TEMPORAL LAND USE PATTERN ANALYSIS WITH THE USE OF NEAREST NEIGHBOR AND QUADRAT METHODS [1]

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Nearest neighbor analysis as developed by Clark and Evans [2] and Thompson [3] has been successfully used by plant ecologists, but with less success and frequency by geographers. Geographers, such as Dacey [4] and Berry [5], who have attempted to use this technique to measure map patterns have criticized it for a number of reasons, the most prominent being insufficient rationale for objectively defining the study area. Nevertheless, we hope to show that the nearest neighbor method is a useful geographic tool if study conclusions "make sense" in light of expectations.

Berry [6], Bachi [7], and others have suggested the use of standard distance measures, after Mahalanobis, in order to describe spatial patterns. However, these measures, geared mainly toward describing dispersion characteristics in a population, do not permit analysis of map patterns in terms of their departures from randomness. Therefore, standard distance measures might best be thought of as a complementary tool for map pattern analysis.

In this paper, hypotheses based on land use patterns within cities are tested. It is felt that the character of an urban transportation system has a great influence on land use patterns. Our analysis was aimed at bringing to light the importance of the transportation technology variable. Although no attempt was made to explore this variable in depth, we have tried to show, quantitatively, how grocery store patterns reflect innovations in transportation technology.

Grocery store locations in the city of Lansing, Michigan, for the time periods 1900, 1910, 1920, 1930, 1940, 1950, and 1960 were used to indicate land use patterns. Patterns described in one period of time are tested for significant changes with patterns in other time periods. As a check on some of this work, a quadrat method, based on the Poisson distribution (as is the nearest neighbor technique) was used. Grocery stores were selected as indicators of commercial land use because of certain theoretical and empirical considerations. A discussion of these considerations follows.

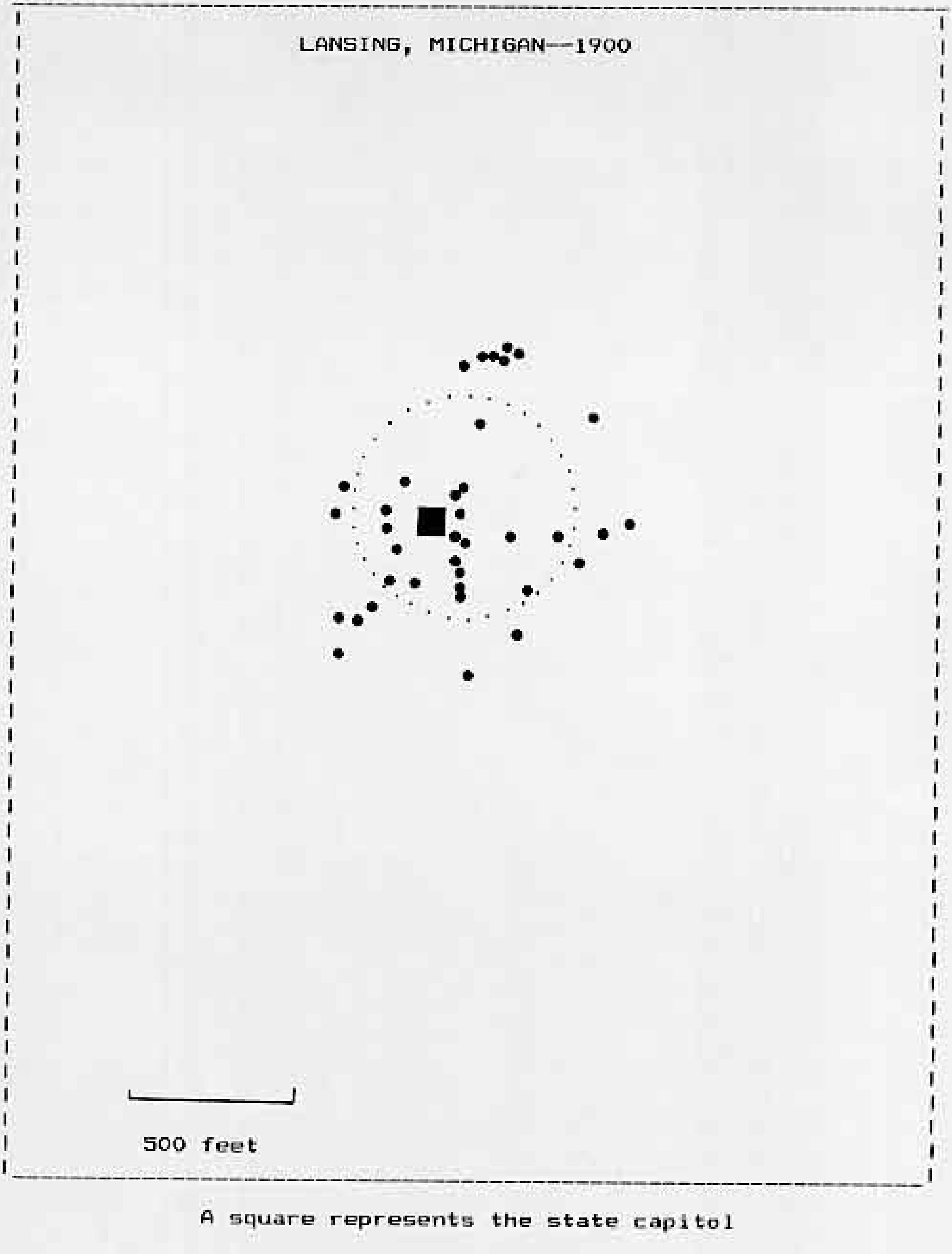
Assuming no market overlap, a central good will locate in the center of the area it serves. Central place theory asserts this proposition for all central goods, but, unlike high order goods, the frequently visited, convenience type firms of low order reflect this proposition rather well. The validity of the market overlap assumption for low order goods appears to make the difference. Goods supplied at grocery stores are of low order, and it can be shown that such stores appear in both large and small shopping centers. Only in well developed central business districts and along interurban arterials do commercial areas exist without grocery stores. In other words, for all practical purposes, all commercial districts have at least one grocery store.

