MONITORING THE EFFECTS OF THE DALLAS/FORT WORTH REGIONAL AIRPORT ON LAND USE AND TRAVEL BEHAVIOR

PAT BURNETT

DAVID CHANG

CARL GREGORY

ARTHUR FRIEDMAN

JOSE MONTEMAYOR

DONNA PRESTWOOD

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Pat Burnett
David Chang
Carl Gregory
Arthur Friedman
Jose Montemayor
Donna Prestwood

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16. Abstract

This report presents new conceptual and methodological frameworks for common problems in modeling urban land use and travel behavior. The impacts of the Dallas/Fort Worth Airport afford case study data to construct and test such frameworks. Four problem areas are explored, namely, 1) the use of factor analytic procedures to identify metropolitan-wide effects of major transportation investment, 2) the development of computer simulation of political models of urban land use change, 3) the examination of travel time cognition and its modeling and policy implications, and 4) the study of problems in the application of multidimensional scaling procedures to intra-urban travel. It is to be hoped that the exploration of these topics will yield useful results for the planner and also for further research.

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EXECUTIVE SUMMARY

INTRODUCTION

This report is in four parts. Each deals with some aspect of the impacts of the Dallas/Fort Worth Regional Airport on land use or travel behavior. At the same time, each part investigates the impacts of the airport as a case study of a more general and currently important problem. Thus, section one deals with showing how a common multivariate technique, factor analysis, can be used to isolate dimensions of land use change following a major transportation investment. Part two presents a model of political decision making in a region particularly affected by transportation change. Part three uses data from Dallas and Fort Worth to study the perception of time during travel; time perception of time from origin to destination influences whether a journey is made or not and the route taken. Time cognition is thus a major influence on traffic flows in cities; therefore, the general modeling and policy implications of time cognition are studied. Finally, travel behavior using existing and new land use facilities is examined. A technique (conjoint measurement) is used to identify how travelers perceive and use different destinations for a given trip purpose. Because this is a new application of the technique, the last part of the report focuses on problems of its application and their resolution.

PROBLEMS STUDIED

Problem 1. Over the past decade, considerable use has been made of factor analysis to isolate the basic dimensions of urban land use structure. As far as the authors are aware, however, no application of the technique has been made in the transportation area. The problem of the application here is to show how the technique can be used to isolate the effects of new transportation investment on urban land use: the effects of the transportation facility are separated from the general effects on land use of growth or decline in the metropolitan economy. Seventy-eight variables are used as surrogates to describe land use in census tracts of the Dallas and Fort Worth SMSA's. A factor analysis was carried out using data for the variables for 1960 (prior to the announcement of the airport) and 1970 (after the announcement of the facility. A factor analysis was also carried out on the 1960-1970 change in the variables for each census tract. The basic problem was to demonstrate the appearance of a factor showing airport-related change in the census tracts in 1970, and through 1960-1970, since in 1960 the factor was not apparent. Also, a secondary problem was to show how factor analysis could identify census tracts most affected by investment: these could be used for in-depth case studies of urban land use change.

Problem 2. In recent years, there has been a trend away from modeling land use for the entire urban system. This has been accompanied by attempts to develop models of decision-making processes at smaller scales to show how land use alterations come about. It is particularly germane to consider how decision makers treat the land use problems which arise from major transportation investment. Accordingly, the second part of the paper comprises a study of computer simulation of urban land use change. This study differs markedly from others on the same topic. Firstly, it does not assume that individuals behave like "rational economic" man in decision making. Decisions come as a result of both the power of groups to which individuals belong and the personalities of leaders. Thus, the simulation model incorporates many postulates about the actions of individuals within groups, the nature of social structures, and the actions of individuals and groups within social structures. The problem of the computer simulation is to convert these postulates into consistent rules of behavior which will govern the outcome of a land use problem posed by transportation investment.

A second difference from other simulations is the development of the model in logical notation. This permits an attempt to allow the suggestion that "much of the logic behind human reasoning is not the traditional two-valued or even multi-valued logic, but a logic with fuzzy truths, fuzzy connectives and fuzzy rules of inference."[1] The model in this second paper is the first attempt at developing a model of land use decision making couched in "fuzzy logic." The major problem of the computer simulation is, therefore, to produce a more realistic approach to urban land use change. The viability

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[1] Zaheh, Lofti A., "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes," in IEEE Transactions on Systems, Man and Cybernetics, New York: The Institute of Electrical and Electronics Engineers, Inc., Volume SMC-3, Number 1, January 1973, p. 28.

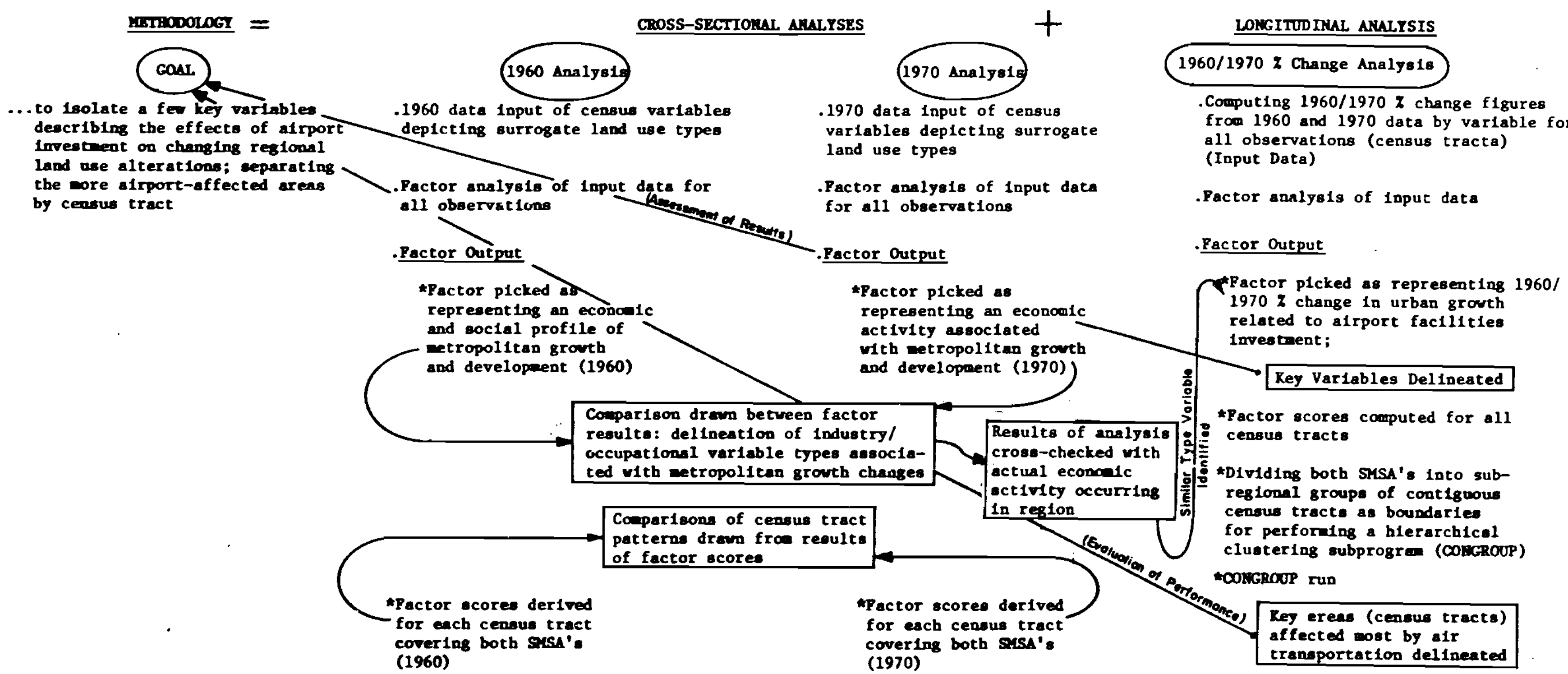

FIGURE 1. DIAGRAM OF METHODOLOGY

of the model is shown through the use of data on decision makers in a case study area identified by the factor analysis of part one, namely, Irving, Texas.

Problem 3. Over the last decade, there have been many studies of the perceived separation of points in space. With very few exceptions, these studies have been of the cognition of physical distance in miles between points; the vast majority of studies have also been concerned with the cognized distance between home and other locations.[2] Yet it has come to be a truism that time distance is more important than physical distance as an influence on the utilization of intra-urban locations. The problems studied, therefore, in the paper comprising section three of this report are 1) to investigate the effects of incorporating perceived time for objective distance in trip distribution models for urban transportation planning, and 2) to demonstrate that a simple mathematical relationship holds between perceived and objective time. In order to demonstrate that a simple relationship exists, the perceived and objective times to destination were examined for a sample of two hundred persons leaving the Dallas/Fort Worth Airport by auto. Thus, looking at the impacts of the Dallas/Fort Worth Airport on travel within the metropolitan areas assists with the general problem of developing improved models for urban transportation planning.

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[2] Golledge, R. G., R. Briggs, and D. Demko, "The Configuration of Distance in Intra-Urban Space," Proceedings of the Association of American Geographers, 1 (1969), pp. 60-65; Stea, D., "The Measurement of Mental Maps: An Experimental Model for Studying Conceptual Space," in: K. R. Cox and R. G. Golledge (eds.), Behavioral Problems in Geography: A Symposium, Evanston, Illinois: Northwestern University, Department of Geography, Studies in Geography, No. 17 (1969), pp. 169-196; Lee, T., "Perceived Distance as a Function of Direction in the City," Environment and Behavior, 2 (1970), pp. 40-51; Lowrey, R. A., "A Method for Analyzing Distance Concepts of Urban Residents," in: R. M. Downs and D. Stea (eds.), Image and Environment: Cognitive Mapping and Spatial Behavior, (1973), pp. 322-337, Chicago:Aldine; Briggs, R., "Cognitive Distance in Intra-Urban Space," unpublished Ph.D. Dissertation, Department of Geography, Ohio State University (1972); R. Briggs, "On the Relation Between Cognitive and Objective Distance," in W. F. Preizer (ed.), Environmental Design Research, Vol. 11, Stroudsberg, PA: Dowden, Hutchinson and Ross (1973), pp. 186-172; Briggs, R., "Urban Cognitive Distance," in R. M. Downs and D. Stea (eds.), Image and Environment: Cognitive Mapping and Spatial Behavior (1973), pp. 361-388, Chicago: Aldine; Lundberg, O., O. Bratfisch, and G. Ekman, "Emotional Involvement and Subjective Distance: A Summary of Investigations," Journal of Social Psychology, 87 (1972), pp. 169-177; Ericksen, R. H., "The Effects of Perceived Place Attributes on Cognition of Distance," Iowa City, University of Iowa, Department of Geography, Discussion Paper No. 23, (1975); Canter, David and S. K. Tagg, "Distance Estimation in Cities," Environment and Behavior, 7 (1975), pp. 59-80.

Problem 4. The general problem here is also to develop improved models for urban transportation planning. In recent years, considerable work has been done on the disaggregate, behavioral modeling of trip distribution. The aim of such models is to determine what causes the individual to behave as he/she does in choosing a destination for a specific trip purpose.[3] It is generally held that an individual, in making a selection, trades off distance with other characteristics of a destination. Multidimensional scaling algorithms (Conjoint Analysis and Torsca) permit 1) the identification of attributes which individuals use to evaluate destinations and 2) the way in which attributes are traded off in destination selection. The main problem of section four of this report is, therefore, to illustrate the power of these techniques in a case study, namely, the utilization of new and existing shopping facilities in Irving, Texas. (It will be recalled that Irving is one of the most affected areas adjacent to the Dallas/Fort Worth Airport; it grew to 116,000 persons in 1960-1970 and many of its shopping facilities were established in that decade.)

[3] Burnett, K. P., "The Dimensions of Alternatives in Spatial Choice Processes," Geographical Analysis, Vol. 5, 1973.

RESULTS ACHIEVED

Problem 1. The macro-scale factor analysis of data describing Dallas and Fort Worth SMSA's was successful. In 1960, the areas were normal in structure, with the main factors of socio-economic status, ethnicity, and stage in life cycle differentiating census tracts. In 1970, however, a factor labeled economic growth profile also appeared. This factor reflected the appearance of industries and households adjacent to the airport. Similarly, over 1960-1970 an airport-related occupation/employment profile appeared. Also, the mapping of census tract scores on these factors, for 1970 and 1960-1970 respectively, revealed groupings of high scoring tracts in the vicinity of, or on roads leading to, the airport. This study therefore demonstrates that factor analysis could be a good analytical tool for isolating metropolitan land use changes in response to major transportation investment. It is a good tool for isolating greatly affected areas for further in-depth surveys of transportation impacts.

Problem 2. In response to the general problem investigated in section two (to produce a more realistic approach to urban land use change) a computer simulation model of urban land use change has been successfully developed. The simulation model identifies which individual in a group of decision makers will emerge as leader of the group, and which of two options, to rezone or not to rezone a piece of land, he/she will take. First, a deterministic model is presented in which group powers are first computed; then the personalities of individuals in the dominant power group are specified in such a way that the leading decision maker is identifiable. Following this the option which the leading decision maker will endorse is specified. Next, it is realized that in the real world decision making is not as mechanistic as the deterministic model presents. The final form of the model therefore employs "a methodological framework which is tolerant of imprecision and partial truths,"[4] but which "is actually quite precise and rather mathematical in spirit,"[5]

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[4]Zadeh, op. cit., p. 29.

[5]Ibid., p. 30.

i.e., the use of "fuzzy" sets and "fuzzy" algorithms. Both the deterministic and stochastic versions of the model are used successfully to isolate the leading land use decision makers in the case study community of Irving. Accordingly, a new kind of land use model has been developed to yield insights into land use decisions consequent on major transportation investment.

Problem 3. The outcome of broaching problem three was also successful. A simple power law apparently relates objective and perceived travel time, namely,

$$Y = aX^b \qquad X = cY^d$$

where

Y = objective time

X = cognized time

and a, b, c, and d are parameters.

This was revealed by analysis of the 200 pairs of perceived and objective times to destination yielded by survey at the Dallas/Fort Worth Airport. It was also found that the a and b parameters did not vary in general by different kinds of population group, or by different trip purposes or by direction of destination. This is a very important result for models of trip distribution. The power law can validly be substituted in such models: carrying out the substitution in aggregative models like the gravity model yields a more realistic explanation of behavior. Carrying out the substitution in disaggregate behavioral models by substituting objective for perceived time also yields a more realistic explanation of behavior. However, the more important result in this case is that some way is being found to make behavioral models operational by including in them objective times and making a correct specification of the relationship between small group travel behavior and travel time.

Problem 4. The application of multidimensional scaling techniques was also successful. Utilizing Dallas and Fort Worth data, a new model of destination choice is presented. The following problems were successfully resolved: 1) the identification of the destination alternatives from which individuals select, 2) the identification of the attributes of destination alternatives which individuals use for destination evaluation, 3) undue complexity in data-gathering procedures, and 4) controversial assumptions about the nature of the time data and their manipulation.

UTILIZATION OF RESULTS

Each of the four parts of this report contain models and methodologies which can be used elsewhere to analyze transportation-related land use change and urban travel behavior. While the models and methodologies are not simple, they have been developed in the context of offering more accurate accounts of factors governing land use and travel. They thus form the basis of new and improved techniques for urban transportation planning.

CONCLUSION

This report presents new frameworks for the analysis of common problems in urban transportation planning. First, the identification of transportation-related urban land use change is addressed. Next, there is a study of the process of land use decision making. Thirdly, the relations of perceived and objective time are treated; the implications for modeling and planning are discussed. Finally, a new approach to destination choice is demonstrated. It is to be hoped that these explorations in land use and travel behavior modeling will be useful in stimulating further research.

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PREFACE

This volume contains reports of four kinds of impact of the new Dallas/ Fort Worth Regional Airport on land use and travel behavior. First, there is an explanation of the effects of the airport on land use at a macro-scale. Changes in land use in both Dallas and Fort Worth SMSA's are investigated. The methodology consists of the application of standard principal components analysis to cluster together those variables which describe basic dimensions of land use in the metropolitan area. The basic dimensions are defined for two time periods, one prior to the airport's construction (1960) and one after the construction was in progress (1970). As well, principal components analysis was applied to data on 1960 - 1970 changes in selected variables describing land use alterations. In 1960, Dallas and Fort Worth had a normal land use pattern, with the basic dimensions of socio-economic status, ethnicity, and stage in life cycle differentiating census tracts in the SMSA. In 1970, however, the principal components analysis isolated a dimension which differentiated census tracts on the basis of airport-related change. A similar dimension appeared when the 1960 - 1970 changes were examined. The major conclusion of the study is that the factor analytic methodology can be successfully used within metropolitan areas in general to isolate and describe changes after new investment in transportation.

The factor analytic methodology also permits the delimitation of areas which are most affected by major transportation investment. In the Dallas/ Fort Worth case, such areas included the city of Irving, which abuts the southeast of the airport. This city was accordingly utilized as a case study area for in-depth surveys of airport-related change.

The second section of this volume hence contains an in-depth analysis of political factors affecting land use decision making. As in the first section, the model of decision making can be applied generally to define the ways in which group power and leader personalities influence land use decisions. However, in this case, data were acquired concerning community leaders and interest groups in Irving to operationalize the model. The special case investigated was whether or not to rezone an area following the development of the airport. The land use decision-making model is a computer simulation model and it is developed in logical notation so that precise and consistent rules determine which leader and group determine the outcome of a land use question. It is obvious that this model must incorporate many postulates about the actions of individuals within groups, the nature of social structures, and the actions of individuals and groups within social structures. The model therefore synthesizes and systematizes many existing concepts from current literature on human behavior. It is unique, however, in at least one respect. The study does not require the existence of a 'rational economic' person as a prior assumption of individual or group behavior. It is designed to allow the suggestion that "much of the logic behind human reasoning is not the traditional two-valued or even multi-valued logic, but a logic with fuzzy truths, fuzzy connectives and fuzzy rules of inference."[1]

Whereas the first two sections of this report focus on land use change, the third and fourth sections deal with changes in travel behavior. The third section focuses on the cognition of travel time, with data from interviews of persons driving vehicles from the airport. It is postulated that objective time to a destination is related to perceived time via Steven's Power Law, or that

$$Y = aX^b$$

where X is perceived time, Y is observed time, and a and b are constants. This law is upheld by the survey data. To make the section on the cognition relevant to transportation planning concerns, the first part of section three discusses the modelling and policy implications of the existence of the power law.

The final section deals with the relations between destination perception and destination choice. A general methodology (conjoint measurement) for relating the two is discussed. A case study is made of the perception of new retail facilities and destination choice in Irving, Texas, by two samples of 50 and 100 respondents, respectively. Because this is an application

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[1] Zadeh, L. A., "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes," in IEEE Transactions on Systems, Man and Cybernetics, New York: The Institute of Electrical and Electronics Engineers, Inc., Volume SMC-3, Number 1, January 1973, p. 28.

of conjoint measurement in a new area, this final section of the report focuses on problems in operationalizing the procedures in general, and specifically in the Irving case. A knowledge of application problems and their resolution should assist with future applications of conjoint measurement in the travel behavior area.

In conclusion, it may be noted that every methodology and model described in this report can be applied elsewhere. Thus, the impacts of the Dallas/Fort Worth Airport on land use and travel behavior provide case studies for the illumination of more general problems.

PART I: A FACTOR ANALYTIC APPROACH TOWARD LAND USE MODELING - THE REGIONAL IMPACT OF THE DALLAS/FORT WORTH AIRPORT, 1960 TO 1970

John Sparks
Pat Burnett
Jose Montemayor

I. INTRODUCTION

This report describes an application of factor analysis techniques to census data drawn from a Standard Metropolitan Statistical Area (SMSA) in an effort to quantitatively assess the effects of a new regional airport on accompanying land use change. Through this method of model development and testing, a few variables, describing the effects of air transportation investment on changing regional land use alterations, are delineated.

Seventy-eight variables are used in the analyses represented by this research. The variables were chosen from census tract data characteristics and depict SMSA differences in housing value and tenure, age and ethnic distributions, family income levels, employment and industry types, migration habits, educational attainment, and mode of transportation to work. These variables are used as land use surrogates, representing quantitative differences among census tract units of observation.

The research centers on the Dallas/Fort Worth Regional Airport and extends to include a ten-county region represented by both Dallas and Fort Worth SMSA's. The regional airport is the seventh largest commercial air center by activity in the nation.[1] It covers roughly 18,000 acres of land in the middle of one of the most populated centers in the southwest. The airport has been planned to serve all air transportation needs of the southwest region as well as acting as a distribution point for the international air industry. It is viewed by its planners as an "integral part" of the surrounding regional environment. The facility is therefore recognized as: "...a permanent regional asset whose related aircraft operations and accompanying economic influence critically influence land development patterns and the expenditure of billions of dollars in physical improvements well outside the airport boundaries, and throughout the entire Dallas/Fort Worth Region."[2]

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[1] Dallas/Fort Worth Regional Airport - 2001, prepared by the Dallas/Fort Worth Regional Airport Board, Dallas and Fort Worth, Texas, 1975, pp. 4-5.

[2] Ibid., p. 35.

The perfection of a working method from which metropolitan growth and development effects of this air facility can be scientifically assessed and monitored is the goal of this investigation.

The methodology adopted to realize this goal may be visualized as two separate but complementary analyses drawn from data depicting different periods of temporal reference. One period, 1960, is represented by raw data figures for both SMSA's before a regional airport had been decided upon. The other, 1970, is a period well beyond the decision date and approaching the airport's completion. By comparing factor analyses of census data collected from both periods, alterations and shifts accompanying air transportation development are patterned by resulting changes in the nature of land use activity by type and intensity of occurrence. In this manner, patterns of air transportation-related urban development are separated and delineated into categorical types associated with regional information and spatial change - air transportation-related industry and accompanying occupational changes being the objective underlying the nature of the search.

The actual method of assessment may be seen as the combination of two separate and distinct analyses: one, a comparison between two separate <u>cross-sectional</u> studies, and the other, a single <u>longitudinal</u> factor analysis. A diagrammatic sketch of the methodology is provided in Figure 1. Cross-sectional factor analyses utilize "raw" census figures for each variable involved whereas a longitudinal analysis inputs identical data expressed as a "quotient" between time periods. In this case, cross-sectional factor analyses are performed on 1960 and 1970 census tract data and their results compared for changes in variable type and spatial patterning. A single longitudinal analysis is then performed for the same data expressed as a percentage-change figure (computed as the relative difference between 1960 and 1970 levels of characteristic occurrences: $\frac{1970-1960}{1960}$). According to the results, cross-sectional differences highlight general growth and <u>aggregate</u> change characteristics by variable type and location of occurrence while longitudinal results focus on specific types of <u>relative</u> characteristic change and subarea spatial alterations. Cross-sectional comparisons are used to identify metropolitan-wide changes whereas subarea shifts are best expressed as relative differences drawn through longitudinal development. Both types of analysis are used as complementary forms of assessment when interpreting overall results.

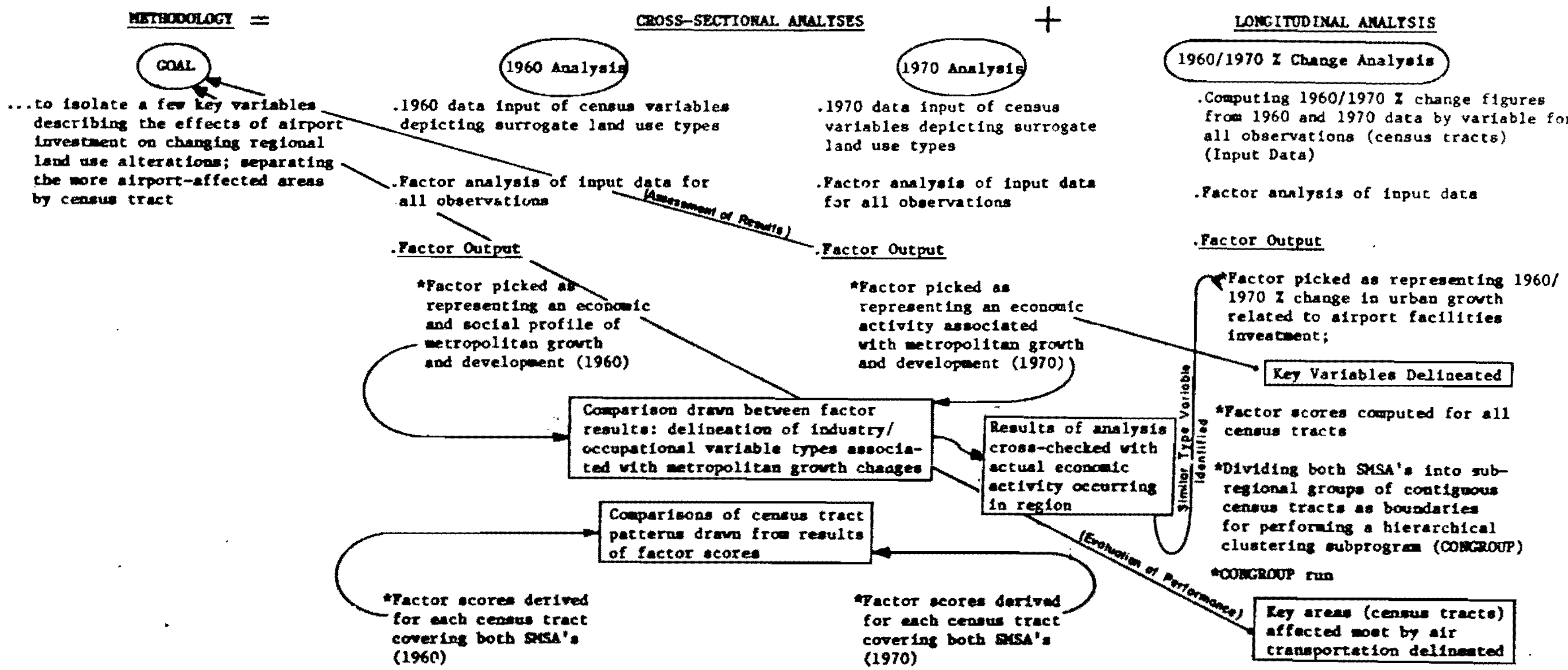

FIGURE 1. DIAGRAM OF METHODOLOGY

CHAPTER BY CHAPTER DEVELOPMENT

The following paragraphs give a brief introduction and summary of the development of each chapter to follow.

Chapter II - Case Study Area. Chapter II describes the location of the Dallas/Fort Worth Regional Airport, graphically displaying the effects of the airport's boundaries on the ten-county study area. Discussion also highlights the level of urban development taking place between 1960 and 1970 by emphasizing suburban, urban, and rural-urban fringe differences. Special attention is focused on population changes occurring between these time periods for the mid-cities' area (an area located between Dallas and Fort Worth metropolitan centers, encompassing the regional airport). Attention is also focused on the comparative and interpretive aspects surrounding the use of census tract information as units of data observation. This includes a brief statement addressing the problem of drawing inferences about behavior of individuals from data summarized by areal unit.

Chapter III - The Factor Model. A brief background and documentation of factor analysis methods and previous research efforts precede a more lengthy discussion of input and output factor criteria. Geographical, social, and political areas of factor-related research typify the compatibleness of factor-oriented regional investigations of "land use." Specific explanations of the mathematical procedures involved in a factor analysis, including the Statistical Package for the Social Sciences' (SPSS) input and output structures, are articulated. "Input variables" reference economic and social differences of occupied space by census characteristic type. "Output results" are explained along with an optional sub-program designed to utilize the factor output as input for computing factor scores for each census observational unit. This factor score "mapping" procedure is used later for delineating the more airport-affected areas from the less affected ones.

