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AN INDETERMINISTIC APPROACH TO THE INVESTIGATION OF CBD COMMUTER FLOWS IN TULSA, OKLAHOMA

by

Bruce R. Bullis

A Thesis
Submitted to the
Faculty of the School of Graduate
Studies in partial fulfillment
of the
Degree of Master of Arts

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Bruce R. Bullis

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CHAPTER I

INTRODUCTION

Preliminary Considerations

Contemporary economic geography is concerned with the description and interpretation of locational patterns, locational structure and interaction processes of economically related phenomena. Transportation geography, a subset of economic geography, is particularly concerned with the analysis and interpretation of transport networks, flow patterns and structures, and processes of spatial interaction. In the last decade, transportation geography's principle contribution to the general field of geography has been in the application of rigorous testing procedures to problems and previously suspected principles of spatial interaction. The field's function, then, has been to stimulate interest in new tools of measure, techniques of hypothesis testing, and, more important, to develop a systematic body of theoretical knowledge concerning processes of spatial interaction.

In a continuing effort to determine and test interaction principles, transportation geographers have experimented with a variety of models. Much interest has

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focused on two types of deterministic models, the predictive model and the normative model. The predictive models, particularly simple and multiple correlation and regression analysis, have been used extensively and with much success. The normative models, essentially linear programming, have been less extensively used but, with increasing availability of computers, offer great promise for future research.

The underlying purpose of model construction is ". . . to create an idealized representation of reality in order to demonstrate certain of its properties."[1] Models are developed in response to the complexity of reality; they are theoretical frameworks which facilitate partial comprehension of a given reality's total complexity.

A basic assumption of deterministic models in human geography is that man's behavior is rational. Given perfect knowledge of forces governing human decision-making processes, these decisions could be absolutely predicted. Philosophic considerations of free-will and determinism aside, perfect knowledge of the forces governing individual decision-making is, for a variety of

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[1]Peter Haggett, Locational Analysis in Human Geography (New York: St. Martin's Press), 1966, p. 19.

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apparent practical reasons, completely out of the question. A considerable element of human behavior will, apparently, always be inexplicable. The accuracy of predictions based on the assumption of rational behavior is directly related to sample size and variability of sample data. They are also statements related to group, not individual, behavior. Clearly, there are limitations in scale (related to group size and size of areal units) to which determinist models can be applied. The assumption of rationality works in the aggregate or at the macrocosmic level, but becomes increasingly less effective at successive levels of refinement.

In spite of these theoretical limitations on deterministic models, examination of the literature in economic and urban geography reveals their continuing utility in fundamental research efforts. The hypothesized real limits in refinement can only be determined by future researchers. Tentative solution to this recognized though not pressing problem, however, is the responsibility of present-day researchers. Restated in terms of its essence, the problem centers on the unrealistic assumption that given absolute knowledge of operating variables, human behavior could be absolutely predicted.

The inexplicable or chance-appearing element in human behavior at the fundamental level has long been

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recognized by social scientists. Ian Burton points out the essential parallel between the social and the physical sciences stating that, "Physicists working on a microcosmic level encounter the same kinds of problems with quanta and energy that social scientists do with people."[2] An important, although tentative, solution to this problem of indeterminism is the Monte Carlo simulation technique, derived from mathematical games theory. Games theory has a long history. One of the first applications, "A Mathematical Theory of Random Migration" by J. Blakeman and Karl Pearson, was made as early as 1906.[3] In 1944 John Von Neuman and Oskar Morgenstern, the former a mathematician and the latter an economist, collaborated to produce their Theory of Games and Economic Behavior, perhaps the earliest application of this technique to a social science.[4] A number of geographers, notably Torsten Hagerstrand who

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[2]Ian Burton, "The Quantitative Revolution and Theoretical Geography," Canadian Geographer, Vol. 7, No. 4 (1963), p. 154.

[3]Stanley Brunn, Stewart Cowre, and Charles E. Trott, A Partial Bibliography of Simulation in the Social and Physical Sciences, an unpublished manuscript (Department of Geography, Ohio State University), 1963.

[4]O. Morgenstern and J. Von Neuman, Theory of Games and Economic Behavior (Princeton, N. J.: Princeton University Press), 1944.

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experimented with the technique extensively in the early 1950's, have since recognized the potential of the simulation model in geographic research.

The Monte Carlo simulation model fuses the rigor of the deterministic models with stochastic or random processes which characterize human behavior at the fundamental level. The model incorporates significant relationships or findings at the macroscopic level with the random element of individual behavior. Briefly describing the mechanics of its application within the areal framework, the simulation model incorporates suspected relationships, interrelationships, and principles as constraints upon the system of movement or locational structure under investigation. The constraints or assumptions determine the probability estimates that a given sub-area will, for example, attract one or more factories of a given type or generate a migrant to another stated area. Probabilities are assigned to each areal subunit of the study area on a continuous basis from 0 to 1. The theoretical pattern is generated by the selection of random numbers, each number representing the specific assignment (according to the above example) of a single factory or migrant. Comparison of generated and actual patterns reveals the model's relative accuracy. New assumptions, based on comparative analysis of

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generated and actual patterns, are incorporated into a revised model and retested. Several variations in the application of Monte Carlo simulation models as used by geographers are discussed at length in Chapter II.

Purpose of Research

This study is concerned with using the Monte Carlo simulation method in investigating work-trips to the Central Business District (CBD) in Tulsa, Oklahoma. The primary purpose of this research is to test three selected general principles of spatial interaction thought to influence all orders and types of movement through space. Long suspected but only recently subjected to rigorous testing, these principles are transferability (distance), intervening opportunity, and complementarity.[5]

Two of these principles, transferability (distance) and intervening opportunity, both of which theoretically function to attenuate interaction, are directly tested when incorporated as assumptions into a succession of probability models. Complementarity, the third

[5] These principles were explicitly compared and discussed in combination for the first time by Edward Ullman. See: Edward Ullman, American Commodity Flow (Seattle: University of Washington Press), 1957.

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interaction principle described above, is tested indirectly.[6]

Four probability models are tested in this research. In all models it is assumed that CBD commutation is in direct proportion to areal variations in supply (or population levels). Only the attenuating element is adjusted in the succession of models, these adjustments being justified in terms of general theory outlined above. Each model will generate seven sets of flows to Tulsa's CBD, the flows corresponding to various categories of real world commuters. The several work-trip patterns generated under the varying assumptions will then be compared with actual work-trip patterns. Comparison of patterns will be accomplished through correlation analysis.

The explanatory power of each model, the degree to which a model can predict actual commuter flows,

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[6]Complementarity attempts to explain flow phenomena in terms of a given supply and demand framework. If either supply of a given commodity at a particular zone or demand for that supply at a given destination district is increased, then complementarity between these zones is also increased. A direct test of this principle is prohibitively involved, requiring consideration of competing demand in all destination districts (forty) for each given set of supply (within each group investigated, also forty). Instead, complementarity is tested indirectly. This is accomplished when variations in demand for group services at the CBD are compared with differential group response to a model predicting CBD flows on the basis of supply alone. This comparison involves consideration of both aspects of complementarity principle, supply and demand.

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indicates the relative significance of each of the three general principles being tested. Also, the particular response of the various groups to each model's constraints should provide insight concerning varying group mobility. Finally, attempts will be made to determine additional operating variables not constructed into the models. These attempts will center on interpretation of regression residuals.

Organization

Chapter II briefly discusses and compares selected dynamic and static applications of the Monte Carlo simulation method to geographic problems. Similarities and differences between procedures used in this (Tulsa) research and two previous flow studies employing simulation techniques are discussed at length.

In Chapter III, the principles of supply (size) and transferability (distance) are incorporated as assumptions into two probability models. The impact of distance on CBD flows is tested directly; complementarity is indirectly tested. In this chapter, measurement procedures, general test results, and particular group responses to each model are compared. Analysis of selected sets of regression residuals will provide further insight into strengths and weaknesses of each model; this procedure will also point up additional operating variables.

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Chapter IV tests the principle of intervening opportunity which, like distance, functions to attenuate interaction. Two models of intervening opportunity are tested. The first model, like those of size and distance, has an exponent of one. In the second model, for reasons to be discussed in Chapter IV, interaction is assumed to be attenuated by the square root of intervening opportunity. This chapter includes discussion of the procedures used in the measure of intervening opportunity, comparative analysis of predictive efficiency characterized by each model, and a comparison with models discussed in Chapter III. As in Chapter III, interpretation of regression residuals supplements general findings summarized by correlation coefficients.

In Chapter V, overall model performance and explanations for differential performance are summarized. This chapter includes a listing and discussion of major conclusions resulting from this investigation of Tulsa CBD commutation. Finally, Chapter V contains suggestions for future research.

Data Used in the Study

In 1963, the city of Tulsa sponsored a metropolitan area transportation study. The preliminary purpose of this study was to determine the kinds and magnitudes of

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individual movement which characterize the metropolitan area. The ultimate purpose was to make these determinations in order to effectively anticipate future transportation needs. Selected variables derived from this transportation study form the basis of this research investigating principles of spatial interaction.

The Tulsa Metropolitan Area Transportation Study (hereafter referred to as TMATS) was a large-scale research effort; the information was collected by means of detailed personal interviews conducted in preselected sample dwelling units. Examination of interview instructions indicate that every effort was made to rigorously adhere to preselected units.[7] Five per cent of the dwelling units in densely populated areas were interviewed, ten per cent in sparsely populated areas. Past transportation studies have demonstrated that travel patterns determined at these sample levels are representative.[8]

Examination of the dwelling unit interview form, a

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[7] TMATS Home Interview Instructions, p. 12. For example, the interviewer was instructed to make every effort to determine when interviewee would be home. After four separate attempts to contact interviewee, the interviewer was to contact his supervisor in regard to further action.

[8] TMATS Home Interview Instructions, p. 1.

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condensed version of which is available as Appendix I, reveals the kinds of detailed information made available by the Tulsa transportation study. Each individual trip is considered a discrete unit; the individual making a given trip is identified as to zones of origin and destination, sex and race, mode of travel, and purpose of trip.[9] If the trip purpose is related to employment, the employee is identified by both occupation and industry. The information on each individual trip is variously classified, coded, and placed on IBM data cards. Selected pieces of information contained in these IBM cards, to be discussed below, provided the basic data necessary to this investigation of Tulsa CBD commuter flows.

TMATS divided the study area into forty-eight areal data collection units from which work-trips originate or to which they are destined. Because several of these units generated no CBD commuters in several occupation categories, and owing to attendant difficulties in the use of zeros in correlation analysis, eight of the original origin-destination units were combined with other

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[9]In TMATS a trip is defined as one-way travel from one point to another and for a particular purpose. A round trip to and from work represents two discrete trips. TMATS allows thirteen possible trip purposes: work employment, employment business, personal business, recreation, school, social, change of travel mode, convenience shopping, goods shopping, medical, eat meal, serve passenger, and home.

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units. Thus the study area consists of forty areal subunits of considerably varying size. The smaller, more densely populated units are located near the CBD. Toward the study area's periphery, areal units increase rapidly in size. The study area and its relative location in a larger areal framework are shown in Figure 1.

The TMATS sample included more than 4,300 sets of work-trip information, each set representing one individual's journey to work within the Tulsa Metropolitan Area. As previously mentioned, TMATS classified each work-trip according to sex, race, and one of seven occupation categories. Owing to the problem of zeros associated with correlation analysis (insufficient commuters in certain areal units), the category of race and several occupation categories were necessarily eliminated from testing.[10] The seven categories which satisfied testing requirements were: (1) All Commuters, (2) Males, (3) Females, (4) Blue Collar, (5) White Collar, (6) Professionals and Managers, and (7) Sales and Clerical. Table 1 shows the various number of commuters within each group; this table also distinguishes between CBD and non-CBD destinations.

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[10]The occupation categories eliminated were Craftsmen-Foremen, Operatives, Laborers, and Service Workers. These four groups were combined into the Blue Collar category.

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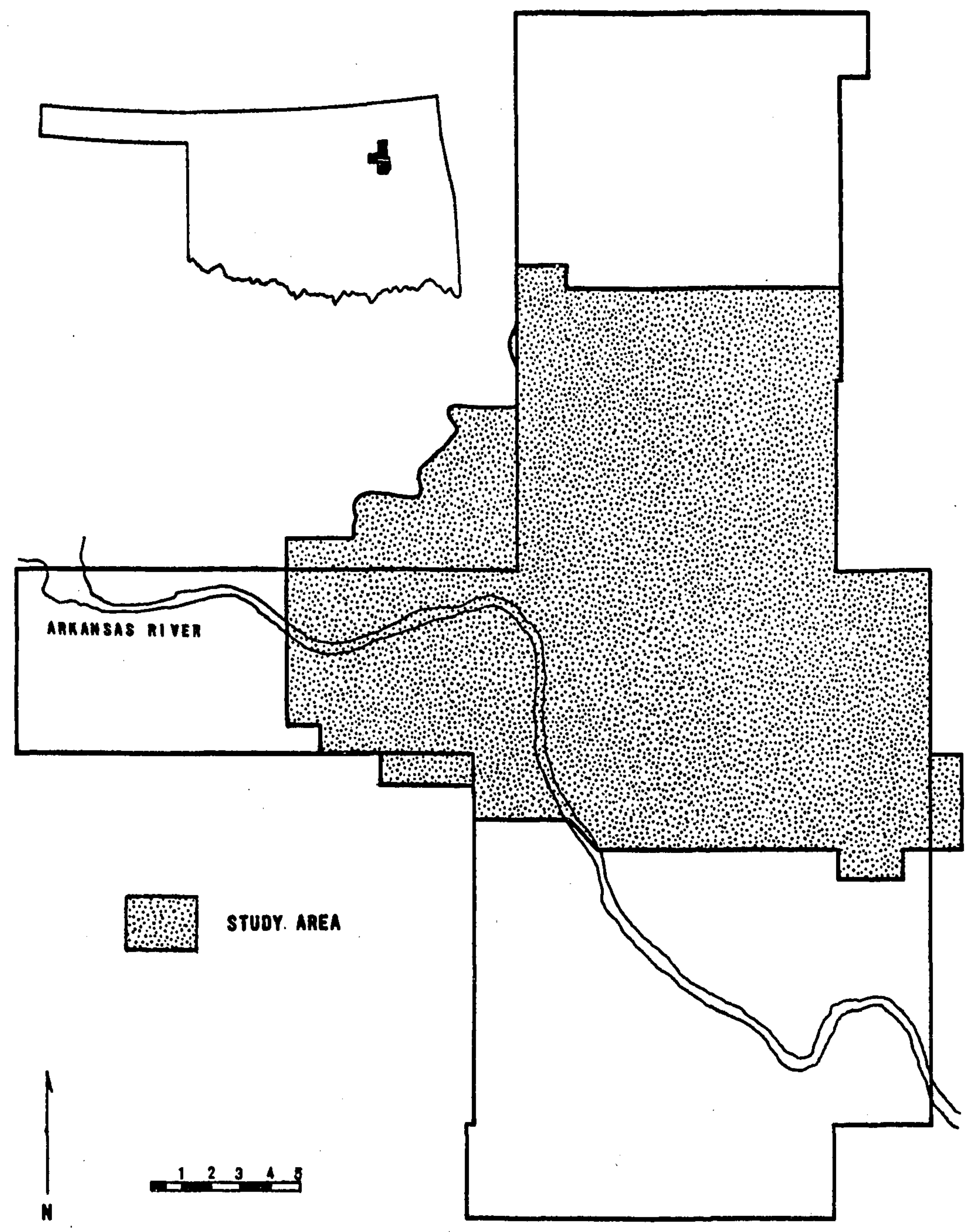

Source: Tulsa Metropolitan Area Transportation Study (1964).

Figure 1.-- TULSA STUDY AREA MAP
Study Area location with reference to Tulsa County and Oklahoma

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TABLE 1

BREAKDOWN OF TMATS SAMPLE WORK-TRIPS BY CATEGORIES INVESTIGATED AND ACCORDING TO CBD AND NON-CBD DESTINATIONS

Destinations	All Commuters	Males	Females	Blue Collar	White Collar	Professional-Managers	Sales-Clerical
CBD	837	498	339	201	636	241	395
Non-CBD	3,512	2,632	880	1,956	1,556	806	750
Total:	4,349	3,130	1,219	2,157	2,192	1,047	1,145

Source: IBM data cards provided by TMATS.

Of the sample 4,349 work-trips, 837 are destined for Tulsa's CBD. The 837 actual CBD work-trips are a basic concern of this research. The flow patterns which characterize each grouping of these 837 commuters function as tests for theoretical flow patterns generated by the probability models. Each model is tested against each of the seven flow patterns; thus there are a total of twenty-eight separate tests performed. This research framework permits within-model comparison of groups at the three levels of aggregation.[11] How, in other words, does each comparable group respond with respect to assumptions constructed in each model? If different, what meaning can be attached to these various responses? The testing format also facilitates between-model comparisons of predictive efficiency. Overall and particular group response to each model will be observed and discussed at length.

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[11]The three levels of aggregation are: (1) All Commuters, (2) Males/Females and White Collar/ Blue Collar, and (3) the further division of White Collar into (a) Professionals-Managers, and (b) Sales-Clerical.

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CHAPTER II

MONTE CARLO SIMULATION IN GEOGRAPHY

The Monte Carlo simulation method, often referred to as stochastic sampling, is an increasingly important research device in the social sciences in general and in geography in particular. Torsten Hagerstrand, in a general discussion of empirical regularities usually associated with the diffusion of an innovation, provides an excellent frame of reference for describing the diffusion of stochastic sampling techniques in geographic research. Diffusion of an innovation is characterized as having a cumulative growth curve. Thus,

> "When the number of adopters . . . is measured over time an S-shaped curve normally appears. This curve shows a slow take-off stage of varying length, an intermediate stage of more rapid development and a final stage of declining growth which asymptotically seems to approach a ceiling. Different innovations run through this process with different speed; also various degrees of irregularity are noted."[1]

Stochastic sampling was first applied in geography

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[1]T. Hagerstrand, "Aspects of the Spatial Structure of Social Communication and the Diffusion of Information," Regional Science Association Papers, Vol. XVI (1965), p. 28.

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by Hagerstrand in 1950. In the early and middle 1950's the application of this technique was largely restricted to Hagerstrand and a group of associates at the University of Lund, Sweden. Diffusion of this innovation, in geography and in the other social sciences as well, was minimal until the late 1950's when the technique was first used in significant numbers. While applications of Monte Carlo simulation grew arithmetically in the 1950's, since 1960 or 1961 they have grown almost geometrically. The correspondence with Hagerstrand's previous findings is apparent. To hazard a guess, adoption of this innovation by geographers is presently in the early phase of the intermediate stage. If Hagerstrand's observations continue to apply, we can expect stochastic sampling to become an increasingly important tool in future geographic research.

Monte Carlo simulation, disregarding future implications, is currently an important instrument of basic research; it has made significant contributions toward the resolution of geographic problems. There are two types of Monte Carlo simulation models--dynamic models and static models. This research is concerned with the development and testing of a static model. In order to: (1) outline similarities and differences in the two approaches, (2) provide insight to the operational characteristics of these models, and (3) provide a frame of

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reference for the present research, the subsequent sections discuss selected dynamic and static stochastic models used by geographers.

Dynamic Simulation Models

Dynamic simulation models are constructed in both time and space frameworks. While the static variety simulates spatial patterns for a single time period, dynamic models combine successive spatial simulations over controlled time intervals. Of the two approaches the dynamic model is the more ambitious, requiring comparable sets of areal statistics over extended time periods and correspondingly more computations. In spite of these limitations, certain studies of necessity require the combined space-time approach. Included in this category would be studies concerned with growth dynamics, economic impact studies, or the analysis of relatively stable flows over extended time periods.