If grocery store organizational characteristics were constant, then we would expect the grocery store location pattern to approximate the population density characteristics. In the pre-supermarket period, the grocery store pattern duplicated the population pattern. Furthermore, in 1961 it was shown that this was approximately the case in Tacoma, Washington, even though organizational characteristics did vary from store to store [8]. It follows that any change in population density characteristics will be reflected in grocery store location patterns, and therefore in all commercial land use patterns.

Knowledge of the urban environment enables us to hypothesize about expected store location patterns. One would expect the density of stores to fall off as distance from the center of the city increases, as is the case with population. This is obvious, but, density gradients vary greatly from city to city. Generally, within cities there is more than one area of dense settlement. Within a city we might expect to find a number of different kinds of patterns, depending on our level of analysis—for example, grouped neighborhood patterns but dispersed city patterns. We would also expect that as a city's population density increases unevenly, as is generally the case, the number of groups of stores would dominate the pattern. However, in the early days of settlement this groupedness would be less evident. As the automobile becomes more important, the population densities would decrease and therefore we would expect a return to the dispersed patterns found in the early days of settlement. Between a period having a grouped and a period having a dispersed, or uniform, pattern one would expect to find a random pattern--that is, a pattern reflecting neither extreme population densities nor very moderate densities. This allows us to test hypotheses based on randomness.

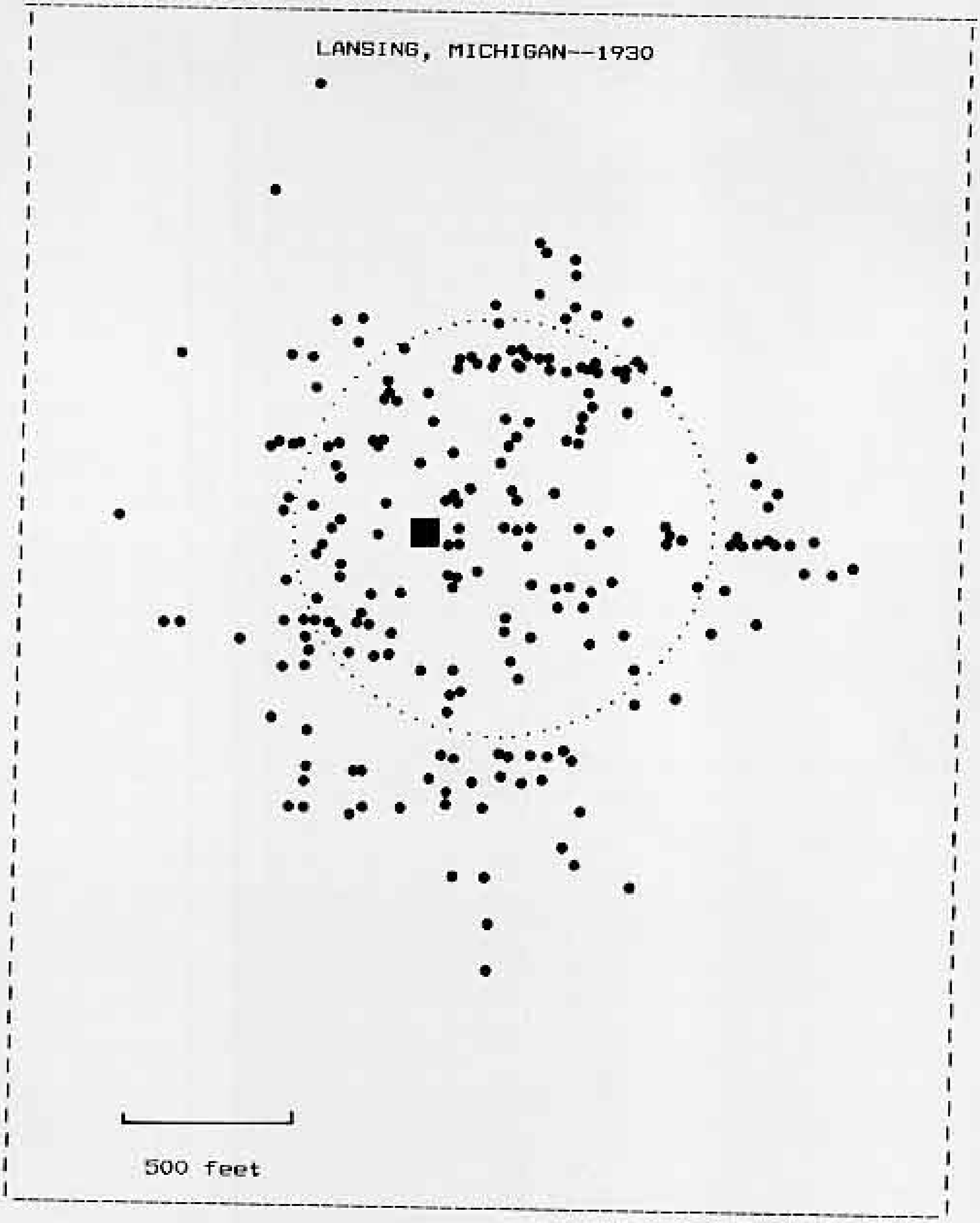
Grocery store location information was collected from Lansing City Directories for each of seven years at ten year intervals, starting in 1900. The data were mapped and the patterns analyzed. It should be noted that nearest neighbor analysis does not allow us to select the entire urbanized region as the study area (nor a larger area than the urbanized region). Rather, the analysis permits us to make statements about the character of the distribution well within the limits of the total pattern. A discussion of this point will be made in the following section.