Chapter IV - Cross-Sectional Factor Analyses. The results of the comparisons drawn between 1960 and 1970 cross-sectional analyses are revealed through a detailed examination of two similar economic/growth related factors.

Labeled "economic attractiveness" and "economic profile," respectively, the factors are examined for similarities and differences according to the type and strength of correlation exhibited toward each factor configuration. In this case, changes in industry type are compared across both 1960 and 1970 analyses in order that metropolitan-wide profiles of economic growth and metropolitan development may be ascertained. By transferring these results back to the observations (census tracts in this case) under consideration (via a factor scoring subprogram), locational patterns of land use and development change are delineated. Consequently, a few variables depicting changing land use patterns from one period in time are compared directly with those from another time period. This method provides a statistical means of examining quantitative data changes by characteristic type, level of occurrence, and locational proximity.

Chapter V - Longitudinal Factor Development. Using the cross-sectional results as a comparative guide, data results of a longitudinal factor analysis are examined for a similar economic growth-related factor. The nature of the data input for this analysis of longitudinal development represents a relative quantitative percentage difference computed between 1960 and 1970 information figures by variable type for all observations (census tracts). A factor depicting similar cross-sectional results was discovered. Industry and occupation variables were used in choosing this factor representing related air transportation service employment types. Factor scores were computed for all census observations covering the entire ten-county area. A hierarchical clustering subprogram was then employed to delineate only those highly affected observations surrounding the airport site.

II. THE CASE STUDY AREA

The Dallas/Fort Worth Regional Airport is located in the heart of one of this nation's more dynamic metropolitan areas. This metropolitan region of 2.5 million persons is noted for its contribution toward both the wholesaling and trade market-related industries. Dallas and Fort Worth also excel in manufacturing trade, banking and lending, volume of insurance administered, and number of corporate headquarters having $1 million or more net worth. The airport, built to service this region, has risen to the seventh largest commercial air facility in the nation. It includes some 18,000 acres of land situated 17 miles from both Dallas and Fort Worth downtown centers.[3] The site was purchased between 1964 and 1965 by the cities of Dallas and Fort Worth with the expectation that air travel and transport would serve their inland market place with a much needed and more direct method of goods and services delivery for both national and international accounts. In effect, the airport fills the need resulting from a regional absence of direct navigable access to seawater shipping lanes.

Indirectly, the air facility has already generated increased national and international corporate headquarters' relocations since its opening in early 1974. The Dallas/Fort Worth (DFW) Regional Airport Board in 1975 reported regional forecasts totaling 4.4 million annual passenger enplanements for 1968, and estimated 1985 increases to 15 million.[4] As the air transport industry develops, DFW airport cargo tonnage is forecast to double between 1975 and 1985, reaching 1 million tons annually by 1985.[5] Fully developed, the regional airport would have the capacity to ship more freight, excluding bulk shipments, than all 13 Texas seaports combined.[6]

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[3] Ibid., p. 35.

[4] Ibid., p. 4.

[5] Sullivan, Thomas M. (Executive Director), Facts - Dallas/Fort Worth Airport, (DFW: The Dallas/Fort Worth Regional Airport Board, 1973) pp. 2-3.

[6] Ibid.

At present, the airport is planned to accomodate over 12 million enplanements by 1980 and 24 million by 1985.[7] By September, 1974, the first financial reporting period showed over 14,000 persons were employed by the facility and generating approximately $100 million in payroll.[8] This figure represents an addition of $200 to $300 million in direct economic activity for the region.[9] To ignore or even underestimate the regional importance and potential significance of the economic activity already generated by the airport would be both tragic and disastrous. Likewise, the urban locational shifts affecting future growth and economic development spawned by this air facility are just as important. Therefore, it is only logical that transportation research efforts should concentrate on ways in which such effects might best be examined, measured, and compared over time.

FORMAL BOUNDARIES

The formal boundaries chosen for study correspond to those Texas county delineations which comprise both Dallas and Fort Worth SMSA's for 1960 and 1970. The two SMSA's lie adjacent to one another and share contiguous county boundaries. In 1960, the SMSA's held a combined total of six counties. These counties were Tarrant, Johnson, Denton, Collin, Dallas, and Ellis (see Figure 2). Four new counties were added in 1970, for a ten-county total. These four additional counties were Kaufman, Rockwall, Parker, and Wise (see Figure 3). A 1960 and a 1970 census total of population for these ten counties are listed in Table 1 so that gross change, as well as relative percentage change, can be compared between time periods under examination. The same figures are also available for the major cities and towns located within these counties (see Figure 4). This table is provided so that general trends of growth can be quickly explained. For example, it is evident that the larger, more established cities, such as Dallas and Fort Worth, contain the larger proportion of the total regional population. However, by comparison,

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[7] Ibid.

[8] Dean, Earnest E.(Executive Director), DFW - A 1974 Report (DFW: The Dallas/ Fort Worth Regional Airport Board, 1975), p. 8.

[9] Ibid.

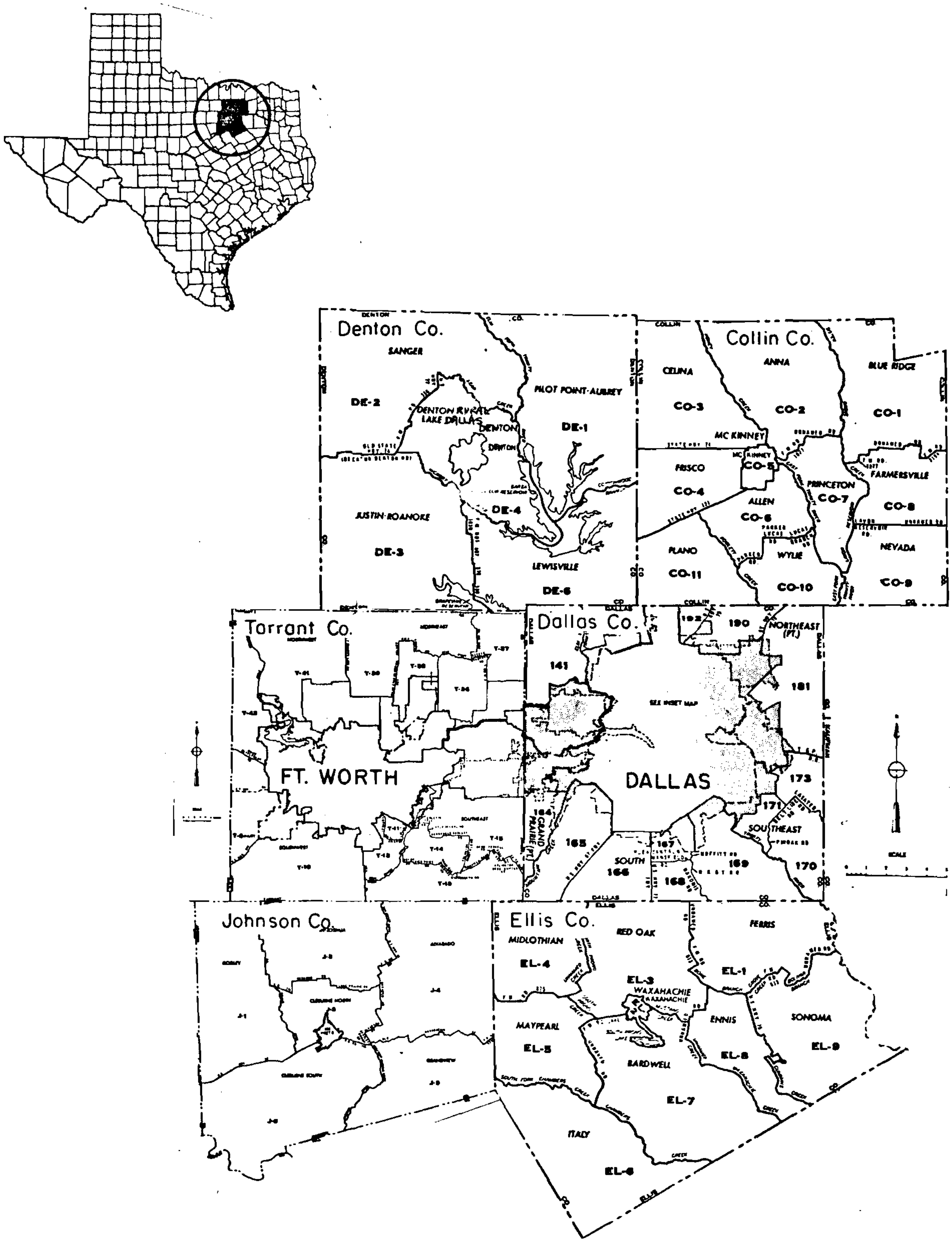

Figure 2. Census Tracts in the Dallas and Fort Worth, Texas, SMSA's and Adjacent Area (1960)

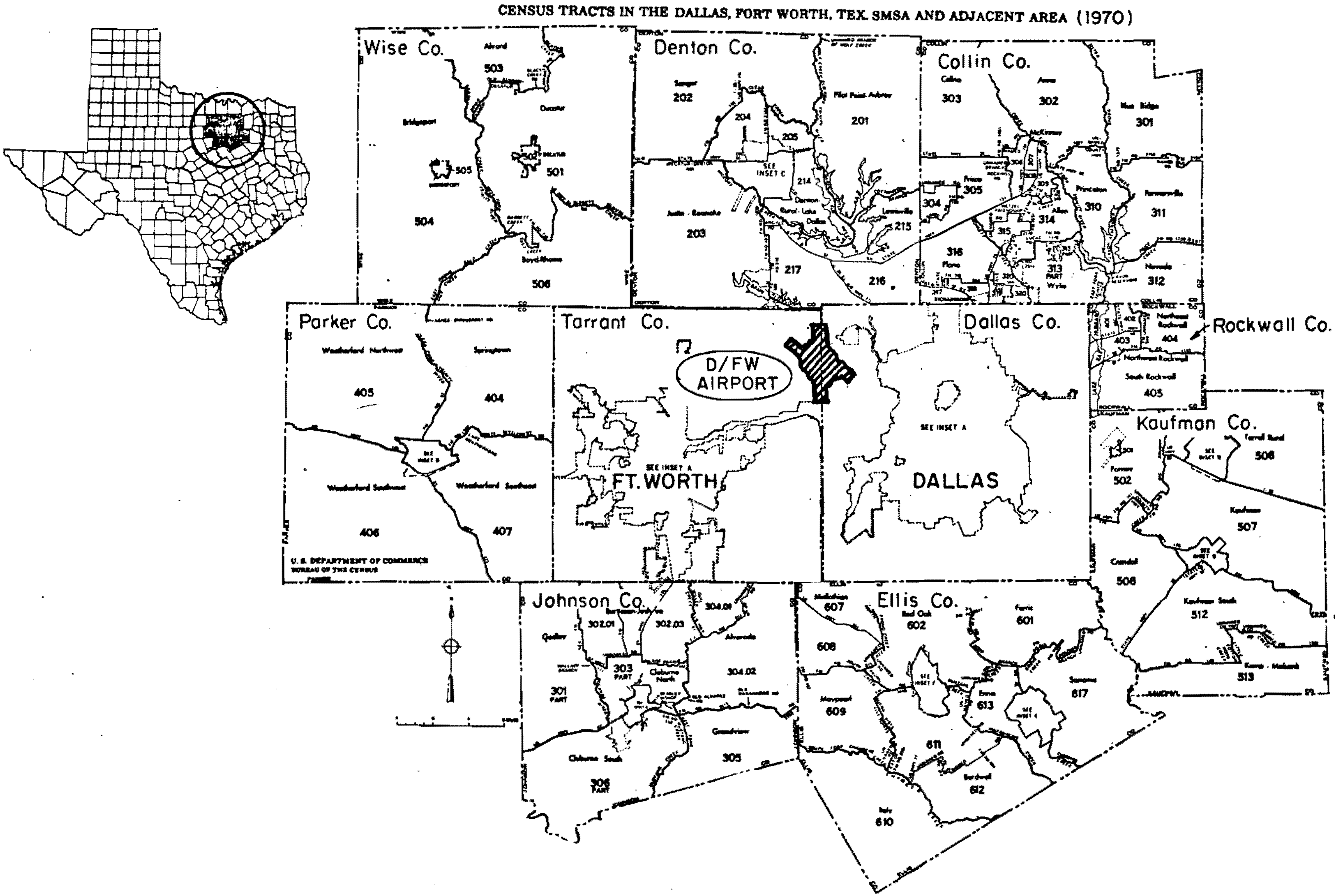

Figure 3. Census Tracts in the Dallas and Fort Worth, Texas, SMSA's and Adjacent Area (1970)

TABLE 1. 1960 AND 1970 POPULATION CHANGE FOR COUNTIES, MAJOR TOWNS, AND CITIES WITHIN THE DALLAS AND FORT WORTH METROPOLITAN AREA

DALLAS SMSA

County, City, or Town	Population 1960	Population 1970	*Gross Chg.	**Percentage Chg.
Collin County	41,247	66,920	25,673	106%
Dallas County	951,527	1,327,321	375,794	139%
Carrollton	4,242	13,855	9,613	327%
Dallas	679,684	844,401	164,717	124%
DeSoto	1,969	6,617	4,648	336%
Duncanville	3,774	14,105	10,331	374%
Farmers Branch	13,441	27,492	14,051	205%
Garland	38,501	81,437	42,936	212%
Grand Prairie	30,386	50,904	20,518	168%
Irving	45,985	97,260	51,275	212%
Lancaster	7,501	10,522	3,021	140%
Mesquite	27,526	55,131	27,605	200%
Plano	3,695	17,872	14,177	484%
Richardson	16,810	48,582	31,772	289%
Denton County	47,432	75,633	28,201	159%
Denton	22,748	39,874	17,126	175%
Ellis County	43,395	46,638	3,243	107%
Waxahachie	12,749	13,452	703	106%
Kaufman County	29,931	32,392	2,461	108%
Terrell	13,803	14,182	379	103%
Kaufman	3,087	4,012	925	130%
Rockwall County	5,878	7,046	1,168	120%

FT. WORTH SMSA

County, City, or Town	Population 1960	Population 1970	Gross Chg.	Percentage Chg.
Johnson County	34,720	45,769	11,049	132%
Parker County	22,888	33,888	11,008	148%
Tarrant County	538,495	716,317	177,822	133%
Arlington	44,775	89,723	44,948	200%
Bedford	2,706	10,049	7,343	371%
Benbrook	3,254	8,169	4,915	251%
Euless	4,263	19,316	15,053	453%
Forest Hill	3,221	8,236	5,015	256%
Fort Worth	356,268	393,476	37,208	110%
Grapevine	2,821	7,023	4,202	249%
Haltom City	23,133	28,127	4,994	122%
Hurst	10,165	27,215	17,050	268%
North Richland Hills	8,662	16,514	7,852	191%
Wise County	17,012	19,687	2,675	116%

*Gross Change - 1970 Pop. - 1960 Pop.
**Percentage Change - 1970 Pop./1960 Pop. X100

Source: 1960 and 1970 Bureau of the Census, U. S. Department of Commerce.

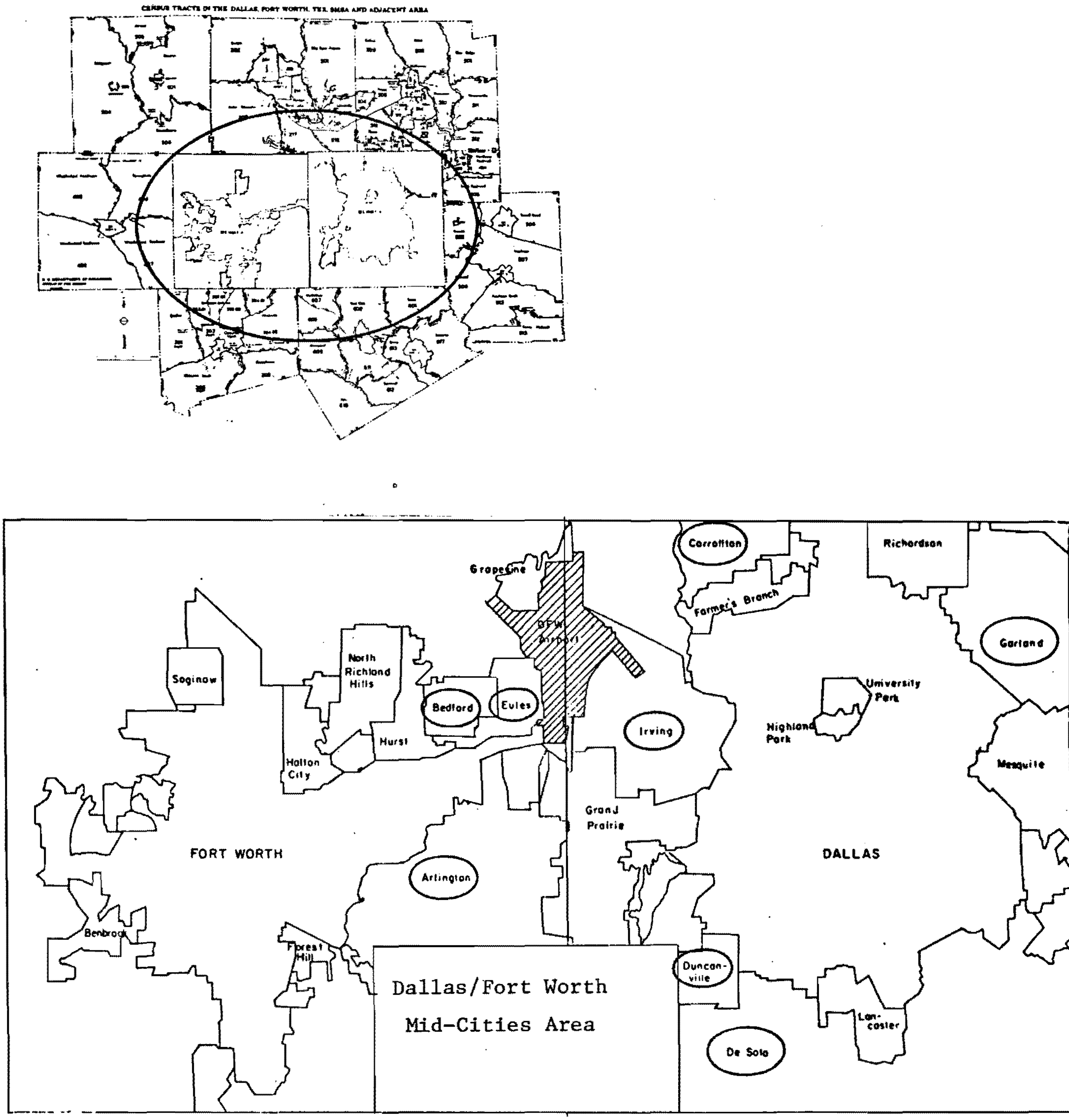

Figure 4. Dallas/Fort Worth Mid-Cities Area

the suburban towns of Irving, Arlington, and Garland each gained more residents over this ten-year period than did Fort Worth. Likewise, the largest percentage rises in population were exhibited by the suburban communities of Plano, Eules, Duncanville, Bedford, DeSoto, and Carrollton. By comparing these population differences, an indication of growth toward suburban fringe areas surrounding Dallas and Fort Worth becomes noticeably apparent, reflecting gross patterns of residential migration between geographical areas. This same principal of comparative quantitative description forms the basis for a more sophisticated, mathematical analysis of the region's growth and development - a ten-year development pattern influenced by the DFW Airport.

REGIONAL SUBDIVISION BY CENSUS TRACT

In the past, the majority of comparative urban spatial studies have relied on census tract data as a primary source of geographically-based subdivision information. The data provided both informational and areal delineations from which a particular social system might be studied and indexed. Likewise, the present research has also chosen to investigate both the Dallas and Fort Worth SMSA's from a similar subunit perspective, although with a different objective in mind. Using the census tracts as observational units, the metropolitan areas are first analyzed by comparing the factors resulting from factor analyses of all observational units describing both SMSA's. One factor, clustering variables (census characteristics) depicting a pattern of economic and occupational types related to airport activity, is chosen. The study variables total 78 while the number of observations ranged between 450 in 1960 and 528 in 1970. Variables depict aggregate population and housing characteristic categories referencing observations (census tracts) measuring age, ethnicity, housing, industry and employment, income, and education. A complete list of these variables is provided in the Appendix while the observational units appear in Figures 5 to 10, which appear in Chapter IV.

Tracts which were subdivided in 1960, so that they would correspond to 1970 boundaries, presented a special problem when computing percentage change figures for the longitudinal analysis. The majority of tract boundaries remained intact between the two periods, with most of the subdivision changes occurring in the more rapid growth areas. These census tract changes between census area differences were converted to percentages corresponding to the 1970 base period. The percentage changes in area differences were used to help compute data changes within and between boundary differences.

A second problem concerning the nature of probabilistic studies should also be addressed since it expressly concerns output generated from areal based units under analytical observation. First, if the size or scale of the observational units were to change, such as to a smaller scale as enumeration districts or a larger scale as planning districts, results would most likely differ as well.[10] The reader is therefore reminded that results reported on only apply to census tracts covering the area which they subdivide. Considering the census tract level of information used, one should also guard against drawing "inferences about the behavior of individuals . . . made from ecological (factor) correlations based on data summarized by areal unit."[11] However, this problem is easily reconciled by recalling that the interest of this study lies with "areas rather than individuals."[12] With these observations, the research now turns to the methodology and a description of the factor model.

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[10] Curry, Leslie, "A Note on Spatial Association," The Professional Geographer, XVIII (March 1966), pp. 97-99.

[11] Murdie, Robert A., Factorial Ecology of Metropolitan Toronto, 1951-1961 (Chicago: Department of Geography, The University of Chicago, 1966), pp. 74-75.

[12] Ibid.

III. THE FACTOR MODEL

The factor analytic model begins with the definition of quantities "considered as overtly observed magnitudes" and proceeds to uncover the relevant interaction relating these quantities "one to another."[13] Quantities are represented by categories of census data referencing individual behavior by life style characteristics. The methodology does not imply, and should not be interpreted as implying, absolute certainty in the explanation of human activity or behavior. Instead, it suggests that basic regularities in the behavior of individuals might be more effectively and economically described from a stochastic approach. The model brings about a more-or-less "conceptual order" from relationships of human activities in physical space by disentangling interrelated variables referencing economic, social, and housing conditions.

The factor model inputs 78 census characteristic measurements for some 500 qualitative observations and proceeds to resolve them into output containing 10 distinct patterns of variation (factors); these characteristic measurements are factored in order that the data can be reduced to a smaller set of independent sources of variation composed of a few source characteristics (or variables) "accounting for the observed interrelations in the original data."[14] By confining the search to one factor, depicting metropolitan change in general and transportation-stimulated changes specifically, source variables are delineated without any appreciable loss of information. In addition, the factor model provides a unique scaling procedure by which the census tract observations are rated and compared on this transportation-related growth factor. This subprogram procedure allows for the geographical charting of an empirical concept, a most innovative spatial-structuring technique.

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[13] Rogers, Andrei, "Theories of Intra-Urban Spacial Structure: A Dissenting View," Internal Structure of the City, Larry S. Bourne (editor), (New York: Oxford University Press, 1971), p. 213.

[14] Nie, Norman, Dale H. Bent, and C. Hadlai Hull, Statistical Package for the Social Sciences (New York: McGraw-Hill Book Co., 1970), p. 209.

FACTOR ANALYSIS

Factor analysis originated in the field of personality evaluation. Psychologists used the technique to isolate fundamental personality components from a barrage of individual personality traits which could be measured. In its transference to the geographical field, areas were used as observations instead of individuals and areal attributes were substituted for personality traits. At the city scale, factor analysis has generally been used to describe dimensions profiling areal urban differentiations among social, economic, and ethnic characteristics. At a national and international scale, geographers, economists, and planners have used the multivariate procedure to address such issues as (1) the regional distribution of welfare and development and (2) national differences concerning social conditions and economic development.[15]

Factor analysis is not a unitary concept. It is composed of a number of consecutive procedures which generally include (1) the preparation of a correlation matrix, (2) the extraction of factors - exploring probable answers of information reduction and simplification, and (3) the rotation of the factors to a final solution or simple structure.[16] The particular analysis chosen for the current model is known as a principal-component analysis. It is expressed most simply by the following equation:

$$Z_j = a_{j1}F_1 + a_{j2}F_2 + \dots + a_{jn}F_n$$

where each of the _n_ observed variables is described linearly in terms of _n_ new uncorrelated components F_1, F_2, ..., F_n, each of which is, in turn, defined as a linear combination of the _n_ original variables.[17]

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[15]Rees, Philip H., "Factorial Ecology: An Extended Definition, Survey, and Critique of the Field," _Economic Geography_, Vol. 47, No. 2 (June 1971), p. 220.

[16]Nie, Bent, and Hull, _op_. _cit_., p. 210.

[17]_Ibid_.

The present research effort uses factor analysis in both cross-sectional and longitudinal studies at a metropolitan scale of investigation. Both types of analysis are concerned with reducing a large number of surrogate variables (referencing land use activity) to a few independent factors accounting for the variation among such variables. One factor representing metropolitan economic activity associated with transportation expansion and airport development in the Dallas/Fort Worth area is delineated and explored. Factors are labeled according to the variable types correlated and the unique concept expressed. The concept of delineating geographical economic-activity impacts using regional census tract comparisons over time forms the basis of this analytical endeavor. The goal of both types of analysis is the delineation of a factor depicting metropolitan land use shifts accompanying the opening of the Dallas/Fort Worth Regional Airport. The factor model accomplishes this task through the identification of "source variables" highlighting just such a concept.

The factor methodology followed is diagrammaticly represented in Figure 1 and expressed by the following steps:

. The assembly of a data matrix X, with measurements for _n_ observations (census tracts) on _a_ variables (census characteristics): an $n \times a$ matrix.

. The data matrix X is then converted to a standard score matrix Z, of the order $n \times a$, in which the variables have been expressed in the standardized form of zero mean and unit variance.

. The new standard score matrix Z is then used to calculate a matrix R of zero-order correlation coefficients between each variable and every other variable, being of the order $a \times a$.

. A matrix F of order $a \times s$ is then produced from a principal components analysis of R, where _a_ represents the dimensions of variance or factors underlying the original variables. Correlation coefficients or loadings (f_{ij}) occupy the cells of the F matrix where _i_ is the variable for any factor _j_. The value of f_{ij} varies between -1.0 and +1.0, the extremes of perfect correlation. Factors are extracted in descending order of magnitude and are independent of one another.

. Factors are then orthogonally rotated (at right [90°] angles to one another) to delineate _distinct clusters_ of relationships or achieve simpler and theoretically more meaningful factor patterns. Generally, this rotational procedure is executed so that each variable will maintain as high a loading as possible on one factor while measuring zero on the other factors. In this instance, the Varimax criterion is employed to accomplish this task.[18]

. In addition, an n × s matrix S is mathematically calculated from the manipulation of the rotated factor loading matrix, the eigenvalues, and the standard score matrix Z.[19] The n × s matrix S contains scores, or component scores, of the order s; where i stands for the observations on factor j. The factor j scores are then normalized to zero mean and unit variance, thus providing a measure for each observation on factor j. These scores are then used to build composite scales of census tract observations representing the "theoretical dimensions associated with the respective factor."[20]

Several terms common to factor analytical results are described below for purposes of future classification and explanation concerning output results which follow in Chapters IV and V.

(1) Factor: the number of factors is the number of substantively meaningful patterns of independent relationships formed between the input variables; factors may be viewed as evidencing the number of different kinds of influence on the data - as presenting categories by which data can be summarized and classified.

(2) Percent or proportion of total variance: measures the relative importance of a given factor in terms of the proportion of the total variance in the data accounted for by the factor; measures a factor's comprehensiveness and strength; is derived by adding the square of the factor loadings together for a particular factor and dividing that sum by the number of variables involved in the analysis.