In order to illustrate the utility and potential of dynamic simulation, Richard Morrill's investigation of development and spatial distribution of towns in Sweden is briefly reviewed.[2] Only the general approach

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[2] Richard Morrill, "The Development and Spatial Distribution of Towns in Sweden: An Historical-Predictive Approach," Annals of the Association of American Geographers, Vol. 53 (1963), pp. 1-14.

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and assumptions tested are described; the specific operations entailed in simulation are discussed in the section on static simulation models.

The purpose of Morrill's research was to develop a dynamic simulation model, based on generally accepted theoretical notions concerning processes of urbanization, and to test the patterns generated by this model with actual patterns of urbanization. The theoretical concepts incorporated as restrictive assumptions were: (1) an ordered, hierarchical arrangement of central places and central place functions, (2) differential historical or locational advantage resulting in differential attractiveness of non-central place functions, (3) differential advantage in attracting new transport connections, and (4) differential migration rates resulting from a variety of related socio-economic factors. To each existent urban pattern in the study area, at twenty-year intervals from 1860 to 1960, new transport links are assigned. These assignments are based on probability statements governed by the theoretical effects of the urban pattern on transportation requirements and on known transport inputs during a given time period. The new transport network in turn partially affects new central place, manufacturing, population, and migration flow assignments. The net shift in the above variables results

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in the initial pattern for the next interval. Similar simulations, each incorporating a new set of controls (inputs) and based on different initial patterns, are then made for each succeeding interval. Theory is tested when the generated development patterns are compared to actual development patterns. Morrill's findings were that, with the exception of some correctable over-simplifying assumptions, the body of theory on which the model was based correctly anticipated development patterns.

The dynamic model developed and tested by Morrill is perhaps the most ambitious simulation experiment performed by a geographer to date. Morrill has demonstrated the immense power of this approach in comprehending complex, interrelated processes.[3] One problem limiting the future use of this approach is the need for comparable sets of data over extended time periods. Another problem is the sheer number of computations involved which increase geometrically with each additional variable and areal subunit. Increasing availability of computers and familiarity with the use of computers, through reduction of time and effort involved in computation,

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[3]For a considerably more detailed discussion of dynamic simulation and the potential of this technique, see Richard L. Morrill, Migration and the Spread and Growth of Towns in Sweden (Lund, Sweden: C. W. Gleerup, Publishers, 1965); see especially Chapters III and IV.

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will tend to minimize and eventually eliminate this problem.

Static Simulation Models

Static simulation models, like their dynamic counterparts, generate spatial patterns based on stated relationships and assumptions; unlike their counterpart, they generate these patterns for a single time period. Two recent studies in transportation geography, employing static probability models, demonstrate the utility of this approach in the investigation of factors influencing commuter patterns.

An Intraurban Application

In 1963 Edward Taaffe used the static model, investigating commuter flows to a peripheral employment zone at the west edge of Chicago, Illinois.[4] The reason for using this approach was Taaffe's feeling that the commuter pattern contained a significant random element. Each individual decision concerning place of employment is based on consideration of a unique set of costs, opportunities, alternatives, and a variety of other less

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[4]Edward J. Taaffe, and Others, The Peripheral Journey to Work: A Geographic Consideration (Evanston: Northwestern University Press), 1963.

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tangible factors including chance. Those decisions for which a rationale can be inferred, those which apparently respond in accord with known relationships or suspected factors, are considered the result of non-random processes. Inexplicable decisions for which no rationale can be inferred are equated with random processes. The problem, then, ". . . is to distinguish between those aspects of the pattern for which a rationale may be inferred . . . and those which seem to be merely the result of random processes."[5] The Monte Carlo simulation model is designed to make this distinction and to treat problems phrased in the above terms.

Taaffe empirically determined that the commuter pattern in part responded to population and distance relationships.[6] The effectiveness of these relationships in the description and, if extended, prediction of flow patterns has been proved on many occasions.[7]

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[5] Ibid., p. 37.

[6] Ibid., p. 56. Taaffe used regression analysis to determine the effect of variations in population-distance relationships (x) on variations in number of actual commuters to the best suburban destination (y). For one square mile grids, 17 per cent of the variation in y was explained by x (46 per cent when converted to logs). For two square mile grids, explained variation increased to 26 per cent (67 per cent when converted to logs).

[7] Among the more important early experiments concerned with the relationships between population, distance and flow phenomena were: John Q. Stewart,

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Models based on these relationships are collectively known as gravity models.[8] Stated in traditional terms, the gravity model holds that interaction is directly proportional to the product of the two populations (measures of mass) between which interaction occurs and inversely proportional to the intervening distance.

Because the traditional model defined above is concerned with reciprocal or two-way interaction, and because Taaffe's object of study was the one-way flow of commuters, a basic modification in the model was necessary. Instead of interaction being directly proportional to the product of the two populations, Taaffe posited that flow from a given unit is directly proportional to that unit's population. Mathematically stated, flow magnitude now equals $\frac{P_i}{D_{ij}}$ rather than $\frac{P_i\ P_j}{D_{ij}}$.

"A Measure of the Influence of Population at a Distance," Sociometry, Vol. 5 (February, 1942), pp. 63-71; George K. Zipf, "The P_1 P_2 Hypothesis: On the Intercity Movement of Persons," American Sociological Review, Vol. 11 (December, 1946), pp. 677-686; and George K. Zipf, Human Behavior and the Principle of Least Effort (Cambridge, Mass.: Addison-Wesley Press), 1949.

[8]For a recent and complete bibliography of gravity models, see: Gunnar Olsson, Distance and Human Interaction: A Review and Bibliography (Philadelphia: Regional Science Research Institute), 1965.

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The posited population-distance relationships are incorporated as assumptions in Taaffe's first probability model. They are formally referred to as the game's decision rules. Application of the mathematical formula to data on originating cells yields a single value associated with each individual cell. These values, reduced as proportions of unity, become probability estimates of each given cell's generating a commuter to the destination zone.

The next operational requirement entails the assignment of individual commuters to respective cells of origin. Each cell, as mentioned above, has a probability estimate of generating a commuter to the terminating zone. These probabilities are again converted, this time into a range of numbers. For example, cells 1, 2, and 3 have respective probabilities of .05, .03, and .13. The respective probabilities and range of numbers would be (cell 1) 001 to 050, (cell 2) 051 to 080, and (cell 3) 081 to 210. This process would be continued through the final originating cell where the terminating number would be 1000.[9] Individual commuters, represented by random

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[9]This number (1000) would, on a table of random numbers, be represented by 000. The 1000 value is included above to show that unity is realized in the accumulation of probabilities.

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numbers, are then assigned zones of origin. According to the above example, if a computer or a table of random numbers presented the number 076, then a commuter would be assigned to cell 2. Generations are continued in this manner until a predetermined number of commuters are assigned. This constitutes a simulation "run."

Upon completion of the "run," the model's assumptions are tested when the simulated pattern is compared with the actual pattern. Taaffe made several independent tests (each a single simulation run) of the population-distance assumptions incorporated into his initial model. Comparative analysis of the mapped actual and simulated commuter patterns proved the model to be an inefficient predictor. Persistent discrepancies (clusters of more commuters than would be expected or areas of less than expected commuters) were evident and relatively consistent for the several simulated patterns.

In an effort to correct the observed discrepancies, Taaffe incorporated a new assumption into the original model. Far fewer commuters than expected originated within a four-mile radius of the destination zone. To compensate for this problem, Taaffe postulated an inner four-mile frictionless-zone. This additional assumption improved the initial model's predictive ability. Other assumptions, related to areal variations in the friction

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of distance,[10] were incorporated into a succession of models in order to better describe and predict the actual commuter pattern. Table 2 shows the successive improvements resulting from incorporation of the various additional assumptions.

Model 4 is the culmination of considerable trial and error experimentation; examination of Table 2 reveals both the assumptions incorporated into this model and the high degree of correspondence with the problem distribution. Application of this model to data on two-square mile grid cells resulted in the model's explaining 84 per cent of the actual variation in commuters to the west-side district.[11]

In the subsequent chapters of The Peripheral Journey to Work, Taaffe considered other factors not incorporated

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[10]Although Taaffe doubles population or the numerator in two of his models, these modifications are largely distance-related. In one model he doubles the probability in cells along adjacent suburban commuter radials. This increase is justified in terms of distance, cells along these radials having greater relative accessibility to the destination district. Probability doubling in all cells outside the Chicago city limits is largely justified in terms of relatively less alternate opportunities in suburban areas. As shall be demonstrated in Chapter IV of this study, alternate opportunities and distance are related attenuators of movement. Consequently, the adjustment based on alternate opportunities is also distance-related.

[11]Taaffe, Ibid., p. 51-52. Correlation analysis revealed that 61 per cent of the variation was explained when model 4 was applied to one-mile square grid cells.

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TABLE 2

PER CENT OF COMMUTERS BY DISTANCE BANDS FOR A SUCCESSION OF PROBABILITY MODELS DEVELOPED BY TAAFFE

Distance Band	Model 1[a]	Model 2[b]	Model 3[c]	Model 4[d]	Actual
0 - 4	19	40	55	53.4	48.9
4 - 6	15	13	12	15.2	16.7
6 - 8	17	12	7	13.1	14.3
8 - 10	16	11	8	8.8	9.3
10 - 12	11	9	6	3.7	5.2
12 - 14	8	4	4	2.2	2.3
14 and over	14	11	8	3.6	3.3

Source: Edward J. Taaffe, The Peripheral Journey to Work, pp. 39-51.

[a]The probability of a given cell's generating a commuter to the west-side destination is directly proportional to population, inversely proportional to distance.

[b]Initial assumptions plus the assumption that distance has no attenuating effect within a four-mile inner frictionless zone.

[c]Above assumptions plus double the probability for two adjacent suburban commuter radials.

[d]Above assumptions plus double the probability for all commuter cells outside the Chicago city limits.

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into the model but which might help understand processes related to the work-trip pattern. These factors included areal variations in the composition of the labor force, groupings of employees, the effect of income on trip length, and the effect of alternate employment opportunity on the distance assumptions built into the model.

Taaffe postulated that interaction is directly proportional to a given areal unit's total population, i.e., total number of inhabitants. This assumption is basically unrealistic. This circumstance results from areal variations in proportion employed and, more basically, variations in the occupational breakdown characterizing each areal unit. Essentially, no two components[12] of the disaggregated labor force have equivalent patterns of residential location. Taaffe recognized this problem and, through map analysis of the residential location patterns of several occupation groupings, made inferences concerning the effect of the various residential patterns on the construction of model 4. He concluded that the model is not general in nature. In order to simulate labor force component patterns

[12] In this context, a labor force component is defined as some meaningful occupational category. Examples would include professionals, sales and clerical, operatives, service workers, and laborers.

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accurately, different probability surfaces would have to be (empirically) determined for each component pattern.[13]

Map analysis of cell variations in income resulted in less conclusive findings. There appeared to be a slight inverse relationship between a unit's median income and the number of commuters generated. Higher income areas tend to generate fewer commuters than expected under model 4 assumptions.[14] Taaffe also examined the effect of alternate employment opportunity on construction of the probability surfaces. The reduced probabilities within Chicago owe their existence to abundant opportunities in less skilled occupation categories and the relative lack of these opportunities in the west-side destination district. The converse, relative paucity of alternate employment opportunities, has resulted in higher probabilities being assigned to suburban zones.

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[13] Ibid., p. 62.

[14] Ibid., p. 93. Taaffe observes that this weak inverse relationship is related to the fact that higher income groups form a considerably smaller proportion of the labor force than do the lower income groups. If these different proportions were taken into account, it seems the effect of income could be more effectively evaluated. This is particularly important in view of the observation (p. 88) that for some destination zones there appears to be a connection between an individual's income and the distance he is willing to travel to place of work. Higher income, in other words, seems to result in an increased willingness to incur greater transport costs.

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The Peripheral Journey to Work, an important contribution to the study of commutation, provides the initial application of Monte Carlo simulation to the problem of the work-trip. This has encouraged at least one parallel study (see below) and has provided the essential framework for the present research on Tulsa CBD commuter flows. In brief, Taaffe has developed a model based on certain generalized population-distance relationships. This model efficiently predicts and serves to describe the total commuting pattern of a destination district. Taaffe's analysis of factors underlying the model's efficiency points up tentative answers (hypotheses) concerning processes associated with patterns of movement. These hypotheses, which are further investigated in this (Tulsa) research, are a second contribution of Taaffe's research.

An Application to Work-trips External to the City

In 1965, two years after the publication of Taaffe's The Peripheral Journey to Work, Richard Lonsdale used stochastic sampling in the analysis of a North Carolina fiber plant's labor-shed.[15] This research is similar in

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[15] Richard E. Lonsdale, "Two North Carolina Commuting Patterns," Economic Geography, Vol. 42 (1966), pp. 114-138.

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many respects to Taaffe's Chicago study. Lonsdale tests a series of probability models (again based on population-distance relationships) in an attempt to develop a "best-fit" model, a model which efficiently predicts the real world commuting pattern under investigation.

In his study, the number of commuters generated (to the fiber plant) by a given areal unit is first posited to be directly proportional to that unit's population and inversely proportional to the intervening distance. Subsequent assumptions were incorporated into a succession of models and commuter patterns generated under these assumptions were tested against the actual pattern. The test results associated with the various models are shown below in Table 3.

In all models the base unit for data collection is the township. Distance, whether in miles or minutes, is measured from the plant to the approximate center of population for each township. Total township population, as determined by the 1960 census, is held constant in all models; only different measures and estimated effects of distance are varied from test to test.

It should be noted that model 7, with the highest coefficient of geographic association, is Lonsdale's "best-fit" model. In this model, the number of fiber plant commuters generated by each township is (1) directly proportional to the township population, and (2) inversely proportional to the distance up to twenty

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TABLE 3

TEST RESULTS UNDER VARIOUS ASSUMPTIONS USED BY LONSDALE IN SIMULATING THE FIBER PLANT COMMUTER PATTERN

	Coefficient of Geographic Association	Assumptions Tested	
Model 1	.851	P/D	
Model 2	.728	P/D^2	
Model 3	.830	0-20 mi P/D	Beyond 20 mi P/D^2
Model 4	.754	0-20 mi $P/20^2$	Beyond 20 mi P/D^2
Model 5	.763	0-20 mi P/20	Beyond 20 mi P/3D
Model 6	.919	0-20 mi P/D	Beyond 20 mi P/20+2D*
Model 7	.934	0-20 mi P/D	Beyond 20 mi P/20+3D*
Model 8**	.758	P/D	
Model 9**	.900	P/D^2	
Model 10**	.849	0-35 min. P/D	Beyond 35 min. P/35+3D
Model 11**	.678	0-18 min. P/D	Beyond 18 min. $P/18+D^2$
Model 12**	.689	$P/(D\text{-}6\ \text{minutes})^2$	

*Beyond 20 miles, in models 6 and 7, distances are respectively doubled then trebled. These values are added to the base distance of 20 miles.

**In models 8-12, distance is equated to time as expressed by minutes.

Source: Richard E. Lonsdale, "Two North Carolina Commuting Patterns," Economic Geography, Vol. 42 (1966), pp. 114-138.

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miles and thrice the distance beyond twenty miles. As a result of this test series, Lonsdale made several general conclusions. He first concluded that irregular population distribution is a significant explanatory factor. Lonsdale also concluded that the specific impact of distance is less evident, and that, although a better fit was achieved when measuring distance in miles rather than minutes, there is "little evidence here to support one over the other . . . ."[16] Lonsdale's possibly most significant general conclusion is that gravity concepts, placed in a probability framework, provide useful approximations of real world interaction patterns.

In an effort to determine other potential operating variables, Lonsdale performed a series of Spearman rank correlations. Counties were ranked by income, wages, road density, percentage of labor force in agriculture, population growth, per cent urban, and level of unemployment. These ranks were then compared with a county ranking of percentage deviation of actual from expected (based on model 7) number of commuters. Lonsdale came to some interesting conclusions as a result of these tests. First, three variables--per capita income,

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[16] Ibid., p. 136.

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population density, and percentage of labor force in agriculture--when ranked were found to closely correspond with variations of actual from expected commuters. Counties with higher incomes, smaller percentage of agricultural workers, and higher population densities tend to generate fewer commuters than expected on the basis of stated population-distance relationships.

There are many readily apparent similarities between the Taaffe and Lonsdale studies. Both studies postulated in all models that the number of commuters in a given area is directly proportional to the area's total population. In either study, only distance was manipulated in the attempt to realize an optimal predictive model. Upon development of their "best-fit" models, which both authors admit could be further but unnecessarily refined, each examines other potential operating variables which possibly influence the problem distribution. Lonsdale found variations in income to be closely associated with deviations between actual and postulated work-trips; Taaffe likewise considered income but determined its effect to be less than clear.

Fundamental to both studies is the conclusion that alternate employment opportunities are a central factor influencing commuter flow patterns. Taaffe determined alternate opportunity to be especially important in

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understanding the commuting pattern of low-skill, low-income groups which were characterized by residential clustering. Alternate opportunities seemed a less important factor for higher-income and more residentially dispersed groups. Lonsdale chiefly explains his significant discrepancies in terms of the lack of alternate opportunities, this lack of opportunities being manifested by declining population, high percentage of the labor force employed in agriculture, and relatively low incomes.

Stochastic Sampling as Applied in this Research

Like the Taaffe and Lonsdale studies, this research centers on the application of probability models in the study of commuter flows to a single destination district. Basic to this approach is the conviction that some proportion of the flow pattern being investigated remains (and perhaps, will always remain) inexplicable. Individual decisions are not always rational. In any large set of individual decisions, as in a flow pattern, there is always a non-rational or apparently random element; stochastic sampling is one solution to this problem of indeterminism.

While this study parallels the Taaffe and Lonsdale research in approach and type of phenomena investigated, certain important differences exist. First, prediction

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of commuter flows is not, as in Taaffe and Lonsdale, restricted to the aggregate group being investigated. In this research the aggregate group is broken down into several different categories; aggregate and sub-group CBD flows are then predicted independently by each of the four models. Analysis of differential group response to each model should yield a more particular and balanced evaluation of an assumption's utility. This format should also yield important observations concerning various groups' mobility. A second difference is that, with one exception, assumptions are not altered in order to realize a "best-fit" prediction. With the exception of the adjusted intervening opportunity model, an exponent of one is accorded each assumption constructed into the models.

A third significant difference between this and Taaffe's and Lonsdale's research is related to the question of testing procedures. Taaffe compared per cent of actual and simulated commuters generated from distance bands extending out from the destination district. Adjustments were intuitive and based on discrepancies between actual and predicted percentages. Lonsdale's testing procedure, based on compact areal units rather than distance bands, was more rigorous--the coefficient of geographic association. In this (Tulsa) research an even more rigorous testing framework

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is employed--correlation analysis. One advantage gained in the use of this technique is its wide acceptance and use among the social sciences. In other words, test results can be more uniformly understood than the less used coefficient of geographic association. Second, correlation allows calculation of the proportion (of actual flow variation) statistically explained by each model. Finally, correlation permits standardized determination of significant discrepancies (regression residuals) between actual and predicted number of commuters. This set procedure is particularly important in view of the large number (twenty-eight) of flow patterns being predicted.

A final important difference between this and the previous studies exists in the definition of size levels or population on which predictions are based. Both Taaffe and Lonsdale used a general measure of population, basing their predictions on the total number of inhabitants in each areal unit. In this study, population is more specifically defined as the number of employees (which varies with each category investigated) in each areal unit. A specific example and the implications of this procedure are discussed in Chapter III.

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CHAPTER III

FINDINGS--POPULATION AND POPULATION/DISTANCE MODELS

The test results of two probability models are presented in this chapter. The first model, entitled the population model, is related to the principle of mass (size). The second model embodies the assumptions of the traditional gravity model, employing a constant exponent of one. The implications and findings of each model are discussed separately. Findings are compared and summarized when residuals from regression are evaluated.