Maps 1-3 show the location of grocery stores in three of the seven time periods. The nearest neighbor method is explained in terms of two dimensional spacing. The dot distribution of grocery stores in part of Lansing for each of the designated time periods was measured, and the manner and degree to which the distribution of points departs from random expectation was noted. The distance from an individual point to its nearest neighbor provided the basis for the initial analysis. Using a randomly selected sample of points, a series of these measures was made. The mean distance to the nearest neighbor is compared statistically to the expected distance, that is, the average distance the points would be in a random pattern of the same



A square represents the state capitol

MAP 1



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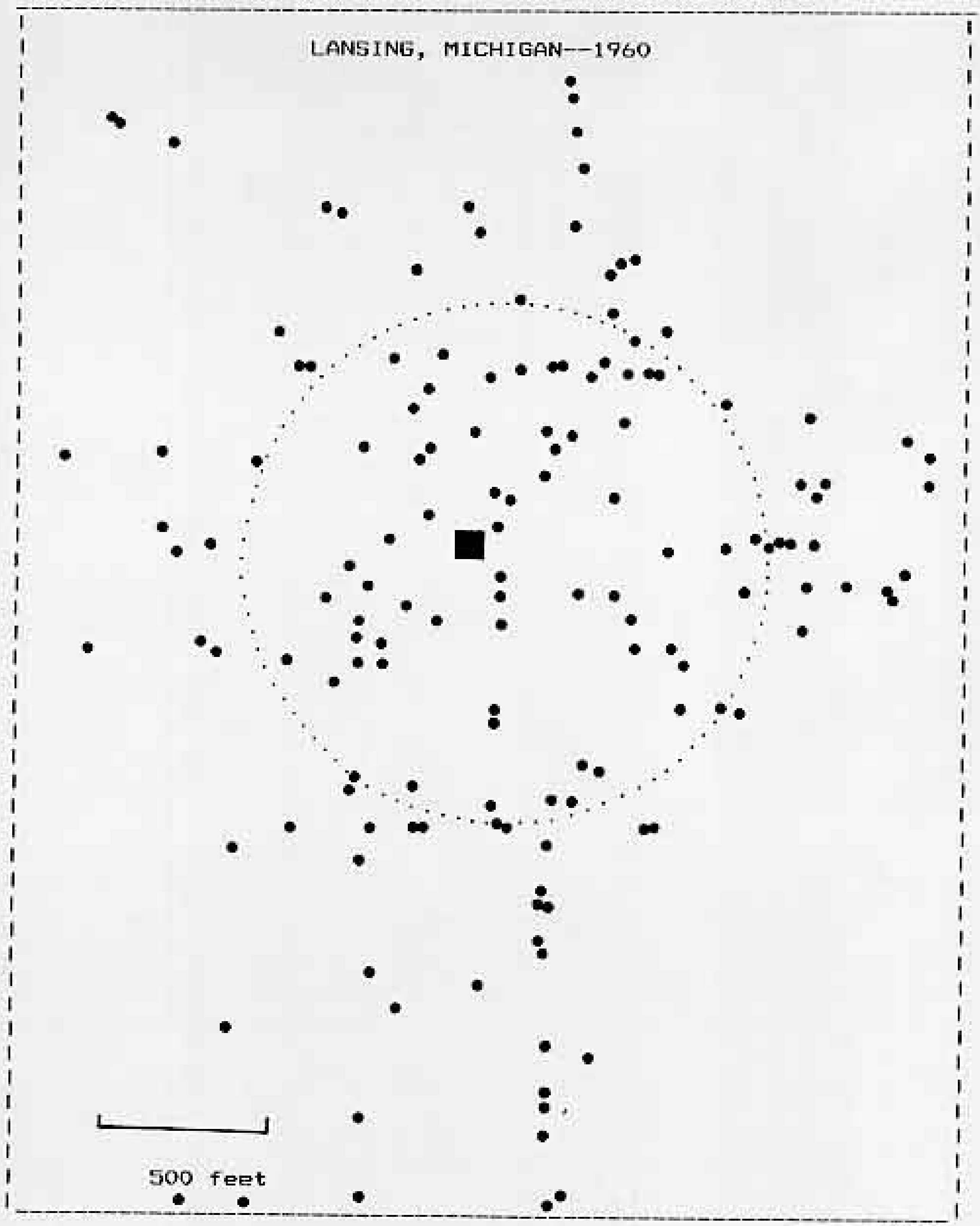
MAP 2



A square represents the state capitol

MAP 3

density as that of the random sample. The ratio of the observed mean distance to the expected mean distance serves as the measure of departure from randomness, and these ratios are compared from one time period to another. The analysis also included measures to three nearest neighbors; a discussion of this is found in the section "An Extension to the Method."

Tests of significance were made about the hypothesis of randomness. Table 1 summarizes the results of the initial nearest neighbor analysis. N is equal to the number of dots used as centers of measurement; ρ is the density of the observed distribution expressed as the number of individuals per unit of area; $\bar{r}_A$ is the mean of the series of distances to nearest neighbors; $\bar{r}_E$ is the mean distance to the nearest neighbor expected in an infinitely large random distribution of density ρ; R is the measure of the degree to which the observed distribution departs from random expectation, $\sigma_{\bar{r}_E}$ is the standard error of the mean distance to the nearest neighbor in a randomly distributed population of density ρ; and Z is the standard variate of the normal curve.

Before we discuss the results of this part of the study, it is important to mention some of the problems of procedure. For tests of significance to be meaningful, a sample rather than the whole population must be used. Because the population is very small in the early periods, small samples had to be selected. For 1900, for instance, only ten randomly selected observations were used. The problem of sample size is most acutely felt when it is realized that the size of the area selected must be well within the total dot pattern. This eliminates many more possibilities. However, in the period from 1920 through 1950 adequate samples of 47 or 50 points were used, and this adds confidence to conclusions drawn about those years.

A second problem of procedure is related to the size of the study area. If the sample area were the size of the State of Michigan, our study would, of course, show that departures from random expectations were extreme in the direction of groupedness. It is evident, then, that the size of area selected will have a great bearing on the results of the analysis. In order to logically consider the spacing of stores, it was necessary to exclude that area of the city where the general dot pattern was altered by low population densities. Nearest neighbor analysis is based on the Poisson distribution, where, supposedly, each location has an equal chance of containing a point. Therefore, the rims of the settled portions of the city were eliminated from the analysis and a circular area within the total dot pattern was selected. In order to choose a realistic area, the location of the center of the circle varies from period to period. Of course, the radius of the circle also varies. One of the problems facing geographers is that of selecting meaningful study areas where spatial bias is minimized.