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[18] Varimax criterion "centers on simplifying the columns of a factor matrix. Such a simplification is equivalent to maximizing the variance of the squared loadings in each column, hence the name Varimax." Ibid., p. 224.

[19] Eigenvalues are the sum of the squared factor loadings for each factor; they indicate the amount and proportion of the total variance in the original data accounted for by each factor. See Harman, Harry H., Modern Factor Analysis (Chicago: The University of Chicago Press, 1965), p. 154.

[20] Nie, Bent, and Hull, op. cit., p. 226.

(3) Factor loading: represents regression weights as well as correlation coefficients; represents a regression weight or linear weight of a variable in terms of a factor - described by squaring the variable loading on a particular factor; the loading itself is referred to as a correlation coefficient between variable and factor. Factor loadings vary between +1.0 and -1.0, the extremes of perfect correlation. As a loading approaches zero, no association between variable and factor is evident. A positive loading implies a direct relationship while a negative one implies the reverse. Importance is attached to variables scoring either very high or very low.

(4) Factor score: standardized measure of a census tract on a particular factor pattern; the score for a tract on a factor is determined by multiplying a tract's data on each variable by the factor weight for that variable. The sum of these "weight-times-data" products for all variables yields the factor score.[21]

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[21] Rummel, R. J., "Understanding Factor Analysis," The Journal of Conflict Resolution, XI (December 1967), pp. 473-476.

IV. CROSS-SECTIONAL FACTOR ANALYSES

The goal of the study is concerned with describing and evaluating the impacts of the Dallas/Fort Worth Regional Airport on the growth of both the Dallas and the Fort Worth SMSA's. The two cross-sectional factor analyses approach this goal through the assessment of categorical growth changes and fluctuations as measured by census data. The data are drawn from time periods occurring before the airport was decided upon and after its construction was nearing completion. These periods represent a ten-year span from which metropolitan-wide changes in land use may be viewed as differences between quantity and quality of occupied space. The problem of separating the airport's influence and effects on metropolitan growth patterns is resolved by analytically identifying specific land use surrogates referencing economic activities which accompany large amounts of air transportation investment.

The factor model uses data of a census tract nature since they most nearly represent the best constant course of reliably accurate information broken down by category and geographic subarea unit. They also serve as a temporal source of aggregate data from which metropolitan areas may be assessed and monitored. An input list containing the census categories chosen to best measure both SMSA's is provided in the Appendix. Both factor outputs identify similar dimensions or factors referencing metropolitan growth according to economic activity. From these two cross-sectional profiles (1960 and 1970), key variable types representing economic change over time are isolated and a set of deviant airport-related subarea units are delineated.

1960 FACTOR ANALYSIS RESULTS

The 1960 cross-sectional factor analysis of census tract data covering both the Dallas and the Fort Worth SMSA's represents a time frame referencing a period extending four years before a decision was formally made to build a new regional air facility between the two metropolitan centers. Therefore, it is assumed that census figures representing these two SMSA's measure "land use activity" at a time in which the regional area was growing without any new or appreciable changes resulting from locational shifts in new air transportation service and investment. However, it should be noted that long-term land speculation had presumably already anticipated the most logical site for the expected airport, thus leading to increased land purchases in and around the airport environs. In turn, land use patterns could have been affected as a result.

A 76-variable matrix was used as the maximum number of input characteristics for the 1960 cross-sectional analysis. Observation totals included 450 census tract subdivisions comprising a contiguous six-county study area. Six separate factor analyses were performed on 1960 data items, representing various input subsets of variables reflecting different demographic, economic, and housing measures. Initially, a 78-variable (maximum total) analysis was attempted but failed when two of the variables showed signs of forming linear combinations with one or more other variables. Table 2 represents the labeled factors output for each of the six factor runs. Although 10 factors were computed for each run set, only the first four factor dimensions were labeled because of the increasing complexity involved in the identification of more theoretical constructs from ever-increasingly less information explained. Table 2 also identifies the number of variables used in each factor analysis and the percent variance explained by factor. The total percent variance explained by each run set is cumulatively represented for the first four factors, as well. Together all four factors collectively account for about 69 percent of the total data explained per set.

Of the six factor run sets, only one resulted in a factor representing the concept of metropolitan growth and economic activity. This factor was appropriately labeled "economic attractiveness." It was identified in run set number five, comprising a 74-variable total indexing income, occupation, industry, education, and residential migration characteristics.[22] (See Table 3 for an in-depth view of each factor composition.) Only those variables

[22] The 74 variables include all 78 variables referenced in the Appendix, except numbers 56, 64, 66, and 68.

TABLE 2. DELINEATION OF FACTORS BY RUN FOR 1960 CROSS-SECTIONAL ANALYSIS

Factor Run	Variable Total	Factor Name *	% Total Variance Explained
1	22	1. Single Family Housing Pattern	34.8%
		2. Multi-Unit Dwelling Pattern	18.6%
		3. Economic Status	14.9%
		4. Nondefinable	6.4%
			74.6% total
2	36	1. Socio-Economic Status	35.2%
		2. Stage in Life Cycle	14.1%
		3. Black Ethnicity	10.7%
		4. Economic Status	7.0%
			67.1% total
3	41	1. Socio-Economic Status	37.9%
		2. Economic Status	15.3%
		3. Life Cycle Stage	9.4%
		4. Nondefinable	6.1%
			68.6% total
4	48	1. Black Ethnicity	47.7%
		2. Socio-Economic Status	13.3%
		3. Family Status	5.9%
		4. Nondefinable	5.0%
			71.9% total
5	74	1. Economic Attractiveness	41.3%
		2. Socio-Economic Status	14.2%
		3. Black Ethnicity	8.0%
		4. Economic Status	4.6%
			68.1% total
6	76	1. Life Cycle Stage	40.9%
		2. Socio-Economic Status	14.2%
		3. Black Ethnicity	8.0%
		4. Multi-Unit Dwelling Pattern	4.6%
			67.7% total

* Orthogonally rotated (Varimax criterion) ten-factor solution with unity in diagonal.

TABLE 3. 1960 CROSS-SECTIONAL FACTOR ANALYSIS (RUN #5)

Factor I. Economic Attractiveness — 41.3% Variance Explained

Variable No.	Factor Loading	Attribute
38	.866	Family income - $10,000 - $14,999
8	.864	Occupation - professional, technical, kindred
73	.823	College completed - 1-3 years
44	.816	Value of housing - $15,000 - $19,999
11	.808	Occupation - sales workers
72	.798	High school completed - 4 years
60	.785	Residence in 1955 - different house outside this SMSA in North and West
43	.774	Value of housing - $10,000 - $14,999
74	.771	College completed - 4 or more years
37	.756	Family income - $5,000 - $9,999
10	.739	Occupation - clerical and kindred
34	.726	Transportation to work - private auto or carpool
27	.710	Industry - wholesale trade
63	.705	Tenure, vacancy - total units owner occupied
61	.697	Residence in 1955 - different house outside this SMSA in south
18	.683	Industry - mining
31	.677	Industry - public administration
22	.664	Industry - machinery
75	.627	Employment status - employed civilians
26	.613	Industry - communications, utilities, sanitary
67	.592	Persons per unit of housing - 3-5 persons
51	.588	Units in structure - one unit structures
24	.577	Industry - printing, publishing, and allied
45	.561	Value of housing - $20,000 - $24,999
62	.555	Residence in 1955 - different house, same county
29	.544	Industry - business and repair services
3	.538	Total population - 20-44 years
78	.528	Employment status - not in labor force

Factor II. Socio-Economic Status — 14.2% Variance Explained

Variable No.	Factor Loading	Attribute
13	.879	Occupation - operatives and kindred workers
12	.805	Occupation - craftsmen, foremen, and kindred
19	.804	Industry - construction
70	.774	School completion - 1-8 years
42	.763	Value of housing - $5,000 - $9,999
71	.747	High school completed - 1-3 years
23	.719	Industry - food and kindred
51	.701	Units in structure - one unit structures
41	.698	Value of housing - under $5,000
36	.692	Family income - less than or equal to $4,999
78	.683	Employment status - not in labor force
57	.675	Residence in 1955 - same house as 1960
21	.654	Industry - metal
75	.624	Employment status - employed civilians
62	.619	Residence in 1955 - different house, same county
63	.616	Tenure, vacancy - total units owner occupied
20	.595	Industry - furniture, lumber, and wood
76	.583	Employment status - unemployed
29	.575	Industry - business and repair services
37	.566	Family income - $5,000 - $9,999
26	.556	Industry - communications, utilities, sanitary
59	.542	Residence in 1955 - different house in other part of this SMSA
31	.519	Industry - public administration

Factor III. Black Ethnicity — 8.0% Variance Explained

Variable No.	Factor Loading	Attribute
14	.923	Occupation - private household workers
6	.900	Total population Negro
15	.855	Occupation - service workers, except household
33	.781	Transportation to work - bus, streetcar
28	.767	Industry - eating and drinking places
76	.639	Employment status - unemployed
48	.626	Gross rent by month - less than $99
36	.616	Family income - less than or equal to $4,999
30	.571	Industry - hospitals
17	.563	Occupation - not reported
68	.512	Persons per unit housing - 6 or more
70	.504	School completed - 1-8 years

Factor IV. Economic Status — 4.6% Variance Explained

Variable No.	Factor Loading	Attribute
40	.899	Family income - $25,000 - over
47	.859	Value of housing - $35,000 - over
39	.837	Family income - $15,000 - $24,999
46	.799	Value of housing - $25,000 - $34,999
45	.638	Value of housing - $20,000 - $24,999
50	.583	Gross rent by month - $200 - over
74	.546	College completed - 4 or more years

Variable Total - 74 — 68.1% Total Variance Explained with +.500 factor loadings or larger were used in labeling each factor since this figure represented a minimum level of statistical significance.[23]

The economic attractiveness factor associated (1) higher levels of educational attainment, (2) middle income and housing values, (3) occupational and industry groups, and (4) the use of private automobiles or car pools for the home-to-work trip, with (5) strong indicators of in-migration for both SMSA's. The variables reflecting in-migration were instrumental in choosing this factor. A closer view of this factor may be indexed from Table 4. According to these results, Dallas and Fort Worth displayed a dimension of economic growth in 1960 characterized by indicators of in-migration and industry-type variables. These significant industry and occupational variables are now used as key indicators or "source variables" with which 1970 growth activity is compared. Variable types include:

Occupations (1) professional, technical, and kindred workers;
(2) sales workers;
(3) clerical and kindred workers;
Industry (4) wholesale trade;
(5) mining;
(6) public administration;
(7) machinery;
(8) communications, utilities, and sanitary services;
(9) printing, publishing, and allied industry; and
(10) business and repair services.

1970 FACTOR ANALYSIS RESULTS

The 1970 factor analysis results are drawn from a data period some six years after a decision had been made to build the world's largest land area air facility between Dallas and Fort Worth, Texas. Data from this period

[23]"The square of the factor loading multiplied by 100 represents the percent variation that a variable has in common with an unrotated or rotated pattern." Therefore, any variable measuring ±.5 on its factor loading represents 25 percent of the variation, a minimum figure quoted from Rummel, *op. cit.*, p. 463.

TABLE 4. 1960 CROSS-SECTIONAL FACTOR OF ECONOMIC ATTRACTIVENESS

Factor I. Economic Attractiveness		41.3% Variance Explained
Variable No.	Factor Loading	Attribute
38	.866	Family income - $10,000 - $14,999
8	.864	Occupation - professional, technical, kindred
73	.823	College completed - 1-3 years
44	.816	Value of housing - $15,000 - $19,999
11	.808	Occupation - sales workers
72	.798	High school completed - 4 years
60	.785	Residence in 1955 - different house outside this SMSA in North and West
43	.774	Value of housing - $10,000 - $14,999
74	.771	College completed - 4 or more years
37	.756	Family income - $5,000 - $9,999
10	.739	Occupation - clerical and kindred
34	.726	Transportation to work - private auto or carpool
27	.710	Industry - wholesale trade
63	.705	Tenure, vacancy - total units owner occupied
61	.697	Residence in 1955 - different house outside this SMSA in south
18	.683	Industry - mining
31	.677	Industry - public administration
22	.664	Industry - machinery
75	.627	Employment status - employed civilians
26	.613	Industry - communications, utilities, sanitary
67	.592	Persons per unit of housing - 3-5 persons
51	.588	Units in structure - one unit structures
24	.577	Industry - printing, publishing, and allied
45	.561	Value of housing - $20,000 - $24,999
62	.555	Residence in 1955 - different house, same county
29	.544	Industry - business and repair services
3	.538	Total population - 20-44 years
78	.528	Employment status - not in labor force

Source: 1960 and 1970 Bureau of the Census, U. S. Department of Commerce.

reflect a decade of quantitative change in census characteristics for 528 observational subarea units. These units represent census tracts covering the six counties included in the 1960 analysis as well as four additional ones. A 78-variable total was available as the 1970 maximum number of input characteristics. As in 1960, various subsets of characteristic measure were utilized to account for perceived social, economic, and housing differences of the populace. A total of seven factor runs were performed on characteristics of 1970 data, and they are presented in Table 5 for inspection. One factor, displaying a remarkable likeness to the 1960 economic attractiveness factor, was identified in four of the factor run sets. It was labeled "economic growth profile" for its theoretical concept portrayed by the significant array of variable loadings. During labeling, special attention was again fixed on the presence of an in-migration measure, loading significantly on this factor. Also, highly correlated occupational and industrial variable types played an important role in the choice of this factor. Results of this successful 78-variable run set are displayed in Table 6.

The economic growth profile factor (Table 7) correlated similar 1960 variables referencing occupation and industry types, income and educational levels, age categories, means of transportation to work, and residential mobility patterns - including a measure of in-migration. This factor explained 37.1 percent of the total variance encountered by the 78-variable factor run. The economic growth profile factor represents a static impression of post-airport metropolitan growth by category of land use activity as represented by census tract data. Industry and occupational categories (serving as source variables) associated with this growth include:

Occupations	(1) operatives and kindred workers;
	(2) craftsmen, foremen, and kindred workers;
	(3) clerical and kindred workers;
	(4) sales workers;
	(5) service workers, except households;
Industry	(6) public administration;
	(7) communications, utilities, and sanitary services;
	(8) construction;
	(9) business and repair services;

TABLE 5. DELINEATION OF FACTORS BY RUN FOR 1970 CROSS-SECTIONAL ANALYSIS

Factor Run	Variable Total	Factor Name *	% Total Variance Explained
1	19	1. Single Family Housing Pattern	31.3%
		2. Multi-Unit Dwelling Pattern	18.9%
		3. Economic Status	15.7%
		4. Nondefinable	7.1%
			73.0% total
2	36	1. Life Cycle Stage	31.6%
		2. Black Ethnicity	12.2%
		3. Socio-Economic Status	8.7%
		4. Nondefinable	6.6%
			59.1% total
3	41	1. Economic Growth Profile	35.7%
		2. Residential Housing Status	11.6%
		3. Socio-Economic Status	7.9%
		4. Nondefinable	5.5%
			60.8% total
4	47	1. Socio-Economic Status	45.9%
		2. Life Cycle Stage	11.3%
		3. Black Ethnicity	5.8%
		4. Dwelling Tenure	4.7%
			67.7% total
5	74	1. Economic Growth Profile	37.7%
		2. Black Ethnicity	11.1%
		3. Single Family Housing Status	7.2%
		4. Multi-Unit Dwelling Pattern	4.6%
			60.6% total
6	76	1. Economic Growth Profile	37.5%
		2. Socio-Economic Status	11.2%
		3. Residential Housing Status	7.4%
		4. Multi-Unit Dwelling Pattern	4.9%
			61.0% total
7	78	1. Economic Growth Profile	37.1%
		2. Socio-Economic Status	11.2%
		3. Multi-Unit Dwelling Pattern	7.8%
		4. Residential Housing Status	5.2%
			61.3% total

* Orthogonally rotated (Varimax criterion) ten-factor solution with unity in diagonal.

TABLE 6. 1970 CROSS-SECTIONAL FACTOR ANALYSIS (RUN #7)

Attribute	I* Economic Growth Profile	II Socio-Economic Status	III Multi-Unit Dwelling Pattern	IV Residential Housing Status
Total population under five years;	.749			
...5-19 years;	.720			
...20-44 years;	.810			
...45-64 years;	.671			
...65 - over years.				
Total population Negro.				
Total population other than negro and white.				
Occupation: professional, technical, and kindred workers;		.771		
...farmers and farm managers;				
...clerical and kindred workers;	.856			
...sales workers;	.592	.716		
...craftsmen, foremen, and kindred workers;	.898			
...operatives and kindred workers;	.920			
...private household workers;				
...service workers, except household;	.577			
...farm laborers and foremen;				
...not reported.				
Industry (employed civilians 14 years and over): mining;		.806		
...construction;	.769			
...furniture, lumber, and wood;				
...metal industry;				
...machinery;	.538			
...food and kindred industry;	.587			
...printing, publishing, and allied;	.699			
...R.R. and railway express;				
...communications, utilities, and sanitary services;	.795			
...wholesale trade;	.680			
...eating and drinking places;	.587			
...business and repair services;	.728			
...hospitals;	.507			
...public administration.	.833			
Means of Transportation to work (14 years and over): R.R.;				
...bus, streetcar;				
...private auto or carpool;	.856			
...walk.				
Family income: less than or equal to $4,999;				
...$5,000 - 9,999;	.814			
...$10,000 - 14,999;	.878			
...$15,000 - 24,999;	.500	.773		
...$25.000 - over.		.902		
Value of housing (owner occupied): under $5,000;				
...$5,000 - 9,999.				
...$10,000 - 14,999;				.560
...$15,000 - 19,999;				.714
...$20,000 - 24,999;				.677
...$25,000 - 34,999;		.576		.552
...35,000 - over.		.659		
Gross rent by month (renter occupied): less than $99;			.578	
...$100 -199;			.811	
...$200 - more.			.536	
Units in structure (all occupied and vacant units): one unit;				.841
...2 unit structures;				
...3-4 unit structures;			.548	
...5-9 unit structures;			.671	
...10 or more unit structures.			.878	
Year housing structure built (all occupied and vacant):				
...1960-1970.				.596
Residence in 1965: same house as 1970;				
...different house in central city of this SMSA;	.502			
...different house in other part of this SMSA;	.760			
...different house outside this SMSA in North and West;				
...different house outside this SMSA in South;	.612			
...different house, same couty.				
Tenure and vacancy status: total units owner occupied;				.871
...total units renter occupied;			.942	
...vacant units.			.761	
Persons in unit (no. of persons all occupied housing units):				
...1-2 persons;			.793	
...3-5 persons;				.827
...6 persons or more.				.549
Years school completed (25 years and over):				
...no school years completed;		.853		
...1-8 years of school;				
...High school, 1-3 years;	.540			
...High school, 4 years;	.681			
...college, 1-3 years;	.856			
...college, 4 or more years.	.769	.556		
Employment status (14 years and over): employed civilians;	.502	.695		
...unemployed;				
...Armed forces;	.877			
...not in labor force.	.824			
Variable Total - 78				
% Variance Explained	37.1	11.2	7.8	5.2
Total % Variance Explained - 61.3				

TABLE 7. 1970 CROSS-SECTIONAL FACTOR OF ECONOMIC GROWTH

Factor I. Economic Growth Profile		37.1% Variance Explained
Variable No.	**Factor Loading**	**Attribute**
13	.920	Occupation - operatives and kindred workers
12	.898	Occupation - craftsmen, foremen, and kindred workers
38	.878	Family Income - $10,000 - 14,999
77	.877	Employment Status (14 years +) armed forces
73	.856	College completed, 1-3 years
10	.856	Occupation - clerical and kindred workers
34	.856	Means of Transportation to work (14 year +) - private auto or carpool
31	.833	Industry - public administration
78	.824	Employment status - not in labor force
37	.814	Family Income - $5,000 - 9,999
3	.810	Total population 20-44 years
26	.795	Industry (employed civilians 14 years +) Communications, utilities, and sanitary services
19	.769	Industry - construction
74	.769	College completed, 4 or more years
59	.760	Residence in 1965 - different house in other part of this SMSA
1	.749	Total population under five years
29	.728	Industry - business and repair services
3	.720	Total population between 20-44 years
24	.699	Industry - printing, publishing, and allied
72	.681	Years school completed (25 years and over) - High School 4 years
27	.680	Industry - wholesale trade
4	.671	Total population between 45-64 years of age
61	.612	Residence in 1965 - different house outside this SMSA in South
11	.592	Occupation - sales workers
23	.587	Industry - food and kindred industry
28	.587	Industry - eating and drinking places
15	.577	Occupation - service workers, except household
71	.540	Years school completed - High School, 1-3 years
22	.538	Industry - machinery
30	.507	Industry - hospitals
58	.502	Residence in 1965, different house in central city of this SMSA
75	.502	Employment status - employed civilians
39	.500	Family Income - $15,000 - 24,999

(10) printing, publishing, and allied fields;
(11) wholesale trade;
(12) food and kindred industries;
(13) eating and drinking places;
(14) machinery; and
(15) hospitals.

These key industries and occupational variables will be compared for changes, resulting from the previous 1960 variable types, after a more general comparison between the 1960 and 1970 growth factor is completed.

1960, 1970 CROSS-SECTIONAL FACTOR ANALYTIC COMPARISON

By comparing the 1960 factor of economic attractiveness with the 1970 factor representing economic growth after the airport location was decided, indicators of economic change between these two periods can be analyzed for connections between the regional airport's impact, accompanying changes in metropolitan land use. Extracting or disaggregating the specific census characteristics associated with changes in quality or urban growth is accomplished by comparing the individual variables forming each factor or dimension. In this case, the two factors representing metropolitan development are analyzed. Each variable is studied in terms of its character as well as its percentage of contribution toward factor formulation (see factor loading). A listing of variables involved in the 1960 and 1970 factors representing economic development for the Dallas and Fort Worth metropolitan regions is presented in Table 8. Each variable is described and its associated factor loading is given.

INDUSTRY

Industry classifications indicate declines in wholesale trade and machinery-related industries between the two periods of analysis. Mining, which played a major role in the 1960 dimensional structure, failed to appear in the 1970 analysis. Printing, publishing, and allied industries, as well as business and repair services, seemed to remain stable between the two cross-sectional analyses. Industry types which showed rises occurring

TABLE 8. 1960-1970 FACTOR COMPARISON

1960 ECONOMIC ATTRACTIVENESS FACTOR

Factor Loading	Variable Description
	Industry
.710	Wholesale Trade
.683	Mining
.677	Public Administration
.664	Machinery
.613	Communications, Utilities, Sanitary Services
.577	Printing, Publishing, Allied
.544	Business and Repair Services
	Occupations
.864	Professional, Technical, Kindred
.808	Sales Workers
.739	Clerical and Kindred
	Family Income
.866	$10,000 - $14,999
.756	$5,000 - $9,999
	Education Attainment
.823	1-3 years of College
.798	High School, 4 years
.771	College, 4 or more years
	Residential Mobility
.785	Residence in 1955: Different house outside this SMSA in North and West
.697	Residence in 1955: Different House outside this SMSA in South
.555	Residence in 1955: Different house, same county
	Employment Status
.627	Employed Civilians
.528	Not in Labor Force
	Total Population
.538	Between 20-44 years
	Transportation to Work
.726	Private Auto or Carpool
	Value of Housing
.816	$15,000 - $19,999
.774	$10,000 - $14,999
.561	$20,000 - $24,999
	Tenure and Vacancy Status
.708	Total Housing Units Owner Occupied
	Persons Per Unit of Housing
.592	3-5 People
	Units of Housing Per Structure
.588	one

1970 FACTOR OF ECONOMIC GROWTH

Factor Loading	Variable Description
	Industry
.833	Public Administration
.795	Communications, Utilities, and Sanitary Services
.769	Construction
.728	Business and Repair Services
.699	Printing, Publishing, and Allied
.680	Wholesale Trade
.587	Food and Kindred
.587	Eating and Drinking Places
.538	Machinery
.507	Hospitals
	Occupations
.920	Operatives and Kindred Workers
.898	Craftsmen, Foremen, and Kindred Workers
.856	Clerical and Kindred Workers
.592	Sales Workers
.577	Service Workers, Except Household
	Family Income
.878	$10,000 - $14,999
.814	$5,000 - $9,999
.500	$15,000 - $24,999
	Education Attainment
.856	1-3 years of College
.769	College, 4 or more years
.681	High School, 4 years
.540	High School, 1-3 years
	Residential Mobility
.760	Residence in 1965: Different house in other part of this SMSA
.612	Residence in 1965: Different house outside this SMSA in south
.502	Residence in 1965: Different house in central city of this SMSA
	Employment Status
.877	Armed Forces
.824	Not in Labor Force
.502	Employed Civilians
	Total Population
.810	Between 20-44 years
.749	Under 5 years
.720	Between 5-19 years
.671	Between 45-64 years
	Transportation to Work
.856	Private Auto or Carpool

Source: 1960 and 1970 Bureau of the Census, U. S. Department of Commerce.

between the 1960 and 1970 studies include public administration and communications, utilities, and sanitary services. Also loading significantly on this 1970 factor of economic growth were food and kindred industries, eating and drinking places, hospital-related industries, and number of employees in the construction industry.

OCCUPATIONS

Occupational shifts between the two economic growth dimensions reveal a generally low status profile emerging in 1970 as compared to 1960. Whereas professional/technical and sales occupations described major 1960 employment areas, 1970 data patterned operatives and craftsmen/foremen type positions. Variables representing clerical occupations seemed to have remained stable throughout each factor while sales workers dropped in importance in 1970. Service oriented employment loaded significantly on the economic growth profile factor in 1970 but failed to emerge at all in the 1960 analysis.

INCOME AND EDUCATION

Family income levels revealed consistent factor variables representing $10,000 to $14,999 annually, followed by worker indications representing those families averaging between $5,000 and $9,999. This income pattern persisted throughout both periods of analysis. The educational attainment category clustered variables representing formal schooling of one to three years of college completed in 1960 and again in 1970. Educational attainments seem to have risen slightly in 1970, with a significant loading of four or more years of college completed.

EMPLOYMENT STATUS AND AGE DISTRIBUTIONS

Differences in employment status between analyses indicate a shift away from the number of employed civilians in the labor force toward a factor affiliation with armed services employment and the number of people not in the labor force. It is presumed that females comprise a large percentage of the population classified as not being in the labor force. Age category distributions reinforce numbers of the total population between twenty and forty-four years of age correlating significantly with each factor chosen to represent economic growth. This is the peak production age group.

HOUSING VALUE, TENURE, AND OCCUPANCY

The 1960 economic attractiveness dimension included three housing values, a housing tenure variable as well as an indicator of housing density and type of dwelling. These variables failed to appear in the 1970 factor associated with economic development. These variables, however, are contained in the residential housing status and multi-unit dwelling pattern dimensions. The 1960 results of housing value reveal an economic level ranging between $15,000 and $20,000 as being the most prominent, followed by houses valued between $10,000 and $14,000. These housing values correlated one-unit, owner-occupied residences with occupancies of three to five persons per unit.

MODE OF TRANSPORT AND RESIDENTIAL MOBILITY

Each of the factors associated with economic growth and development for 1960 and 1970 contains a strong affinity for numbers of people using private automobiles and carpools as a means of transportation to work. This is to be expected, considering the large expansion of highway systems occurring in this decade coupled with a general lack of mass transport facilities.

Residential mobility variables indicating Dallas/Fort Worth in-migration from outside the region were key characteristics used in selecting factors representing economic attractiveness and growth for each period of analysis. These variables only loaded significantly on the chosen growth related factors of 1960 and 1970. The 1960 results reveal the strongest factor affinity occurring from those persons moving into the metropolitan area from the north and west. The 1970 data failed to correlate this variable significantly with any factor. In-migration occurring from the south correlated with both factors, indicating a continued ten-year pattern of migration. Comparatively, migration from the north and west occurring in 1960 seems to have slowed while intrametropolitan residential movements accelerated in 1970. At the same time, residential migration coming into the area from the south has remained a relatively stable measure of new economic growth for this region.