Population Model

The most important single feature of the population model is its simplicity. This model tests an isolated principle (size or mass) thought to partially explain flow phenomena; only a single decision rule governs the game which assigns CBD commuters to various areal units (cells) throughout the study area. Stated verbally, it is assumed that commuters generated from a given cell are in direct proportion to that cell's employed population. Mathematically stated, $P_i = \frac{C_i}{\Sigma C_i}$, where P_i equals the

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probability of a CBD workers coming from a particular zone, and where C_i equals the number of workers in a given category residing in zone i.

Probability Surfaces and Simulation Procedure

The reader will note the specificity with which the population parameter is defined. Unlike traditional formulations of this statement which take the entire population into account, the population statistic used in this study relates only to the phenomena investigated. This phenomena is the sample employed population within the study area, and sub-groups within that larger classification. Irrelevant variation (such as variation in proportion employed) manifest in the total population is thus eliminated. In the study of sub-groups, this definition is particularly important. Variation in sub-group patterns of residential location are taken into account. If each set of flows (seven are predicted, one for each category of employees) were predicted on the basis of entire cell population, the flows would differ only in magnitude and not in kind. Each flow is largely governed by its own probability surface. If entire populations were used in each set, then all probability surfaces would be identical. Flows generated from these identical surfaces would differ mainly in the number of

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assignments (representing commuters); small differences in kind would be the result of chance.

Because seven sets of flows are simulated, it is necessary to construct seven probability surfaces. The various steps involved in development of a probability surface and the simulation procedure are best served by an example--Blue Collar workers. Appendix II shows a sample total of 2,157 Blue Collar workers in the study area. This is the initial step involved in construction of the probability surface--summing class members residing in all forty areal units. Each part is then divided by the total, resultant values being statements concerning each cell's probability of generating a CBD commuter. Examination of Blue Collar statistics in Appendix II reveals that cells 6 and 9 (each with 100 Blue Collar residents) would have the highest probabilities of generating a CBD commuter; cells 12 and 29 (each with 9 Blue Collar residents) would have the lowest probabilities. All probability statements, considered in combination, constitute the probability surface.

Each probability was then converted to a range of four digit numbers (for example, 0001 to 0170 for a cell 1

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probability of .0170) as described in Chapter II. The range representing each areal unit was placed on IBM data cards; random number assignments, each representing a CBD commuter, were then generated by an IBM 1620 computer. The number of assignments equaled the actual number of CBD commuters for each occupation category, thus maintaining a one-to-one ratio between actual and theoretical CBD flows. Examination of Appendix III, which shows actual CBD commuters by occupation category and areal unit, indicates that 201 assignments were made for Blue Collar workers.

In order to eliminate potential confusion when subsequent models are discussed and evaluated, it is emphasized that each model requires construction of seven probability surfaces, one for each group investigated. The stages or steps involved in the construction of each set of probability surfaces, and the commuter assignment or simulating technique, are identical to procedures used in Model I. In subsequent models, however, the incorporation of additional assumptions result in different cell probabilities and consequent probability surfaces.

The Evaluation of Model Performance

In the research framework employed in this study,

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there are two concerns with and manifestations of model performance. The first concern is with overall performance. Overall performance is manifest by variations in correlation coefficients, these coefficients indicating degrees of correspondence between actual and model predicted CBD commuters. This first testing procedure facilitates: (1) comparative analysis of within-model group response to the particular assumptions incorporated into each model, (2) analysis of group response to revised assumptions incorporated into models subsequent to Model I, and (3) statements concerning the relative overall efficiency of each model and attendant assumptions on which each model is based (accomplished when degrees of accuracy are averaged for the seven groups predicted by each model).

The second concern with model performance is related to the question of areal variations in performance. This aspect of model performance is manifest by regression residuals, residuals indicating places and areal patterns of model overestimates or underestimates. Areal variations in regression residuals, often useful in the detection of additional operating variables, are examined in the final section of this chapter. Analysis of mapped regression residuals is, however, considered secondary or supplemental to the analysis of overall performance determined through correlation analysis.

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Testing Procedure and Model I Results

Overall correspondence between hypothesized (simulated) and actual commuter flows was determined by means of Pearson's Product-Moment correlation formula. In this formula,

$$r = \frac{N \sum XY - (\sum X)(\sum Y)}{\sqrt{N \sum X^2 - (\sum X)^2}\ \sqrt{N \sum Y^2 - (\sum Y)^2}}$$

where r equals the coefficient of correlation, X equals the number of commuters predicted, Y equals the actual number of commuters, and N equals the number of paired variables (40 in all cases, one for each areal unit). Actual commuters from each cell (and for each group) functioned as the dependent variable, simulated commuters the predicting or independent variable. Perfect correspondence between paired variables would result in a correlation coefficient (r) of 1.0. Absolute non-correspondence would be indicated by an r value of 0. Because the total number of simulated commuters corresponds with the total actual, perfect correspondence would also be indicated by an intercept (a) of 0 and a slope (b) of 1.

Table IV summarizes the findings resulting from application of the population model. This table contains the coefficients of correlation (r), intercepts (a), regression coefficients or slopes (b), coefficients of

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determination (r^2), and standard errors of the estimate (Sy) computed for each set of relationships between simulated and actual commuters.

TABLE IV

CORRELATION AND REGRESSION COEFFICIENTS RESULTING FROM APPLICATION OF THE POPULATION MODEL

Group	r	a	b	Sy	r^2
Total	.6814	-2.06	1.10	11.92	.4643
Males	.7301	-1.49	1.12	7.99	.5330
Females	.6594	1.42	.83	5.28	.4348
Blue Collar	.3901	2.77	.44	3.19	.1521
White Collar	.9045	-1.78	1.11	6.60	.8182
Professionals-Managers	.7902	-1.31	1.22	5.70	.6244
Sales-Clerical	.8825	1.33	.87	3.77	.7789

Source: Calculated from data provided by TMATS.

In view of the population model's elementary character, predicting flows on the basis of supply alone, coefficients of correlation shown in Table IV were unexpectedly high. All correlation coefficients, except that for Blue Collar workers, are statistically significant at the .001 confidence level; the Blue Collar coefficient is

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significant at the .05 confidence level.

Although results are generally favorable, closer inspection of Table IV (the coefficient of determination column) reveals considerable group differentiation in per cent of variation statistically explained by the model. This statistic indicates the degree to which the model correctly anticipates actual cell variation in CBD commuters. Of the mutually exclusive groups,[2] greatest differences exist between Blue and White Collar groups. Blue Collar CBD commuters (r^2 = .1521) were poorly anticipated by the model; White Collar commuters (r^2 = .8182), on the other hand, were effectively anticipated. Smaller differences exist between the two other mutually exclusive groups. Male commuters were slightly better anticipated than Females; Sales and Clerical commuters were better predicted than were the Professionals and Managers group. Forty-six per cent of the aggregate or total CBD flow pattern is explained by cell variations in the number of employees. Parenthetically, this statistic is near

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[2]The mutually exclusive groups are: (1) Males and Females, (2) Blue Collar and White Collar, and (3) Professionals-Managers and Sales-Clerical. Sets (1) and (2), when the two sub-groups of which are combined, are both equal to the total group. When sub-groups of set (3) are combined, they are equal to the White Collar category.

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the average (fifty-one per cent) of all Model I coefficients of determination.

The Interpretation of Overall Model I Results

As previously mentioned, the population model is elementary in character and attempts to predict CBD commuter flows on the basis of supply alone. It is implicitly assumed that distance and intervening opportunity are meaningless variables, that the cost of movement is zero.

Given the elementary character of Model I, how can the unexpectedly high overall results shown in Table IV be explained? Two tentative answers to this question are offered, both derived from close inspection of differential group response to Model I assumptions shown in Table IV.

The first potential explanation or hypothesis for Model I efficiency relates to the question of destination demand. According to this interpretation, extremely high employee demand at the CBD (more than nineteen per cent of the entire study area sample labor force) tends to at least minimize the attenuating affect of either distance or intervening opportunity. The logic of this argument is best demonstrated by an extreme, hypothetical example. If demand for White Collar services, for example, were exclusively restricted to the CBD, then White

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Collar commuter flows could be near perfectly predicted by the population model. Under these conditions, there would be a total absence of alternative sites which function as the basis of individual distance-minimization efforts. According to this construction, the degree to which demand is concentrated at a single destination zone has a direct bearing on the relative consequence of distance, total absence of alternatives resulting in total irrelevance of distance.

If this hypothesis is valid, then variations in demand for group services at the CBD should correspond with variations in group response (accurate prediction) to Model I.

Testing of the destination demand hypothesis was accomplished through use of a Spearman's rank correlation test. The proportion of each group employed in the CBD was calculated, then ranked from high to low. The Spearman's correlation test, performed between this order and the ordering of correlation coefficients shown in Table IV, resulted in verification of the destination demand hypothesis. In this test, R = .7143--significant at the .05 confidence level. In Table V these significantly related group characteristics are compared.

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TABLE V

COMPARISON OF GROUP POPULATION MODEL COEFFICIENTS WITH VARIATIONS IN GROUP DEMAND AT THE CBD

Occupation Category	Per Cent Employed in the CBD	Population Model Correlation Coefficients
Sales-Clerical	34.5 (1)	.883 (2)
White Collar	29.0 (2)	.905 (1)
Females	27.8 (3)	.659 (6)
Professionals-Managers	23.0 (4)	.790 (3)
All Commuters	19.2 (5)	.681 (5)
Males	15.9 (6)	.730 (4)
Blue Collar	09.3 (7)	.390 (7)

Source: Calculated from data provided by TMATS.

Apparently, as group demand at the CBD increases, the destination districts' power of attraction or employment field also increases. Even more important, increasing pull at the destination district manifests itself unequally throughout the expanding employment field. Attraction at the employment field's periphery seems to increase at a disproportionate rate. Essentially, as destination demand increases, the cost of movement becomes an increasingly meaningless variable. This

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change manifests itself most conspicuously in outlying areas where distance inputs are, owing to a generally central concentration of employment, naturally higher.

Variations in destination demand, then, seem at least partially responsible for the population model's effectiveness. Another interpretation concerning Model I effectiveness is that, in the aggregate, the Tulsa population is highly mobile--little affected by the friction of distance. Accordingly, sub-group deviation from the aggregate correlation coefficient could be construed as deviations from mean mobility. Correlation coefficients could be construed as indices of group mobility. Evaluation of this interpretation is intuitive, based on comparison with previous research findings.

Mobility is a widely used term in the social sciences which, depending on context, has been variously defined. In this context, mobility is generally understood as the propensity (some combination of willingness and ability) of an individual or group to travel. Previous researchers in travel behavior generally agree that males are more mobile than females.[3] Also, some researchers have tentatively noted a connection between

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[3]See, for example: Edward J. Taaffe, The Peripheral Journey to Work: A Geographic Consideration (Evanston: Northwestern University Press), 1963.

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occupational status and mobility, high-status occupations being more mobile.[4] It is apparent that the Tulsa findings accord with those of previous research. The three high-status White Collar groupings, being best predicted on the basis of supply alone, are the most mobile. Conversely, the relatively low-status Blue Collar group is the least mobile of the seven investigated. Finally, Males were found more mobile than Females--this in spite of relatively high demand for females in the CBD.

In review, the population model proves a relatively efficient predictor of CBD commuter flows. Plainly, labor supply is an extremely important factor in regulation of place-to-place movement, accounting for a considerable proportion of variation in cell capacity to generate CBD commuters. Two explanations for overall Model I efficiency were offered: relatively high demand at the CBD and relatively high overall mobility of Tulsa's CBD commuters. Both hypotheses, separately and in combination, proved useful in explaining differential group response to the model. Consequently, both are tentatively accepted.

The question of explanation priority or relative

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[4]See: James O. Wheeler, "Occupational Status and Work-Trips: A Minimum Distance Approach," Social Forces, Vol. 45 (June, 1967), pp. 508-515.

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importance is answered in the following section. In this section the specific impact of distance on CBD flows is determined when distance is incorporated into a second probability model. Incorporation of distance, as shall be seen, results in more satisfactory estimates of group mobility. This result, in turn, permits more meaningful comparison of destination demand and mobility as explanations for Model I effectiveness.

Population/Distance Model

The population/distance model embodies the assuptions of the traditional gravity model and is very similar to the initial formulations used by Taaffe and Lonsdale. The only difference between this model and those used by Taaffe and Lonsdale is the specificity of the population element. Stated verbally, this model assumes that CBD commuters generated by a given cell are in direct proportion to that cell's employed population and inversely proportional to the distance between the cell and the CBD. Mathematically stated, $P_i = \frac{C_i/D_{ij}}{\sum C_i/D_{ij}}$, where P_i equals the probability of a commuter being generated from a particular zone, where C_i equals the number of workers in a given category residing in zone i, and where D_{ij} equals intervening distance between the i^{th} cell and the CBD.

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In this model the P_i values correspond to those used in the population model. Intervening distances were measured in units of straight (airline) connection. This procedure required visual location of control points in each of the forty areal units, then a simple measure of point separation between each cell and the CBD. Cost of movement within the CBD was estimated as slightly less than the most proximate (to the CBD) unit.

Methods used in construction of probability surfaces, with the exception that employed population statistics were divided by intervening distances, were the same as those described in the population model. Simulation and testing procedures, operations performed simultaneously for both Models I and II and the initial intervening opportunity model, were also identical. The same dependent variable, actual commuters, was used in all models.

Test Results and Interpretation

The P/D model tests the interrelated effect of two elements--supply (mass) and distance--on Tulsa CBD commuter flows. The specific impact of distance is evaluated when test results between this (P/D) model are compared with those of the population model. Table VI shows correlation and regression coefficients resulting from comparison of model postulated and actual flows. Like

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Table IV, this table shows correlation coefficients (r), intercepts (a), slopes (b), standard errors of the estimate (Sy), and coefficients of determination (r^2).

TABLE VI

CORRELATION AND REGRESSION COEFFICIENTS RESULTING FROM APPLICATION OF THE POPULATION/DISTANCE MODEL

Group	r	a	b	Sy	r^2
Total	.6645	9.33	0.56	12.17	.4416
Males	.5144	5.42	0.57	10.03	.2647
Females	.7633	4.27	0.50	4.55	.5826
Blue Collar	.7503	2.62	0.49	2.29	.5630
White Collar	.7501	6.40	0.60	10.24	.5626
Professionals-Managers	.7553	0.54	0.91	6.09	.5704
Sales-Clerical	.7734	5.56	0.44	5.08	.5981

Source: Calculated from data provided by TMATS.

Examination of Table VI reveals that correlation coefficients are relatively high; all coefficients are statistically significant at least at the .01 confidence level. Unexpectedly, however, the incorporation of distance resulted in no significant improvement in overall predictive ability. In fact, as shown in Table VII,

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explanatory power concerning the aggregate CBD flow declined 4.9 per cent. When coefficients are averaged for each model, predictive efficiency was reduced by 5.8 per cent.

TABLE VII

COMPARISON OF COEFFICIENTS OF DETERMINATION BETWEEN POPULATION AND POPULATION/DISTANCE MODELS

Group	P Model (r^2)	P/D Model (r^2)	Per Cent Change
Blue Collar	.1521	.5630	+270.2
Females	.4348	.5826	+ 34.0
Total	.4643	.4416	- 4.9
Professionals-Managers	.6244	.5704	- 8.6
Sales-Clerical	.7789	.5981	- 23.2
White Collar	.8182	.5626	- 31.2
Males	.5330	.2647	- 50.3
Mean	.5436	.5118	- 5.8

Source: Calculated from data provided by TMATS.

Further examination of Table VII reveals another characteristic of the population/distance model--consistency of predictive efficiency. While the population model was highly variant in its predictions, with coefficients of determination ranging from .1521 to .8182,

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population/distance model coefficients exhibit a relatively narrow range. The formerly high White Collar coefficients have been considerably reduced, the previously low Blue Collar coefficient significantly increased. How, it may be asked, can these changes in predictive efficiency be explained? What are the implications of these changes? Subsequent discussion of these questions should clarify not only the meaning of the gravity model, but should also serve to clarify the dual explanation offered for the population model's success.

In the previous section on the population model, two tentative explanations concerning differential group response were offered. Differential group response (variations in r) was thought to reflect the combined effect of group mobility and demand for the group at the CBD. No attempt was made or could be made concerning the relative impact of each variable on differential correlation coefficients. Incorporation of distance in the second (P/D) model, when findings are compared with those of the population model, results in specific observations concerning the effect of distance on the several categories. In effect, demand and mobility are separated as explanatory variables in the population model. The differential impact of distance on prediction of group CBD flows, shown in the per cent change column in Table

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VII, is a more specific, isolated measure of group mobility. Positive response to the addition of distance, i.e., Blue Collar workers and Females, indicates relative immobility. Blue Collar workers, whose proportion explained has been improved 270 per cent, are easily the least mobile group. The three White Collar groups and Males, the coefficients of which have been reduced, are apparently less affected by distance. The proportion of cell variation explained in Male CBD flows has been reduced by 50 per cent. Accordingly, they are the most mobile group, exhibiting the greatest propensity to travel.

The Population Model Revisited--Destination Demand or Mobility?

If relative group mobility is a function of the differential impact of distance, as postulated, then the relative impact of mobility and destination demand on population model findings is easily determined. The reader will recall that a rank correlation was performed between group population model coefficients and group destination demand. The test score, R = .7143, demonstrated a relationship significant at the .05 confidence level. As mobility was defined in terms of correlation coefficients, no comparable mobility-correlation coefficient test could be performed. By definition, R would

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the other hand, the addition of distance in varying degree diminished success for the remaining five groups. This fact, in combination with an apparent non-relationship between mobility and population model success, results in the conclusion that, overall, distance is less significant than either supply or demand. According to this construction, CBD flows are largely governed by complementarity. Within each group framework of supply and demand, varying group propensity (willingness and ability) to travel is a third and less important factor explaining group flow characteristics.

Although correlation coefficients resulting from application of the two models were generally high, a considerable proportion of the variation in actual commuter flows remain unexplained ($1 - r^2$). As described above, some part of this unexplained element is very probably accounted for by group differences in CBD demand.[5] Nevertheless, it is also likely that factors not yet observed work to shape each set of flows. In the subsequent section, an attempt is made to identify these additional factors through analysis of mapped regression residuals.

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[5]The reasons for not incorporating demand were discussed on pages 6 and 7.

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Residuals from Regression

In brief review, the correlation coefficient is a measure of average relationship between sets of paired variables. The regression line, defined in terms of slope and intercept, mathematically describes the linear relationship between sets of paired variables. Regression residuals, when correlation is used in an areal framework, are simply statements of areally significant deviations between actual (y) and regression predicted (yc) values. In this study, residuals essentially reflect important differences between actual and model predicted commuters.

There are two basic types of regression residuals--absolute and relative residuals. Relative residual types are weighted to take size variations into account; absolute residual types are unweighted, simple expressions of absolute difference between actual and expected values. The residual used in this study is of the absolute, unweighted type. One weakness of this class of residuals is that they tend to emphasize large numbers in the dependent variable. This problem was thought preferable to that attendant with the use of a relative residual, de-emphasis of large magnitudes in the dependent

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variable.[6] Given this limitation, the precise type of absolute residual used is discussed next.

Divided by the standard error of the estimate (Sy), raw residuals (yc - y) are expressed in standard deviation units from the regression line. Negative residuals (yc < y) indicate model understatement, significantly less predicted than actual commuters. Positive residuals (yc > y) indicate model overstatement. Mapped results include two degrees or levels of significant deviation from the regression line: more than one standard error and more than two standard errors. Owing to space limitations, map presentation is selective. Of fourteen possible residual maps, five are included. Both aggregate and Blue Collar group residual patterns are illustrated by two maps each, showing residuals generated under both Models I and II. Only Model I residuals are shown for the White Collar group. These maps were thought representative, reflecting the entire range of possible patterns. Analysis will procede from the general to the particular, beginning with residual maps for the aggregate CBD flow.