For further discussion on the mechanics of the analysis, readers are referred to Clark and Evans [9], Clark [10], Thompson [11], Berry [12], and Dacey [13]. There are a few unpublished papers in the geographical literature which demonstrate the empirical use of the technique. However, to the author's knowledge only Dacey has attempted an empirical analysis that has been published, and this work is applied to a special case and is therefore of limited value [14]. If the ratio of the observed distribution to the random expectation is equal to R=1, then this would signify a random observed distribution. If the value is R=0, this would signify maximum aggregation, that is, all observations are at the same place. Clark and Evans have shown that under conditions of maximum spacing, that is, when the points are distributed in an hexagonal pattern, each point being equidistant from six other points, the value of R is 2.1491 [15]. The range of R, then, allows us to determine the degree to which an observed distribution departs from randomness. Statistical statements can be made with regard to significant departures from randomness. Also, it is possible to conclude that an R value of 0.5, for example, indicates that nearest neighbors are, on the average, half as far as expected under conditions of randomness. One unfortunate characteristic of the nearest neighbor technique, when only the first nearest neighbor of a point is used, is that a repeated pattern of two or more closely spaced points occurring far from one another would yield a low value of R, even when the pattern may appear dispersed. This problem can be alleviated to some degree by using measures to more that the first nearest neighbor and obtaining new values of R. In the section "An Extension to the Method" this type of analysis is discussed.

Table 1 shows that the R values for the different time periods are all less than 1. This means that all of the patterns show tendencies toward groupedness. However, in the case of 1900 the R value of 0.721 was shown not to be significant at the .15 level. All other values were significant at less than the .01 level. Figure 8 shows the trend in R values over time. It appears that in recent years the value is increasing and from this it might be predicted that in the not too distant future the R value will not be significantly different from a random expectation. The greatest tendency for groupedness appears in the year 1920, and again in 1940 the value is very low. These values indicate the very dense arrangements of grocery stores in those years.

Table 2 summarizes the results of a series of "student's t" tests made on all combinations of study periods. These tests are designed to show whether or not significant differences exist between R values of the various time periods [16]. In eleven of the 21 tests, significant differences were found. The 1900 pattern differs significantly from the 1920, 1930, and 1940 patterns. The 1960 pattern differs significantly from all patterns but that of 1900. Since the 1900 and 1960 patterns were rather similar, patterns between these two periods might be thought of as coming from a different population. Tests on variations in the period from 1910 to 1950 show that in three cases these patterns were significantly different; 1920 different from 1930 and 1950, and 1940 different from 1950.

It appears that the most radically different pattern is that of 1960--more significant departures with other patterns were found. The thesis that present-day patterns are similar to the

TABLE 1

Summary of Nearest Neighbor Measures [a]

YEAR	N	ρ	$\bar{r}_A$	$\bar{r}_E$	R	$\sigma_{\bar{r}_E}$	Z
1900	10	.000393	18.20	26.25	0.721	4.18	-1.69
1910	16	.000577	10.81	20.82	0.519*	2.72	-3.68
1920	47	.000607	7.72	20.29	0.380*	1.55	-8.11
1930	50	.000577	10.86	20.69	0.525*	1.53	-6.42
1940	50	.000475	9.08	23.49	0.387*	1.70	-8.48
1950	50	.000451	12.80	23.55	0.543*	1.74	-6.19
1960	34	.000248	18.41	31.75	0.580*	2.85	-4.68

[a] One map distance unit equals 36.36 feet. For example, the $\bar{r}_A$ value of 18.20 is equivalent to 666.175 feet.

*Significant at the .01 level.

TABLE 2
Student's t Values for Difference Between Means Test on All Combinations of Study Periods

	1900	1910	1920	1930	1940	1950	1960
1900	--	1.58	3.56**	2.14	2.94*	1.61	0.04
1910		--	1.55	0.02	0.80	0.84	2.22*
1920			--	2.05	0.99	3.41*	5.11**
1930				--	1.13	1.15	3.33*
1940					--	2.42*	4.38**
1950						--	2.50*

*Significant at the .01 level.
**Significant at the .001 level.

TABLE 3

R Values for One, Two, and Three Nearest Neighbors by Study Time Periods

Year	1st	2nd	3rd
1900	0.72	0.82	0.83
1910	0.52	0.74	0.77
1920	0.38	0.58	0.78
1930	0.53	0.63	0.63
1940	0.39	0.53	0.63
1950	0.54	0.57	0.62
1960	0.58	0.67	0.69

early developmental patterns, and much more dispersed than those of the middle period, is borne out in these tests. Although the R value of the 1960 pattern shows significant departures from randomness in the grouped direction, still the pattern is significantly less grouped than those of earlier periods. Since the 1950 pattern is statistically significantly different from that of 1940, one might conceive of the automobile revolution beginning between 1940 and 1950. Data on the number of stores operating in Lansing show a downward trend in the depression years, a rise, and then a new decrease starting about 1940.

An Extension To the Method

A more incisive analysis would consider distance to more than the first nearest neighbor. Clark and Evans [17] and Dacey [18] suggest techniques where measures to two to six nearest neighbors can be made and R values obtained. Dacey provides a table for expected mean distances in a random distribution when one to six nearest neighbors are used. In our analysis three nearest neighbors were used. The technique provided by Dacey involves dividing a circle into three equal sectors, placing the center of the circle over each randomly selected point, and measuring the distance to the nearest neighbor in each of the sectors. The closest neighbor is considered the first nearest neighbor; the closest neighbor in either of the two sectors not containing the first nearest neighbor is considered the second nearest neighbor; and the closest neighbor in the remaining sector is the third nearest neighbor. It was hoped that this analysis would give some idea of the more general pattern, rather than the limited idea available using only first nearest neighbors.