OVERALL CHARACTER OF INDUSTRIAL CHANGES IN EMPLOYMENT: 1960, 1970

The characteristics of industry related employment shown in Table 9 best represent the quality of economic activity delineated from the factor analyses of 1960 and 1970. These characteristics serve as indicators referencing categories of industries which have risen, declined, or remained stable between the two periods of data analysis, before and after airport construction. Activity changes are exemplified in associated land uses depicted by industry type. The degree of contribution each characteristic or variable displays toward its associated factor is represented by the factor loading, in parentheses. By comparing the loading of each characteristic, relative change between 1960 and 1970 results is expressed. In this manner, change in industry employment types is described and patterns disaggregated. Table 9 clearly depicts those variables which rose in terms of indicators of economic growth and those which declined. Key industry source variables describing economic growth change by land use surrogate are identified by these cross-sectional analyses as:

(1) Construction;
(2) Food and kindred industries;
(3) Eating and drinking places;
(4) Hospitals;
(5) Printing, publishing, and allied industry;
(6) Communications, utilities, and sanitary services;
(7) Business and repair services; and
(8) Public administration.

Both factors will be incorporated in separate factor score mapping routines as conceptual dimensions referencing land use activity related to airport-associated economic growth for Dallas and Fort Worth. Comparisons will be drawn between these factorially derived land use changes and those uses actually found in the area most affected by the location of the regional airport.

TABLE 9. 1960-1970 FACTOR COMPARISON OF INDUSTRY CHARACTERISTICS

I. Industry Variables

1960 Factor Loading	1960 Attribute	1970 Factor Loading	1970 Attribute
(.710)	Wholesale Trade	(.680)	Wholesale Trade
(.683)	Mining		
(.677)	Public Administration	(.833)	Public Administration
(.664)	Machinery	(.538)	Machinery
(.613)	Communications, Utilities, Sanitary Serv.	(.795)	Communications, Utilities, Sanitary Serv.
(.577)	Printing, Publishing, Allied	(.699)	Printing, Publishing, Allied
(.544)	Business and Repair Services	(.587)	Business and Repair Services
		(.769)	Construction
		(.587)	Food and Kindred
		(.587)	Eating and Drinking Places
		(.507)	Hospitals

II. Industry Change 1960-1970

	Rising Categories	Declining Categories	
New 1970 Additions	Construction Food and Kindred Eating and Drinking Places Hospitals	Mining	1960 Category which failed to reappear in 1970
Previous Categories on the rise in 1970	Printing, Publishing Communications, Utilities, Sanitary Serv. Business and Repair Services Public Administration	Wholesale Trade Machinery	Previous Categories of 1960 which declined in 1970

SPATIAL REPRESENTATIONS OF 1960 AND 1970 FACTOR DELINEATED ECONOMIC GROWTH

Measures of the highest scoring observational units (census tracts) derived from the 1960 and 1970 factors of economic attractiveness and economic growth profile have been mapped by factor score for Dallas and Fort Worth SMSA's. Factor scores were analytically derived, scaled, and spatially plotted to determine resulting areas most heavily associated with the factor concept.[24] In this manner, relative factor importance is attached to areal units subdividing the Dallas and Fort Worth metropolitan areas.

The spatial patterns resulting from the plotting of the highest scoring census tracts by three successive ranges on both the 1960 and 1970 economic growth factors are represented in Figures 5 to 10. Scores are scaled for a mean of zero and about two-thirds of their values lie between +1.0 and -1.0. Only those greater than or equal to +1.0 are depicted in the figures. Scores of +1.0 and above account for about 15.8 percent of all cases under investigation or over one standard deviation above the mean. Scores lying between +2.0 and +3.0 represent some 2.28 percent of all the cases, while any score over +3.0 accounts for .13 percent. This procedure of scaling the resulting factor scores aids in delineating only the unusually high scoring census units produced through the mapping procedures.

PERCEIVED GROWTH SHIFTS, 1960 - 1970 COMPARISONS

Census tracts scoring high on both 1960 and 1970 factors generally appear to align themselves along and adjacent to major transportation routes traversing Dallas and Fort Worth. Changing spatial patterns forming along these transportation lines between the two time periods indicate a northeasterly development associated with <u>new growth</u> for both Dallas and Fort Worth in 1960. Few growth related tracts seem to be scoring significantly high near the future airport site for 1960 results. Tracts 143 and 144 in Dallas reflect related growth in and around Irving in 1960 but are overshadowed by high scoring tracts located near Farmers Branch, Richardson, and the intersection of Loop 12 at Texas Highway 78. (See Figures 7 and 8.)

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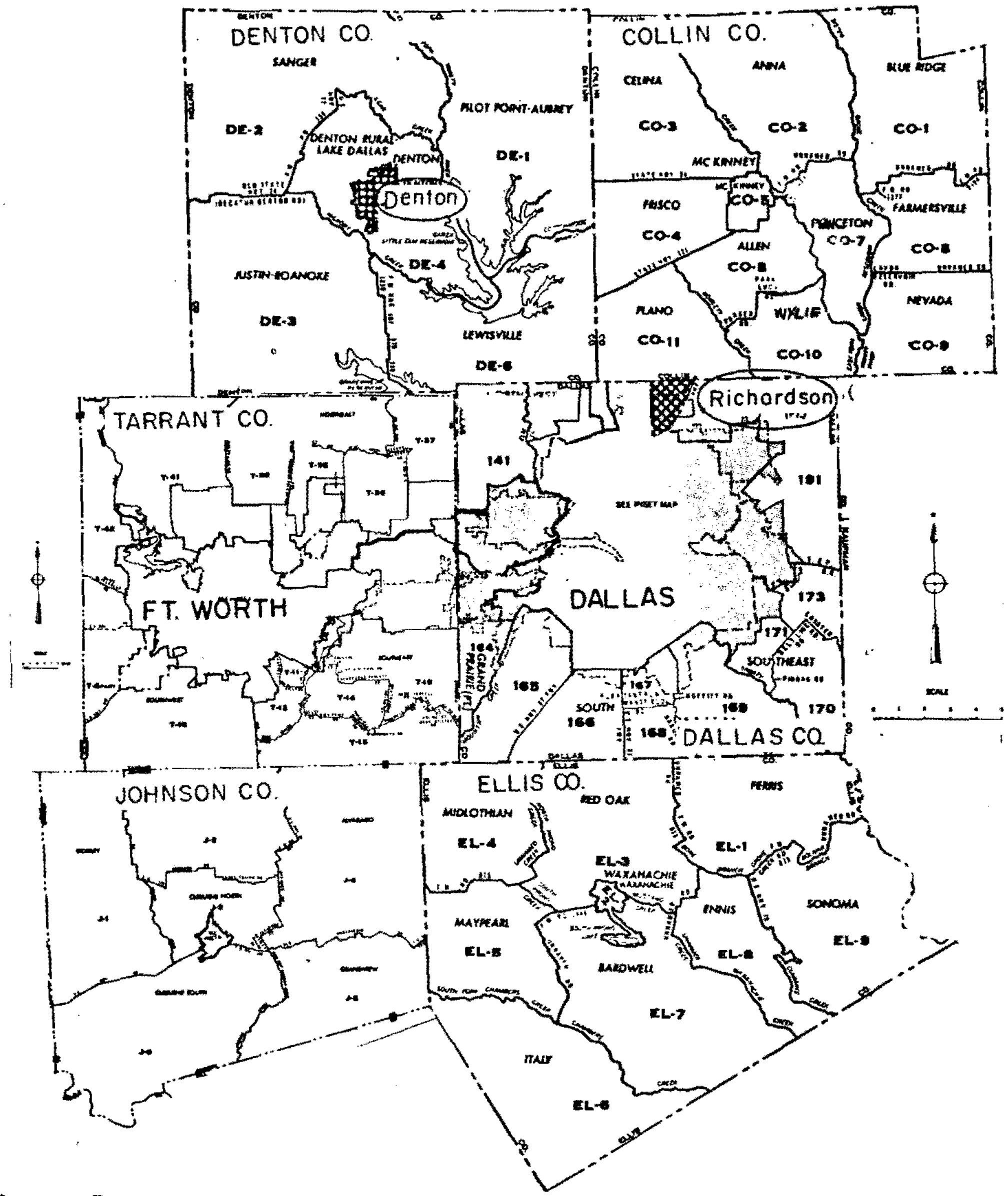
[24] Rummel, *op. cit.*, p. 469.

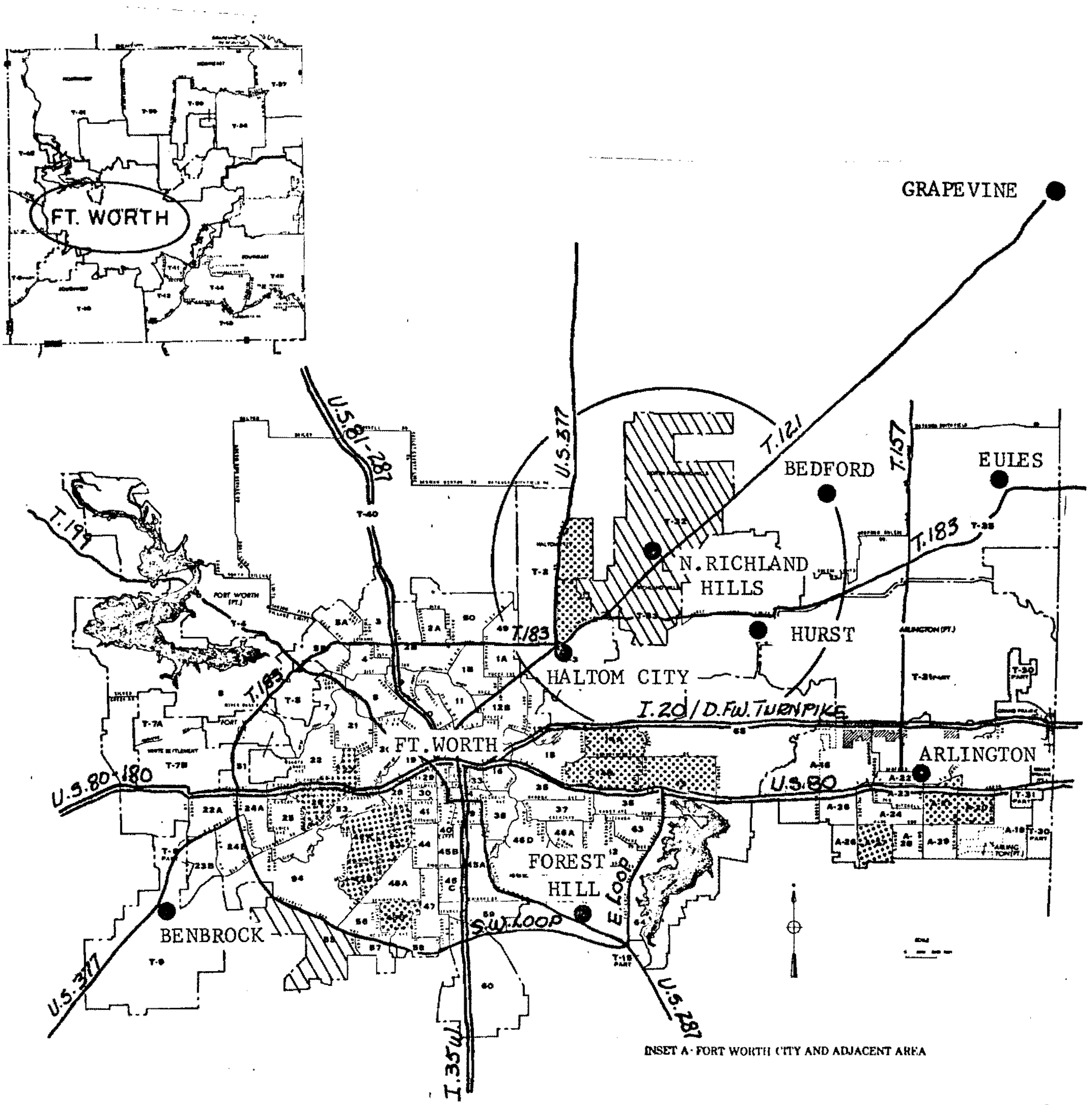


Factor Score Range

1.0 - 1.9
2.0 - 2.9
3.0 - over

Source: 1960 and 1970 Bureau of the Census, U. S. Department of Commerce.

Figure 5. Factor Scores by Range for Dallas/Fort Worth SMSA's 1960 Cross-Sectional Analysis



Factor Score Range

1.0 - 1.9
2.0 - 2.9
3.0 - over

Figure 6. Factor Scores by Range for Fort Worth and Tarrant Co., 1960 Cross-Sectional Analysis

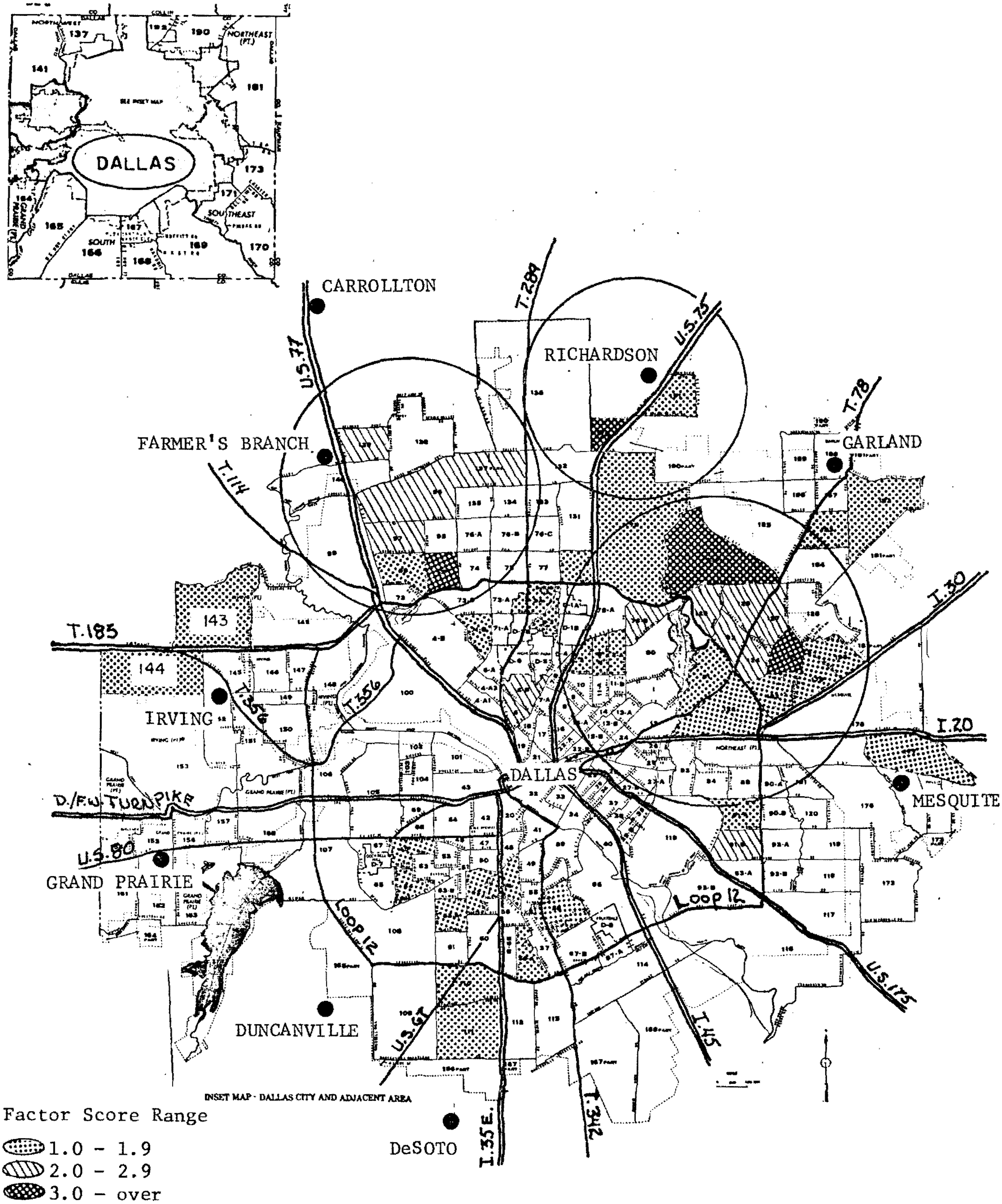


Figure 7. Factor Scores by Range for Dallas City & County, 1960 Cross-Sectional Analysis

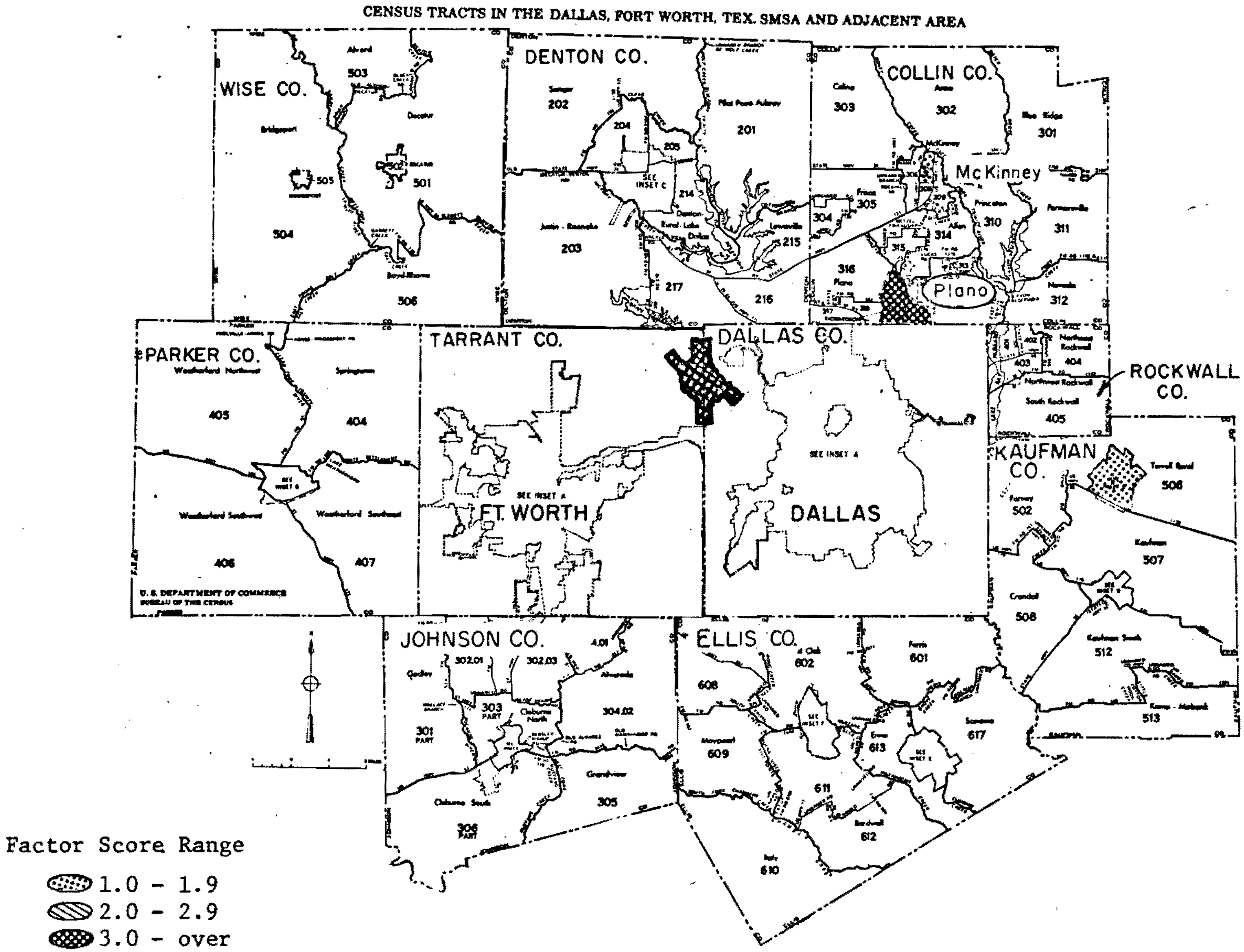
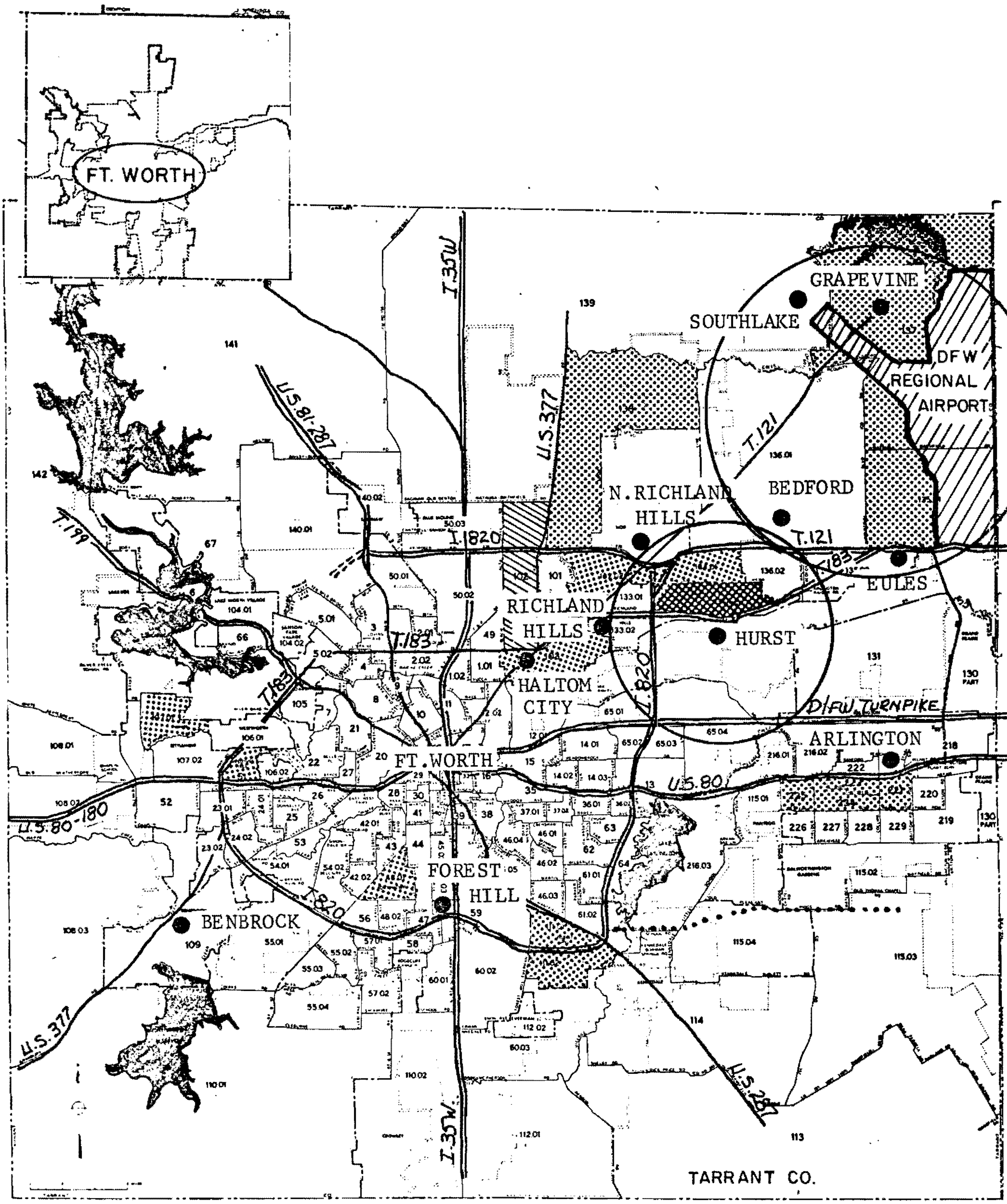


Figure 8. Factor Scores by Range for Dallas and Fort Worth SMSA's, 1970 Cross-Sectional Analysis

Figure 9. Factor Scores by Range for Fort Worth and Tarrant Co., 1970 Cross-Sectional Analysis

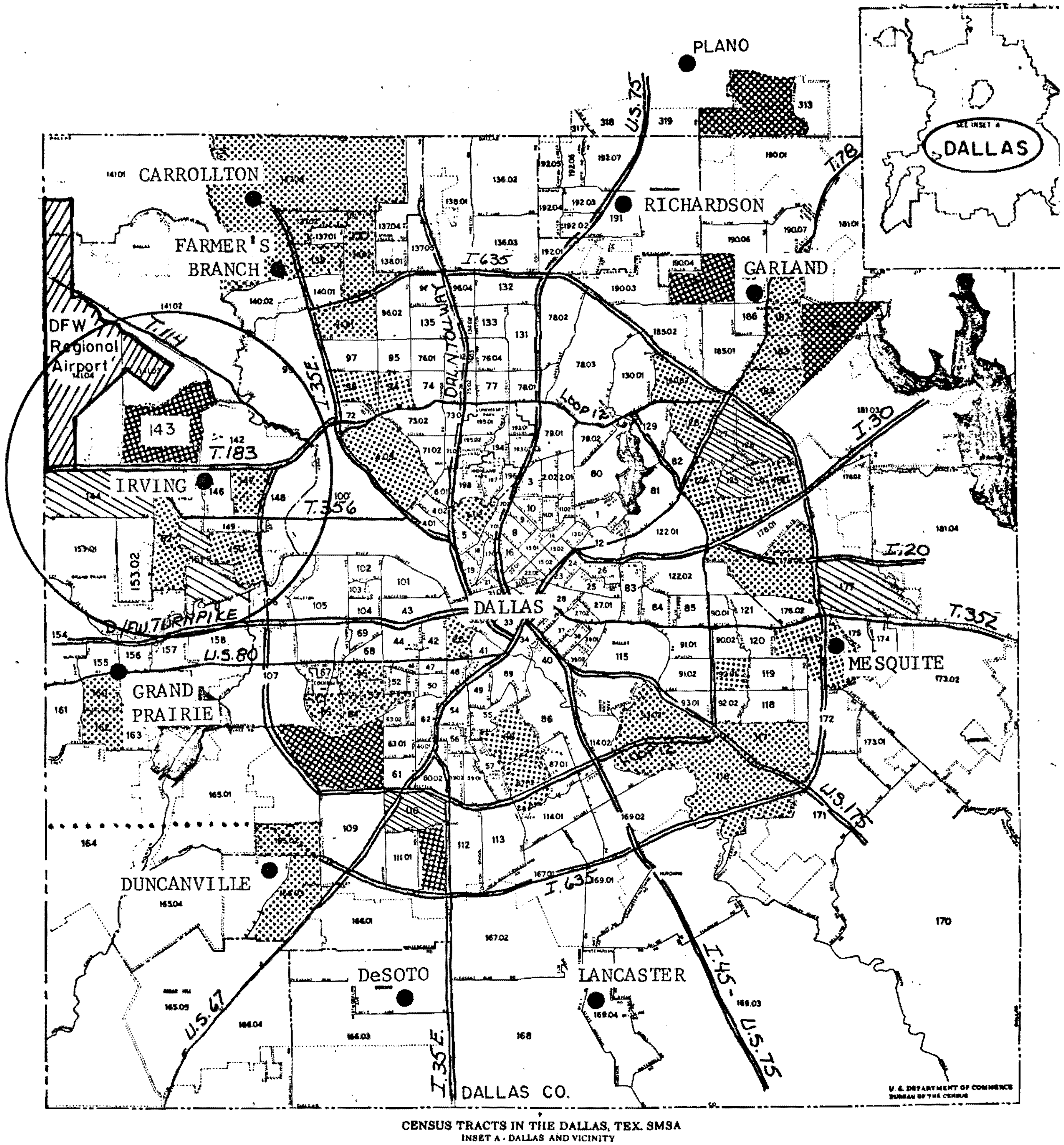


CENSUS TRACTS IN THE FORT WORTH, TEX. SMSA AND ADJACENT AREA
INSET A - FORT WORTH AND VICINITY

Factor Score Range

- 1.0 - 1.9
- 2.0 - 2.9
- 3.0 - 3.9

Figure 10. Factor Scores by Range for Dallas City and County, 1970 Cross-Sectional Analysis



Factor Score Range

- 1.0 - 1.99
- 2.0 - 2.99
- 3.0 - over

Contrasts of the 1960 pattern of economic attractiveness with 1970 spatial changes related to an economic growth profile are manifested in three ways. First, Fort Worth results exaggerate the pattern of growth occurring along Texas Highway 121 leading toward the regional airport and adjacent to Texas Highway 183 connecting Haltom City, Richland Hills, Hurst, and Eules. (See Figure 9.) Hurst scored especially high in 1970, indicating a more pronounced move toward the northeast. Second, Dallas' one-sided (1960) development, moving away from the city center in a northeasterly direction, has shifted markedly to other areas of the region. Third, the strong indication of Denton's high scoring in 1960 has all but disappeared in 1970, showing a marked slow down in that city's growth profile (Figures 7 and 8). These contrasts reinforce the already established pattern of growth occurring in Fort Worth and point with even stronger evidence in 1970 that this development could be associated with the Dallas/Fort Worth Regional Airport. This is indicated by high scores in 1970 for census tracts associated with Southlake, Grapevine, and Eules which had scored low in 1970. Contrasting the relatively lower scores in and around Irving for 1960, seven high scoring census tracts emerged in the 1970 analysis (See Figure 10). Three of the seven census units in this cluster had scores of +2.0 or above. In fact, the highest factor score of the entire 1970 analysis of five hundred and twenty cases occurred in the Irving area (this score was 5.917 for census tract 143). This compact group of seven contiguous tracts (in the Irving area) indicates an economic growth-related area adjacent to the new regional airport. Mapping indications delineated this set of contiguous census tracts as analytically homogeneous with overtones of resulting airport-related growth and development. Accordingly, this area in and around Irving is declared a major airport-related growth region identified by the cross-sectional analysis.