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[6]For an extensive discussion of these two types of regression residuals, see: Edwin N. Thomas, Maps of Residuals from Regression, Department of Geography Publications, State University of Iowa, 1960.

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Total Group Residuals

Figure 2 is a composite statement of Model I (population model) significant errors. This map, fairly representative of all Model I maps, exhibits the model's general tendency to overpredict in units at the study area's periphery. This, in combination with underprediction in units closer to the CBD, tentatively indicates a need for distance. Closer inspection of Figure 2, however, combined with known non-improvement resulting from incorporation of distance in Model II, indicates the operation of alternative factors. Close inspection reveals that overstatements are not restricted to the study area's periphery. Also, underpredictions are not tightly clustered about the CBD but extend south and southeast five or six miles into a low-density, expensive residential area. This association between high quality housing and Model I negative residuals led to the initial hypothesis that significant Model I errors in prediction may be related to variations in income.

Comparison of Figure 2 with Figure 3, which shows large unit variations in income throughout the study area, resulted in tentative confirmation of the income hypothesis. No low income unit[7] generated more actual than

[7]That is, no unit with less income than the study area median income. In 1964, median income was estimated at $6,255.

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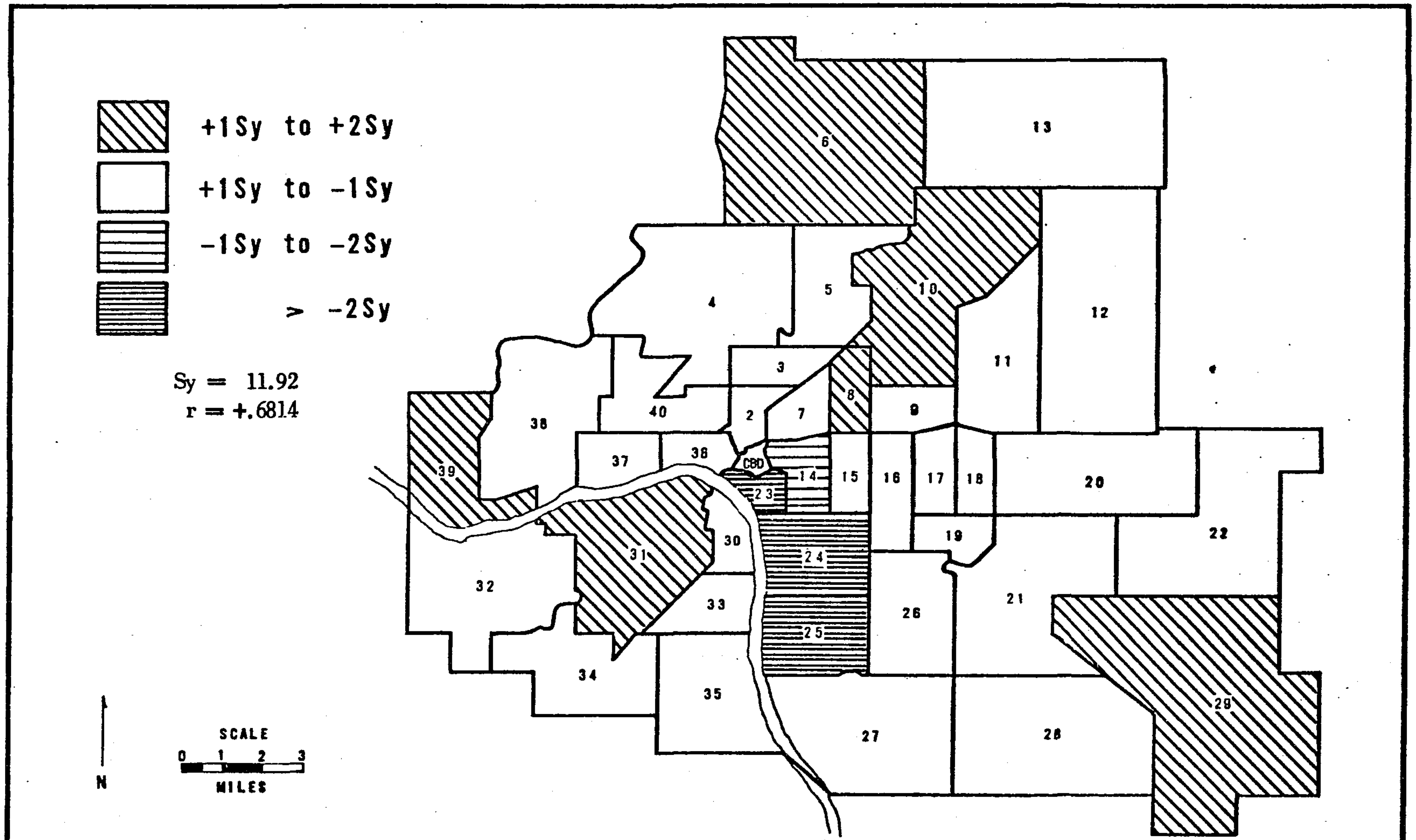
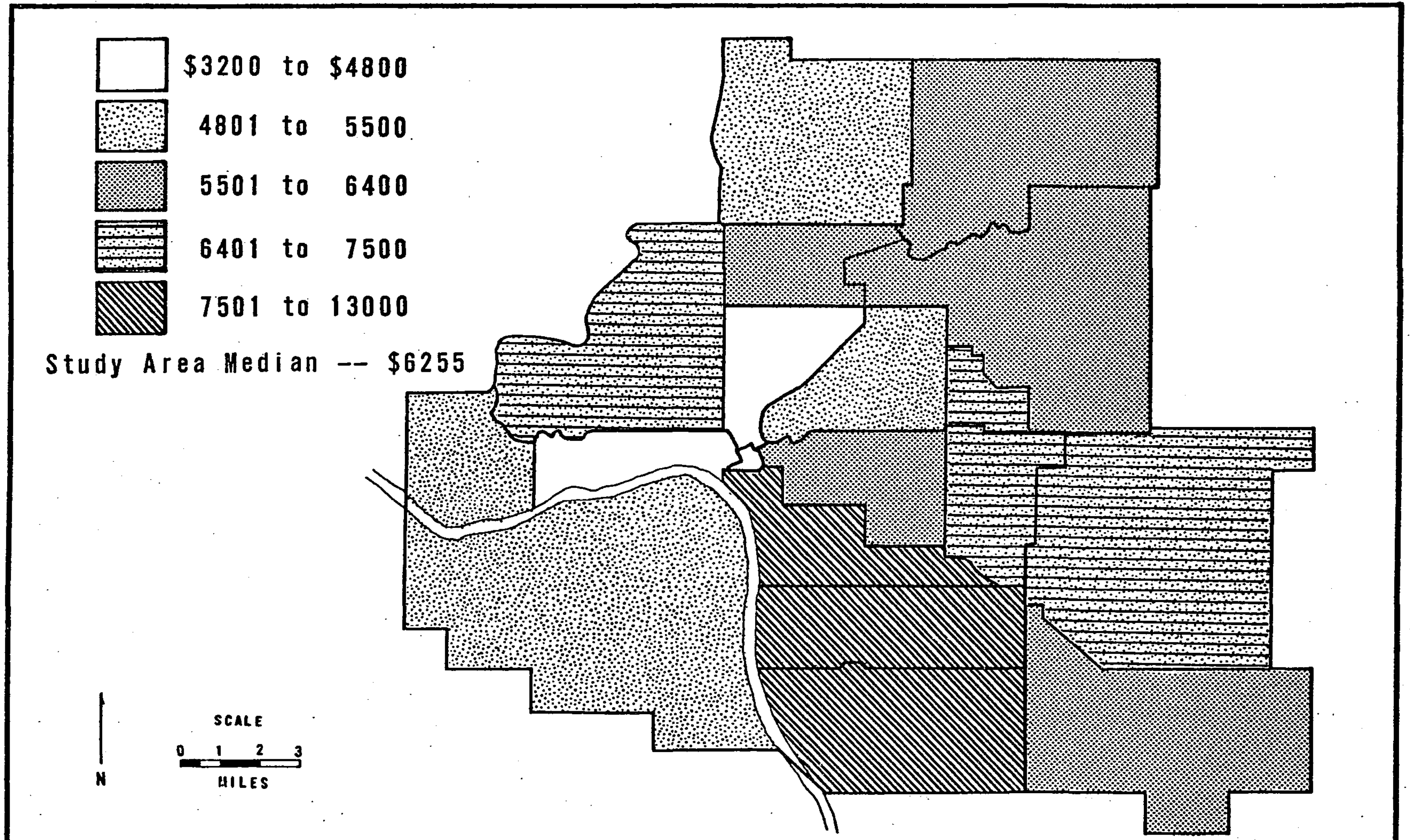


Data compiled from Tulsa Metropolitan Area Transportation Study (1964).

Figure 2.-- TULSA MODEL I AGGREGATE GROUP REGRESSION RESIDUALS



SOURCE: Tulsa Metropolitan Area Transportation Study (1964).

Figure 3.-- AREAL VARIATIONS IN ESTIMATED MEDIAN INCOME (1964)

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Model I predicted commuters. Conversely, Model I underpredictions are restricted to high income units. It should be recalled, parenthetically, that both Taaffe and Lonsdale also found this apparent direct relationship between income and propensity to travel.

A second factor, more thoroughly investigated in Chapter IV, which helps to explain the Figure 2 pattern of overstatements is intervening opportunity. To the northeast of the CBD are two of the largest employment centers in the study area--Douglas Aircraft and American Airlines. This point of concentrated employment may well account for overstatements in cells 8 and 10, distant from the CBD but not peripheral to the study area. Similarly, cell 31--southwest of but almost adjacent to the CBD--contains the Mid-Continent and Texaco Refineries. This is another point of concentrated employment opportunities which potentially limits the number of CBD commuters.

Figure 4 is also concerned with the aggregate CBD flow. Residuals are here, however, based on Model II (population/distance model) predictions. It is apparent that the pattern shown in Figure 4 is considerably different than that in Figure 2. In this second pattern, both positive and negative residuals are concentrated within a seven-to-eight mile radius of the CBD. Negative

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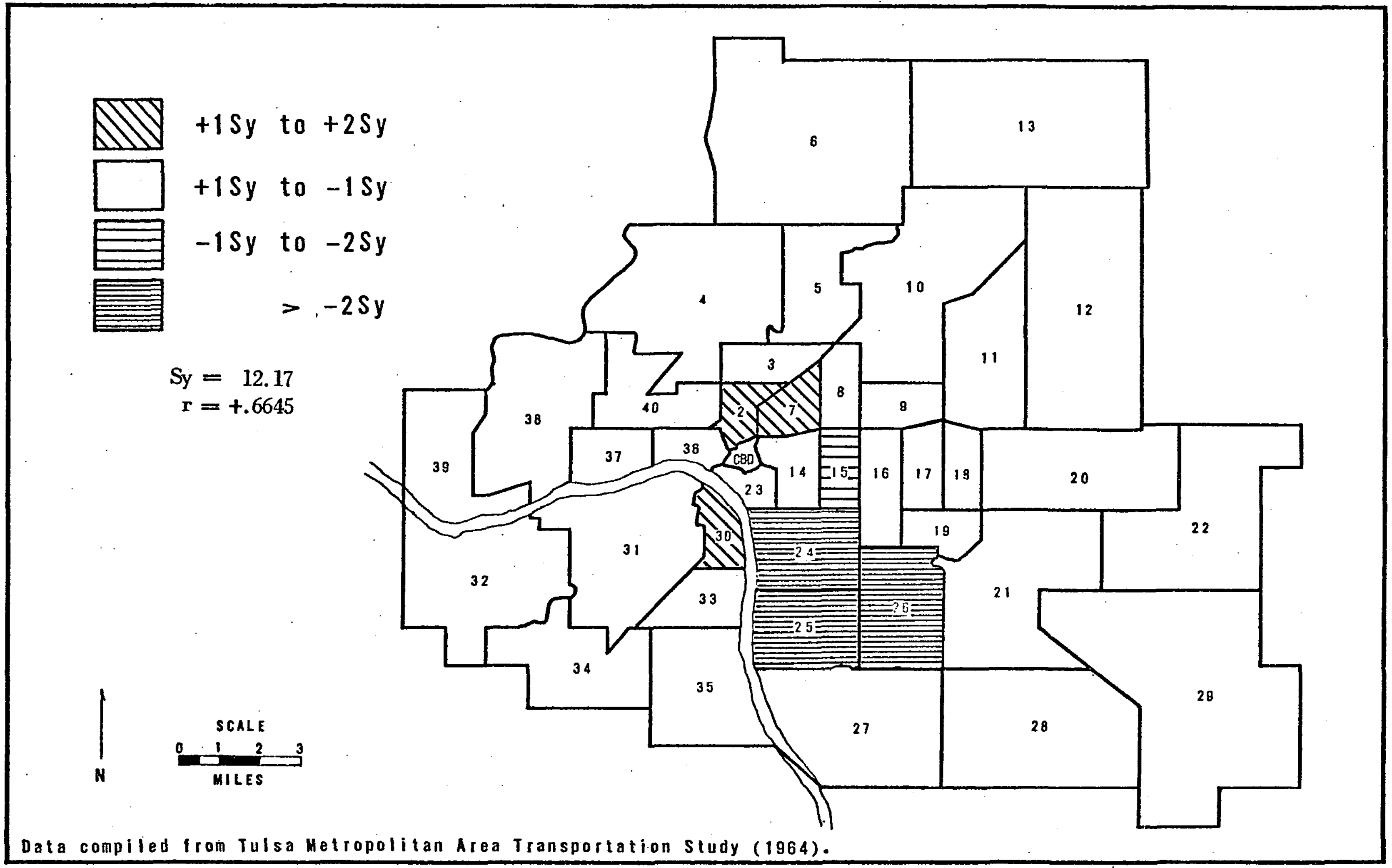

Figure 4.— TULSA MODEL II AGGREGATE GROUP REGRESSION RESIDUALS

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residuals (model understatements) are in the same general location, southeast of the CBD, but have now moved outward slightly. Conversely, all peripheral positive residuals have been eliminated, positive residuals now clustering in cells close to the CBD. What factors, it may be asked, account for this different pattern of regression residuals? Theoretically, Figure 4 presents a pattern free of distance bias and should facilitate closer approximation of additional operating variables.

Preliminary examination of Figure 4 (and the other six Model II maps) results in rejection of Taaffe's hypothesized frictionless zone concept which worked in Chicago. This concept held that while distance attenuates interaction, the attenuating effect near the destination district is overstated relative to more distant areas. Although the incorporation of this postulate improved flow predictions in Chicago, it is apparent from overstatement locations in Figure 4 that distance, instead of being reduced close to the CBD, should be increased. Why the reversal between Taaffe's and the Tulsa findings occurred is difficult to estimate. One possibility is that the proportion employed near both destination districts is high relative to their respective study areas. To the degree that this circumstance exists, flow estimates in near Tulsa's CBD would be proportionately higher than the Chicago study (where P

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equalled total population). Another possibility is that real costs of movement are higher, owing to greater traffic congestion, near the Tulsa CBD than the peripheral destination district in Chicago. For whatever reason, distance costs near Tulsa's CBD are understated; precisely the opposite circumstance prevailed in Chicago. Disregarding the Chicago findings, one plausible reason for Model II overstatement near the CBD, an explanation related to Tulsa's structure of home and work, is complementarity. This explanation, which proved useful in previous interpretations, finds general application, also accounting for significant underpredictions or negative residuals.

Cells proximate to the CBD are characterized by high population densities, intense commercial and often light industrial land use, and generally older residential structures. Rent costs are typically lower, this reflecting frequently less than favorable living conditions. As previously noted, median incomes are less than average; there are proportionately greater numbers of low-status employees. Because Model II aggregate group prediction <u>did not separate</u> according to occupation class, and because there is relatively little demand for low-status employees in the CBD, Figure 4 positive residuals may only reflect the relatively small degree of complementarity between these cells and the CBD. Relatively little

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complementarity, in other words, precludes interaction levels expected as a result of proximity between these overstated cells and the CBD. Conversely, underpredictions (negative residuals) in high income suburban areas to the southeast may reflect an unusually high degree of complementarity. High-status White Collar workers, for whom there is a considerable demand at the CBD, are highly concentrated in these underpredicted cells.

White Collar Residuals

Figure 5 shows Model I regression residuals for the general class of White Collar employees. This group was selected owing to its high Model I correlation coefficient ($r = .905$), and to its apparent high mobility or disregard for distance. Comparison of Figure 5 with Figure 2 reveals that positive residuals are less dispersed than those for the aggregate group; also, Model I overpredictions are less distant from the CBD. Comparison of these two maps functions as a cross-check against an earlier conclusion. Specifically, decreasing dispersal of positive residuals indicates that White Collar workers are less influenced by distance than is the aggregate group. Parenthetically, Model I patterns for Males and Professionals-Managers compare favorably with

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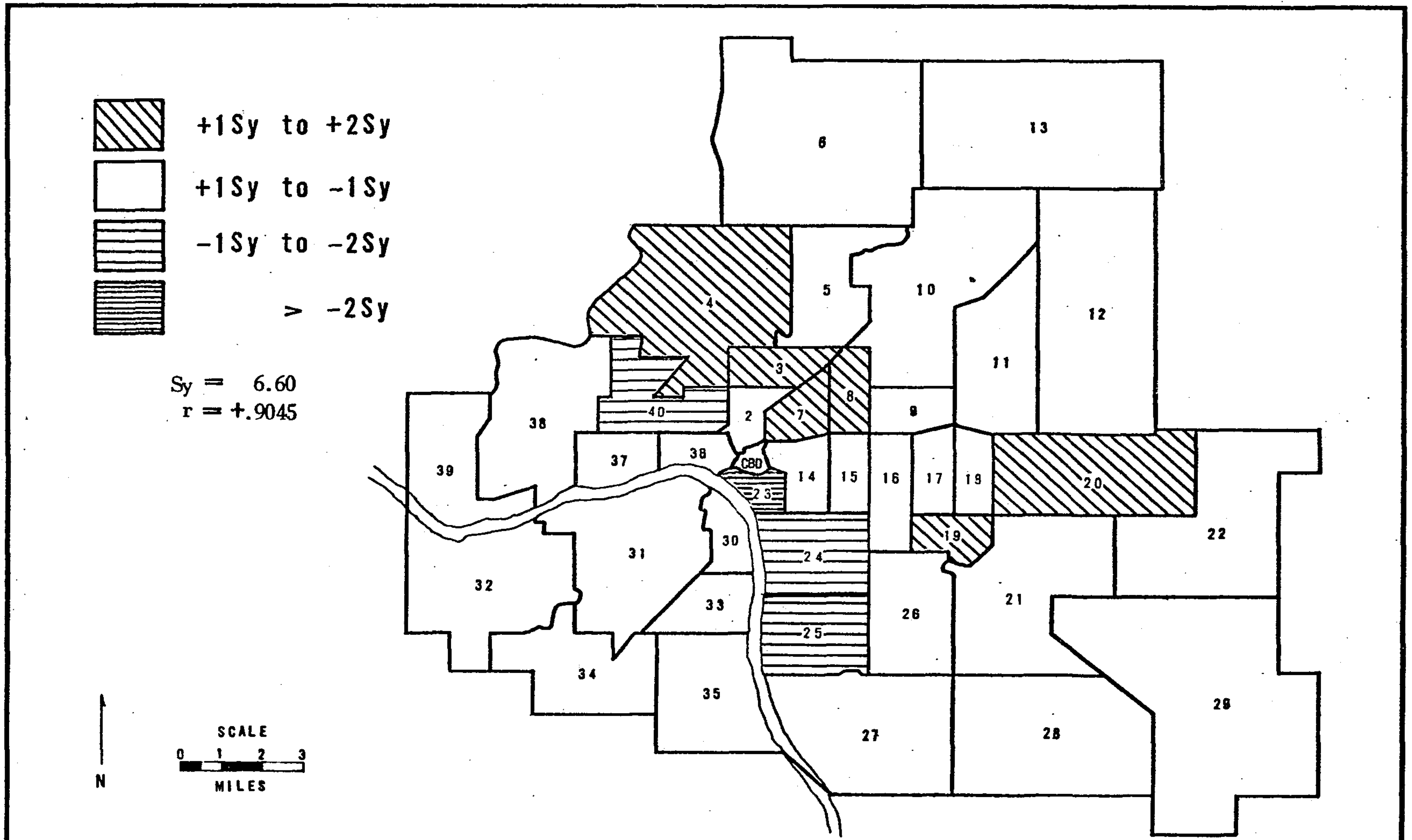

Data compiled from Tulsa Metropolitan Area Transportation Study (1964).