Although significance tests were not made, nor tests between various time periods carried out, still the R values were obtained and differences from the first nearest neighbor R values noted (see Table 3). In all cases the R value increased; all of the patterns, if not random to start with, were approaching randomness. These results shed light on grouping characteristics of grocery stores. As second and third nearest neighbors are included in the analysis, the R values show less of a tendency toward grouping, and a more dispersed pattern emerges. In the case of the 1920 R values, the tendency to group locally is much in evidence, but the more general pattern appears to be similar to the others.

Preliminary Conclusions

The results of the nearest neighbor analysis allow us to make statements regarding the evolution of land use patterns in the Lansing area. With increased accessibility in an urban area, the urban landscape approaches the isotropic surface assumed by Christaller. All areas in the city are becoming equally accessible. The advent of new and faster means of transportation, better roads, and the ability of nearly all of our gainfully employed people to own an automobile have caused a transportation revolution. With increased accessibility, the functional land use structure spreads itself out until it approaches an even pattern. However, there appears to be a lag effect in the consummation of that scheme. Further research will be aimed at discovering the characteristics of this lag effect.

Although one might argue that the pattern is simply returning to its original configuration, the pattern of 1900, and although statistically this is a sound conclusion, I would like to propose that the pattern in the past was never <u>even</u> in its arrangement, while the pattern of the future will approach evenness. In the formative stages of a community, there is a period when the city fills its empty areas with homes, and, appropriately, a rather haphazard, random pattern of commercial land use develops, only to become more grouped as population densities increase. The original random pattern is not caused by the same phenomena as the random pattern expected in the near future. The first is an initial city form evolving from the single shopping area of the village, while the expected pattern is a transitional form, standing between the grouped pattern of the pre-automobile period and the dispersed or even pattern of the mature period of adjustment to the automobile's influence. The size of grocery stores is indicative of this trend. Until 1940, most stores, including those of chain organizations, were of the service type--small and dependent on a limited number of customers. There are still many of these small stores in existence, but they are declining rapidly in number. The large supermarket is an answer to the automobile revolution, and it is only a matter of time before the smaller stores cease to exist in their present form. Other studies have provided us with information. In one study it was found that the threshold level, in terms of dollars of sales, for supermarkets is nearly twice that of the service type of store [19]. In another it was found that only about 25% of the stores under a particular proprietor are still under the same proprietorship ten years later [20]. This latter fact indicates that patterns can possibly change very rapidly. While it is true that some large regional shopping centers contain more than one supermarket, we feel that present diseconomies of scale are short lived.

<u>The Quadrat Method</u>

The Poisson distribution was the foundation for nearest neighbor analysis. The same probability distribution can be used to determine the expected occurrence of points in a cell of a plane divided into many cells. At this time a short discussion of the Poisson distribution is in order.

Following the notation of Dacey, the Poisson distribution is given by

$$(m^x e^{-m})/(x!)$$

where m is the average number of points per cell and x is the number of points expected in a randomly chosen area within the designated plane [21]. e is the base for natural logarithms. The basis for the development of this distribution comes from a probability situation where the number of observations (cells) is large and the probability of occurrence (points) is small.

In the quadrat method, the plane is divided into a number of equal sized cells, and the number of points occurring in each cell or in randomly selected cells is noted. Tests are made about the hypothesis of randomness. If the observed frequency of points occurring in cells does not approximate the expected distribution which is derived from the observed density function, then the distribution can be thought of as either grouped or dispersed, depending on the direction in which the observed values differ from the expected values.

A major shortcoming of the technique is the effect of various quadrat sizes on the results. In fact, the probable reason for the method's disuse is this shortcoming. A related problem facing geographers is finding appropriate cell sizes for quadrat analysis. However, the technique does not depend on a random sample--the entire population may be used, thereby adding more information and permitting more meaningful conclusions. In our analysis we used three different cell sizes and compared results with each other and with the nearest neighbor results. In this way the method can be thought of as being supplementary to the nearest neighbor technique; and possibly as a test of the significance of nearest neighbor results.

Table 4 gives the results of the quadrat analysis for cell sizes $(545)^2$ feet, $(909)^2$ feet, and $(1{,}818)^2$ feet. One useful characteristic of the Poisson distribution is that the variance equals the mean. Tests of significance can be made using the chi-square statistic because the distribution of chi-square approximates the ratio of the sum of squares to the variance. Therefore, the equation

(1) $$\chi^2 = (\sum (x - \bar{x})^2) / \sigma^2$$

but,

(2) $$\chi^2 = (\sum (x - \bar{x})^2) / \bar{x}$$

The ratio of the mean to the variance would equal 1 in a random distribution, and values higher or lower than 1 would be equivalent to the R values found in the nearest neighbor work.

(3) $$R = (N\bar{x}) / (\sum (x - \bar{x})^2)$$

The values for R and chi-square were obtained and are summarized in Table 4. In all but one case the R value is below 1, signifying a tendency toward groupedness. A test was made for significance based on percentiles of chi-square as a ratio to the number of degrees of freedom. In all three cell size analyses, the 1900, 1910 and 1960 R values were not significantly different from random, but in the 1960 case there appears conclusive evidence of randomness. In fact, the results of these tests more closely follow our pre-study expectations than the nearest neighbor tests. Let us look at one of the analyses in more detail. When the cell size is $(1{,}818)^2$ feet the R values start at a value of 0.6562 in 1900. This value did not differ