COMPARING FACTOR ANALYSIS RESULTS WITH ACTUAL LAND USE OCCURRENCES - VERIFICATION OF THE MODEL

This section is concerned with cross-checking the factor results with known land uses occurring in and around the Dallas/Fort Worth Regional Airport. To do this, comparisons were drawn between categories of rising occupational and industrial variables by the analyses and actual land uses classified as being airport related. Actual land uses related to the location of the Dallas/Fort Worth Regional Airport have been charted and explained by Harry Wolfe in a 1974 memo entitled A Preliminary Analysis of the Effects of the Dallas/Fort Worth Regional Airport on Surface Transportation and Land Use.[25]

Factor variables chosen as indicators of economic vitality and development between these two periods include: (1) public administration; (2) communications, utilities, and sanitary services; (3) construction; (4) printing, publishing, and allied industry; (5) business and repair services; (6) food and kindred industries; (7) eating and drinking places; and (8) hospitals. These factor delineated characteristics are arranged beside the corresponding airport-related land uses actually delineated in the region for 1974 by Wolfe (See Table 10). Comparisons between the two groups represent likely occurrences of related land use character and type of activity. Since public administration, communication, utilities, and sanitary services, construction, and printings, publishing and allied industry variables displayed the highest percent of variation contributed toward the 1970 economic profile factor, their relationships with commercial office space, personal services, building materials, and light and heavy industry should be especially noted. New categories of food and eating/drinking related employment also indicate hotel-motel related activity as well as retail sales. Land uses associated with new medical complexes are also directly comparable with the factor-delineated variables depicting number of people employed in hospital-related industries.

Examples of expanded air freight-related industries being directly connected with the operation of the Dallas/Fort Worth Airport include: (1) Garland Foods; (2) Frito-Lay; (3) Aberdeen Manufacturing; (4) Texas Color Printers; (5) Circuit Industries; (6) Communications Systems; (7) General Systems Computer; and (8) Acme Machine Company, just to name a few.[26] These

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[25] Wolfe, Harry, A Preliminary Analysis of the Effects of the Dallas/Fort Worth Regional Airport on Surface Transportation and Land Use, Council for Advanced Transportation Studies, Memo, Austin, Texas, April 1974.

[26] Ibid., p. 22.

TABLE 10. CROSS CHECK OF FACTOR RESULTS AS COMPARED WITH ACTUAL OCCURRENCES

I. Actual Airport-Related Indicators of Land Uses Occurring in and Around the Dallas/Fort Worth Regional Airport. (Wolfe)	II. New or Rising Categories of Industry Delineated by Factor Comparison. (1960-1970)
1. Light and Heavy Industry	Construction Printing, Publishing, Allied Communications, Utilities, Sanitary Services Business and Repair Services
2. Warehousing	
3. Commercial Office	Printing, Publishing, Allied Communications, Utilities, Sanitary Services Public Administration
4. Retail	Food and Kindred Eating and Drinking Places Business and Repair Services
5. Personal Services	Communications, Utilities, Sanitary Services Business and Repair Services
6. Commercial Amusement	
7. Hotel-Motel Activity	Food and Kindred Eating and Drinking Places
8. Medical Complexes	Hospitals
9. Building Materials	Construction
10. Conference Centers and Malls	

airport-related companies each employ over one hundred people. Comparative factor-delineated variables showing similar industry related trends include printing/publishing and food and kindred employment, as well as communications, utilities, and sanitary services.

Major commercial/residential developments in Tarrant and Dallas counties reportedly affected by the airport include Trail Creek in Southlake, International Village and H.E.B. Medical Complex in Eules, and Los Colinas located in Irving. The commercial sectors of these developments are expected to include office buildings, hotel-motels, conference centers, and shopping malls. According to Wolfe, all these land use activities are "interpreted as being associated with airport related development." This being the case, the factor analysis results - delineating variables associated with public administration, business and repair services, eating and drinking places, and clerical and sales employment - clearly conform with these actual trends.

Through this cross-checking of factor affiliation with actual land uses, results have further demonstrated the fact that factor delineated variables can and do indicate economic trends associated with Dallas and Fort Worth development between 1960 and 1970. The actual comparisons confirm the analytical results, demonstrating the effectiveness of the analysis. The results of these two cross-sectional comparisons will now be utilized to help sort the results arrived at in the longitudinal analysis.

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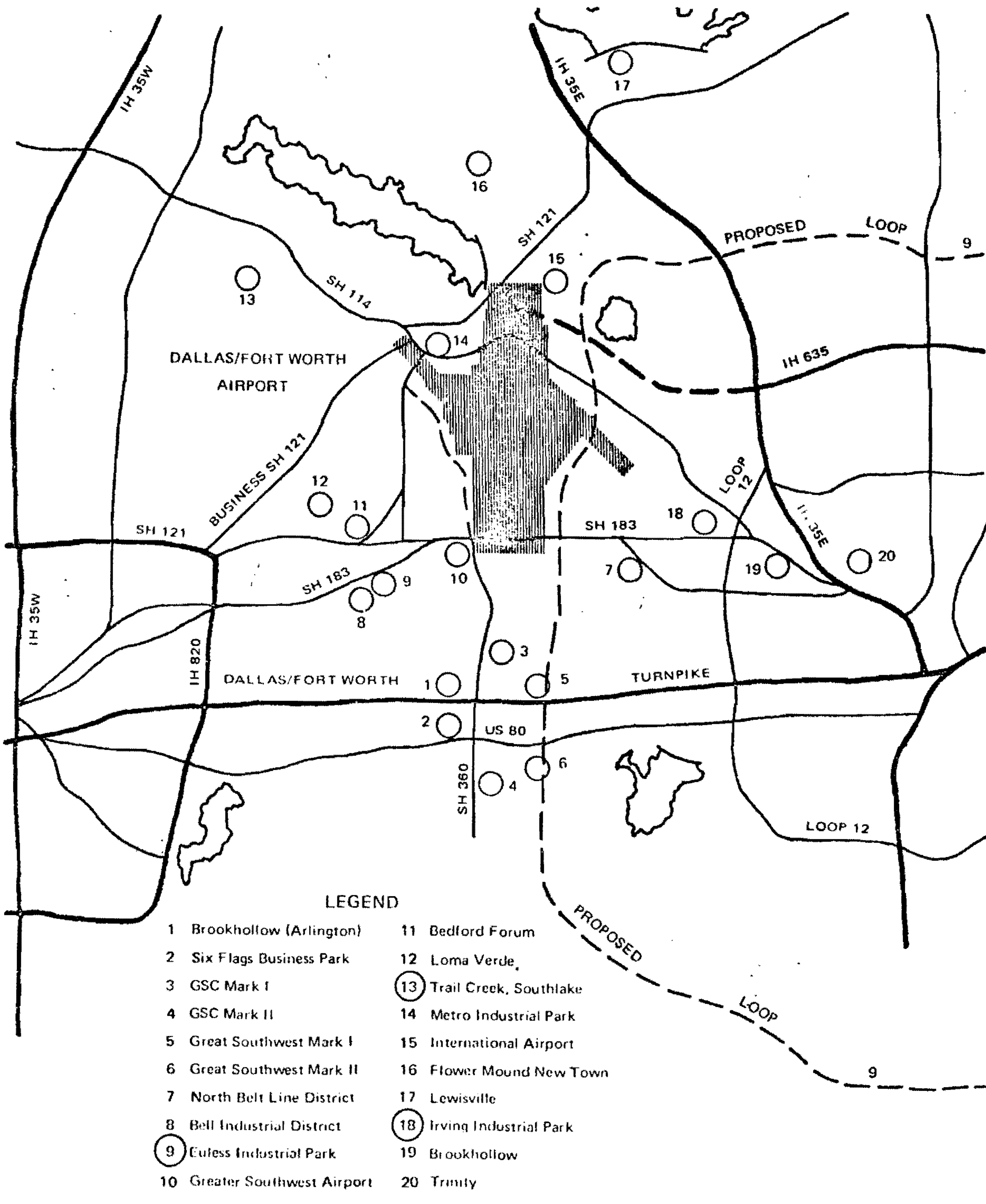
[27] _Ibid._, p. 23; also see Figure 11, representing major industrial, commercial, and residential development in the Dallas/Fort Worth area.



Source: The North Texas Commission, Industrial Districts and Parks

Figure 11. Major Industrial, Commercial, and Residential Developments in the Mid-Cities Area

V. LONGITUDINAL FACTOR DEVELOPMENT

The longitudinal analysis analyzes percentage change figures computed from the census figures previously used in both cross-sectional studies. Instead of analyzing the data figures from two separate time periods or data reference points, the longitudinal study analyzes the data expressed as relative percentage change figures computed for each variable category on each and every census tract observation. Quantitative census information, represented as relative change quotients between 1960 and 1970 data periods, is factor analyzed to uncover the underlying regularities and irregularities describing Dallas' and Fort Worth's longitudinal development. The results are seen as quantitatively measuring the relative qualitative changes between census tracts and census variables. From this analysis one factor, representing employment and industry growth indirectly influenced by regional airport development, is isolated. Through factor score plotting procedures, hypotheses concerning the uniformity and deviance of differing subregional rates of metropolitan growth are explored and compared with actual airport related effects.

IMPACT STRUCTURE

Both Dallas and Fort Worth SMSA's are again used as study boundaries. Only the original 1960 county boundaries were available for this percentage change analysis, since differences could not be computed for tracts which were not included under both time frames.

Data were separated by years of occurrence (1960 or 1970) and then referenced according to a ratio of change computed between the periods under analysis. This was accomplished by expressing the tract data in the following manner:

$$C_{ij} = \frac{D_{ij}1970 - D_{ij}\,1960}{D_{ij}1960} \times 100 = \text{Percentage Change}$$

where $D_{ij}1960$ = the value for tract $\underline{i}$ on variable $\underline{j}$ in 1960,

$D_{ij}1970$ = the value for tract $\underline{i}$ on variable $\underline{j}$ in 1970, and

C_{ij} = the percent change for variable $\underline{i}$ on tract $\underline{j}$.

The ratio was computed for each of the 78 variable measures according to each of 508 tracts. Figures represented a 508 × 78 total. Using these resulting figures as input, a standard principal components factor analysis was performed and rotated to a Varimax solution.

OUTPUT RESULTS

Results of the longitudinal analysis confirm a 55 percent total variance explanation for the first four factors (see Table 11). The first factor accounted for the majority of the variation in the data (38.2 percent). It was labeled socio-economic status (I) because of its general nature and characteristic development. Remaining factors were labeled transient (III), low-income housing profile (IV), and airport-related occupational/employment profile (II). The occupational/employment factor (II) was chosen as being airport affiliated because of the significant economic variable it reflected. It was seen as the most appropriate choice for isolating a specific underlying growth dimension from a more generalized pattern referencing socio-economic status (I). This airport-related factor represents a conceptual profile relating types of industry and occupational characteristics with "middle class" educational attainment and housing status (See Table 12). Together, these variables most nearly represent the type of secondary and service-sector economy related to recent urban development trends in and around the airport region.[28]

SPATIAL RESULTS OF THE LONGITUDINAL ANALYSIS

The mapping procedure for the longitudinal analysis differs slightly from the procedures used in both cross-sectional studies. Instead of ranging factor scores by three levels, a hierarchical grouping subprogram (CONGROUP)[29] was employed to delineate related census tracts by group in descending order

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[28]See Wolfe, Harry, op. cit., pp. 17-28.

[29]CONGROUP - "A stepwise multivariate grouping of observations." This algorithm was used to cluster positive and negative factor scores into similar groupings representing ranges from the highest to the lowest score. The data are "considered as consisting of n single-membered groups initially. At each step of the grouping procedure, two groups (either single or multiple-membered) are joined to form a new group. All observations are lumped into one large group at the end of n-1 steps." See Briggs, Ronald, Congroup, Computer Programs for Spatial Analysis (Austin: Department of Geography, The University of Texas at Austin).

TABLE 11. 1960/1970 PERCENTAGE CHANGE FACTOR ANALYSIS

Attribute	I Socio-Economic Status	II* Airport Related Occupational/ Employment Factor	III Transient	IV Low Income Housing Profile
Total population under five years;	.783		.590	
...5-19 years;	.951			
...20-44 years;	.887			
...45-64 years;	.953			
...65 - over years.	.797			
Total population Negro.				
Total population other than negro and white.				
Occupation: professional, technical, and kindred workers;	.965			
...farmers and farm managers;				
...clerical and kindred workers;	.982			
...sales workers;	.554	.693		
...craftsmen, foremen, and kindred workers;	.896			
...operatives and kindred workers;				
...private household workers;				
...service workers, except household;	.765	.562		
...farm laborers and foremen;				
...not reported.				
Industry (employed civilians 14 years and over): mining;				
...construction;	.747		.547	
...furniture, lumber, and wood;				
...metal industry;		.590		
...machinery;		.789		
...food and kindred industry;				
...printing, publishing, and allied;				
...R.R. and railway express;				
...communications, utilities, and sanitary services;	.946			
...wholesale trade;	.959			
...eating and drinking places;		.552		
...business and repair services;	.921			
...hospitals;	.810	.507		
...public administration.	.934			
Means of Transportation to work (14 years and over): R.R.;				
...bus, streetcar;				
...private auto or carpool;				.521
...walk.				
Family income: less than or equal to $4,999;	.502		.800	
...$5,000 - 9,999;	.814			
...$10,000 - 14,999;	.875			
...$15,000 - 24,999;				
...$25,000 - over.				
Value of housing (owner occupied): under $5,000;				
...$5,000 - 9,999.				.716
...$10,000 - 14,999;	.725			
...$15,000 - 19,999;	.732			
...$20,000 - 24,999;	.824			
...$25,000 - 34,999;				
...35,000 - over.				
Gross rent by month (renter occupied): less than $99;				.849
...$100 -199;		.622		
...$200 - more.				
Units in structure (all occupied and vacant units): one unit;				.902
...2 unit structures;				
...3-4 unit structures;				
...5-9 unit structures;				
...10 or more unit structures.				
Year housing structure built (all occupied and vacant):	.943			
...1960-1970.				
Residence in 1965: same house as 1970;				
...different house in central city of this SMSA;				
...different house in other part of this SMSA;	.520		.564	
...different house outside this SMSA in North and West;	.883			
...different house outside this SMSA in South;			.885	
...different house, same couty.	.944			
Tenure and vacancy status: total units owner occupied;	.594			.752
...total units renter occupied;				.777
...vacant units.	.664	.629		
Persons in unit (no. of persons all occupied housing units):				
...1-2 persons;				.899
...3-5 persons;	.601			.570
...6 persons or more.	.912			
Years school completed (25 years and over):				
...no school years completed;				
...1-8 years of school;	.836			
...High school, 1-3 years;		.784		
...High school, 4 years;				
...college, 1-3 years;		.890		
...college, 4 or more years.	.635	.647		
Employment status (14 years and over): employed civilians;	.939			
...unemployed;	.816			
...Armed forces;				
...not in labor force.	.945			
Variable Total - 78				
% Variance Explained	38.2	6.6	5.8	4.5
Total % Variance Explained - 55.1				

Source: 1960 and 1970 Bureau of the Census, U. S. Department of Commerce.

TABLE 12. 1960/1970 AIRPORT RELATED OCCUPATIONAL/EMPLOYMENT FACTOR STRUCTURE

Factor Loading	Variable Description
	Industry
.789	Machinery
.590	Metal Industry
.552	Eating and Drinking places
.507	Hospitals
	Occupations
.693	Sales Workers
.562	Service Workers, except households
	Education Attainment
.890	1-3 Years of College
.784	High School, 1-3 Years
.647	College, 4 or more years
	Residential Housing Status
.629	Tenure and Vacancy Status; vacant units
.622	Gross rent by month; $100 - 199

Source: 1960 and 1970 Bureau of the Census, U. S. Department of Commerce.

of magnitude. The hierarchical grouping program only permitted a maximum of 80 census tracts to be clustered per run set. This meant that study boundaries had to be subdivided into independent groups of contiguous tracts, not to exceed an eighty tract limit. This was accomplished, resulting in eight distinctive groups covering the entire 508 tract region. From these eight groups, one, representing the mid-cities and regional airport between Dallas and Fort Worth, was chosen for critical evaluation.[30]

The highest factor scoring census tracts lying closest to the airport were identified by CONGROUP and are represented by intensity via shading as shown in Figure 12. These highest scoring tracts include:

(1) census tract #136.02 near Bedford (score +1.01);
(2) census tract #135.01 near Eules (score +.038);
(3) census tract #141.04 (score +1.32) occupying the eastern border of the DFW Airport; and
(4) census tracts #143 (score +.165), #153.02 (score +.171), and #100 (score +20.57), all within the corporate limits of Irving.

IMPACTED GROWTH AREAS DELINEATED BY FACTOR SCORE

As delineated through this longitudinal analysis, the mid-cities region showed the highest resulting factor scores lying near the suburban towns of Irving, Eules, and Bedford. The Irving area supports the largest number of tracts and land area referenced by this factor, clustering four of the six tracts within its geographical boundaries. Census tract #100 had the highest factor score for the entire 508 cases (over four times higher than the next highest score). The remaining census tracts displayed considerably lower scores, indicating a definite skew toward this tract delineation. Tract #141.04 rated the second highest score in this group. The remaining shaded tracts in Figure 12 were positive (indicating a direct relationship between factor and observation, but most fell below the +1.0 mark).

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[30]Although all 8 groups were analyzed according to the grouping program, only this subregional area was of special spatial significance because of its proximity to the airport, both Dallas and Fort Worth urbanized areas, and adjacent suburban communities.

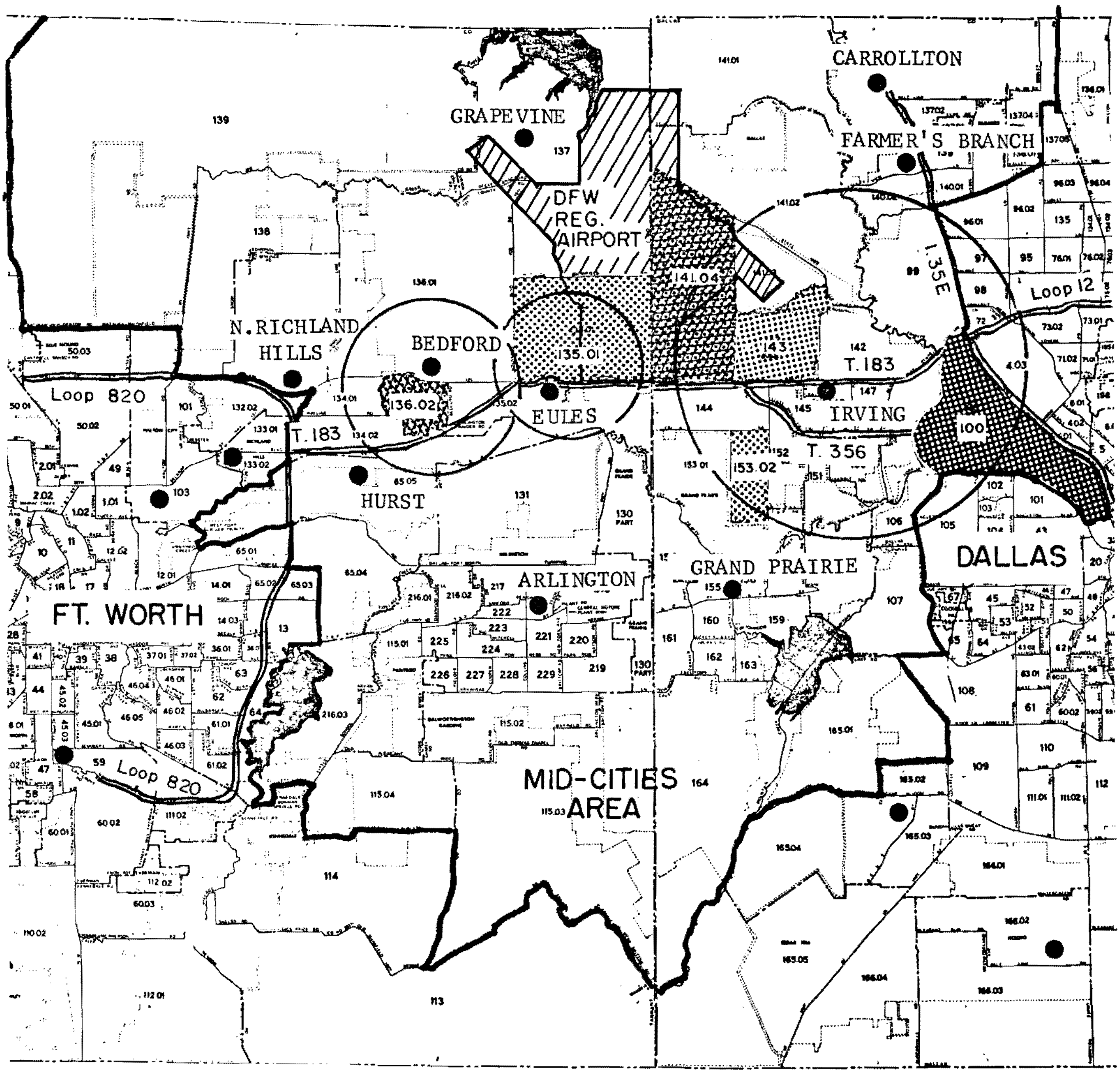

Figure 12. Delineation of Census Tracts Scoring High on 1960/1970 Longitudinal Analysis for Mid-Cities Area

Several theoretical assumptions regarding the changing spatial structure of both Dallas and Fort Worth are evident from these results. Strong indications suggest northwesterly development radiating from Dallas' urbanized center toward the new regional airport site (see Figure 12). This growth seems to parallel two major roadways. One, Interstate Highway 35E leading from Dallas' CBD northward through Farmer's Branch; the second system branches off the first midway through census tract #100 and continues westwardly through Irving to the southern entrance of the DFW Airport. This is Texas Highway 356. Both of these accessways have facilitated the increased rates of growth between Dallas and the airport, which is uniquely illustrated by the unusually high factor score of tract #100 - lying directly between the two at I.35E and Texas Highway 356.

One other Dallas highway also appears to have enhanced the flow of intra-urban migration between Dallas and the regional airport between 1960 and 1970. This is Texas Highway 183, extending east and west between Dallas' Loop 12 and Fort Worth's Loop 820 (See Figure 12). This ground transportation route intersects Hurst and Eules in Fort Worth, carrying through Irving to Loop 12 in Dallas. It provides a direct ground access link between both north Dallas and Fort Worth, their suburban mid-cities communities, and the south-most entrance to the regional airport. It would appear that Irving, Eules, Bedford, and Hurst have all benefited from this ground/air transportation relationship. It seems obvious that both air and ground transportation investments have worked together between these years to influence the spatial structure of metropolitan growth throughout the mid-cities and SMSA regions. This comes as no surprise, since both the literature and actual field surveys concur.[31]

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[31] Wolfe, Harry, <u>op</u>. <u>cit</u>., pp. 17-28; See also Figure 11.

VI. EVALUATION OF PERFORMANCE - ASSESSMENT OF RESULTS

The goal of this investigation has been concerned with describing, explaining, and evaluating the impacts of the new Dallas/Fort Worth Regional Airport on the growth of both the Dallas and the Fort Worth SMSA's. The research was designed to assist in isolating the most important dimensions of airport-related urban changes by delineating a few key variables depicting area changes in land use structure associated with airport development. In turn, these variables were used to assist with separating less airport-affected from more affected areas.

To accomplish these tasks, quantitative factor analytic measurement techniques were utilized in helping separate airport-related growth effects on SMSA development from other, more normal, effects. This probabilistic model input census tract characteristics used as surrogate attributes referencing quality and quantity of occupied space. Attributes or variables indexed change in "quantity of space occupied for different purposes, by census tract, as well as indicating change in quality of space use."[32] In this manner, alterations and shifts in land usage accompanying regional air transportation development were patterned.

The actual methodology followed involved the combination of two separate and distinct factor analyses. The first compared two cross-sectional modes between periods prior to and after construction had begun on the Regional Airport (1960 and 1970). Results highlight the makeup or quality of metropolitan growth for both periods as well as the delineation of actual census tracts experiencing growth changes. The second, a factor analysis of the percentage change differences for each variable characteristic between 1960 and 1970, disclosed those variable types which experienced high differential (ratio) change between time periods. Results revealed the quality of metropolitan growth and development influenced most by the differences in aggregate characteristic change. Again, census tracts experiencing the type of urban

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[32]Burnett, Pat, "Monitoring the Effects of the Dallas/Fort Worth Regional Airport," Task 1, Topic III-B, Council for Advanced Transportation Studies, University of Texas at Austin, Austin, Texas.

change associated with airport development were identified and scaled according to the degree to which they characteristically represented this change. Both of these forms of metropolitan analysis complement one another while, at the same time, remaining distinctly unique. A comparative diagram of these analytical findings is shown in Figure 13. An explanation of the results follows.

AIRPORT-RELATED EMPLOYMENT SHIFTS: 1960 - 1970

Each of the two cross-sectional analyses isolated comparable dimensions of airport-associated urban change. Key occupational and industrial variables depicting an informational profile indirectly associated with airport development were references. These key variable types displayed a quality of metropolitan economic viability for each of the time periods. They included variables measuring the numbers of persons employed in wholesale trades, public administration, machinery, communications/utilities/sanitary services, printing and publishing, and business and repair services. Three characteristic types are interpreted as representatives of "normal" increases in the quality of metropolitan growth between 1960 and 1970. Characteristics representing new employment additions in construction, food and kindred industries, eating and drinking places, and hospitals are seen as more "abnormal" indicators of growth shifts in employment areas economically compatible with secondary, airport infrastructure, development, and activity.