Figure 5.-- TULSA MODEL I WHITE COLLAR REGRESSION RESIDUALS

the White Collar residual map. The Sales-Clerical class, high in proportion female, appears more affected by distance than the general White Collar class.

Returning to Figure 5, the previously noted positive relationship between income and travel propensity is verified within the White Collar group. However, the relationship is less clear than with the aggregate group. In support of this observation, witness cells 4 and 40 just north-northwest of the CBD. Both cells are contained in a single tract of higher than average income, and yet one generates significantly more and the other less than actual commuters. Also, a considerable number of low income cells are effectively predicted by Model I.

Alternate White Collar employment opportunities, the more important concentrations of which are shown in Figure 6, appear significant in the explanation of residuals shown in Figure 5. The reader will note the secondary concentration of White Collar employment, north-south in orientation, to the east of the CBD. Particularly interesting is the significant increase in office space and commercial activity in cells 16, 17, and 18 five to six miles east of the CBD. This concentration appears important in the attenuation of CBD flows generated from cells 19 and 20, cells also characterized by low to moderate incomes. To the north and northeast of the CBD,

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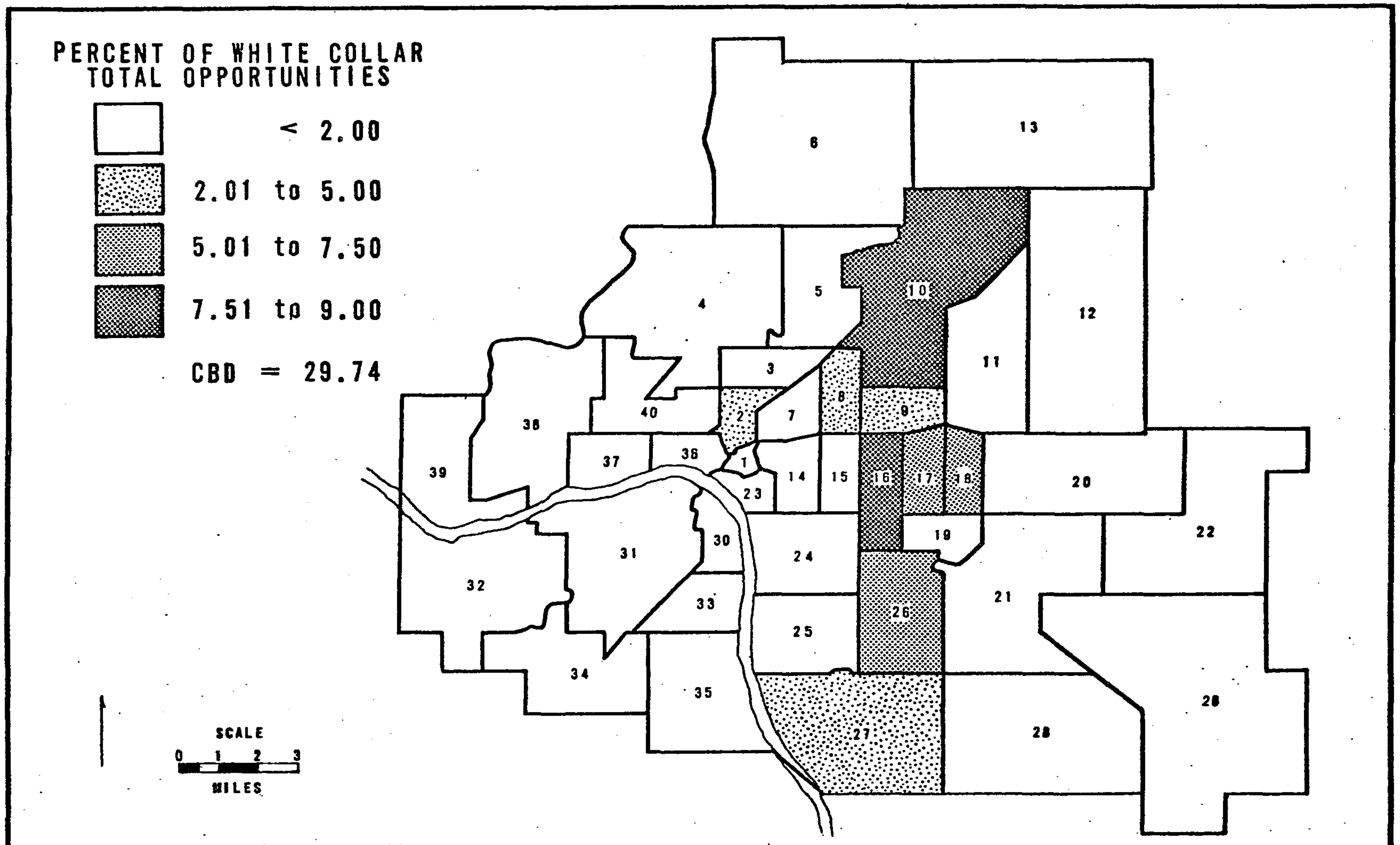

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Figure 6.-- SIGNIFICANT CONCENTRATIONS OF ALTERNATE WHITE COLLAR EMPLOYMENT OPPORTUNITIES

other concentrations of alternate employment opportunities have a similar effect. This would include office space for American Airlines and Douglas Aircraft in cell 10. The absence of significant overstatement in other cells in similar circumstance (for example, cells 11, 12, and 13) is probably related to the small number of White Collar workers residing in these cells.

Viewed in this context of intervening opportunity, the distribution of negative residuals is even more interesting. It is evident from comparison of Figures 5 and 6 that White Collar workers in these (negative residual) cells have an abundance of nearby, alternate opportunities. These alternate opportunities are not perceived as such, however, CBD commutation from these cells far exceeding Model I predictions. In these cells, particularly 24 and 25, there is an apparent trade-off between travel inconvenience and a combination of CBD prestige and amenities of low-density suburban living conditions.

Blue Collar Residuals

Blue Collar residual maps were selected because of the group's immobility relative to other employment groupings. Examination of Figure 7, which again shows Model I regression residuals, shows an almost symmetrical, distance-related dispersion of residuals. This pattern is

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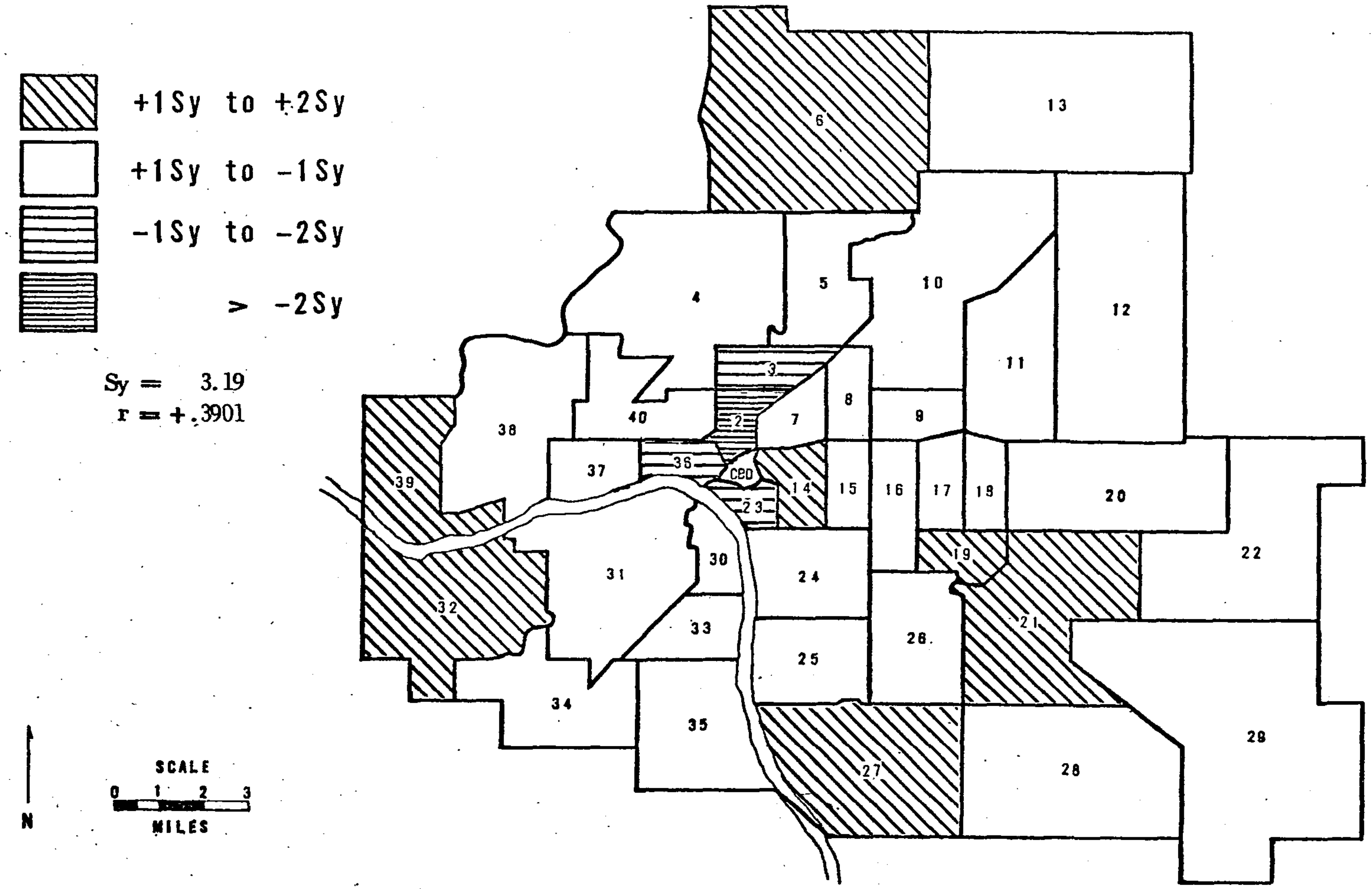

Data compiled from Tulsa Metropolitan Area Transportation Study (1964).

Figure 7.-- TULSA MODEL I BLUE COLLAR REGRESSION RESIDUALS

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more balanced than its aggregate group counterpart, considerably more balanced than its White Collar equivalent. With one exception, cell 14, overpredictions are well spaced, almost equidistant from the CBD. Conversely, underpredicted cells are tightly clustered, nearly surrounding the CBD. The relationship between residual pattern and distance is clear. This relationship verifies the earlier conclusion that this group is least mobile, most regulated by distance.

Figure 8, which shows Model II Blue Collar regression residuals, owing to non-systematic distribution of residuals, is extremely difficult to interpret. The location of positive residuals adjacent to the CBD, previously explained in terms of increasing traffic congestion near the CBD, is countered by equally proximate negative residuals. This mixed pattern close to the CBD is succeeded by a north-south line of negative residuals which in turn are succeeded by two isolated units which are overpredicted.

Examination of the distribution of Blue Collar employment concentrations, except for the possibility of cell 10, negated the idea that perhaps the Figure 8 distribution could be explained in terms of intervening opportunity. Also, there is little apparent connection between income and the Model II distribution of Blue Collar residuals. One possible explanation is that,

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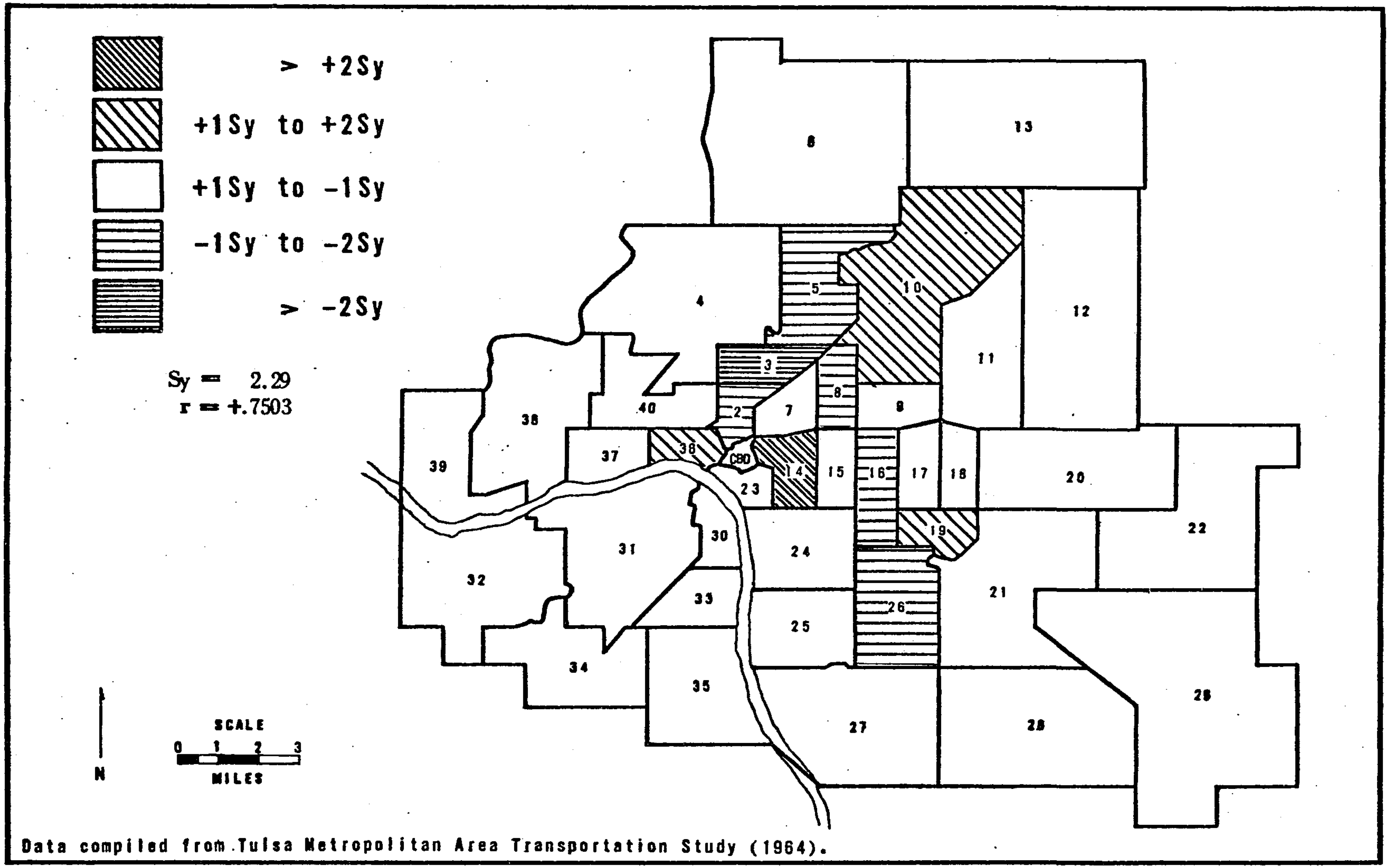

Figure 8.-- TULSA MODEL II BLUE COLLAR REGRESSION RESIDUALS

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having eliminated the only significant variable--distance, the pattern is related only to chance generation of random numbers. The small standard error of the estimate associated with this group in Model II correlation analysis, shown in Table VI, would tend to magnify such chance errors. According to this construction, elimination of the single significant explaining variable (distance) has resulted in a meaningless pattern of regression residuals. Given the operation of additional factors, these factors are of less consequence than chance.

In this chapter, the principles of supply and distance were directly tested when incorporated into two probability models attempting to predict Tulsa CBD commutation. Supply and, through indirect testing, demand were found to be considerably more important than distance in the regulation of CBD flows. Supply and demand in combination are equated to the principle of complementarity. Complementarity, therefore, according to the various tests performed in this chapter, is considered more significant than distance. A third established interaction principle, intervening opportunity, was tested indirectly with mixed results, some favorable and some unfavorable, through analysis of mapped regression residuals. In Chapter IV, intervening opportunity is

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directly tested when incorporated into two additional probability models predicting CBD commutation.

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CHAPTER IV

FINDINGS--INTERVENING OPPORTUNTTY MODELS

In an investigation of the relationship between movement and distance, S. A. Stouffer in 1940 introduced the general concept of intervening opportunity.[1] In his initial study Stouffer developed an intervening opportunity model to account for intracity migration in Cleveland. Verbally, Stouffer hypothesized that ". . . the number of persons going a given distance is directly proportional to the number of opportunities at that distance and inversely proportional to the number of intervening opportunities."[2] Vacancies (opportunities) in area Y can be thought of as supply on which interaction with all other areas is predicated. Demand, the number of competing outmigrants from each of the remaining areas, for this supply is inversely proportional to each areal units' number of intervening opportunities. In an operational definition, ". . . vacancies *which are closer* (italics mine) to his former residence in X than the

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[1]Stouffer, S. A., "Intervening Opportunities: A Theory Relating Distance and Mobility," *American Sociological Review*, Vol. 5 (1940), pp. 845-867.

[2]*Ibid.*, p. 846.

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dwelling unit he occupied in Y, we shall call intervening opportunities."[3] The words which are closer indicate that no directional constraints were placed on the count of opportunities. Intervening opportunities were measured within a circle the size of which depends on the distance between interacting areas. Vacancies (opportunities) were disaggregated accoring to rent levels, relatively specific measures. Because model predicted and actual migrants compared favorably, the intervening opportunity hypothesis was tentatively verified.

Subsequent research along similar lines has resulted in further verification.[4] Indeed, as noted in Chapter II, the idea has since penetrated theoretical geography, elevated to the status of a major interaction principle.[5] In Chapter III, the intervening opportunity concept was implicitly examined with mixed results through interpretation of regression residuals. In this chapter, intervening opportunity is specifically tested when incorporated

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[3] Ibid., p.

[4] For example, see Folger, J., "Some Aspects of Migration in the Tennessee Valley," American Sociological Review, Vol. 18 (1953), pp. 253-260. Also see Isbell, E. C., "Internal Migration in Sweden and Intervening Opportunities," American Sociological Review, Vol. 9 (1944), pp. 627-679.

[5] Ullman, Edward, American Commodity Flow, (Seattle: University of Washington Press), 1957. In particular, see Chapter III, pp. 21-22.

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into two models attempting to predict Tulsa CBD commuter flows.

Population/Intervening Opportunity Model

The first model, Model III in this research framework, closely resembles that used by Stouffer in his Cleveland research. In structure, it also resembles the population/distance model tested in Chapter II. In Model III, it is hypothesized that commuters generated from a given cell are in direct proportion to that cell's employed population (supply) and inversely proportional to the number of intervening opportunities. Mathematically stated, $P_i = \frac{C_i}{I.O._{ij}} \Big/ \sum \frac{C_i}{I.O._{ij}}$, where P_i equals the probability of a CBD commuter coming from a particular cell, C_i equals the number of workers in a given category residing within that cell, and $I.O._{ij}$ equals the number of intervening opportunities within a circle described by the radius between the i^{th} cell and the CBD. As in the Stouffer model, there is no directional limitation in the enumeration of intervening opportunities. Unlike the Stouffer model, which attempted to predict a total pattern of intracity movement, destination opportunities no longer function as the supply variable generating movement. Supply is instead equated to the employed population within each generating cell. This shift in

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emphasis entails no logical problems and is required by the nature of the research, prediction of one-way flows to a single destination district.