TABLE 4

Summary of Quadrat Method Data and Measures

Frequency of Points Per Cell	0	1	2	3	4	5	6	7	8	9	10	11	al Points	Total Cells	Mean Points Per Cell	R	Probability of a greater X^2 than that observed
(a) Size: $(545)^2$ Feet Per Cell																	
1900	89	13	3										19	105	0.181	0.882	.16
1910	112	20	4	3									37	139	0.266	0.696	.0005
1920	261	43	12	2	3	1							110	322	0.342	0.762	.0005
1930	315	66	18	5	3								129	407	0.317	0.679	.0005
1940	389	82	15	5	2	2							145	495	0.293	0.640	.0005
1950	433	76	15	5	1								125	530	0.236	0.746	.0005
1960	589	64	4										72	657	0.110	0.999	.50
(b) Size: $(909)^2$ Feet Per Cell																	
1900	24	9	2		1								17	36	0.472	0.681	.027
1910	32	12	7	2	1	1							41	55	0.764	0.614	.002
1920	69	20	12	8	1		2						84	112	0.750	0.509	.0005
1930	83	41	15	12	4	1		1					135	157	0.860	0.585	.0005
1940	103	47	23	8	2		2		1				145	186	0.780	0.545	.0005
1950	115	59	11	11	2		1						129	199	0.643	0.682	.0005
1960	231	45	14										73	290	0.252	0.884	.064
(c) Size: $(1,818)^2$ Feet Per Cell																	
1900	1	2	2	1			1						15	7	2.143	0.656	.10
1910	1	5	1	5	1	1		1	1				46	16	2.875	0.607	.035
1920	7		3	8	3	3		1	1	2			90	28	3.214	0.467	.0005
1930	6	6	7	8	3	6		4		2	1		142	43	3.302	0.484	.0005
1940	7	7	15	8	1	5	5	2		2		1	163	53	3.075	0.480	.0005
1950	9	13	8	9	7	2	1	2	2				130	53	2.453	0.562	.0005
1960	23	20	17	8	1								82	69	1.188	1.044	.54

significantly from random at the 10% level. With succeeding time periods the R values decrease to 0.4669 in 1920 and remain close to that level until 1950 when a less grouped pattern begins to assert itself. By 1960 the value has actually passed the 1 level. Although the degree of groupedness differs between the various cell sizes, still this same pattern of high then low then high R values is evident in all. This same pattern was borne out in the nearest neighbor analysis.

Conclusions

In a recent study Muth carried out a multiple regression analysis using an independent variable based on certain characteristics of the housing market's density gradient. He concluded that, "in line with central place theory, the spatial distribution of retail sales appears to be a result rather than a cause of urban population distribution" [22]. This lends greater credibility to the assertion that the location of grocery stores corresponds to population density patterns. Wingo has stated that cities which grew the most from 1920-1950 tended to have substantially lower gross densities than those whose primary growth took place before the impact of the automobile [23]. Wingo and others have rightly concluded that various aspects of the changing urban transportation system are responsible for these differences. Measuring a transportation variable is a difficult task; usually, indirect methods are used. We feel that, with the use of nearest neighbor analysis and the associated quadrat analysis, a rather simple, straightforward transportation variable might be derived. Of course, the derivation would have to be made in terms of the expected effect of transportation changes on urban land use changes.

Our results give hope to geographers and planners who are interested in measuring land use change in light of transportation innovation. The numerous shortcomings of the two techniques, it is felt, should not seriously inhibit their use. Common sense modifications might add much to their potential value. We were able to show quantitatively how land use patterns in Lansing, Michigan changed over time. Values for the relative spacing of grocery stores in one time period were tested against the values in another. Significant differences in the land use patterns were evident between certain time periods. These differences, for the most part, followed our previous notions on the evolution of land use patterns in light of population density and transportation changes. The nearest neighbor and the quadrat methods provide useful tools for such measurements and tests.

Footnotes

1. The author would like to thank Professor P. J. Clark, Michigan State University, for his comments and suggestions.

2. P. J. Clark and F.C. Evans, "Distance to Nearest Neighbor as a Measure of Spatial Relationships in Populations," Ecology. Vol. 35 (1954), pp. 445-453.

3. H.R. Thompson, "Distribution of Distance to n-th Neighbor in a Population of Randomly Distributed Individuals," Ecology. Vol. 37 (1956), pp. 391-394. For a review of nearest neighbor procedures with regard to patterns of points see P. Greig-Smith, Quantitative Plant Ecology, New York: The Academic Press, 1957.

4. Brian J. L. Berry, "Methods and Problems of Taxonomy." Unpublished working paper. University of Chicago. Portions of this work were discussed in a paper entitled "Statistical Tests of Value in Grouping Geographic Phenomena" given at the Annual Meeting of the Association of American Geographers, Pittsburgh, 1959.

5. Michael F. Dacey, "Analysis of Map Distributions by Nearest Neighbor Methods," Department of Geography, University of Washington, unpublished Discussion Paper Number 1, March 8, 1958, and Idem. "Analysis of Central Place Patterns by Nearest Neighbor Method," Department of Geography, University of Washington, unpublished Discussion Paper Number 20, May 15, 1959.

6. Brian J. L. Berry, op. cit.

7. Roberto Bachi, "Statistical Methods for Spatial Analysis," unpublished paper submitted to the Second European Congress of the Regional Science Association, Zurich, 1962.

8. Arthur Getis, "The Determination of the Location of Retail Activities with the Use of a Map Transformation," Economic Geography, Vol. 39, No. 1, January, 1963, pages 14-22.

9. P. J. Clark and F. C. Evans, op. cit.

10. P. J. Clark, "Grouping in Spatial Distributions," Science, Vol. 123 (1956), pp. 123-125.

11. H. R. Thompson, op. cit.

12. Brian J. L. Berry, op. cit.

13. Michael F. Dacey, op. cit., and idem. "Comments on the Experimental Design of the Nearest Neighbor Statistic," Department of Geography, University of Washington, unpublished Discussion Paper Number 13, December 12, 1958, and idem. "A Note on the Derivation of Nearest Neighbor

Distances," Journal of Regional Science, Vol. 2, No. 2, Fall, 1960, pp. 81-87.

14. Michael F. Dacey, "The Spacing of River Towns," Annals of the Association of American Geographers, Vol. 50, No. 1, March 1960, pp. 59-61.

15. P. J. Clark and F. C. Evans, op. cit., p. 447.

16. Strictly speaking, multiple t tests are illogical. The probability of more than one t value to yield spurious results is greater than .05. However, the results are indicative of the comparable character of the data.