The 1960/1970 longitudinal analysis for this same metropolitan region resulted in a somewhat similar factor profile. Census results referencing employment changes associated with urban and airport development included eating and drinking, hospitals, service workers, salesworkers, machinery, and metal fabricators. These longitudinal results are reflected in similar cross-sectional results; however, differences are visable (see Figure 13). Conceptually, longitudinal results also reflect an emergence of a strong secondary service-sector economy associated with Dallas' and Fort Worth's occupational development between 1960 and 1970. Factor II, the airport-related occupational/employment dimension (see Table 11), represents a foundation from which to measure Dallas' and Fort Worth's changing economic fabric - one which the regional airport indirectly helped influence.

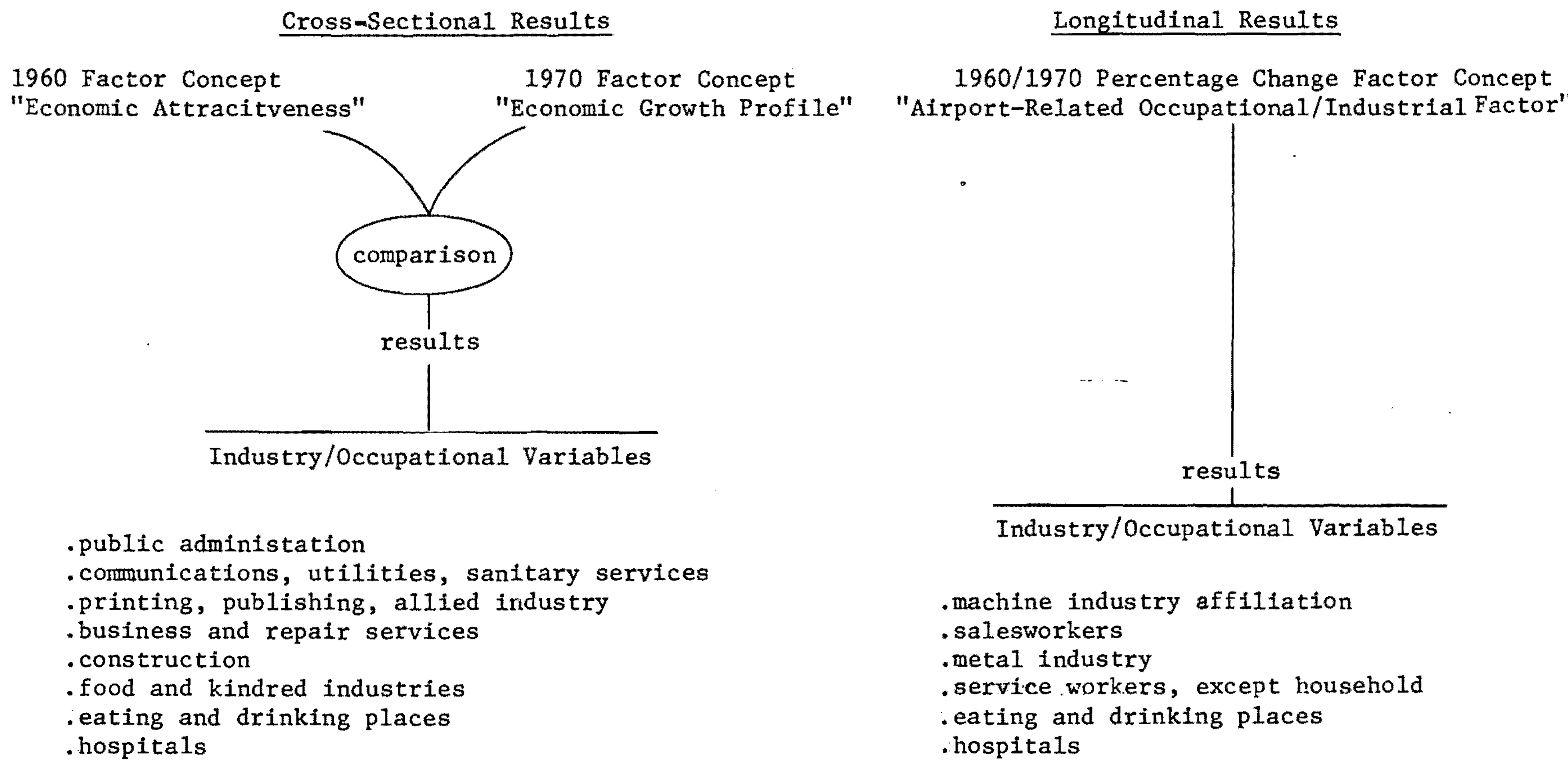

Figure 13. Comparison Between Cross-Sectional and Longitudinal Results

Factor II's occupational and industrial mix compares quite favorably with actual changes in industry and commercial land use developments occurring in and around the airport site between 1960 and 1970. It is hoped that the census characteristics delineated in this longitudinal factor can be monitored from 1970 forward so as to further verify the results reached during this analysis. The systematic monitoring of occupational and employment levels by geographical area would, hopefully, result in a clearer understanding between the changes in subregional physical growth patterns and ensuing socio-economic changes accompanying large regional airport sitings.

AIRPORT-RELATED SPACIAL CHANGES IN URBAN DEVELOPMENT; 1960 to 1970

Spatially, airports are seen as the transfer point from local to intercity vehicle. As in the Dallas/Fort Worth case, geographic, cost, and land requirements (to mention just a few) necessitated the airport's location outside both central business districts and at some distance from their urban influence. For a number of other reasons (i.e., infrastructure development, transport accessibility, etc.), airports and urban/suburban development share a symbiotic relationship although airports are also independent focal points for economic activity in their own right. The sheer size of the DFW Regional Airport implies subregional and regional job market shifts. Consequently, airports often trigger service and retailing employment expansions (additions to regional service-sector activity). These economic effects are often referred to as "multiplier effects."[33] In the past, contributions affected most by airports have included decentralization of restaurants and the proliferation of motel/hotel accomodations.[34] Specific contributions of service sector growth affected by the DFW Airport may be interpreted from the longitudinal factor II, referencing occupational and industrial employment categories. Geographical areas (in this case census tracts) most affected by this service sector economic activity were isolated

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[33] "Major Airports and Their Effects on Regional Planning." Prepared for the fourth meeting of the Urban Environmental Sector Group, Organization for Economic Cooperation and Development, Paris (May 1973); Available through the Superintendent of Documents, U.S. Department of Printing Office, Washington, D.C. 20402.

[34] Ibid.

by degree of occurrence (according to residency) via the longitudinal factor-score subprogram. They may again be inspected by viewing Figures 9, 10, and 11. A visual comparison between the cross-sectional and longitudinal results reveals:

(1) the resulting delineation of two common census tracts for each of the separate analyses - #143, near Irving and the DFW Airport, and #135, located between Eules and the Airport;

(2) the highest scoring cross-sectional census tract is #143 (Dallas) and tract #100 (Dallas) is the highest scoring in the longitudinal analysis;

(3) generally similar spatial findings showing the greatest indirect airport-related shifts in land usage occurring in the suburban communities of Irving, Eules, Bedford, and Hurst.

In judging the results of both forms of factor analysis (cross-sectional and longitudinal), it has been concluded that the longitudinal development of Dallas and Fort Worth is a more accurate measure of developmental change simply because of the nature of the input data (being a 1960/1970 percentage change figure). Consequently, the results are viewed as a more dynamic representation of urban land use change. Thus, census tract #100 (Dallas), paralleling I 35E between Dallas and Irving, is acknowledged as being the most concentrated subarea impacted by the location and anticipated operation of the DFW Regional Airport.

MODEL EVALUATION

The factor model suggests that basic regularities in the behavior of intra-urban spatial structuring can be reduced to more relevant and economically more manageable patterns of interrelated socio-economic occurrences over time. From these generalized patterns of informational mix, more specific, less generalized, patterns have been sought. In particular, a variable pattern or factor representing the effects of a new major airport has been the quest. The approach entailed a quantitative research effort aimed at isolating one cluster of interrelated census characteristics economically associated with indirect airport-related employment changes. From this point, the model proceeded to geographically plot the highest occurrences of these interrelated characteristics by individual census tract.

The results confirmed a logical spatial relationship between airport size and suburban infrastructure (roadways, land use, etc.) development. However, the extent to which this model, or any other, can isolate the influence of an airport on a region from urban development trends in general is unknown.[35] Nonetheless, it is hoped that this model has helped toward realizing a more objective approach of separating the two. Perhaps by assessing some of the model's benefits and limitations, it will help in evaluating the model's potential in light of its actual performance.

Actual Benefits

Actual benefits gained in analyzing census tract information by computer activated factor analytical techniques include savings in both time and cost. With the ability to handle large amounts of information via computerization, factor analysis (like multiple regression) has become a most economical form of evaluation, especially from an areal perspective. Thousands of calculations can be made simultaneously in a matter of seconds. The average time involved in factoring one of the 78 variable - 500 observational matrices - was 150 seconds. Factor scores for this analysis were computed in 15 seconds while the subprogram, CONGROUP, took 13. This savings in time and manpower is directly linked to the savings in cost, since calculations such as these would have taken days and probably would have required a staff of trained assistants. Actual computer costs ranged from $9.50 for a factor analysis to $.85 for CONGROUP - with an additional $1.00 going toward the computation of factor scores.

Indirect savings were also realized as a result of time/cost savings in error reduction and software/hardware compatibility. Minimization of calculation error was realized directly through computerization of information storage and verification of reliability (via storage structure sampling). Little time is involved in checking and rechecking stored figures whenever proper sampling techniques are accurately applied. Since the majority of the software programs used in the model are "canned" packages, they are inexpensive to use and compatible with almost any available computer system.

[35] Ibid.

Potential Benefits

The factor model is not only fast and accurate, it also remains highly versatile. Input data may be restructured and analyzed endlessly. This allows countless alternative forms of analytical investigation while having to acquire only one initial set of characteristic measures. The model also retains the unique ability of being able to convert interrelated data measures to observational z-score scales quickly and accurately. In this manner, an information domain may also be comparatively studied. After analyzing a domain, it may be monitored from time to time using the reduced set of "source" variables resulting from the factoring procedure. By applying simple random or stratified sampling techniques, a domain may also be monitored using up-to-date measures of source variables - thus providing periodic checks for changes which might alter original factor concepts. A substantial savings in time and cost should be realized as a result.

Constraints

Artificially imposed constraints were deemed necessary if the successful outcome of the longitudinal analysis was to be insured. Two explicit conditions were imposed on the calculations of percentage change input data. The first involved the problems of division by zero while the later was a subjective decision to establish a minimum threshold on the difference between 1960 and 1970 variable data figures. During the process of computing the differences between 1960 and 1970 census measures $(\frac{1960-1970}{1960})$, the computer program was instructed to record any 1960-1970 difference less than 30 as a zero. In addition, if any 1960 measure was zero, the program was ordered to replace it with a one. These constraints were added to eliminate insignificant changes between periods as well as to avoid division by zero.

Likewise, constraints were also encountered in the programs themselves. Program constraints were encountered in two of the three areas of analytical undertaking. For one, the initial factor analysis matrix was limited to an eighty item array. As a consequence, the research was able to factor only 78 census variables whereas it would have been beneficial to have included more. With added variable capacity, new factor concepts might well have emerged. The SPSS version of factor analysis was also void of an adequate Q-mode factor capability.[36]

The subprogram CONGROUP was also plagued with limited data input capacities. Instead of a needed 500 item capability, the research had to settle for an eighty item maximum.

One overlooked item, which could have an influence on future research efforts, concerns theoretical presupposition. R. J. Johnston, in a somewhat dated Economic Geography article, additionally warns against taking for granted the inherent linearity which seemingly underlies all urban factorial studies.[37] Johnston makes a point that some of the relationships between information changes might be curvilinear and suggests that perhaps the techniques of path analysis might be appropriately applied to explore additive and asymmetric relationships as well as determining the "relative strength of various causal influences."[38] In future studies, these comments might warrant changes. Additionally, it should be remembered that the basic methodological steps followed during this research are by no means only an end in themselves. Similar conceptual sequences, utilizing different data measures structuring different domains, are just as suitable for factor study. Extensions of this model remain open-ended, requiring only the imagination, information, and calculation for their transference.

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[36] The present research was only concerned with R-mode factor analysis, in which attributes (or variables) are factored for all observations under consideration. The Q-mode analysis is concerned with factoring observations for all attributes under study. In this case, 78 attributes were factored for 500 observations (R-mode analysis). Since a factor matrix is limited to 80 items, a potential Q-mode analysis of 500 observations for 78 attributes was not possible. For a further explanation of the two modes, refer to Nie, Bent, and Hull, op. cit., p. 210.

[37] Johnston, R. J., "Some Limitations of Factorial Ecologies and Social Area Analysis," Economic Geography, Vol. 47, Supplement (June 1971), pp. 314-323.

[38] Ibid., p. 321.

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APPENDIX

Variables Used in the 1960, 1970, and 1960/1970 Analyses

TABLE 13. VARIABLES USED IN THE 1960, 1970, AND 1960/1970 ANALYSES

Variable 1. Total population under five years;
2. ... 5 - 19 years;
3. ... 20 - 44 years;
4. ... 45 - 64 years;
5. ... 65 - over years;
6. Total population Negro;
7. Total population other than Negro and White;
8. Occupation: professional, technical, and kindred workers;
9. ... farmers and farm managers;
10. ... clerical and kindred workers;
11. ... sales workers;
12. ... craftsmen, foremen, and kindred workers;
13. ... operatives and kindred workers;
14. ... private household workers;
15. ... service workers, except household;
16. ... farm laborers and foremen;
17. ... not reported.
18. Industry (employed civilians 14 years and over): mining;
19. ... construction;
20. ... furniture, lumber, and wood;
21. ... metal industry;
22. ... machinery;
23. ... food and kindred industry;
24. ... printing, publishing, and allied;
25. ... R.R. and Railway Express;
26. ... communications, utilities, sanitary services;
27. ... wholesale trade;
28. ... eating and drinking places;
29. ... business and repair services;
30. ... hospitals;
31. ... public administration.
32. Means of transportation to work (14 years and over): railroad;
33. ... bus, streetcar;
34. ... private auto or carpool;
35. ... walk;
36. Family income: Less than or equal to $4,999.00;
37. ... $5,000 - 9,999;
38. ... $10,000 - 14,999;
39. ... $15,000 - 24,999;
40. ... $25,000 - over.
41. Value of housing (owner occupied): under $5,000;
42. ... $5,000 - 9,999;
43. ... $10,000 - 14,999;
44. ... $15,000 - 19,999;

(continued)

TABLE 13 (cont.)

Variable 45. Value of housing (owner occupied): $20,000 - 24,999;
46. ... $25,000 - 34,999;
47. ... $35,000 - over.
48. Gross Rent by month (renter occupied): less than $99.00;
49. ... $100 - 199;
50. ... $200 - more.
51. Units in structure (all occupied and vacant units): one unit; structure;
52. ... 2 unit structures;
53. ... 3 - 4 unit structures;
54. ... 5 - 9 unit structures;
55. ... 10 or more unit structures.
56. Year housing structure built (all occupied and vacant): 1960 and before.
57. Residence in 1955 (65): same house as 1960 (70);
58. ... different house in central city of this SMSA;
59. ... different house in other part of this SMSA;
60. ... different house outside this SMSA in North and West;
61. ... different house outside this SMSA in South;
62. ... different house, same county.
63. Tenure and vacancy status: total units owner occupied;
64. ... total units renter occupied;
65. ... vacant units.
66. Persons in unit (no. of persons all occupied housing units): 1 - 2 persons;
67. ... 3 - 5 persons;
68. ... 6 persons or more.
69. Years school completed (25 years and over): no school years completed;
70. ... 1 - 8 years of school;
71. ... high school, 1 - 3 years;
72. ... high school, 4 years;
73. ... college, 1 - 3 years;
74. ... college, 4 or more years.
75. Employment status (14 years and over): employed civilians;
76. ... unemployed;
77. ... armed forces;
78. ... not in labor force.

(Source: U.S. Bureau of the Census, Population and Housing, Census Tracts for Dallas/Fort Worth SMSA's, 1960 and 1970.)

PART II: COMPUTER SIMULATION OF POLITICAL MODELS OF URBAN LAND USE CHANGE

David Chang
Arthur Friedman
Carl Gregory
Pat Burnett

I. INTRODUCTION

This paper describes the design concepts used to implement a computer simulation of the land use decision model postulated in Chang and Koegal, et al., "Towards Political Decision Models of Urban Land Use Change."[1] To briefly summarize the relevant features of that model, decision making is investigated from both conflict and power perspectives. Conflict occurs as a result of competition (incompatible goals) among behavioral units (groups).[2] Power is the potential of one or more actors to change and attain goals within a social system, while decisions are choices among alternatives that result from the exercise of power (influence).[3] Decision making, then, occurs within structures describing patterns of influence, based on power structures describing patterns of potential influence, operating within a context of conflicting groups. Aiken's decision-making "structure of factions" integrates the above perspectives.[4] While this suggests a group-dominant context,[5] group aims are seen to be expressed by individual leaders (thus allowing

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[1] Chang, D. and J. Koegal, et al., "Toward Political Decision Models of Urban Land Use Change," manuscript for U. S. Department of Transportation by the Council for Advanced Transportation Studies, The University of Texas at Austin, Austin, Texas, 1975.

[2] Boulding, K. E., Conflict and Defense: A General Theory, New York: Harper and Brothers, 1962.

[3] Clark, T. N., "The Concept of Power," in T. N. Clark (ed.), Community Structure and Decision Making: Comparative Analyses, San Francisco, California: Chandler Publishing Company, 1968.

[4] Aiken, M., "The Distribution of Community Power: Structural Bases and Social Consequences," in M. Aiken, et al. (eds.), The Structure of Community Power, New York: Random House, 1970.

[5] Presthus, Robert A., Men at the Top: A Study in Community Power, New York: Oxford University Press, 1964.

utilization of Dahl's concepts of individual-dominant decision making)[6] who gain ascendancy on the basis of three variables: their role perception,[7] their risk-taking propensities,[8] and their unique personalities.[9] These same variables influence the decision-making processes among groups of leaders, with an additional factor being the relative power of the groups each leader represents. The final picture of the model, then, is one of dominant groups and their leaders interacting with subdominant groups and their leaders, while both types of groups also interact among themselves.

It is obvious that this model incorporates many postulates about the actions of individuals within groups, the nature of social structures, and the actions of individuals and groups within social structures. What bearing this has upon the development of a computer simulation can best be seen by first distinguishing between "computer" and "gaming" methods of simulation. Given that simulation is "an attempt to present . . . some facets of reality in a convincing manner for purposes of explanation, manipulation, and analysis,"[10] and that a simulation model is a simulation "governed by some predetermined and consistent rules for handling and manipulating events and information as they are introduced into the simulation,"[11] then a computer simulation is a simulation model in which society is treated "as a system of

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[6]Dahl, Robert A., Who Governs?, New Haven: Yale University Press, 1961.

[7]Kaplan, Harold, Urban Political Systems: A Functional Analysis of Metropolitan Toronto, New York: Columbia University Press, 1967.

[8]Horowitz, Ira, Decision Making and the Theory of the Firm, New York: Holt, Rinehart, and Winston, Inc., 1970.

[9]Megargee, Edwin Inglee, The California Psychological Inventory Handbook, San Francisco: Jossey Bass, 1972.

[10]Kibel, Barry M., Simulation of the Urban Environment, Washington, D. C.: Association of American Geographers, 1972, p. 13.

[11]Ibid., p. 13.

interacting variables which blindly respond to data introduced into the system externally,"[12] while a gaming simulation is a simulation model "in which the model of some institution or organization is imbedded into the rules of a game"[13] that is then played by human actors.[14] The task of the computer simulation of land use decision making, then, is to convert those postulates incorporated within the above model into consistent rules that will govern the manipulation of information independently of human intervention.

Since the postulates of the decision-making model come from a variety of sources, the emphasis on the consistency of rules is crucial in designing the simulation.[15] However, an additional design constraint is imposed by the subject matter of the model itself, namely, the nature of human behavior. This study does not require the existence of "rational economic man"[16] as a prior assumption to the rules of individual or group behavior, but allows the suggestion that "much of the logic behind human reasoning is not the traditional two-valued or even multi-valued logic, but a logic with fuzzy truths, fuzzy connectives, and fuzzy rules of inference."[17] To accomodate these two constraints, the development of the computer simulation occurs in two phases:

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[12] Ibid., p. 13.

[13] Ibid., p. 14.

[14] While this study intends to construct a computer simulation of political decision making, gaming simulations may be used for testing the validity of the computer model, as described in the conclusion.

[15] The Chang and Koegal, et al. paper particularly notes the difficulty of interfacing axioms regarding the nature of variables that are not always instrumentalized to the same degree, citing the variety of approaches by their sources as the cause if disparity in instrumentalization.

[16] Chang and Koegal, et al., op. cit.

[17] Zadeh, Lofti A., "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes," in IEEE Transactions on Systems, Man and Cybernetics, New York: The Institute of Electrical and Electronics Engineers, Inc., Volume SMC-3, Number 1, January 1973, p. 28.

first, the construction of a rigorous rule framework in three stages,[18] followed by a second phase of converting definitive rules into more probabilistic statements at each stage. Each phase of development and simulation is described separately below, followed by a discussion of procedures for testing the validity of the simulation and the predictions of land use decisions based on the results of the simulation. The data used to construct the simulation are the responses of selected leaders, as described in Chang and Koegal, et al.[19] A diagram of the full simulation procedure is shown in Figure 1.

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[18] 1. The definition of profile variables for individual leaders: role-perception, risk-taking tendency, personality measures
2. The effect on "leader" interactions of the positions of their groups within the social power structures.
3. The effect on "leader" interactions of their personality variables.

[19] Chang and Koegal, et al., op. cit. Leaders are selected via the reputational method and responses measured by an abbreviated form of the California Psychological Inventory, as noted in later sections.

DIAGRAM OF MODEL DESIGN PROCESS

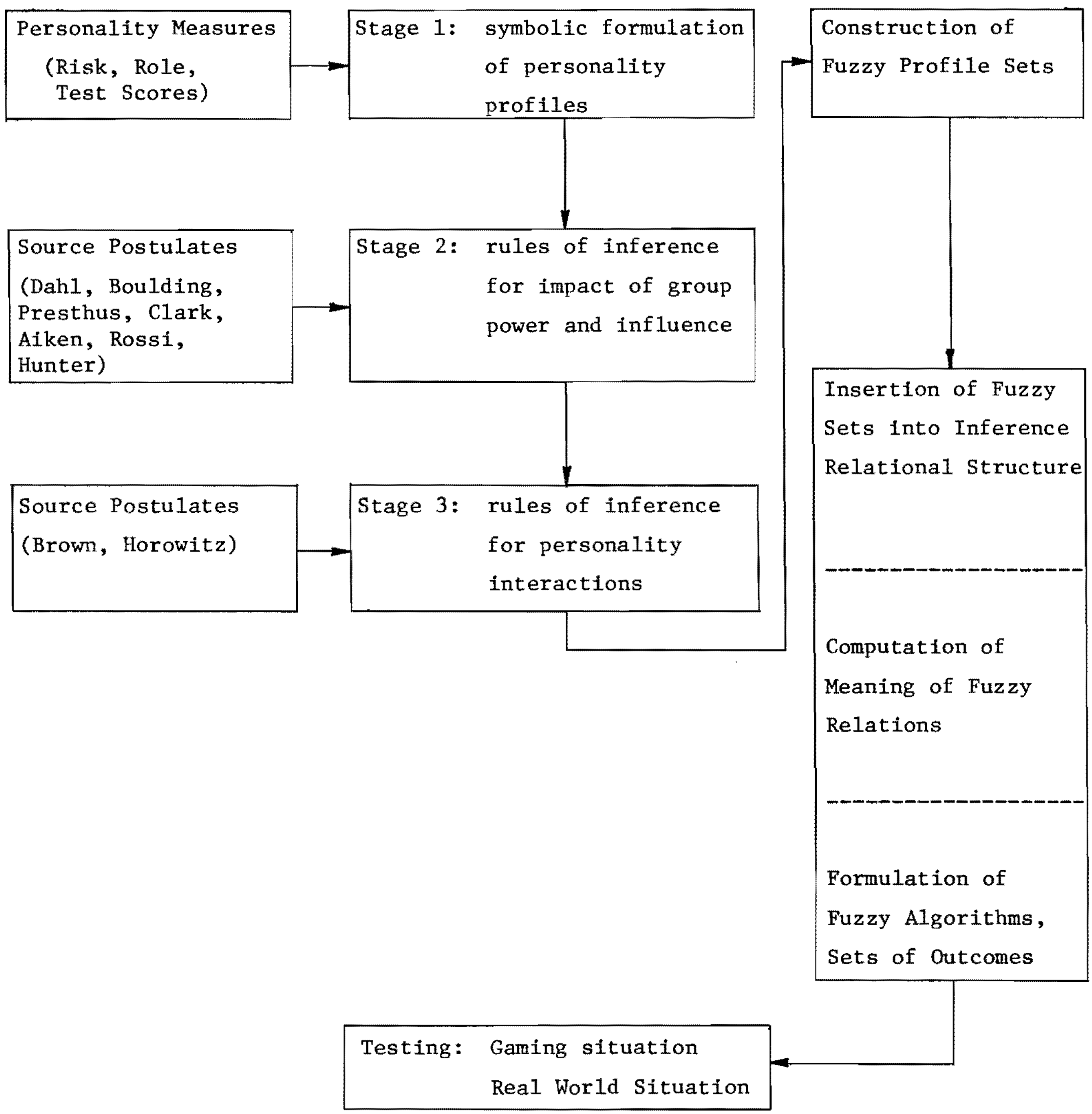

Figure 1.

II. PHASE I: DETERMINISTIC MODEL OF LAND USE DECISION MAKING

INTRODUCTION

The governing rules of the land use decision-making simulation are defined in symbolic logic notation. Briefly, such a notation consists of symbols representing statements, and a means of describing relations between statements. The value of symbolic logic notation in designing the computer simulation is threefold:

a. Mathematical Rigor - the use of symbols is concise, while mathematical logic is both consistent and powerful.

b. Applicability to Linguistic Definitions - the variety of sources for the model postulates have stated those postulates in various forms (for example, Horowitz is generally equational in his description, while other sources are linguistic). The symbolic logic provides a common denominator for expressing both "natural language" and equational statements, an additional contribution of consistency to the simulation design.

c. Convertability to Algorithmic Form - many computer programming languages routinely provide for algorithmic implementation of symbolic logic statements and relations.

The statements symbolized are the definitions and postulated rules of decision-making behavior derived from the noted sources. The conflict and power perspectives described in the previous section produce the four assumptions on which the model is based; the operational definitions follow these assumptions and, together with the resulting behavior postulates, constitute the deterministic model. A discussion of programming procedures is then presented; a listing and sample output from the programmed simulation appear in Appendix A.