Procedure Used in the Measure of Intervening Opportunity

The operational definition of an intervening opportunity is an opportunity which is closer to a potential commuter's place of residence than is the CBD. Because TMATS provided destination data by occupation and sex categories, opportunities by areal unit for each category were easily determined, accomplished by sorting of coded IBM cards. The net result of this procedure, place variations in employment opportunity by category, is shown in Appendix IV. These statistics provide the base data for calculation of intervening opportunities.

The next procedure entailed the plotting of (forty) points on a map, the points representing the estimated center of employment activity in each areal unit. Point location was made with reference to street patterns and a small-scale land use map indicating commercial and industrial activity. This single point pattern was assumed representative of all categories investigated. Next, a circular area of intervening opportunity, defined by the radius between generating cell and the CBD, was drawn for each of the generating cells. Each circle, superimposed

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on the above described point pattern, allowed a listing of <u>intervening opportunity areas</u>--each area being defined by its representative points. No matter how close, points outside the circle were disallowed; points falling on the line or within the circle were included in the set.

Each generating cell, then, has a unique set of points or intervening opportunity area. Although the same for each <u>category</u>, each cell has an individual set of listed intervening cells. Application of this list to Appendix IV, which shows both category and place variation in employment opportunity, resulted in determination of individual sets of intervening opportunity. As each category has an individual employment or opportunity structure, application of these idential point listings nevertheless resulted in between-category cell differences in intervening opportunity. These differences are both in magnitude and, more importantly, proportions of category totals.

As in Model II, cell employed populations were divided by the attenuating element, in this case cell intervening opportunities. Within-category dividends were then summed, after which cell proportions of category totals were calculated. These values, forty for each of the seven categories, are statements concerning each cell's probability of generating a CBD commuter

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under Model III assumptions. As in the two previous experiments, commuters are assigned the several probability surfaces by random number, one number for each actual CBD commuter. The model's predictive efficiency is determined when simulated and actual patterns are compared.

Test Results and Interpretation

Like Tables IV and VI, Table VIII presents group correlation and regression statistics resulting from comparison of actual and model simulated commuter patterns. Included in this table are correlation coefficients (r), intercepts (a), slopes (b), coefficients of determination (r^2), and standard errors of estimate (Sy).

Preliminary inspection of Table VIII immediately reveals that Model III correlation coefficients are considerably lower than results shown for the previous two models. Comparison with Model I results revealed that average explanatory power has been reduced by sixty-four per cent.[6]

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[6]This per cent change value was determined as follows:

Per cent change =

$$\frac{\sum \frac{\text{Model III Group } r^2\text{'s}}{N} - \sum \frac{\text{Model I Group } r^2\text{'s}}{N}}{\sum \frac{\text{Model I Group } r^2\text{'s}}{N}}$$

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TABLE VIII

CORRELATION AND REGRESSION COEFFICIENTS RESULTING FROM APPLICATION OF THE POPULATION/ INTERVENING OPPORTUNITY MODEL

Group	r	a	b	r^2	Sy
Total	.3682	15.24	.2718	.1356	15.14
Males	.2312	9.90	.2048	.0545	11.38
Females	.4063	5.90	.3035	.1651	6.43
Blue Collar	.6918	2.96	.4132	.4786	2.50
White Collar	.3948	10.48	.3250	.1559	14.23
Professionals-Managers	.4120	3.05	.4930	.1697	8.47
Sales-Clerical	.4510	7.22	.2684	.2034	7.15

Source: Calculated from data provided by TMATS.

Similarly, comparison of Model III with Model II coefficients of determination indicate that, under Model III assumptions, average explanatory power has been reduced sixty-one per cent. With the exception of Blue Collar commuter predictions (r = .6918), it is evident that the intervening opportunity model is a relatively inefficient predictor of CBD commuter flows.

What factors, it may be asked, account for Model III's relative inefficiency? This question is particularly important in view of (1) previously successful

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intervening opportunity experiments noted above, and (2) wide acceptance of intervening opportunity in geography as a major interaction principle. There are two possible general answers to this question. First, in Tulsa or perhaps only in movement to Tulsa's CBD, intervening opportunity may not in fact be a significant regulating factor. Although useful in explaining particular place errors (as seen in Chapter III residual interpretation) and perhaps Blue Collar flows, intervening opportunity, unlike distance, may not be of general utility. The only alternative explanation for Model III inefficiency is that intervening opportunities were incorrectly measured, incorrect measures being related to excess aggregation in the count of intervening opportunity or to erroneous Model III assumptions. For a number of reasons discussed below, the former hypothesis, that intervening opportunity is not a significant factor regulating CBD flows, is subsequently rejected. The latter hypothesis, that Model III inefficiency is related to either measurement error or to erroneous assumptions, on the other hand, is accepted. Several deductive arguments supporting this latter hypothesis are offered in suspected order of importance, from least to most important.

The first possible error source in the measure of

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intervening opportunity is excessive group aggregation levels. This argument attacks the implicit assumption that within each group, all opportunities apply to every member. The model did not or could not[7] recognize sub-variations within each group. This inability, in turn, precludes precise measure of intervening opportunity. In effect, what constitutes an intervening opportunity for one class member may not for another. A steam-fitter (Blue Collar), for example, would not likely consider assembly line work (also Blue Collar) an intervening opportunity. Despite this fact, in the enumeration of Model III opportunities, no such distinction was made. Central to this argument is the assumption that over the entire study area, individual discrepancies will not be eliminated by the law of averages. To the degree this assumption is correct, results shown in Table VIII could have been compromised. Contrary to this assumption (and its attendant argument) is the estimate that, in the main, the law of averages does function to eliminate individual discrepancies. Except in cells proximate to the CBD where sub-type concentrations of

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[7]Further disaggregation of groups was disallowed because of the correlation testing procedures used in this study. Further disaggregation is attended by an increasing number of cell zeros, zeros being undesirable when using correlation analysis.

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employment opportunity could result in important distortions, the area affected and distortion within that area is suspected as small. Although some portion of the Model III inefficiency can be explained in terms of excess aggregation, this portion is estimated as small.

A second explanation for Model III inefficiency centers on assumption that intervening opportunities are concentrated at points throughout the study area. This assumption, it could be argued, in combination with the arbitrary rule concerning point inclusion or exclusion, results in an unrealistic count of actual alternate opportunities. Like the previous argument, this argument denies that positive and negative errors negate one another. Also, like the previous argument, significant problems are most likely concentrated in the smaller intervening opportunity areas characterizing cells near the CBD. In these smaller areas chance for important distortion is considerably increased. Finally, the net effect of these possible distortions resulting from condensing reality is suspected as small. Proof that explanations one and two are of minimal importance is offered in the subsequent section, which demonstrates the importance of explanation three.

This third and most significant explanation for unexpectedly poor results shown in Table VIII centers on

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another Model III implicit assumption. The specific assumption questioned is that all opportunities within the defined intervening opportunity area are of equal consequence, given equal weights. Before demonstrating the ways in which this assumption is in error, a brief review of the meaning of intervening opportunity will prove useful. According to theory, intervening opportunity, like distance, functions to attenuate interaction between points. The reason for this attenuation is as follows: given a choice between places of employment, an individual will tend to minimize his travel effort. All other factors being equal, an individual will prefer the less expensive location--i.e., the intervening opportunity.

Returning to the initial problem, the Model III assumption that all intervening opportunities are of equal consequence can be questioned on two counts. First, it is difficult to acknowledge that all intervening opportunities will be equally perceived. The more distant an opportunity, the less likely it will be perceived. Greater relative knowledge of total alternatives (potential choices) will exist in cells proximate to the CBD. Intervening opportunity areas are smaller in the proximate cells; greater proportionate knowledge of alternatives in these smaller areas should result in greater relative opportunity consequence. Thus, this

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explanation argues that opportunity weight should be increased in cells proximate to the CBD, decreased in peripheral cells. The second argument against equal weights is exactly the opposite, maintaining that weights should be increased in the more distant cells. As distance between cell and CBD increases, differential savings between average intervening opportunity and the CBD also increase. Intervening opportunities, in other words, become increasingly attractive alternatives in outlying cells. Because potential minimization is greater in outlying cells, weight should be increased toward the periphery.

Each of these arguments is again considered in the subsequent section, which presents results and interpretation of an adjusted opportunity model.

Model IV--An Adjusted Intervening Opportunity Model

In past studies concerned with predicting flows, both distance and intervening opportunity have proved useful. Distance was used with considerable success in Chapter III. A number of other studies were cited in Chapter II and in the introduction of this chapter. While both prove useful approximators of the way in which movement is attenuated, distance is to a considerable degree dependent on intervening opportunity in explaining why flows are attenuated. If demand were concentrated at one

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point, if there were no intervening opportunities, distance would be a meaningless variable. When data are aggregated opportunities are usually dispersed in space and rarely concentrated at single points. Under these usual conditions and for this reason, distance functions as a good approximator of intervening opportunity. Only intervening opportunity, however, (aside from other factors not considered here) can explain why flows are reduced.

The above remarks preface discussion of Model IV, also serving to illustrate why Model III results were so perplexing. Model II, which only approximates the effect of intervening opportunity, was a far more efficient predictor than Model III which tested opportunity influence directly.

The considerable difference in efficiency (between Models II and III) stimulated speculation that some major measurement error had been perpetrated, error resulting from implicit Model III assumptions. By deduction, two potential sources of significant error were hypothesized. First, individual commuters are probably less aware of distant opportunities (of which there are proportionately more with each increase in distance between cell and CBD) than proximate opportunities. Model III, according to this hypothesis, erroneously assumed that all intervening

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opportunities were perceived equally. The second potential explanation for Model III inefficiency is as follows: as distance between cell and CBD increases, differentials in average cost between opportunities and the CBD also increase. Intervening opportunities, in other words, should on balance provide more meaningful alternatives in outlying areas. Model III assumes all intervening opportunities are equally meaningful.

It was previously observed that these two hypothesized error sources, to the degree each is correct, would result in opposite effects. The first hypothesis, greater overall awareness of available opportunities in cells proximate to the CBD, if correct, should result in over-predictions in cells proximate to the CBD and under-predictions in distant cells. Individuals decide according to what is known; more complete knowledge of available alternatives in the smaller intervening opportunity areas should result in relatively greater flow reduction in cells proximate to the CBD. The second hypothesis, on the other hand, should result in over-prediction in the outlying cells. Because differentials in cost between alternative opportunity and the CBD increase as a function of distance, alternate opportunities in distant cells should be relatively more attractive. The net effect of this circumstance should, all things otherwise

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being equal, result in over-predictions in outlying cells and under-predictions in proximate cells.

Thus there are two contradictory explanations for Model III inefficiency. Assuming momentarily that each explanation is valid, if both were equally important the forces they represent should have been self-negating. Model III would have very likely been an efficient predictor of CBD flows. Model III inefficiency is a strong indicator that one of these explanations is more important than the other.

There are two possible procedures to determine which of the Model III potential error sources is more significant. Both procedures require construction of an adjusted intervening opportunity model which attaches weight favoring one possible explanation or the other. The reader will recall that each generating cell had an intervening opportunity set, a number representing the count of total intervening opportunities. Typically, set sizes increase with increasing distance from the CBD. If weights are attached in the direction of increasing set sizes, toward the study area periphery, we test the hypothesis that increasing differentials in cost between an opportunity and the CBD is more important than proportionate knowledge of possible alternatives. If revised predictions are more efficient than Model III

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prediction, the hypothesis would be verified. The opposite hypothesis, which if verified would indicate that proportionate knowledge of opportunities is more important, could be tested if greater weight were given to smaller opportunity sets characterizing proximate cells. Mathematically, the former hypothesis could be tested by squaring intervening opportunity sets. This would result in a proportionately greater increase in large numbers. The opposite hypothesis could be tested by taking the square root of each intervening opportunity set; this procedure would increase the relative importance of smaller sets characterizing cells proximate to the CBD. Preliminary analysis of Model III regression residuals indicated that testing of the second hypothesis would prove more useful.

Verbally, the adjusted Model IV postulates that the number of CBD commuters generated from a given cell is in direct proportion to that cell's employed population and inversely proportional to the square root of the cell's set of intervening opportunities. Although based on the same sets of original numbers used in Model III, Model IV weighs opportunity values according to a hypothesized better estimate of real world conditions. Model IV postulates a spatially varying influence of intervening opportunity, variations resulting from differences in

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proportions of total opportunities known. Known opportunities exist in greater proportion in smaller areas; consequently smaller sets of opportunity (distributed over a smaller, more compact area) are given greater weight. Stated as a formula: $P_i = \frac{C_i}{\sqrt{I.O._{ij}}} / \sum \frac{C_i}{\sqrt{I.O._{ij}}}$, where P_i and C_i are the same as formulated in Model III, and where $\sqrt{I.O._{ij}}$ equals the square root of the i^{th} cell's intervening opportunity--the re-stated estimate of opportunity influence. If Model IV is a more efficient predictor than Model III, the hypothesized varying influence of intervening opportunity will be affirmed.

Results

Examination of correlation coefficients shown in Table IX, when compared with Model III results shown in Table VIII, indicates that considerable improvement is realized under the revised assumptions incorporated in Model IV. While some improvement was expected, the degree of change realized was not. Specific magnitudes of change from group to group are shown in Table X, this table comparing coefficients of determination resulting under both models. Examination of column 3, which shows per cent change in proportion of flow variation explained under revised assumptions, clearly affirms the general

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hypothesis that intervening opportunity has a variable influence. Improvements range from 150 to 300 per cent. Only the Blue Collar group experienced a reduction in proportion explained; this reduction was only 20 per cent.

TABLE IX

CORRELATION AND REGRESSION COEFFICIENTS RESULTING FROM APPLICATION OF THE POPULATION/ $\sqrt{\text{INTERVENING OPPORTUNITY}}$ MODEL

Group	r	a	b	Sy	r^2
Total	.6968	1.04	.951	11.68	.4855
Males	.3880	4.20	.663	10.78	.1505
Females	.6462	2.55	.699	5.37	.4175
Blue Collar	.6189	1.96	.610	2.72	.3830
White Collar	.7920	.20	.987	7.46	.6272
Professionals-Managers	.7037	-.36	1.060	6.60	.4952
Sales-Clerical	.7534	2.87	.710	5.26	.5678

Source: Calculated from data provided by TMATS.

The magnitude of change shown in Table X, then, demonstrates that intervening opportunities have different consequences dependent on cell location with respect to the CBD. A specific rationale was offered for this variable affect, namely, greater proportionate knowledge

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of available intervening opportunities in cells closer to the CBD. Two facts argue against the conclusion that Model IV improvements are the exclusive result of differential knowledge of available alternatives. The first fact is the sheer magnitude of change which averaged 178 per cent. It is extremely doubtful that any single factor could bring about such significant improvement.

TABLE X

COMPARISON OF GROUP COEFFICIENTS OF DETERMINATION RESULTING FROM APPLICATION OF MODELS III AND IV

Group	Model III (r^2)	Model IV (r^2)	Per Cent Change
White Collar	.1558	.6272	+302.6
Total	.1356	.4855	+258.0
Professionals-Managers	.1697	.4952	+191.8
Males	.0535	.1505	+181.3
Sales-Clerical	.2034	.5678	+179.2
Females	.1651	.4175	+152.9
Blue Collar	.4785	.3830	- 20.0

Source: Calculated from data provided by TMATS.

The second fact is that these improvements were realized against a counterforce--increasing alternate opportunity attractiveness in peripheral locations--which, if

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eliminated, would theoretically result in even greater improvements. Intuitively, owing to the above two considerations, some factor or factors not yet observed operate in addition to differentials in proportion of opportunities known to bring about the observed Model IV improvements.

The general hypothesis that intervening opportunities have a variable influence, then, is affirmed. One specific reason for increasing influence in cells proximate to the CBD is greater relative knowledge of available alternatives. A second explanation relates to the findings made in Chapter II concerned with variations in group mobility and group patterns of residential location. It was previously noted that Blue Collar workers were (1) relatively immobile and (2) more residentially concentrated in the inner-city. White Collar workers, in converse, are relatively mobile and tend to reside in peripheral locations. The second explanation would maintain that greater proportionate numbers of more immobile individuals (Blue Collar, for example) in cells proximate to the CBD result in available alternates having a greater impact. By definition, relatively immobile individuals more actively attempt to minimize their travel costs. Accordingly, these more active efforts, in combination with greater knowledge of available alternates, are the

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principle reasons why opportunities are more significant in areas closer to the CBD. Together, these are highly important factors accounting for Model IV improvements.

A Note on the Relationship between Distance and Intervening Opportunity

In the beginning of this section, it was asserted that success of distance as a predictor of flow attenuation (supply and other factors being equal) mainly results from its coincident relationship with intervening opportunity. Distance, in other words, is not in itself intrinsically significant. The key to distance as a predictor results from its composite reflection of various actual attenuators, most important among which is intervening opportunity, which are intrinsically significant. According to this interpretation, Model II (the Distance Model) efficiency results from coincident correspondence between variations in distance and intervening opportunity. More specifically, efficiency results from distance reflecting opportunity sets which decline in consequence with increasing distance from the CBD.

Proof of this estimate is offered in Table XI, which shows comparable kinds and magnitudes of group response resulting under different assumptions incorporated in Models II and IV. Table XI shows three kinds of information. These are: (1) group coefficients of

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determination resulting from application of each model, (2) computed per cent change when Model II and Model IV group coefficients are compared with corresponding Model I coefficients, and (3) within-model rank orders of response (from positive to negative) to assumptions other than supply (Model I). As in Chapter III, positive response to attenuating assumptions can be construed as relative group immobility. Negative response, depending on degree of response, indicates degrees of group mobility.

TABLE XI

MODEL II AND IV COEFFICIENTS OF DETERMINATION AND PER CENT CHANGE IN THESE COEFFICIENTS WHEN COMPARED WITH RELATED MODEL I FINDINGS

Group	Model II (r^2)	Per Cent Change[a]	Model IV (r^2)	Per Cent Change[a]
Blue Collar	.5630	+270.2(1)	.3830	+163.2(1)
Females	.5826	+ 34.0(2)	.4175	- 4.0(3)
Total	.4416	- 4.9(3)	.4855	+ 4.6(2)
Professionals-Managers	.5704	- 8.6(4)	.4952	- 20.7(4)
Sales-Clerical	.5981	- 23.2(5)	.5678	- 27.1(6)
White Collar	.5626	- 31.2(6)	.6272	- 23.3(5)
Males	.2647	- 50.3(7)	.1505	- 71.6(7)

[a]When compared with corresponding Model I Group r^2's.

Source: Calculated from data provided by TMATS.

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Examination of Table XI without question demonstrates comparable kinds and magnitudes of group response to the different assumptions incorporated in Models II and IV. High positive response to the distance assumption (Blue Collar) almost exactly corresponds with favorable response under the revised intervening opportunity assumption. Grades of negative response, indicators of increasing mobility, are also nearly the same. A Spearman's Rank Correlation was performed on these grades of response (ranked according to degree and whether positive or negative in Table XI). The result: R = .9286 demonstrates that distance and the revised measure of intervening opportunity are significantly related measures of attenuation.