17. P. J. Clark and F. C. Evans, op. cit., p. 450.

18. M. F. Dacey, 1960, op. cit.

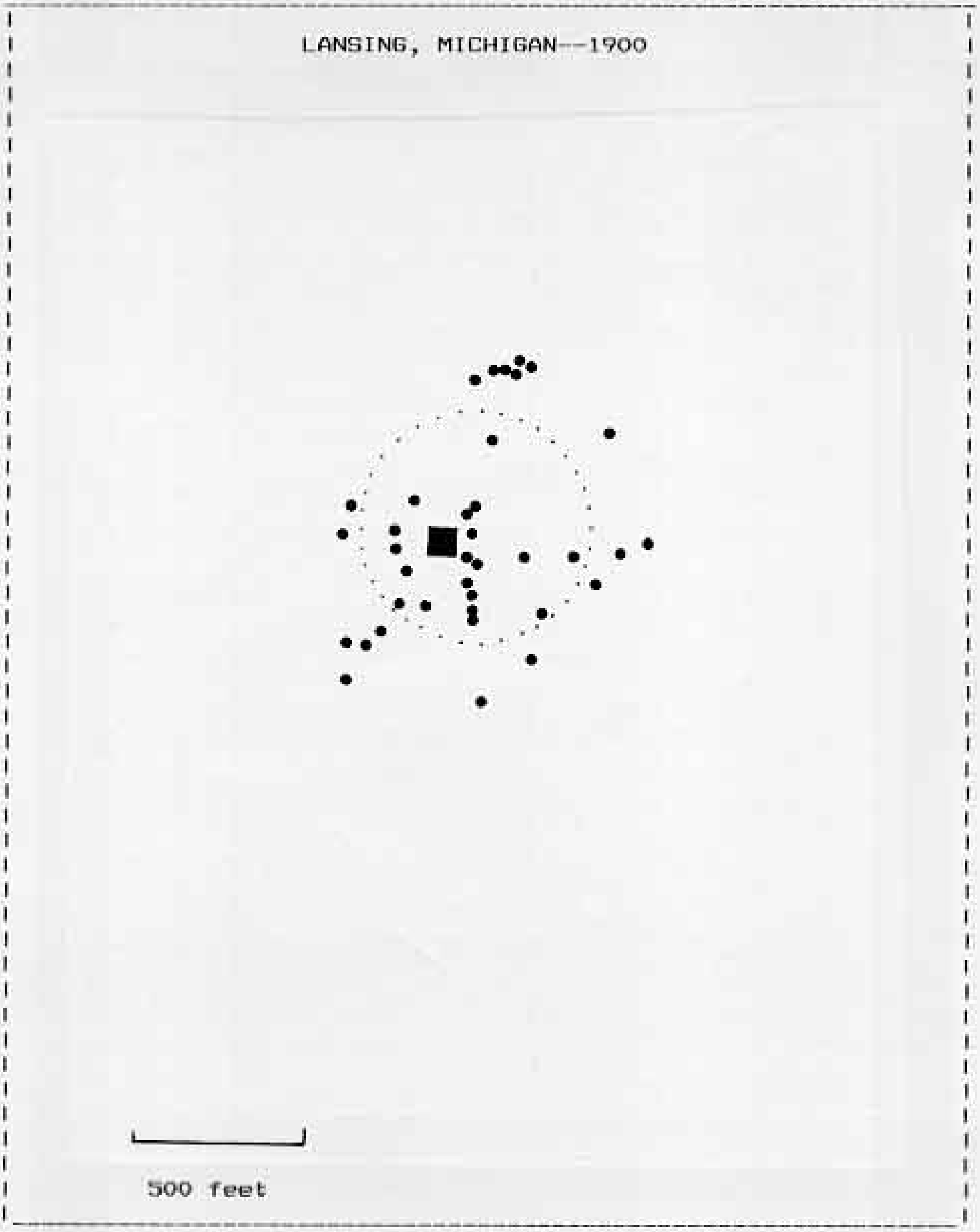
19. A. Getis, "The Service Function of Cities," abstract of paper in Annals of the Association of American Geographers, Vol. 50, No. 4, December 1960.

20. This conclusion was based on examination of the data used in this study.

21. M. F. Dacey, 1960, op. cit.

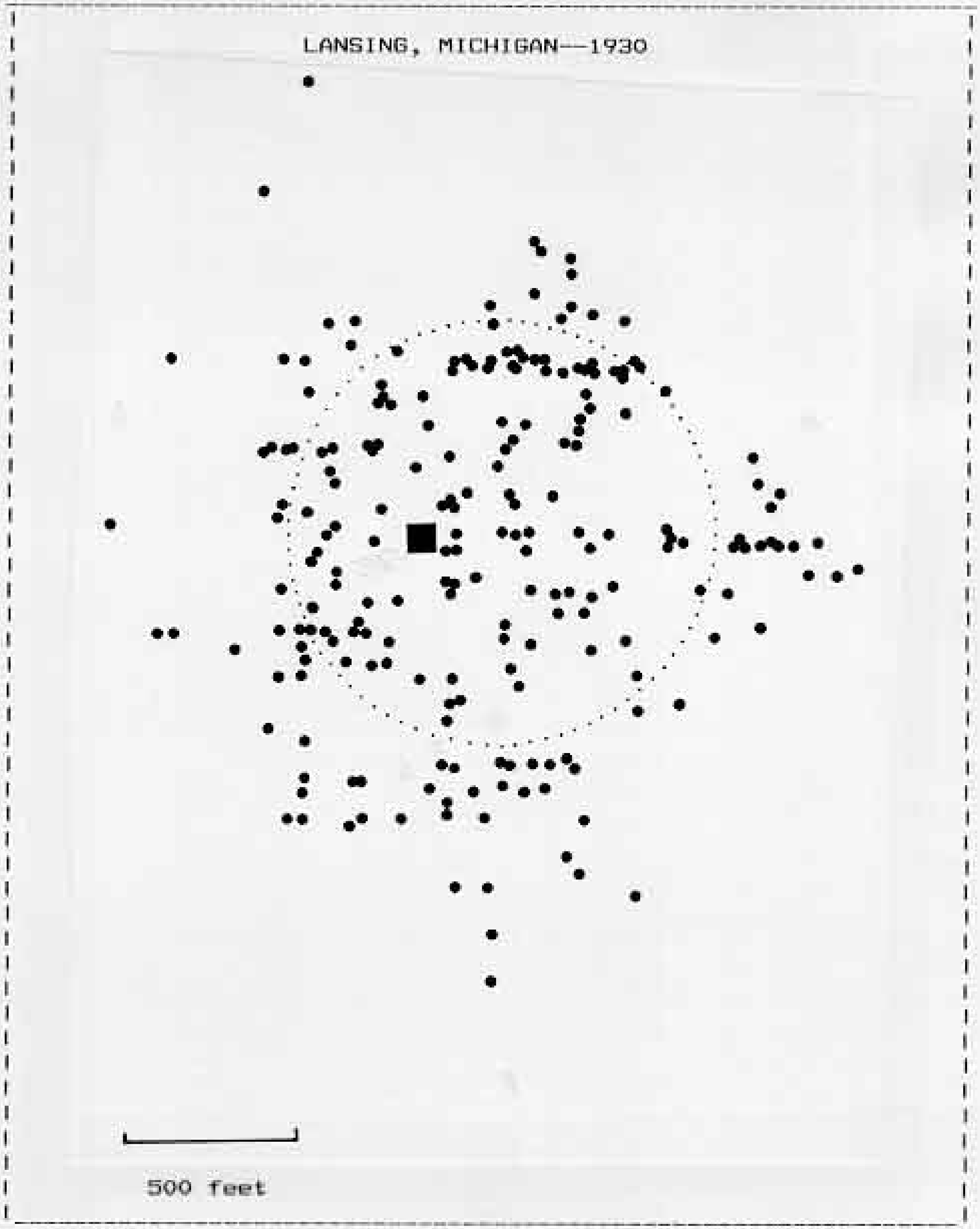
22. Richard F. Muth, "The Spatial Structure of the Housing Market," Papers and Proceedings of The Regional Science Association, Vol. 7, 1961, p. 218.