MODEL DESCRIPTION

The deterministic model is based upon four assumptions. First, land use is seen as the outcome of decisions of informal or small groups whose members are leaders or representatives of various social groups. Second, land use issues are exogenous with two options, that is, a group is given a choice between an uncertain alternative and a maintenance of the status quo (a guaranteed option) with some relation between the payoffs for each alternative[20] known beforehand by members of the decision-making group (DMG). Third, the relative power of the social groups represented and the personality profiles of their leader-representatives contribute to the formation of a hierarchy within the DMG from which a single leader emerges. Finally, the view of this emergent leader towards the issue under consideration is assumed to prevail. The assumptions are incorporated in three sets of operational definitions:

A. Notational definitions:

a. Personality profile measures:[21]

CS	capacity for status
RE	responsibility
TO	tolerance
SC	self-control
SO	socialization
DO	dominance
FX	flexibility
IE	intellectual efficiency
AC	achievement via conformance
RN	risk neutral
REV	risk evader
RT	risk taker

b. Resources controlled by social groups:[22]

KT	knowledge and specialized technical skills
MC	money and credit
MM	control of mass media
CJ	control over jobs
CV	control over interpretation of values
CO	manpower and control of organizations
SA	social access to community leaders
SS	subsystem solidarity
PO	popularity and esteemed personal qualities
ST	high social status
CF	commitment of followers
LE	legality
RV	the right to vote

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[20] Horowitz, op. cit.

[21] Megargee, op. cit.

[22] Clark, op. cit., pp. 57-58; Rossi, P. H., "Theory, Research, and Practice in Community Organization," in C. R. Adrion (ed.), Social Science and Community Action, East Lansing, Mich.: Institute for Community Development and Services, Michigan State University, 1960; Hunter, F., et al., Community Organization, Chapel Hill, North Carolina: The University of North Carolina Press, pp. 37-39; Dahl, op. cit., pp. 266ff.

c. Additional symbols:

G_M	group represented by leader (M)
L_M	set of profile measures and groups for leader (M)
O_M	option selector (M)
DMG	decision-making group
V(R)	value of resource (R)
GVR	social group rating
O_R	a risky or uncertain option
O_G	a safe or guaranteed option

d. Operations:

$\wedge$	and
$\vee$	or
$\sim$	not
$\rightarrow$	implication (if ... then)
+	arithmetic sum

B. Definitions describing the group structure and the impact of social groups on hierarchy formation:

a. A social group is defined as the set of resources it provides its leader-representative.

$$\begin{aligned} G:\ & (KT \vee \sim KT) \wedge (MC \vee \sim MC) \wedge (MM \vee \sim MM) \wedge \\ & (CJ \vee \sim CJ) \wedge (CV \vee \sim CV) \wedge (CO \vee \sim CO) \wedge \\ & (SA \vee \sim SA) \wedge (SS \vee \sim SS) \wedge (PO \vee \sim PO) \wedge \\ & (ST \vee \sim ST) \wedge (CF \vee \sim CF) \wedge (LE \vee \sim LE) \wedge \\ & (RV \vee \sim RV) \end{aligned}$$

b. A leader (representative) is defined as the set of profile measures and social groups represented by that leader.

$$\begin{aligned} L_M:\ & (CS \vee \sim CS) \wedge (RE \vee \sim RE) \wedge (TO \vee \sim TO) \wedge \\ & (SC \vee \sim SC) \wedge (SO \vee \sim SO) \wedge (DO \vee \sim DO) \wedge \\ & (FX \vee \sim FX) \wedge (IE \vee \sim IE) \wedge (AC \vee \sim AC) \wedge \\ & (RN \vee REV \vee RT) \wedge G_M \end{aligned}$$

c. A decision-making group consists of representatives (or leaders) of social groups.

$$DMG:\ L_1 \wedge L_2 \wedge L_3 \wedge \ldots \wedge L_M$$

d. A social group's rating is the sum of the exchange, prestige, institutional importance, power, or general applicability values of its resources.[23]

$$GVR: V(R_1) + V(R_2) + \ldots + V(R_N) \qquad (N \leq 13)$$

$$V = V_{EXCH} \vee V_{PRST} \vee V_{INST} \vee V_{POWR} \vee V_{GAPP}$$

e. The option selectors are members of the decision-making group who represent the social group(s) with the highest rating(s) present.

$$GVR(G_M) > GVR(G_N) \rightarrow O: L_M$$

C. Definitions describing the impact of personality on hierarchy formation:[24]

a. If a leader is intellectually efficient and is a risk-taker, the leader is risky.

$$IE \wedge RT \rightarrow RISKY$$

b. If a leader is responsible and has high achievement via conformance and socialization, the leader is likable.

$$RE \wedge AC \wedge SO \rightarrow LIKABLE$$

c. If a leader is dominant and flexible and has high capacity for status and achievement via conformance, the leader is a participator.

$$DO \wedge FX \wedge CS \wedge AC \rightarrow PARTICIPATOR$$

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[23] Ibid.

[24] Megargee, op. cit.; Brown, R., Social Psychology, New York: The Free Press, 1965, pp. 583-585.

From the assumptions and definitions above, the following postulates are made describing the formation of the option selector hierarchy, the identification of the DMG leader, and the option selected by that leader:

A. The option selector hierarchy:[25]

a. If a leader is a participator and is likable and is risky, the leader is the first option selector.

$$\text{PARTICIPATOR} \wedge \text{LIKABLE} \wedge \text{RISKY} \rightarrow O_1$$

b. If a leader is a participator and is likable and is not risky, the leader is the second option selector.

$$\text{PARTICIPATOR} \wedge \text{LIKABLE} \wedge \sim\text{RISKY} \rightarrow O_2$$

c. If a leader is a participator and is not likable and is risky, the leader is the third option selector.

$$\text{PARTICIPATOR} \wedge \sim\text{LIKABLE} \wedge \text{RISKY} \rightarrow O_3$$

d. If a leader is not a participator and is likable and is risky, the leader is the fourth option selector.

$$\sim\text{PARTICIPATOR} \wedge \text{LIKABLE} \wedge \text{RISKY} \rightarrow O_4$$

e. If a leader is a participator and is not likable and is not risky, the leader is the fifth option selector.

$$\text{PARTICIPATOR} \wedge \sim\text{LIKABLE} \wedge \sim\text{RISKY} \rightarrow O_5$$

f. If a leader is not a participator and is not likable and is risky, the leader is the sixth option selector.

$$\sim\text{PARTICIPATOR} \wedge \sim\text{LIKABLE} \wedge \text{RISKY} \rightarrow O_6$$

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[25] after Brown, op. cit.

g. If a leader is not a participator and is likable and is not risky, the leader is the seventh option selector.

$\sim$ PARTICIPATOR $\wedge$ LIKABLE $\wedge$ $\sim$RISKY $\rightarrow O_7$

h. If a leader is not a participator and is not likable and is not risky, the leader is the eighth option selector.

$\sim$ PARTICIPATOR $\wedge \sim$ LIKABLE $\wedge \sim$ RISKY $\rightarrow O_8$

i. The decision-making group leader is the highest ranked option selector present.

B. Option selection:

a. The choice consists of an uncertain option, a guaranteed option, and some relationship between the two options.

$(O_R > O_G) \vee (O_R = O_G) \vee (O_R < O_G)$

b. If the DMG leader is a risk taker, the uncertain option is chosen.

$RT \rightarrow O_R$

c. If the DMG leader is linear in risk, the guaranteed option is chosen.

$RN \rightarrow O_G$

d. If the DMG leader is a risk evader and $O_R > O_G$, the uncertain option is chosen.

$REV \wedge (O_R > O_G) \rightarrow O_R$

e. If the DMG leader is a risk evader and $O_R \leq O_G$, the guaranteed option is chosen.

$REV \wedge (O_R \leq O_G) \rightarrow O_G$

SIMULATION PROGRAM DESCRIPTION

The simulation model is written in APL for a DEC-10 model computer. As opposed to a language like FORTRAN, APL is a functional code with little branching, subroutine calling, or matrix definition apparent in the coding sequence; the principal advantage of using APL is the power of its operators in manipulating matrix structures (as shown, personality profile and social group resource data are assembled in arrays). Analysis of the code, however, is difficult for the untrained: arrays are defined interactively and so are not printed with the program listing, the precise effect of the specialized operations on the data is not readily apparent, and text presentation is sparse due to the weak formatting and alphanumeric storage capabilities of the language.

A precise analysis of the programming output is necessarily left to the programmer trained in APL. The algorithms for simulating the various model statements are presented, and the program routines responsible for the algorithm execution are noted.

A. Data representation:

Social groups are defined as vectors of resources, while leaders are two-dimensional arrays consisting of a vector of personality profile measures and a vector of social groups represented. Group, profile, and resource symbols are numbered sequentially and defined as variables for indexing purposes: a leader's measure of capacity for status, for example, may be referenced by either L[1] or L[CS] .

a. Social groups identified for this study include:[26]

CC	City Council
ZB	Zoning Board of Adjustments and Appeals
ZC	Zoning Commission
CD	City Departments
SB	School Board
RC	Real Estate/Banking
SOB	Southern Baptist Convention
OTH	Other Religious Groups
COC	Chamber of Commerce
LWV	League of Women Voters
RP	Republican Party
COG	Council of Governments

[26] Pertinent social groups were identified, through leader interviews and other social contacts in the study area, according to control of social resources identified by the study.

b. Array values for leaders:

    1 : profile score above midrange (e.g., CS)
    0 : profile score below midrange (e.g., ~CS)
    1 : member of social group (e.g., CC)
    0 : non-member of social group (e.g., ~CC)

c. Vector values for social groups:

    1 : control of resource (e.g., KT)
    0 : non-control of resource (e.g., ~KT)

B. Definition algorithms:

a. The DMG is defined as a three-dimensional array LEADERS of the leader arrays. The first index is the leader number, the second is 1 for the leader's profile vector and 2 for the leader's group representation vector. These may be accessed singly or en masse; thus, LEADERS [; 1 ; CS , DO] and LEADERS [; 2 ; LWV] refer to <u>all leaders'</u> capacity for status, dominance, and membership in the League of Women Voters.

b. Social groups are collected in the array of group vectors GRESOURCES, while RATINGS consists of the resource values for each index.[27] Rating values are computed as the cross product of GRESOURCES and RATINGS by function GPOWER. GRANK orders the social groups from highest to lowest rating and GPRESENT determines which social groups are represented by the DMG leaders; DECIDERS then isolates those leaders who are members of the highest ranking groups.

c. Leaders who are risky, likable, and participators are isolated in routines RISKY, LIKABLE, and PARTICIPATOR, respectively. The algorithms used are direct executions of the symbolic definitional statements.

C. Postulate algorithms:

a. The function HIERARCHY sequentially executes the symbolic postulate statements to determine the highest ranked option selector present.

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[27] See note 22.

b. The "driver" function CHOOSE prints the LEADERS matrix, identifies the CHOOSER selected by HIERARCHY, determines CHOOSER's risk-taking propensity, and selects the predicted option choice.

All execution of the program is interactive; arrays are displayed by entering their names, functions are listed by executing the function DOCUMENT, and the simulation is enacted with the "command" (functional call): LEADERS CHOOSE OPTIONS.

III. PHASE II: STOCHASTIC MODEL OF LAND USE DECISION MAKING

INTRODUCTION

As mentioned in the introduction, it is not the wish of this study to model decision-making behavior as though human actors blindly obey textbook postulates describing the expected behavior. Yet, in order to provide a consistent rule framework for the simulation from a variety of source data, the design thus far described is necessarily mechanistic. The next task of the design process is to replace deterministic rules of inference with more probabilistic statements of behavior while preserving mathematical precision and logical consistency in the simulation rule framework.

One approach to this task can be to inject a quasi-randomness to the rules of inference by assigning probabilities to their expected occurrence, rather than assuming their certainty. For example, rather than stating that "given two leaders with profiles L_1 and L_2, the decisions of L_1 will be carried out," the model would assign "weights" to the impacts of the profile variables for L_1 and L_2 so that some value of expected result might be stated: "The decisions of L_1 will be carried out 73 percent of the time." These statements would then be testable postulates of the simulation model.

Such an approach, however, is very dependent on a subjective weighting system, which very likely could not be justified by only a single piece of source material. The danger is of applying patchwork adjustments for the sake of "realism" to a logical rule framework designed to <u>overcome</u> the discrepancies between diverse source materials, which is clearly at cross purpose with the first phase of design. So while the "weighting" approach might serve as an intermediate step for checking purposes, a preferable approach to the task of the second design phase is to employ "a methodological framework which is tolerant of imprecision and partial truths..."[28] but "is actually quite precise and rather mathematical in spirit,"[29] i.e., the use of fuzzy sets and fuzzy algorithms.

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[28] Zadeh, <u>op</u>. <u>cit</u>., p. 29.

[29] <u>Ibid</u>., p. 30.

DESCRIPTION OF FUZZY METHODOLOGY

The development of the "fuzzy" approach to the analysis of decision processes is largely the work of Zadeh.[30] An understanding of this approach requires some definitions of fuzzy sets, operations, and algorithms, which in turn utilize a unique notation for their expression. While no notation is universally used to represent logical expressions, and thus no symbology may be called "standard," Zadeh's notation is particularly divergent from that used previously in this study and from mathematical notations in general. Especially confusing is the use of $\int$ to represent a set, + to denote the union of two elements or sets, $\vee$ for maximum, and $\wedge$ for minimum. Since the land use decision model utilizes $\vee$, $\wedge$, and + to represent the operations <u>and</u>, <u>or</u>, and <u>arithmetic sum</u>, respectively, alternate symbols taken from the APL character set are used in the definitions below.

A. Fuzzy Notation and Operations[31]

A <u>fuzzy set</u> consists of a set of elements and their corresponding degrees of membership in that set. Thus, for each element y_n in a set A there exists a membership function $\mu_A(y_n)$ which defines the extent to which y_n "belongs to" A as a number in the range $0 \le \mu_A(y_n) \le 1$. The fuzzy set A is then defined as the union of all its elements with associated membership functions $(\mu_A(y_n)/y_n)$. Specifically, for a set of scores which measure Capacity for Status,

CS: {0, 1, 2, ..., 11, 12} ,

the fuzzy set for the descriptive measures "high, moderate, and low" capacity for status are defined:

HIGH CS: .1/2 ∧ .2/3 ∧ .2/4 ∧ .4/5 ∧ .5/6 ∧
.6/7 ∧ .8/8 ∧ .8/9 ∧ .9/10 ∧ 1/11 ∧ 1/12

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[30] Zadeh, 1973, <u>op</u>. <u>cit</u>.; see also Zadeh, "Quantitative Fuzzy Semantics," <u>Information Sciences</u>, Vol. 3, 1971.

[31] Zadeh, 1973, <u>op</u>. <u>cit</u>., pp. 30-34 except as symbolic differences are noted.

MODERATE CS: $.1/1 \wedge .2/2 \wedge .5/3 \wedge .8/4 \wedge .9/5 \wedge 1/6 \wedge$
$.9/7 \wedge .8/8 \wedge 5/9 \wedge .8/10 \wedge .1/11$

LOW CS: $1/0 \wedge 1/1 \wedge .9/2 \wedge .8/3 \wedge .8/4 \wedge .6/5 \wedge$
$.5/6 \wedge .4/7 \wedge .2/8 \wedge .2/9 \wedge .1/10$

Thus, for a leader L_M whose profile score for CS is 11,

$$\mu_{HIGH\ CS}(L_M) = 1$$

$$\mu_{MED\ CS}(L_M) = .1$$

$$\mu_{LOW\ CS}(L_M) = 0$$

Since the score for L_M is more completely a member of HIGH CS than of MED CS or LOW CS, the leader may be said to have "high capacity for status," or

$$CS = HIGH/L_M \quad \text{for} \quad (\mu_{HIGH\ CS}(L_M) > \mu_{MED\ CS}(L_M)) \wedge (\mu_{HIGH\ CS}(L_M) > \mu_{LOW\ CS}(L_M))$$

The following operations are then applied to fuzzy sets and their elements:

a. Maximum $(a \ulcorner b)$

$$a \ulcorner b = \max(a,b) = \begin{cases} a, & \text{if } a \geq b \\ b, & \text{if } a < b \end{cases}$$

b. Minimum $(a \llcorner b)$

$$a \llcorner b = \min(a,b) = \begin{cases} a, & \text{if } a \leq b \\ b, & \text{if } a > b \end{cases}$$

c. Union $(A \vee B)$

$$A \vee B = \{\mu_u(y)/y : \mu_u(y) = \mu_A(y) \ulcorner \mu_B(y)\}$$

d. Intersection $(A \wedge B)$

$$A \wedge B = \{\mu_i(y)/y : \mu_i(y) = \mu_A(y) \llcorner \mu_B(y)\}$$

e. Complement $(\neg A)$

$$\neg A = \{\mu_c(y)/y : \mu_c(y) = 1 - \mu_A(y)\}$$

f. Product (AB)

$$AB = \{\mu_p(y)/y : \mu_p(y) = \mu_A(y) \cdot \mu_B(y)\}$$

corollary:

for $\alpha > 0$,

$$A^{\alpha} = \{\mu_e(y)/y : \mu_e(y) = (\mu_A(y))^{\alpha}\}$$

$$\alpha A = \{\alpha\mu_A(y)/y\}$$

g. Concentration (CON A)

$$\text{CON } A = A^2$$

h. Dilation (DIL A)

$$\text{DIL } A = A^{0.5}$$

i. Contrast Intensification (INT A)

$$\text{INT } A = \begin{cases} 2A^2 & \text{for } 0 \le \mu_A(y) \le 0.5 \\ \neg[2(\neg A)^2] & \text{for } 0.5 \le \mu_A(y) \le 1 \end{cases}$$

The specific effects of each of these operations are shown in the description of the fuzzy logic model.

B. Overview of Changes and Extensions

Some preparatory remarks may help in understanding the specific features of the fuzzy logic model. Four basic features of the deterministic model are affected by the introduction of the fuzzy methodology. First, personality profile measures for each leader are now given descriptors (HIGH, MED, LOW) according to their membership in the corresponding fuzzy sets. The attributes of likability, participator, and riskiness may also have fuzzy descriptors which are functions of the descriptors for the profile measures; moderate likability, for example, is determined by a leader's "moderateness" in responsibility, achievement via conformance, and socialization. Thus, while there are no "scores" for participation, likability, and riskiness for leaders, these attributes still have certain degrees of membership in the fuzzy descriptor sets HIGH, MED, and LOW. Decision-making activity is then discussed, not according to a leader's <u>being</u> likable, risky, or a participator, but according to each leader's degree of likability, riskiness, or participation.

Second, the concept of rating represented social groups remains presently unchanged. The procedure of determining group ratings through the use of resource measurements has the effect of assigning each group a membership in a fuzzy set labeled "powerful" or "influential," and so constitutes an approximate fuzzy algorithm. The necessary steps for truly fuzzifying the impact of represented social groups on the land use decision are 1) to make each group's membership in "powerful" a function, not only of resources, but of the nature of the issue under consideration, and 2) to make each leader's influence a function of his degree of membership in the various social groups. Presently, simple inclusion in a social group is all that has been measured by this study.

The third feature of the deterministic model affected by the fuzzy methodology is the concept of hierarchy formation within the DMG. While this concept has served to sensitize the study to the dynamics of personality factors and emergent leadership in decision-making processes, it has also caused some specific modeling problems. More characteristic of formal organizations, hierarchy formation tends to be inflexible as a theoretical concept for informal groups. The static roles defined by a hierarchy are used to advantage in the deterministic model: more than two leaders can "qualify" for the same hierarchical position, but the role played in the decision process is what is crucial to the model, not the number of DMG members who exercise that role. A stochastic model must have the ability to distinguish more accurately the dynamics of the individual personalities being modeled; the emphasis is now placed on the development of the option selectors' dispositions toward an issue and how these separate tendencies produce an aggregate decision. To implement this aggregate behavior, a theoretical structure based on the polarization effect in group discussion is formed.[32]

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[32]Meyers, D. G. and H. Lamm, "The Polarizing Effect of Group Discussion," American Scientist, Vol. 63, May-June 1975.; Brown, op. cit.; This effect is an expansion of what was termed the "shift to risk."

Finally, the option selection process is fuzzified. Land use issues are still assumed to be exogenous; the choice is still basically between a guaranteed and an uncertain alternative. However, a measure of the option selectors' perceptions of the relative payoffs of the two alternatives is defined as a fuzzy singleton, which through the option selection process produces a "score" for the group's disposition toward the issue. As in the case of the attributes of likability, participation, and riskiness, this "score" is theoretical, but its membership in the fuzzy descriptor sets HIGH, MED, and LOW allow the option selectors' tendency toward change to be examined in terms of the issue at hand. HIGH or LOW tendencies indicate the choice of the uncertain or guaranteed option, respectively. The ability to measure a moderate tendency in either direction allows the model to indicate the likely introduction of a third option from within the DMG; this is seen as a first step toward the modeling of endogenous issue definition in land use decisions, as will be discussed in the final section.

MODEL DESCRIPTION

The fuzzy logic model is based on the following Assumptions:

A. Land use is the outcome of the decisions of informal or small groups.

B. A decision-making group (DMG) acts on an exogenous issue with two options: to choose an "uncertain" alternative or a "guaranteed" option (usually to maintain the status quo).[33] The group perceives some relation of payoff between the alternatives, and an additional possibility of group ambiguity toward the two options exists, indicating the probability that a third alternative may arise.

C. A subgroup of option selectors emerges according to the power of social groups represented by members of the DMG, and according to the personality profiles of the leader-representatives.

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[33] The classic notion of "guarantee" and "uncertainty" does not imply that the expected payoff of the guaranteed option is necessarily higher than that of the uncertain alternative; indeed, the latter may sometimes be less "risky" than the former (see Horowitz, op. cit.). The model does not demand that these labels hold to the von Neumann definition; the choice may be between two "uncertain" alternatives with some perception of relative payoff. In this case the "uncertain" option is the "riskier" option. "It is one thing to purloin finely-tempered steel, and another to take a pound of literary old iron, and convert it in the furnace of one's mind into a hundred watchsprings, worth each a thousand times as much as the iron."(Anon.)

D. The Option Selector subgroup (OS) reinforces its perceived relationship between the options (i.e., the OS "shifts") to form some predisposition; the aggregate OS disposition is derived from this "shifted" predisposition, which determines the group's tendency toward change.

E. A DMG's decision is a function of its tendency toward change.

These assumptions require the following Operational Definitions:

A. Notational definitions:

a. Personality Profile Symbols:

CS	Capacity for Status
RE	Responsibility
TO	Tolerance
SC	Self-Control
SO	Socialization
DO	Dominance
FX	Flexibility
IE	Intellectual Efficiency
AC	Achievement via Conformance
RSK	Risk-taking propensity

b. Group Resources:

KT	Knowledge and Specialized Technical Skills
MC	Money and Credit
MM	Control of Mass Media
CJ	Control Over Jobs
CV	Control Over Interpretation of Values
CO	Manpower and Control of Organizations
SA	Social Access to Community Leaders
SS	Subsystem Solidarity
PO	Popularity and Esteemed Personal Qualities
ST	High Social Status
CF	Commitment of Followers
LE	Legality
RV	The Right to Vote

c. Additional Symbols:

DMG	Decision-Making Group
G	Represented Social Group
L	Leader (member of DMG)
OS	Option Selector Subgroup
$V_N(R)$	Value of Resource (R) according to scale N (N = EXCH, PRST, INST, POWR, GAPP)
EXCH	Exchange value scale
PRST	Prestige value scale
INST	Institutional Importance value scale

POWR	Power value scale
GAPP	General Applicability value scale
VR(G)	Value Rating of (G)
AG	"Guaranteed" Alternative
AU	"Uncertain" Alternative
PD	Predisposition towards issue
DP	Disposition towards issue
PC	Perception of issue

B. Definitions describing group structure and the impact of groups on the makeup of the DMG:

a. A social group is defined as the set of resources which it provides its leader-representatives.

$$G : (KT \vee \sim KT) \wedge (MC \vee \sim MC) \wedge (MM \vee \sim MM) \wedge (CJ \vee \sim CJ) \wedge (CV \vee \sim CV) \wedge (CO \vee \sim CO) \wedge (SA \vee \sim SA) \wedge (SS \vee \sim SS) \wedge (PO \vee \sim PO) \wedge (ST \vee \sim ST) \wedge (CF \vee \sim CF) \wedge (LE \vee \sim LE) \wedge (RV \vee \sim RV)$$

b. A representative or leader is defined as the set of personality profile measures and groups represented.

$$L : \mu_{CS}(L) \wedge \mu_{RE}(L) \wedge \mu_{TO}(L) \wedge \mu_{SC}(L) \wedge \mu_{SO}(L) \wedge \mu_{DO}(L) \wedge \mu_{FX}(L) \wedge \mu_{IE}(L) \wedge \mu_{AC}(L) \wedge \mu_{RSK}(L) \wedge G$$

c. A decision-making group is composed of leaders of social groups.

$$DMG = L_1 \wedge L_2 \wedge L_3 \wedge \ldots \wedge L_M$$

d. The rating of a social group is the sum of the values of its resources according to a particular scale.

$$VR_N(G) : V_N(R_1) + V_N(R_2) + \ldots + V_N(R_M) , M \leq 13$$

C. Personality trait definitions:

a. A leader's intellectual efficiency and his risk-taking propensity determine his "riskiness."

$$IE \wedge R \rightarrow RSKY$$

b. A leader's responsibility and his achievement via conformance and his socialization determine his "likability."

$$RE \wedge AC \wedge SO \rightarrow LIKABLE$$

c. A leader's dominance and his flexibility and his capacity for status and his achievement via conformance determine his "participation."

$$DO \wedge FX \wedge CS \wedge AC \rightarrow PARTICIPATE$$

Given the preceding assumptions and operational definitions, the model asserts the following Postulates describing the land use decision-making process:

A. Emergence of Option Selector subgroup

a. The option selectors are members of the decision-making group who represent the social group(s) with the highest rating(s) present.

b. The option selectors are members of the DMG who participate highly and are highly likable.

$$OS : L(HIGH/PARTICIPATE) \wedge L(HIGH/LIKABLE)$$

c. If no members of the DMG participate highly and are highly likable, the option selectors are members of the DMG who participate highly.

$$OS : L(HIGH/PARTICIPATE)$$

d. If no members of the DMG participate highly, the leader of the DMG is any risk-taker, and the uncertain alternative is chosen.[34]

e. If no member of the DMG is a risk-taker, the guaranteed option is chosen.[35]

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[34] i.e., the process "defaults" to a leader-dominant hierarchy in the absence of participation. See Brown, op. cit., p. 687.

[35] i.e., the process "defaults" to inertia in the absence of participation and risk-taking.

B. Option Selection

a. The "payoff" of choosing the uncertain alternative is perceived by the option selectors as either greater than, equal to, or less than the "payoff" of choosing the guaranteed option. The uncertain alternative is then regarded as safe, neutral, or risky, respectively.

$$(AU > AG \rightarrow SAFE/AU) \vee (AU = AG \rightarrow NEUTRAL/AU) \vee (AU < AG \rightarrow RISKY/AU)$$

b. The perception of the uncertain alternative is determined either as an inherent quality of the issue, or as the average of the risk-taking characteristics of the option selectors.[36]

$$PC : \frac{\Sigma OS_{RSK}}{\#OS}$$

c. If the uncertain alternative is perceived to be risky, the subgroup's predisposition toward the issue is the set of intensified risk-taking characteristics of the option selectors.[37]

$$PD : INT(OS_{RSK})$$

d. If the uncertain alternative is perceived to be neutral, the subgroup's predisposition toward the issue is the set of risk-taking characteristics of the option selectors.[38]

$$PD : OS_{RSK}$$

e. If the uncertain alternative is perceived to be safe, the subgroup's predisposition toward the issue is the set of diluted risk-taking characteristics of the option selectors.[39]

$$PD : DIL(OS_{RSK})$$

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[36] Meyers and Lamm, op. cit., p. 298.

[37] Zadeh, 1973, op. cit., p. 32.

[38] Ibid., p. 30.

[39] Ibid., p. 32.

f. The subgroup's final disposition toward the issue is the average of the members' "shifted" predispositions.[40]

$$PD : \frac{\Sigma PD}{\#PD}$$

g. If the subgroup's final disposition is risky, the uncertain alternative is chosen.