Given that these measures of attenuation are significantly related, and given that success of distance is not intrinsically significant, then the principle reasons why distance proves an efficient estimator of attenuation in Tulsa have been determined. Distance is efficient because variations in distance apparently coincide with variations in intervening opportunity which declines in influence away from the destination district. The specific reasons cited for declining influence in peripheral areas were decreasing awareness of total opportunities available and increasing concentrations of more

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mobile individuals. In these more peripheral locations, less perception of possible alternatives combine with less efforts at travel minimization to reduce the consequence of intervening opportunity. Because distance effectively approximates these and opposite conditions in the inner-city, it provides an effective measure of attenuation. Model IV, which incorporates these conditions, although a slightly less efficient predictor, is consequently considered more meaningful than Model II.

Model III and IV Regression Residuals

As in Chapter III presentation of mapped regression residuals is selective, only four of fourteen possible maps being shown. Comparison of residual patterns for each of the seven groups, resulting first from Model III then from Model IV, indicated much less within-group change than expected. Consequently, pattern change that did occur is illustrated at the most representative level: in the aggregate group. Model IV significant errors are more closely examined through comparison of White Collar and Blue Collar residual patterns.

Examination of Figure 9, which shows significant Model III prediction errors for the aggregate group, reveals the general Model III tendency to overpredict in cells proximate to the CBD. Negative residuals, with

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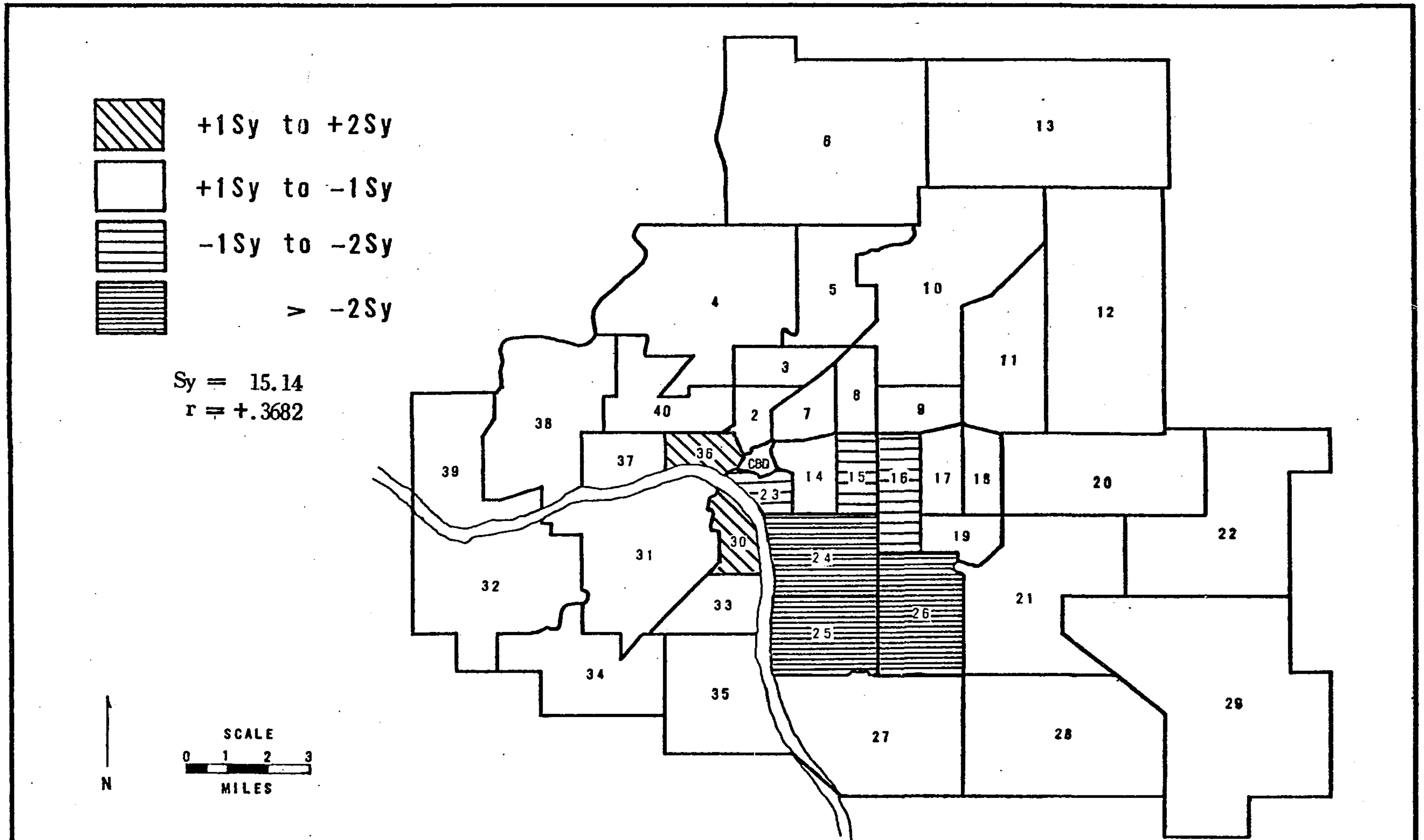

Data compiled from Tulsa Metropolitan Area Transportation Study (1964).

Figure 9.-- TULSA MODEL III AGGREGATE GROUP REGRESSION RESIDUALS

the exception of the contradictory cell 23, are located more distant from the CBD. Examination of Figure 10, showing residuals for the aggregate group Model IV predictions, indicates the expected shift toward the periphery of positive residuals. As mentioned above, the change in pattern is much less than expected. Negative residuals particularly manifest this minimal shift; the only change which occurred was elimination of significant underprediction in cell 16 to the east of the CBD.

Inspection of Model III regression residuals (such as Figure 9) indicated a less than expected spatial dichotomy between positive and negative residuals. The principle problem lay in the non-peripheral, although outlying, distribution of negative residuals. Two possible answers for this problem are offered. First, the absolute residuals used have a tendency to reflect size differences. Cells in the study area periphery have relatively small populations; the residual type used does not take this into account, tending to emphasize size differentiation and minimize spatial differences. If this is taken into account, negative residuals shown in Figure 9 are peripheral to Tulsa's developed area. A second reason for the less than expected dichotomy is that intervening opportunities external to the study area could not be enumerated. Inclusion of these external

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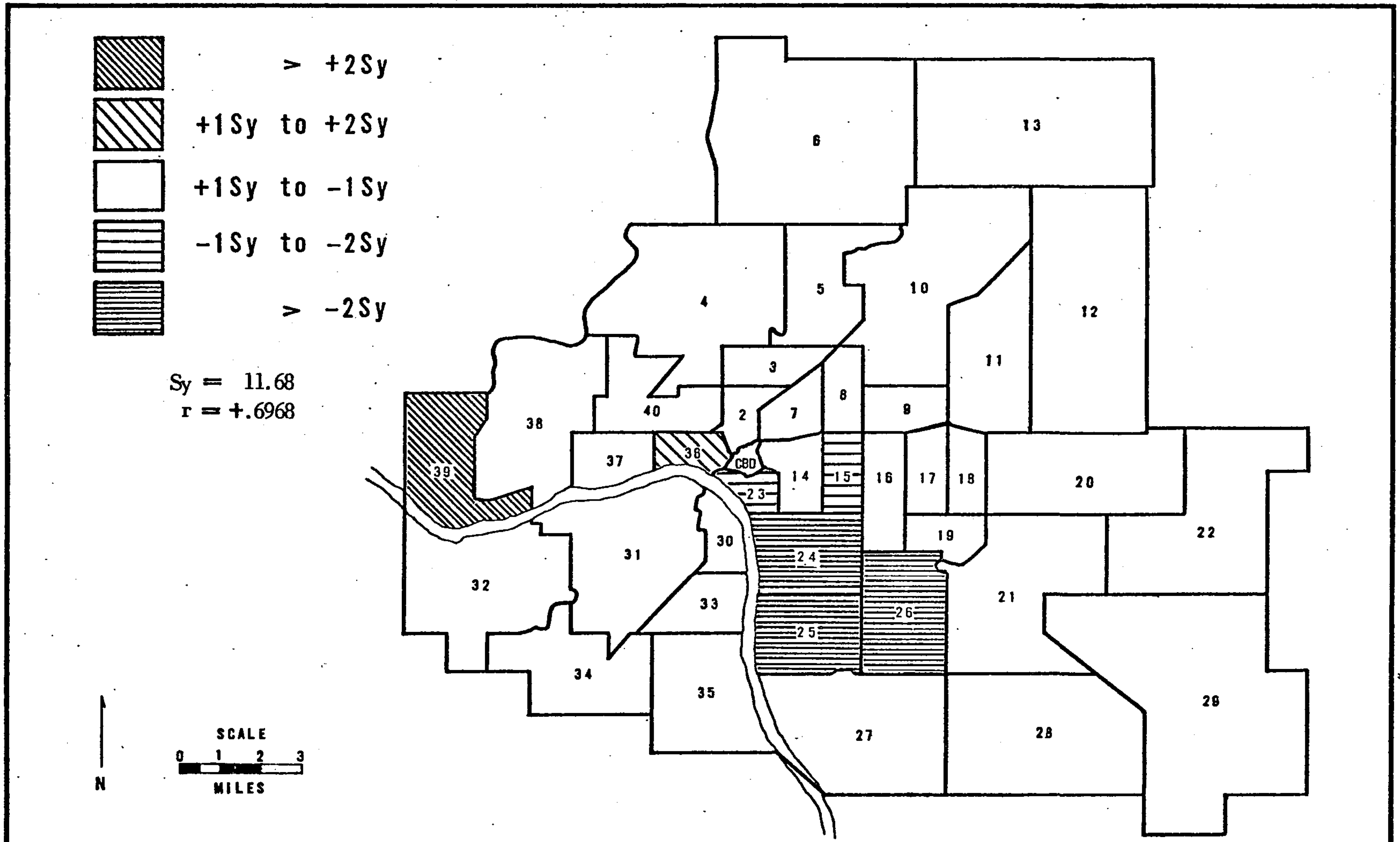

Data compiled from Tulsa Metropolitan Area Transportation Study (1964).

Figure 10.-- TULSA MODEL IV AGGREGATE GROUP REGRESSION RESIDUALS

opportunities would increase peripheral attenuation, very probably resulting in an outward shift of underprediction.

Figure 11 shows the Model IV residual pattern for the Blue Collar group. The reader will recall that this was the only category not favorably responding to the revised estimate of opportunity influence. In effect, within this group intervening opportunity has a continuous rather than a spatially varying influence. Instead of decreasing with increasing distance from the CBD, distant opportunity sets are at least equally, if not more, significant. Apparently, this is a function of relative group immobility. Increasing cost differentials between average opportunity and the CBD, within and only within this group, is acted upon. This action, another manifestation of group efforts at cost minimization, apparently negates the hypothesized decreasing awareness of potential alternatives. Among Model IV residual maps, Figure 11 is unique in its degree of dichotomy between positive and negative residuals. The influence is clearly spatial; opportunities, if weighted at all, should be weighted toward the periphery. This manifests group immobility and continuity of immobility within the group.

Figure 12, Model IV residuals for the White Collar group, contrasts sharply with Blue Collar residuals shown

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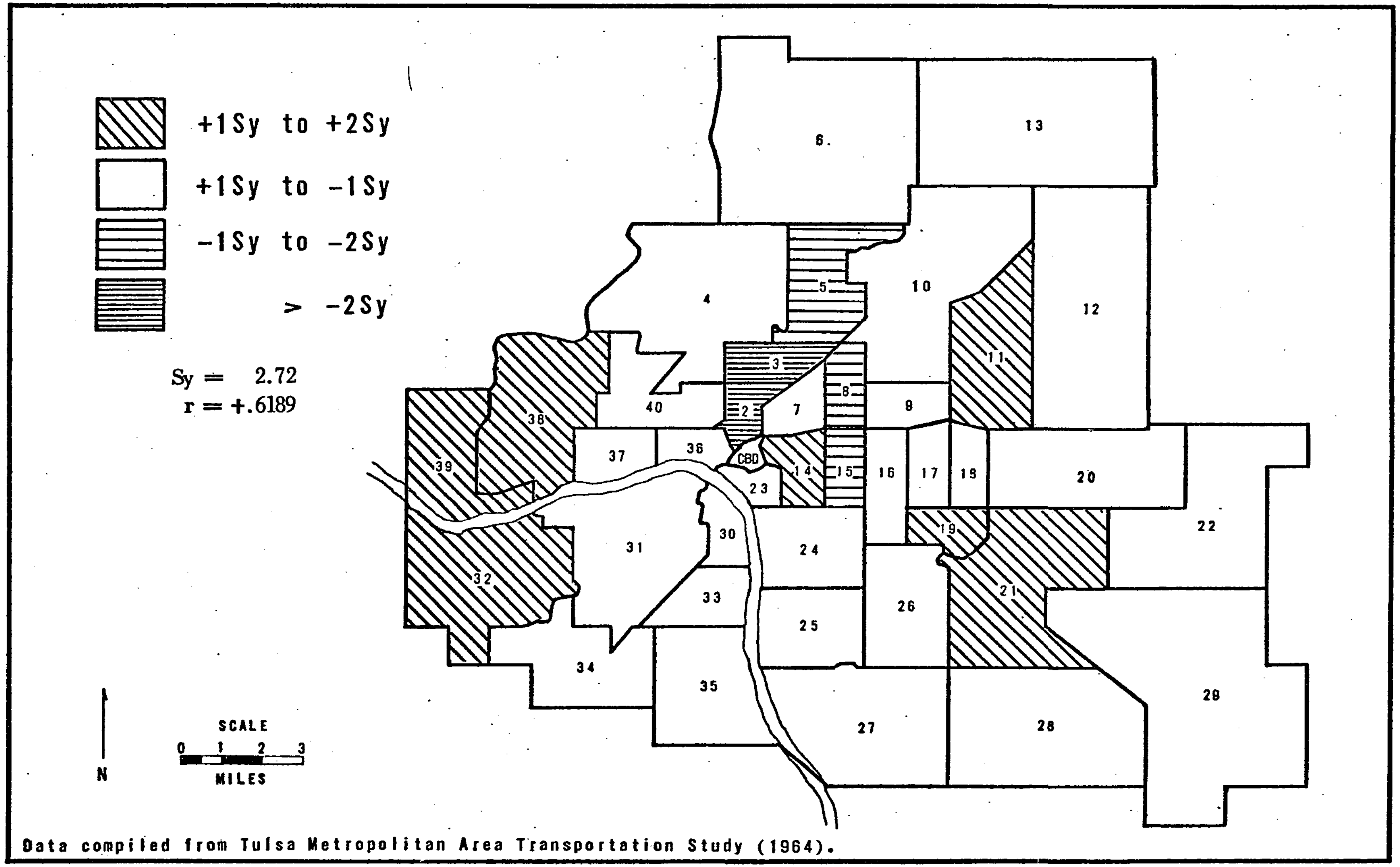

Figure 11.-- TULSA MODEL IV BLUE COLLAR REGRESSION RESIDUALS

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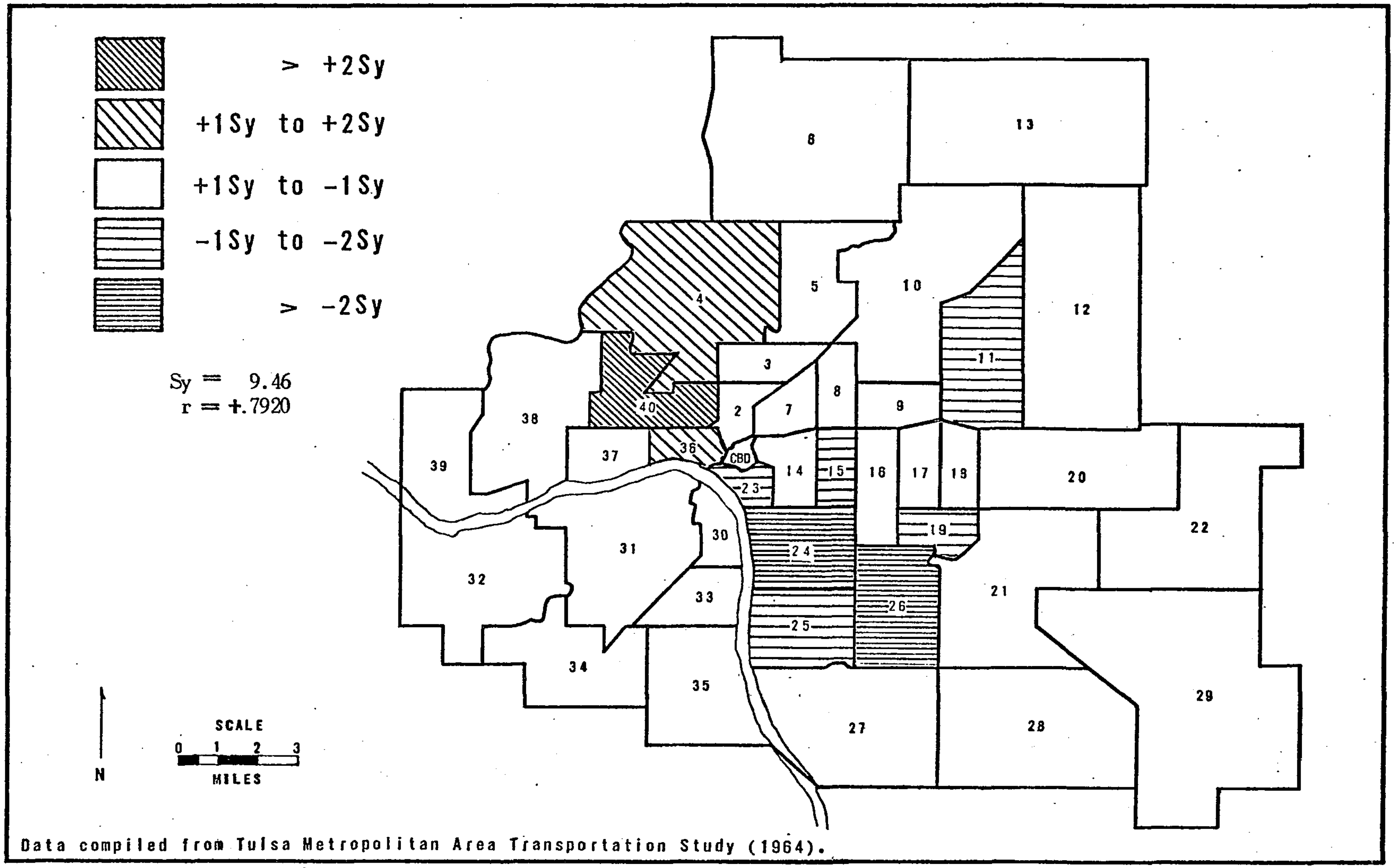

Figure 12.--TULSA MODEL IV WHITE COLLAR REGRESSION RESIDUALS

in Figure 11. Underpredictions are principally concentrated within the high income area to the south-southeast of the CBD. Overpredictions, unlike Figure 11, are also concentrated but to the northwest of the CBD. This pattern, unlike that shown in Figure 11, is clearly unrelated to distance. One factor suggested by this pattern is income. The cluster of over-predicted cells have considerably lower incomes than do the under-predicted cells to the southeast. Satisfactory predictions in other low income cells caution against overemphasizing the influence of low income in over-predicted cells. High income, which tends to eliminate the need for travel minimization, is probably significant in the under-predicted cells. Over-predicted cells are less understood, possibly related with insufficient complementarity between these cells and the CBD. For a number of possible reasons, White Collar CBD opportunities are not perceived as such--intervening opportunities having an inordinate influence.

In review, expected shifts in residual patterns were realized but not to the degree expected. This was traced to the type of residual used and to non-enumeration of intervening opportunities external to the study area. Examination of two contrasting types of Model IV residual patterns demonstrated again the existence and consequences of differential group mobility.

