlated with residential growth by Hansen, is based on the potential model:[27]

$$A_1 = \frac{S_1}{T^X_{1-1}} + \frac{S_2}{T^X_{1-2}} + \ldots \frac{S_n}{T^X_{1-n}}$$

where A_1 is the accessibility rating (a relative value) of zone 1; Sn is the size of the activity in zone n; T_{1-n} is the separation between zones 1 and n; and X is a constant. Different measures were used for S, the zone size, including employment, population and retail sales; for T, the travel time (including terminal time) was used; and the exponent, X, was varied according to the activity involved.

In an empirical examination based on data from Washington, D.C., Hansen correlated these values with a measure of residential growth - the development ratio. This was the ratio of the actual growth in each zone over a period of seven years, to the growth allocated to that zone on the basis of its proportion of the region's vacant land. Growth was measured in terms of dwelling units. Accessibility ratings were computed for the travel time and land use pattern at end of the seven-year period.

The development ratio for each zone was plotted on

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27. Walter G. Hansen, "Accessibility and Residential Growth," Op cit p.5.

log-log paper against its accessibility rating; the following values for the coefficient of correlation (r) and the reduction in variance (r^2) were determined:

	r	r^2
Accessibility to Employment	-0,9052	.82
Accessibility to Population	-0,8917	.80
Accessibility to Shopping	-0,8563	.74

The correlation indicated by these values is considerably higher than those found in the investigation of retail accessibility in this thesis. One reason for these high values is mentioned by Hansen; the correlations are not based on the actual numerical values of the variables themselves, but rather on the basis of the logarithms of these values, "In as much as the variation between logarithms of two numbers is numerically much less than the numerical variations between the two numbers, the correlations between the logarithms will be higher than a correlation between the actual variables."[28]

Another reason for this high degree of correlation may be the effect of aggregations. By measuring residential growth in relatively large units (in one zone the increase was more than 9,000 dwelling units), the influence of accessibility may have been exagerrated.

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28. *Ibid* p. 18.

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