23. Lowdon Wingo, Jr., Transportation and Urban Land, Resources for the Future Inc., 1961, pp. 23, 25.



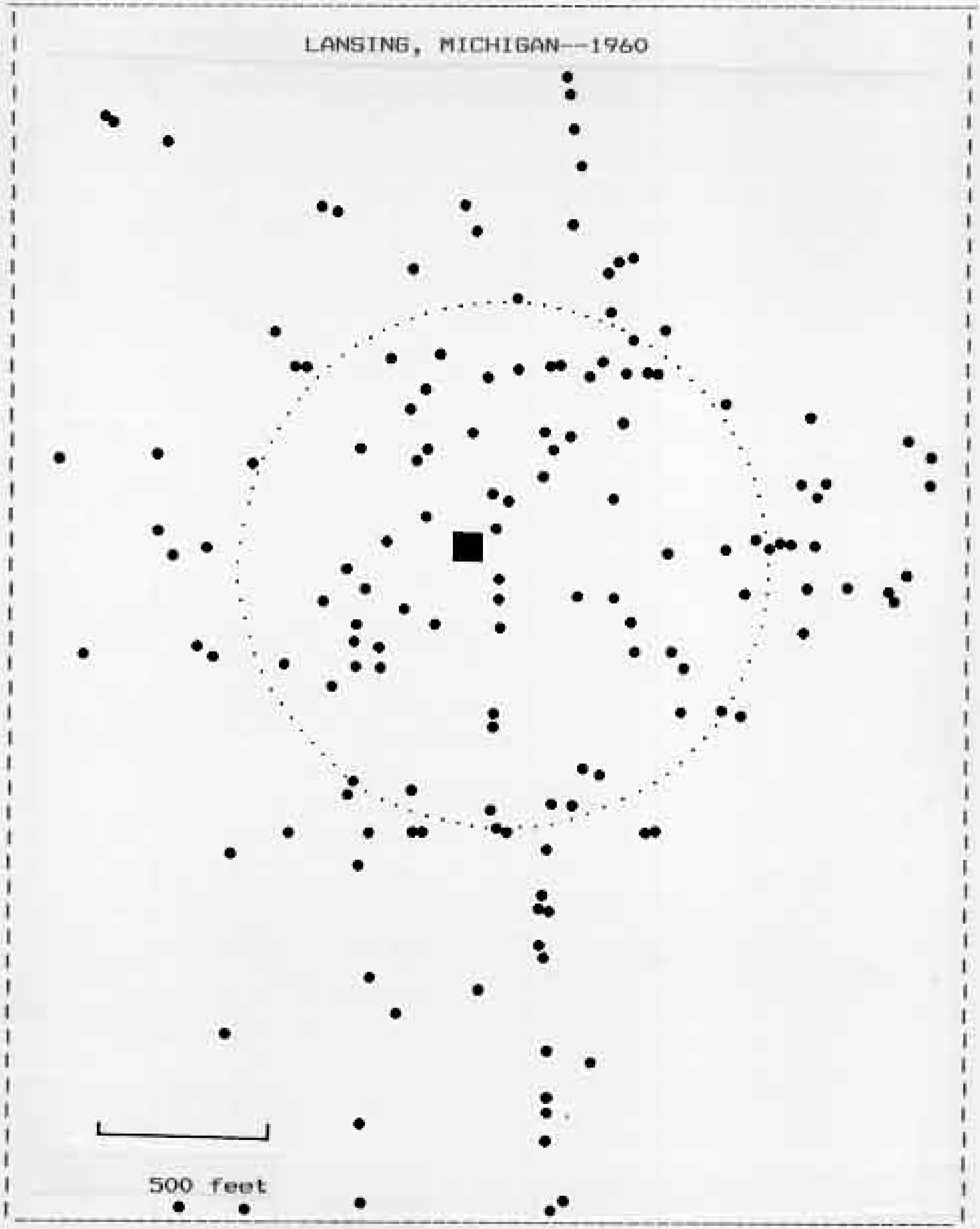
A square represents the state capitol

MAP 1



A square represents the state capitol

MAP 2



A square represents the state capitol

MAP 3