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Analysis of regression residuals, then, confirmed the general hypothesis that intervening opportunity has a spatially varying influence. For all groups except Blue Collar, opportunity sets decline in consequence with increasing distance from the CBD. The Blue Collar group, on the other hand, is more correctly described as uniformly affected by intervening opportunity. It is possible that the influence even increases as a function of distance. This atypical response was indicated by negative (compared with Model III) Model IV results and by a unique pattern of regression residuals, this pattern reflecting uniform group efforts to reduce travel costs.

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CHAPTER V

CONCLUSION

In this research concerned with Tulsa CBD commutation, interest focused on the development and testing of four indeterministic models each attempting to predict identical, known CBD flow patterns. Each model was based on some factor or combination of factors, known as interaction principles, thought to influence all orders and types of flow phenomena. It is the purpose of this chapter to summarize the findings resulting from application of these models, also estimating the differential importance of principles on which the models were based. Finally, in the last section of this chapter, potentially useful lines of future related research are suggested.

Summary of Model Performances

Model I, the population model, assumed that CBD commuter flows would be governed only by variations in supply of workers. Implicitly, the cost of movement was assumed to be zero. On balance, this model proved the most efficient overall predictor of commuter flows to Tulsa's CBD. Two explanations for Model I efficiency

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were offered. First, and most important, unusually high cencentrations of employment opportunities in the CBD, high destination destrict demand, account for a considerable proportion of Model I efficiency. Differentials in group response to Model I were directly traced to variations in demand for group services at the CBD. CBD flows of the White Collar groups, in greatest demand at the CBD, were most effectively anticipated on the basis of supply alone. Conversely, the Blue Collar groups, of all groups in least demand, were least effectively anticipated by the population model. The second and less important explanation for Model I efficiency related to differences in group mobility, mobility being defined in terms of differential group willingness or ability to travel. According to this hypothesis, differential group response to Model I is explained in terms of differential group ability to absorb transportation costs. In other words, movement of groups more able or willing to absorb transport costs should be more effectively anticipated by a model assuming the cost of movement to be zero. Formal testing of this hypothesis, when compared with the demand hypothesis, indicated that variations in group mobility are of less consequence than are variations in demand for group services at the destination district.

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Model II, like Model I, assumed CBD flows would be in direct proportion to cell variations in supply of workers. Unlike Model I, this Model assumed that flows would be attenuated by distance, distance being measured in units of airline connection. Most significantly, the addition of distance resulted in a slight average decrease in predictive efficiency. Only two groups, Blue Collar and Female workers, groups often noted for their relative immobility, responded favorably to the addition of distance. All other categories, including Aggregate and Male groups, and the three White Collar groupings, were less effectively predicted than in the more elementary Model I. Absence of overall improvement expected from the addition of distance served to indicate that, in general, the population being investigated is relatively mobile. In movement to Tulsa's CBD, with the exception of two groups, Blue Collar and Female, the effect of distance is limited. Certainly, distance is of less consequence than variations in supply and demand, variables which in combination are equated to the principle of complementarity.

A final important observation concerning the distance model is that variability in degree of accurate prediction is minimal. Of the four models tested, Model II produced the least variable set of correlation coefficients, coefficients indicating degree of favorable

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group response to each model's assumptions. Consistent anticipation of variously mobile groups characterized also by divergent structures of home and work may be considered the most useful feature of the distance model.

Model III, the initial intervening opportunity model, assumed CBD flows would be in direct proportion to a given cell's number of intervening opportunities. The attenuating element, alternate opportunities, were counted within a circular area defined by the radius between each cell and the CBD. Although the enumeration area was identical for each group in a given cell, differing locational patterns of employment resulted in different group opportunity counts.

Model III proved a considerably less efficient predictor of CBD flows than either Models I or II. With the exception of the Blue Collar group, all Model III correlation coefficients were significantly diminished when compared with either previous model. These unfavorable results were preplexing on two counts. First, the intervening opportunity hypothesis had been tested successfully on numerous occasions by a variety of different researchers. In fact, the concept has proved so useful that it has become a major principle of spatial interaction. The second reason why Model III inefficiency was perplexing is that, logically, any flow reductions successfully anticipated by distance should be

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dependent on the distribution of alternate opportunities. Distance, in other words, is not an intrinsically significant attenuator of intra-urban commuter flows. Hence, relative success of the distance model coupled with definite non-success of the opportunity model stimulated consideration of several hypotheses attempting to explain Model III inefficiency.

Two potential sources of Model III inefficiency were considered. First, it was thought that some error in the measure or count of intervening opportunities had been perpetrated. The consequence of this problem, related to potential excess aggregation in category and cell counts of intervening opportunity, was estimated as minimal. The second potential source of error related to an implicit Model III assumption, namely, that all alternate opportunities are of equal consequence--i.e., equally perceived and equally acted upon. Theoretically, the average alternate opportunity in cells distant from the CBD should, because of greater potential savings, be relatively more attractive than the average opportunity in cells proximate to the CBD. According to this idea, alternate opportunities should be given greater weight in cells peripheral to the CBD. On the other hand, high concentrations of relatively immobile individuals in cells proximate to the CBD, individuals with a greater

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need to minimize costs, should result in greater opportunity consequence in cells proximate to the CBD. Another argument for weighting opportunities in the direction of the CBD is that, because opportunity areas are smaller in cells proximate to the CBD, individuals residing in these proximate cells will have a greater relative awareness of potential alternatives.

Preliminary analysis of Model III regression residuals suggested that opportunities should be weighted in the direction of the CBD. In Model IV, this was accomplished by dividing supply by the square root of cell sets of intervening opportunity, sets which increase in magnitude toward the study area periphery. The adjusted estimate of opportunity influence proved highly successful. In all groups except Blue Collar, improvements in predictive efficiency ranged from 150 to 300 per cent. With the exception of one group, Blue Collar, intervening opportunity has an areally varying influence, opportunities declining in consequence with greater distance from the CBD. Blue Collar workers, on the other hand, are better described as being uniformly affected by alternate opportunities, opportunities perhaps even having a greater influence on class members residing in peripheral cells.

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Conclusions

In this investigation of Tulsa CBD commuter flows, two interaction principles--tranferability (distance) and intervening opportunity--were directly tested when incorporated as constraints in a succession of simulation models. A third principle, complementarity, was indirectly tested when differential group response to Model I (the supply model) was compared with differential demand for group services in Tulsa's CBD. The conclusions outlined in this section are of a general character--estimates of explanation priority or the differential effectiveness of interaction principles tested.

Of the three principles tested, complementarity is estimated as the most significant variable responsible for the general flow pattern to Tulsa's CBD. As indicated in the summary of model performance, the averaged set of flow patterns predicted on the basis of supply alone proved the most accurate. More significantly, considerable variations in individual group response were almost directly traced to variations in demand for group services at the CBD. When favorable conditions of CBD demand existed, predictions based upon supply alone proved highly accurate. On the other hand, decreasing demand for the services of a particular group

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corresponded almost precisely with decreasingly accurate Model I flow predictions. The considerable overall demand exercised by Tulsa's CBD on the study area, i.e., the existence of a generally positive condition of complementarity, is offered as the principle explanation for successful predictions based on supply alone. Similarly tested, differential group mobility accounted for only a very small proportion of Model I predictive success.

As demand at the CBD diminished, that is, as the condition of complementarity deteriorated, the operation of various interrelated attenuating elements (distance, intervening opportunity, and the relative inability or unwillingness of certain groups to absorb transportation costs) became manifest. Of these several additional factors influencing CBD flow patterns, intervening opportunity is estimated as the most important.

Distance and the revised measure of intervening opportunity (alternate opportunities declining in consequence with increasing distance from the CBD) were found to have significantly related effects on flow predictions. Relatively immobile groups or groups in little demand at the CBD, under both revised constraints, were more effectively predicted. The flow patterns of mobile groups or groups in greater demand at the CBD, on the other hand, were less effectively anticipated than in Model I.

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Although both distance and intervening opportunity had comparable effects, distance, by deduction dependent on the distribution of intervening opportunities, has no intrinsic significance in the regulation of movement. According to this construction, distance is only useful in approximating the affect of intervening opportunity. In this Tulsa research, distance effectively approximated the affect of alternate opportunities which declined in consequence toward the study area periphery. The declining consequence of intervening opportunity was traced to two factors, differential mobility and differential awareness of potential alternatives. As distance between each areal unit and the CBD increases, individual mobility also tends to increase. Next, as distance increases the size of intervening opportunity areas also increases, thus reducing each individual's relative perception of all possible intervening employment opportunities. These two factors combine to reduce effectiveness of a model postulating equal influence of all intervening opportunities. Influence is unequal, declining in consequence toward the study area periphery.

Suggestions for Future Research

While the observations and conclusions generated by this Tulsa research in the main substantiate previous

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theory, certain of these findings were sufficiently unusual or were sufficiently interesting that they warrant particular recognition. These items are thought to constitute useful approaches to future commutation studies.

First, the degree of predictive success realized by the elementary population model, predicting flows on the basis of employee supply alone, was definitely unexpected. Generally, the degree of Model I success was explained in terms of unusual demand exercised at the CBD destination district. A smaller proportion of this success was attributed to group mobility differentials. The overall success realized by this model is sufficient argument for further experimentation in other metropolitan areas and in destination districts other than the CBD. A comparison of results between metropolitan areas could indicate that some degree of Model I success in Tulsa is related to either an unusually mobile Tulsa population or to the central location of Tulsa's CBD. Experimentation in destination districts other than the CBD, districts characterized by lesser degrees of demand, would more rigorously investigate the interrelationships between predictive success, demand, and mobility.

Second, the development of a partially successful intervening opportunity model is evidence that continued

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experimentation along similar lines could be rewarding. Model IV postulated that intervening opportunities would decline in consequence with increasing distance. Commuter flows generated by supply in individual areal units were attenuated by the square root of all possible intervening opportunities. This revised hypothesis of opportunity influence, although only approximating the reduced influence of distant opportunities, proved successful; this finding argues for an even more refined measure of opportunity influence, a measure which more directly takes distance into account. Distance, although not in itself significant, is important when operating in a framework of intervening opportunity.

Finally, important differences in group response to identical constraints and to revised assumptions demonstrates the utility of an approach which centers on groups having different socio-economic characteristics. If only the total flow pattern is investigated, potentially significant differences among the parts of this total cannot be determined. Without disaggregation, estimates concerning the impact of different operating variables affecting the composite flow are generalizations of limited use. With disaggregation, dependent on the degree to which disaggregation is possible, estimates become increasingly specific and useful

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statements. Although disaggregation requires considerably more effort in the collection and manipulation of data, this additional effort is seemingly necessary in future studies of urban commutation.

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APPENDIX I

A CONDENSED VERSION OF THE TMATS DWELLING UNIT INTERVIEW FORM

General Information and Summary Data

A. STRUCTURE TYPE (CHECK ONE)

1. Single Family--Detached
2. Single Family--Attached
3. 2 Family--Duplex
4. 3-4 Family--Apartments
5. 5 or more Apartments--Low Rise
6. 5 or more Apartments--High Rise
7. Hotel--Motel
8. Rooming House
9. Dormitories
0. House Trailer

B. DAY OF TRAVEL: Month____________ Day____________

C. HOW MANY PERSONS LIVE IN THIS DWELLING UNIT?

1. How many are 5 years of age or older?
2. How many are employed?
3. How many unemployed are available for work?
4. How many passenger cars are owned by persons living at this address?
5. How many passenger cars are garaged at this address?

D. HOW LONG HAS HEAD OF HOUSEHOLD LIVED AT THIS ADDRESS?

E. TOTAL NUMBER OF PERSONS 16 YEARS OF AGE OR OLDER?

1. Licensed to drive.
2. Not licensed to drive.

F. RENTER OR OWNER OCCUPIED DWELLING UNIT?

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APPENDIX I (continued)

G. INCOME LEVEL? (One of five possible levels estimated by interviewer.)

H. TOTAL NUMBER OF TRIPS REPORTED AT THIS DWELLING UNIT. (Include Visitor Trips.)

1. Number of persons 5 years of age or older making trips. (Do not include visitors.)

2. Number of persons 5 years of age or older making no trips. (Do not include visitors.)

3. Number of persons 5 years of age or older with trips unknown. (Do not include visitors.)

I. TOTAL NUMBER OF AUTO DRIVER TRIPS REPORTED AT THIS DWELLING UNIT.

J. TOTAL NUMBER OF AUTO PASSENGER TRIPS REPORTED AT THIS DWELLING UNIT.

K. TOTAL NUMBER OF TRANSIT PASSENGER TRIPS REPORTED AT THIS DWELLING UNIT.

L. TOTAL NUMBER OF TAXI, TRUCK AND SCHOOL BUS TRIPS REPORTED AT THIS DWELLING UNIT.

M. TOTAL NUMBER OF PERSONS UNDER 16 YEARS OF AGE.

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APPENDIX I (continued)

Specific Individual Trip Information

Occupation and Industry	Person Number	Trip Number	Sex and Race	Where Did This Trip Begin? Address and Land Use	Where Did This Trip End? Address and Land Use
			1	Address	Address
			2		
			3	Land Use	Land Use
			4		
			5		
			6	L. U. Code Address Code	L. U. Code Address Code

APPENDIX I (continued)

Mode of Travel	Time Of Starting	Time Of Arrival
1. Auto Driver 2. Auto Passenger 3. Transit 4. Taxi Passenger 5. Truck Passenger 6. School Bus 7. Walk to Work (1st Trip)	A.M. P.M.	A.M. P.M.

Total Persons in Car	Car Pool	Type Parking (Driver Trips Only)
	Yes 1 No 2	1. Street Free 2. Street Meter 3. Lot Free 4. Lot Paid 5. Garage Free 6. Garage Paid 7. Service or Repairs 8. Residential Property 9. Cruised 0. Not Parked

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APPENDIX I (continued)

From	Trip Purpose	To
	1. Work Employment	
	2. Emp. Business	
	3. Personal Business	
	4. Recreation	
	5. School	
	6. Social	
	7. Change Travel Mode	
	8. Shopping (Conv.)	
	9. Shopping (Goods)	
	10. Medical	
	11. Eat Meal	
From Code ______	12. Serve Passenger	______ To Code
	13. Home	

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APPENDIX II

TULSA SAMPLE EMPLOYED POPULATION BY CATEGORY AND AREAL UNIT

Cell	Total	Males	Females	Blue Collar	White Collar	Professionals -Managers	Sales-Clerical
1	15	8	7	10	5	0	5
2	120	73	47	93	27	8	19
3	116	75	41	83	34	15	19
4	163	125	38	94	69	29	40
5	89	63	26	60	29	7	22
6	141	102	39	100	41	19	22
7	80	57	23	61	10	10	9
8	167	122	45	90	77	35	42
9	169	123	46	100	69	16	53
10	128	92	36	87	41	13	28
11	156	122	34	85	71	32	39
12	15	13	2	9	6	3	3
13	55	48	7	37	18	11	7
14	168	93	75	64	104	45	59
15	136	79	57	38	98	38	60
16	210	141	69	69	141	64	77
17	102	75	27	37	65	33	32
18	107	88	19	46	61	27	34
19	126	95	31	22	104	62	42
20	123	98	25	61	62	31	31

APPENDIX II (continued)

21	89	75	14	24	65	47	18
22	54	46	8	32	22	12	10
23	150	92	58	49	101	37	64
24	188	134	54	29	159	96	63
25	178	130	48	46	132	74	58
26	168	132	36	31	137	89	48
27	32	27	5	10	22	16	6
28	17	15	2	9	8	4	4
29	130	94	36	80	50	28	22
30	55	46	9	46	9	5	4
31	132	101	31	92	40	15	25
32	72	54	18	45	27	9	18
33	103	70	33	63	40	14	26
34	82	56	26	65	17	6	11
35	26	20	6	12	14	9	5
36	82	49	33	48	34	14	20
37	109	83	26	68	41	16	25
38	104	76	28	65	39	19	20
39	106	75	31	72	34	9	25
40	86	63	23	26	60	30	30
Totals:	4,349	3,130	1,219	2,157	2,192	1,047	1,145

Source: Tulsa Metropolitan Area Transportation Study (1964).

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APPENDIX III

TULSA SAMPLE ACTUAL CBD COMMUTERS BY CATEGORY AND AREAL UNIT

Cell	Total	Males	Females	Blue Collar	White Collar	Professionals -Managers	Sales-Clerical
1	9	3	6	4	5	0	5
2	25	19	6	18	7	1	6
3	21	16	5	14	7	1	6
4	22	13	9	6	16	3	13
5	16	7	9	9	7	1	6
6	14	7	7	4	10	1	9
7	9	3	6	8	1	0	1
8	22	13	9	8	14	4	10
9	24	11	13	6	18	3	15
10	10	8	2	3	7	2	5
11	22	13	9	4	18	3	15
12	3	3	0	1	2	1	1
13	6	3	3	2	4	1	3
14	39	17	22	4	35	10	25
15	44	21	23	7	37	11	26
16	41	22	19	6	35	13	22
17	14	12	2	4	10	5	5
18	18	11	7	4	14	3	11
19	28	21	7	0	28	14	14
20	15	12	3	5	10	3	7

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APPENDIX III (continued)

21	17	15	2	1	16	13	3
22	9	7	2	5	4	1	3
23	59	27	32	10	49	17	32
24	71	53	18	6	65	42	23
25	51	54	17	4	47	24	23
26	57	51	6	6	51	35	16
27	6	5	1	1	5	4	1
28	3	2	1	1	2	0	2
29	12	8	4	3	9	4	5
30	7	4	3	6	1	0	1
31	20	6	14	6	14	2	12
32	7	3	4	1	6	1	5
33	21	5	16	5	16	3	13
34	6	1	5	4	2	0	2
35	3	1	2	2	1	0	1
36	21	7	14	7	14	3	11
37	15	8	7	6	9	1	8
38	15	10	5	5	10	3	7
39	8	2	6	1	7	1	6
40	27	14	13	4	23	7	16
Totals:	837	498	339	201	636	241	395

Source: Tulsa Metropolitan Area Transportation Study (1964).

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APPENDIX IV

TULSA SAMPLE EMPLOYMENT OPPORTUNITIES BY CATEGORY AND AREAL UNIT

Cell	Total	Males	Females	Blue Collar	White Collar	Professionals -Managers	Sales-Clerical
1	837	498	339	201	636	241	395
2	110	88	22	67	43	20	23
3	80	69	16	48	32	14	18
4	49	25	24	28	21	15	6
5	21	12	9	13	8	7	1
6	20	10	10	8	12	7	5
7	150	126	24	92	58	31	27
8	115	97	18	69	46	25	21
9	50	35	15	30	20	11	9
10	80	70	10	47	33	19	14
11	477	424	53	308	169	99	70
12	18	16	2	13	5	5	0
13	18	14	4	9	9	6	3
14	309	211	98	154	155	82	73
15	120	77	43	43	77	40	37
16	47	30	17	17	30	16	14
17	120	89	31	57	63	23	40
18	103	76	27	49	54	19	35
19	56	25	31	26	30	14	16
20	19	17	2	14	5	4	1

APPENDIX IV (continued)

21	135	87	48	93	42	22	20
22	13	13	0	12	1	1	0
23	242	147	95	87	155	63	92
24	132	77	55	43	89	52	37
25	72	48	24	35	37	18	19
26	133	98	35	61	72	36	36
27	33	115	18	20	13	10	3
28	11	7	4	3	8	3	5
29	57	33	24	31	26	16	10
30	65	51	14	40	25	13	12
31	183	172	11	137	46	24	22
32	5	3	2	4	1	1	0
33	22	21	1	18	4	3	1
34	17	9	8	9	8	3	5
35	14	12	2	8	6	3	3
36	111	100	11	78	33	16	17
37	27	24	3	21	6	3	3
38	52	36	16	32	20	8	12
39	97	67	30	62	35	12	23
40	10	3	7	9	5	2	3
Totals:	4,230	3,027	1,203	2,092	2,138	1,007	1,131

Source: Tulsa Metropolitan Area Transportation Study (1964).

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