RISKY/DP → AU

h. If the subgroup's final disposition is safe, the guaranteed option is chosen.

SAFE/DP → AG

i. If the subgroup's final disposition is neutral, no decision is predicted, indicating either a "default" to status quo maintenance or an ambiguous situation in which group interaction could produce a more satisfactory third alternative due to the introduction of new information.

SIMULATION PROGRAM DESCRIPTION

A listing of the APL language simulation of the stochastic model appears in Appendix B. A description of the algorithm used to implement the model is presented using the operational definitions above, followed by some discussion of certain programming techniques. The simulation is enacted by the "driver" function, EXECUTE.

A. Fuzzy set definition for personality profile measures:

For each profile measure, the leader receives a score in the range $0 \leq SCORE \leq MAX$. The fuzzy descriptor sets HIGH, MED, and LOW are defined, respectively, by projecting ascending, peaking, and descending sections of the cosine curve onto this range according to the formulae:

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[40]Meyers and Lamm, op. cit., p. 298.

$$\mu_{HIGH} = \frac{1 + \cos[\pi(1 + \frac{SCORE}{MAX})]}{2}$$

$$\mu_{MED} = \frac{1 + \cos[\pi(1 + 2(\frac{SCORE}{MAX}))]}{2}$$

$$\mu_{LOW} = \frac{1 + \cos[\pi(\frac{SCORE}{MAX})]}{2} \quad .$$

A graphic representation of the resultant curves for each profile measure appears in Appendix C. Note that while scores occupy discrete points, the descriptor sets are still seen as continuous curves for application to characteristics such as likability which have no scores but only computer membership in the descriptor sets.

Risk-taking propensity is itself a descriptor, with the labels EVADER, NEUTRAL, and TAKER standing for membership functions of 0, 0.5, and 1, respectively.

APL functions: HIGH, MED, LOW, MUHIGH, MUMED, MULOW

B. Algorithms for computing personality trait membership in fuzzy descriptor sets:

Zudeh correlates the linguistic connectives and, or, and the negation not with the operations intersection, union, and complement,[41] respectively. The algorithms, then, follow directly from the operation definitions and personality trait definitions above, and involve simply taking the minimum of relevant membership functions for each leader.

$$\mu_{HIGH\ RSKY}(L) = [\mu_{HIGH\ IE}(L)] \lfloor [RSK(L)]$$

$$\mu_{MED\ RSKY}(L) = [\mu_{MED\ IE}(L)] \lfloor [RSK(L)]$$

$$\mu_{LOW\ RSKY}(L) = [\mu_{LOW\ IE}(L)] \lfloor [RSK(L)]$$

$$\mu_{HIGH\ LIKABLE}(L) = [\mu_{HIGH\ RE}(L)] \lfloor [\mu_{HIGH\ AC}(L)] \lfloor [\mu_{HIGH\ SO}(L)]$$

$$\mu_{MED\ LIKABLE}(L) = [\mu_{MED\ RE}(L)] \lfloor [\mu_{MED\ AC}(L)] \lfloor [\mu_{MED\ SO}(L)]$$

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[41]Zadeh, 1973, op. cit., p. 32.

$$\mu_{LOW\ LIKABLE}(L) = [\mu_{LOW\ RE}(L)] \llcorner [\mu_{LOW\ AC}(L)] \llcorner [\mu_{LOW\ SC}(L)]$$

$$\mu_{HIGH\ PARTICIPATE}(L) = [\mu_{HIGH\ DO}(L)] \llcorner [\mu_{HIGH\ FX}(L)] \llcorner [\mu_{HIGH\ CS}(L)] \llcorner [\mu_{HIGH\ AC}(L)]$$

$$\mu_{MED\ PARTICIPATE}(L) = [\mu_{MED\ DO}(L)] \llcorner [\mu_{MED\ FX}(L)] \llcorner [\mu_{MED\ CS}(L)] \llcorner [\mu_{MED\ AC}(L)]$$

$$\mu_{LOW\ PARTICIPATE}(L) = [\mu_{LOW\ DO}(L)] \llcorner [\mu_{LOW\ FX}(L)] \llcorner [\mu_{LOW\ CS}(L)] \llcorner [\mu_{LOW\ AC}(L)] .$$

APL functions: RSKY, LIKABLE, PARTICIPATE

C. Algorithms for postulate implementation:

Social group definition, rating, ranking, and selection is performed as in the deterministic model simulation.

APL functions: GPOWER, GRANK, GPRESENT, DECIDERS.

a. The selection of highly likable leaders who participate highly follows from the example given in Fuzzy Notation and Operations above, i.e.,

$$\text{PARTICIPATE} = \text{HIGH}/L_M \quad \text{for } [\mu_{HIGH\ PARTICIPATE}(L_M)] > [\mu_{MED\ PARTICIPATE}(L_M)]$$

$$\text{and } [\mu_{HIGH\ PARTICIPATE}(L_M)] > [\mu_{LOW\ PARTICIPATE}(L_M)]$$

$$\text{PARTICIPATE} \wedge \text{LIKABLE} = \text{HIGH}/L_M \quad \text{for}$$

$$\{[\mu_{HIGH\ PARTICIPATE}(L_M)] \llcorner [\mu_{HIGH\ LIKABLE}]\} > \{[\mu_{MED\ PARTICIPATE}(L_M)] \llcorner [\mu_{MED\ LIKABLE}(L_M)]\}$$

$$\text{and} \{[\mu_{HIGH\ PARTICIPATE}(L_M)] \llcorner [\mu_{HIGH\ LIKABLE}]\} > \{[\mu_{LOW\ PARTICIPATE}(L_M)] \llcorner [\mu_{LOW\ LIKABLE}(L_M)]\} .$$

Each leader is represented as a vector in the matrix of profile scores that represents the DMG; selection then is simply a process of isolating row indices for the matrix.

APL function: OSS

b. The OS group's perception of the issue, if not given, is the complemented average of the riskiness of the OS members:

$$PC = \neg \left| \frac{\Sigma\mu_{HIGH\ RSKY}(OS_M)}{M} \right|$$

The descriptors SAFE, NEUTRAL, and RISKY correspond to LOW, MED, and HIGH, respectively:

$$\mu_{SAFE\ PC}(OS) = \frac{1 + \cos[\pi(PC)]}{2}$$

$$\mu_{NEUTRAL\ PC}(OS) = \frac{1 + \cos[\pi(1 + 2PC)]}{2}$$

$$\mu_{RISKY\ PC}(OS) = \frac{1 + \cos[\pi(1 + PC)]}{2}$$

APL functions: COM, ENACT

c. The shifting process, essentially reinforcing the initial perception,[42] utilizes either the INT or DIL function, or none at all, as defined in Fuzzy Notation and Operations above. An option perceived to be safe will encourage risk-evaders to take the uncertain option; thus DIL, which raises the average perception, is used to form the "shifted" predispositions. An option perceived to be risky will intensify the conflicting tendencies of risk-taking and risk-evasion; INT either raises or lowers the average perceptions according to the initial distribution of risk-taking propensities. INT and DIL operate on the set of OS riskiness measures, and so must be averaged to produce the OS group's

[42]Meyers and Lamm, op. cit., p. 298.

final disposition. Thus,

$$PD_{OS} = \begin{cases} INT(\mu_{HIGH\ RSKY}(OS)) & \text{for } PC = RISKY/OS \\ \mu_{HIGH\ RSKY}(OS) & \text{for } PC = NEUTRAL/OS \\ DIL(\mu_{HIGH\ RSKY}(OS)) & \text{for } PC = SAFE/OS \end{cases}$$

and

$$DP = \frac{\Sigma PD_{OS}}{\#OS} \quad .$$

APL functions: INT, DIL, CON, ENACT

d. The final disposition is evaluated as SAFE, NEUTRAL, or RISKY as in (b), above. The option selection then follows directly from the Postulate descriptions.
APL function: DECISION

D. Comments on peculiarities of fuzzy logic techniques:

The fuzzy methodology possesses a logical consistency that allows direct development from statement to symbology to algorithm to programmed simulation. In any system of interacting algorithms, the ability to "trace" what is actually happening to the data decreases as the complexity of the system increases;[43] that the simulation of fuzzy procedures exhibits this phenomena while retaining logical consistency enhances the potential of the fuzzy technique as a tool that can utilize complexity rather than confront it. It is sometimes necessary to remember, however, that what would be flaws in another method are expected facets of fuzzy design.

The formulae for determining membership functions, for example, are basically arbitrary; fuzzy procedures require "threshold curves" of some sort but the curves need only intuitive plausibility since the fuzzy procedures tend to dilute the importance of the exact shape of the curves. Thus, the exact point of crossover between the descriptors LOW and MED is not as crucial as the more basic requirement that membership in LOW declines

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[43]Zadeh calls this the "principle of incompatibility," 1973, op. cit., p. 28.

as scores rise from 0, while membership in MED "peaks" for scores midway between 0 and the maximum possible.[44]

Another initially disconserting example is the fact that fuzzy descriptor sets need not be collectively exhaustive. It is possible for a score to be ¬LOW, ¬MED, and ¬HIGH i.e., to be nondescript within the defined descriptive terminology. The advantage of the fuzzy technique is that such scores may remain so and not disrupt the functioning of the fuzzy procedures.

A final peculiarity of the fuzzy methodology is the difficulty of intuitively understanding the effects of fuzzy operations on the data, particularly for operations such as Union and Intersection which may be confused with familiar functions in standard logic or set theory traditions. This difficulty is especially pertinent to analyzing and debugging the computer simulation program; however, no significant difference was experienced in the debugging of the deterministic and stochastic model simulations by this study. In general, fuzzy operations, once defined, more easily facilitated the translation of stated postulates into algorithmic form than did standard logic operations.

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[44] Lakoff, G., "Hedges: A Study in the Meaning Criteria and the Logic of Fuzzy Concepts," Journal of Philosophical Logic 2, 1973, p. 481ff.

IV. CONCLUSION

TESTING AND PREDICTABILITY

The accuracy of any simulation model is a measure of both its replicative and predictive capabilities. A proposed method for testing both features of the land use decision-making model is the use of gaming simulations (described in the Introduction). As noted earlier, source postulates concerning the implications of social power and influence structures are imbedded in the game rules of play, with decisions being made by human players in turn. A gaming simulation, then, provides a set of move options which might be used as the set of possible outcomes described in Phase II: the model is prepared to "play" a game.

Of significance for testing purposes is the possibility of having the surveyed leaders, or groups of them, play a simulated land use game so that the transcript of their play can be compared to the moves chosen through operating the simulation model with the profiles and group power structures of the "leader-players" involved. Some games assign roles to the players by giving them different goals for game "success" (see, for example, URBAN POLITICS).[45] The simulation may be tested with such games for its accuracy in representing the play of leaders in roles both similar and dissimilar to the roles suggested by their profile and power structures. Alternatively, games such as the Cornell Land Use Game (CLUG)[46] make no player role assignments, providing a test of the simulation in a more constraint-free environment.

"Predicting" behavior in a gaming situation is, of course, only one step toward making predictions about decisions in a "real" social environment over time. Some rules of inference imbedded in the simulation model framework assume certain social power and influence structures (see Introduction) that may differ from the constrained environments postulated for various gaming activities. Any broad predictive capabilities of a decision-making simulation model will depend on the ability of the model design to incorporate

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[45] Kibel, op. cit., p. 115.

[46] Ibid., p. 54.

the structures and rules of "the ultimate game:" the actual land use options, social, political and economic structures, and leadership personalities occurring dynamically in an urban environment. The task of assembling comprehensive data for these variables is by itself beyond possibility, as any modeling effort soon discovers.

The result is that either some variables must be omitted in order to gather a manageable amount of data from which intricate predictions are possible, or else intricate predictive capability is sacrificed in favor of a more general modeling of the interactions of as many factors as possible. A compromise is attempted here, with the inclusion of social structure, power structure, and personality variables for a group of decision makers concerned with land use decisions only. By not considering other types of decisions, this study hopes to reduce the need to gather data on the effects of social and power structures on other types of decisions, especially avoiding the inclusion of national influences (political, social, and economic) on the use of land. In this way, examination of the intracacies of local decision-making dynamics is made feasible, yet including as wide a range as possible of micro-scale variables. "Local" effects on land use are thus studied in detail, while predictions of land use with regard to national economic or political forces are less precise.

Even within the framework of this compromise, the ability to predict precise land use patterns is improbable at this time. A greater degree of precision than other techniques provide is expected; however, the ultimate benefit of this study is rather the isolation of critical factors affecting land use decisions within social and decision-making groups, the behavior tendencies formed as a result of those factors, and the narrowed range of land use options defined by the tendencies of decision-making behavior.

This model, then, will more often be enlightening than predictive, describing behavior tendencies within constraints rather than predictable decision outcomes in an absolute sense. It is the purpose of the simulation design, however, that a high level of precision will be achieved in the meaning of the described decision-making tendencies. It is hoped that this study will aid both the development of future simulation modeling conceptions and the exploration of the applicability of fuzzy mathematics to the study of complex humanistic systems.

PROPOSED FUTURE EXPANSIONS

The critical assumption of economic and gaming theories of decision-making behavior is that a choice between options is perceived, and that the chooser picks the option that optimizes his or her benefit according to some scale of values.[47] The attempt to model such behavior further assumes that options, perception, and value scale may all be measured in some way so that the optimum benefit may be computed and thus the decision predicted. The chooser, then, adopts the role of "rational economic man" whose major function is the computation of optimum benefit;[48] uncertainty about the receipt of benefit leads to an analysis of the riskiness of the decision.

This study tentatively retains the conception that issues arise in the form of options, and that uncertainty about the results of a decision creates a perception of risk. The optimizing nature of the decision process, however, is challenged as an unnecessarily restrictive view of human behavior, particularly in regard to choices about the use of land. The assumption is made here that the interactions of personalities in the context of small or informal social groups is a more realistic representation of human decisions about land use. The measurement of personality traits is not limited to risk-taking behavior, but such behavior remains a necessary element of the model so long as land use issues are envisioned as sets of options with uncertain results.

In terms of further development of the modeling effort presented in this study, then, the ways in which issues arise is seen as the crucial facet of the land use decision process to be addressed. The most obviously contrived assumption made in this model is that choices are made between only two options; the real possibilities of use for a given piece of land are rarely so small. The most tempting modeling response is to construct a range of options which are evaluated in a decision table or similar "gaming" technique, assessed according to the probability and size of "payoffs," and selected according to the final disposition of the DMG.

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[47] Horowitz, op. cit.; see also Baumol, W., Economic Theory and Operations Analysis, Englewood Cliffs, N.J.: Prentice Hall, Inc., 1965, sections on General Equilibrium Theory and Utility Theory.

[48] Baumol, op. cit., p. 521.

It is felt, however, that land use issues may be modeled more realistically than through an ever-expanding attempt to include all available options. Personalities make use of land, and persons address land use issues according to their interest in the issue, the applicability of the issue to themselves, and the scope of the issue among the other decisions with which they are concerned. In this context, decision-making groups are "formed" informally; different issues involving different land areas interest different personalities, each with a perception of the options involved. The social groups which each DMG member may be seen as representing also vary according to their pertinence to the issue around which the DMG is formed; a person may "represent" his profession as a realtor in a subdivision development decision, while his status as a neighborhood resident may be more pertinent to his interest in a highway being constructed two blocks from his home. Even if a set of options is inherent to a given land use issue, the options may be altered or added to by the personalities making up the DMG or by the introduction of new information during the decision process, according to the influence and activity of the various DMG members and the effect of the centrality of their positions in the DMG on their differential access to the environment of information.

The stochastic model of land use decision making incorporates the situation in which conditions exist for the introduction of new options. A suggested modeling expansion in the formulation of choices as functions of the personalities, social group resources, and information present in DMG interactions. The first step toward this expansion would be a fairly precise description of the specific social structures within which land use decisions are being made. Such a description is implied by the present model in the list of social groups delineated and personalities identified; a larger and more detailed context of environmental and social factors would allow issues to be defined in terms of the context, decision-making groups in terms of the issues, and choices in terms of DMG activity.

To assert that land use decisions are made within a social and environmental context rather than an isolated computation of optimized gain is an intuitive step toward realism in modeling. The difficulties in actualizing this step are not underestimated, but they need not be overstated. The conceptualization and description of a local socio-environmental context for land use change is quite within the realm of possibility; this study has found the fuzzy methodology to be an excellent tool for the translation of linguistic descriptions into modeling algorithms. The conclusion, then, is that more useful models of behavioral phenomena wait only upon the ability of researchers to describe these phenomena as accurately as possible.

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APPENDIX A

```
    DOCUMENT
  ∇  L CHOOSE OO; O; A; CHOOSER; DECISION; CHOICE
[1]    O←⍳1↑⍴OO
[2]    'SITUATION DESCRIPTION?'
[3]    A←⍞
[4]    A←3⍴A
[5]    →(A≠'YES')/CHEW
[6]    'OPTIONS:'
[7]    OO
[8]    'LEADERS PRESENT:'
[9]    PROFILE L
[10]  CHEW:A←DECIDERS L
[11]   CHOOSER←HIERARCHY A
[12]   →(D<CHOOSER)/CHNONE
[13]   'THE EMERGENT LEADER IS NUMBER:'
[14]   A[CHOOSER; 2; NUM]
[15]   'PROFILE:'
[16]   A←A[CHOOSER; ; ]
[17]   PROFILE A
[18]   DECISION← 1  0  2
[19]   DECISION[2]←((O[SQUO]>O[CHANGE]),O[SQUO]≤O[CHANGE])/⍳⍴O
[20]   CHOICE←A[1; HRN,HRE,HRT]/DECISION
[21]   'THE DECISION IS:'
[22]   OO[CHOICE; ]
[23]   →CHOUT
[24]  CHNONE:'NO DECISION IS INDICATED'
[25]  CHOUT:'.....'
  ∇

  ∇  DINDX←DECIDERS A;POWERV;DPOWERV;LBGRP;TGRPS;DN
[1]    POWERV←GPOWER
[2]    DPOWERV←GRANK POWERV
[3]    'THE ORDERED GROUPS (HIGHEST-LOWEST):'
[4]    GRPS[DPOWERV;]
[5]    LBGRP←A[;2;∊GROUPS]
[6]    LBGRP←LBGRP×(⍴LBGRP)⍴POWERV
[7]    DINDX←⌈/LBGRP
[8]    DINDX←(2,⍴DINDX)⍴DINDX,⍳⍴DINDX
[9]    'THE RATING VALUES FOR EACH LEADER:'
[10]   ⌽⍉DINDX
[11]   LBGRP←LBGRP=⍉(⌽⍴LBGRP)⍴⌈/LBGRP
[12]   DHERE←GPRESENT LBGRP
[13]   LBGRP←+/LBGRP×(⍴LBGRP)⍴⍳¯1↑⍴LBGRP
[14]   TGRPS←(DPOWERV∊DHERE)/DPOWERV
[15]   'NUMBER OF GROUPS REPRESENTED:'
[16]   ⍴TGRPS
[17]   'ORDERED LIST OF GROUPS REPRESENTED:'
[18]   GRPS[TGRPS;]
[19]   'ENTER NO. OF TOP GROUPS TO DECIDE'
```

```
[20]     DN←⍞
[21]     DN←(LBGRP∊TGRPS[⍳∊DN])/⍳1↑⍴A
[22]     'NUMBER OF LEADERS IN TOP GROUPS:'
[23]     ⍴DN
[24]     'PROFILES:'
[25]     PROFILE A[DN;;]
[26]     DINDX←A[DN;;]
       ∇

       ∇ GPWR←GPOWER
[1]      'ENTER GROUP RATING DIMENSION( EXCH,PRST,INST,POWR,GAPP)'
[2]      '(I.E.,GROUPS WILL BE ORDERED BY:)'
[3]      GPWR←⍞
[4]      GPWR←GRESOURCES+.×RATINGS[∊GPWR;]
       ∇

       ∇ GPINDX←GPRESENT A
[1]      GPINDX←(∨/⍉A)×∊GROUPS
       ∇

       ∇ GINDX←GRANK A
[1]      GINDX←⍒A
       ∇

       ∇ HINDX←HIERARCHY A;R;L;P;HI
[1]      →((⍴⍴A)=2)/HONE
[2]      D←1↑⍴A
[3]      →HGO
[4]    HONE:D←1
[5]    HGO:R←RISKY A
[6]      L←LIKABLE A
[7]      P←PARTICIPATOR A
[8]      →(∨/HI←P∧L∧R)/GOTCHA
[9]      →(∨/HI←P∧L∧~R)/GOTCHA
[10]     →(∨/HI←P∧(~L)∧R)/GOTCHA
[11]     →(∨/HI←(~P)∧L∧R)/GOTCHA
[12]     →(∨/HI←P∧(~L)∧(~R))/GOTCHA
[13]     →(∨/HI←(~P)∧(~L)∧R)/GOTCHA
[14]     →(∨/HI←(~P)∧L∧(~R))/GOTCHA
[15]     →(∨/HI←(~P)∧(~L)∧(~R))/GOTCHA
[16]     HI←(⍴A)⍴0
[17]   GOTCHA:(D<HINDX←HI⍳1)/'NO LEADER EMERGES'
       ∇

       ∇ LINDX←LIKABLE A
[1]      →((⍴⍴A)=2)/LONE
[2]      LINDX←∧/A[;1;RE,AC,SO]
[3]      →LOUT
[4]    LONE:LINDX←∧/A[1;RE,AC,SO]
[5]    LOUT:LINDX←LINDX
       ∇
```

```
    ∇  PINDX←PARTICIPATOR A
[1]     →((ρρA)=2)/PONE
[2]     PINDX←∧/A[;1;DO,FX,CS,AC]
[3]     →POUT
[4]    PONE:PINDX←∧/A[1;DO,FX,CS,AC]
[5]    POUT:PINDX←PINDX
    ∇

    ∇  PROFILE A
[1]     '  CS   RE   TO   SC   SO   DO   FX   IE   AC   HRN  HRE  HRT  LRN  LRE  LRT'
[2]     '  CC   ZB   ZC   CD   SB   RC   SOB  OTH  COC  LWV  RP   COG  ---  ---  NUM'
[3]     A
    ∇

    ∇  RINDX←RISKY A
[1]     →((ρρA)=2)/RONE
[2]     RINDX←∧/A[;1;IE,HRT]
[3]     →ROUT
[4]    RONE:RINDX←∧/A[1;IE,HRT]
[5]    ROUT:RINDX←RINDX
    ∇

    ∇  COLS←Y A
[1]     COLS←∊A
    ∇
```

```
      )VARS
AC        CC        CD        CF        CHANGE    CJ        CO        COC       COG
CS        CV        D         DHERE     DO        DONEG     EXCH      FX        GAPP
GRESOURCES          GROUPS    GRPS      GUY       HRE       HRN       HRT       IF
INST      KT        LE        LEADERS   LRE       LRN       LRS       LRT       LWV
M         MC        MEASURES            MM        NUM       OPTIONS   OTH       PO
POWR      PROF      PRST      RATINGS   RC        RE        RESOURCES           RP
RV        SA        SB        SC        SO        SOB       SQUO      SS        ST
TO        VALUES    X         ZB        ZC
      )FNS
CHOOSE    DECIDERS            DOCUMENT            GPOWER    GPRESENT            GRANK
HIERARCHY           LIKABLE   PARTICIPATOR        PROFILE   RISKY     STATUS    Y

      GROUPS
CC,ZB,ZC,CD,SB,RC,SOB,OTH,COC,LWV,RP,COG
      ⍴GROUPS
1  2  3  4  5  6  7  8  9  10  11  12

      RESOURCES
KT,MC,MM,CJ,CV,CO,SA,SS,PO,ST,CF,LE,RV
      ⍴RESOURCES
1  2  3  4  5  6  7  8  9  10  11  12  13

      VALUES
EXCH,PRST,INST,POWR,GAPP
      ⍴VALUES
1  2  3  4  5

      MEASURES
CS,RE,TO,SC,SO,DO,FX,IF,AC,HRN,HRE,HRT,LRN,LRE,LRT
      ⍴MEASURES
1  2  3  4  5  6  7  8  9  10  11  12  13  14  15

      GRESOURCES
 1 1 0 1 1 1 1 1 0 1 1 1 1
 0 0 0 0 0 0 1 1 0 1 0 1 1
 0 0 0 0 0 0 1 1 0 1 0 0 1
 1 0 0 0 0 0 1 0 0 0 0 1 1
 0 1 0 1 1 1 1 1 1 1 0 1 1
 1 1 0 1 0 1 1 0 0 1 1 0 1
 0 1 0 0 1 0 1 0 0 1 1 0 1
 0 0 0 0 0 0 0 0 0 0 0 0 0
 1 1 0 0 1 1 1 0 0 1 1 0 1
 0 0 0 0 1 0 1 0 1 1 1 0 1
 0 0 0 0 1 0 1 1 0 0 1 0 1
 1 0 0 0 0 0 0 0 0 0 0 1 1

     RATINGS
  9   7   7   6   3   1   0  ¯1  ¯3  ¯4  ¯4  ¯8  ¯9
  3   3   2   2   2   1   2   1   3   3   1   2   1
  2   2   3   1   3   1   2   2   2   2   2   3   2
  3   3   3   2   3   2   3   2   2   2   2   3   2
  8   8   8   5   8   4   7   5   7   7   5   8   5
```

LEADERS CHOOSE OPTIONS

SITUATION DESCRIPTION?

YES

OPTIONS:

DO NOT REZONE

REZONE

LEADERS PRESENT:

CS	RE	TO	SC	SO	DO	EX	IE	AC	URN	URE	URT	LRN	LRE	LRT
CC	ZB	ZC	CD	SB	PC	SOR	OTH	COC	LWV	RP	COG	---	---	NUM
1	1	1	0	1	1	0	1	1	1	0	0	0	1	0
0	0	0	0	0	1	0	0	0	0	0	1	0	0	1
1	1	1	1	1	1	0	1	1	0	0	1	0	1	0
1	0	0	0	0	0	0	0	1	0	0	0	0	0	2
1	1	0	0	1	1	0	1	1	1	0	0	1	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	3
1	1	0	0	1	1	0	1	1	1	0	0	1	0	0
0	0	0	0	0	1	0	0	1	0	0	1	0	0	4
1	1	1	0	1	1	1	1	1	0	1	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	5
1	1	0	0	1	1	1	1	1	0	1	0	0	1	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	6
1	1	1	1	1	1	1	1	1	0	1	0	0	1	0
0	0	0	0	0	0	0	0	1	0	0	0	0	0	7
1	1	1	1	1	1	0	1	1	0	1	0	0	1	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	8
1	1	1	0	1	1	0	1	1	0	1	0	0	1	0
0	0	0	0	0	1	0	0	1	0	0	0	0	0	9
1	1	1	1	1	0	1	1	1	0	1	0	0	1	0
0	0	0	1	0	1	0	0	0	0	0	0	0	0	10
1	1	1	1	1	1	0	1	1	0	1	0	0	1	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	11
1	1	1	1	1	1	0	1	1	0	1	0	0	1	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	12
1	1	1	1	1	0	0	1	1	0	1	0	0	1	0
0	0	1	0	0	0	0	0	0	0	0	0	0	0	13

```
   1    1    1    0    1    1    0    1    1    0    1    0    0    1    0
   0    0    1    0    0    0    0    0    0    0    0    0    0    0   14

   1    1    1    1    1    1    0    1    1    0    1    0    0    1    0
   0    0    0    1    0    0    0    0    0    0    0    0    0    0   15

   1    1    1    0    0    1    0    1    1    0    1    0    0    1    0
   0    0    1    0    0    0    0    0    0    1    0    0    0    0   16

   0    1    1    0    1    1    0    1    1    0    1    0    0    1    0
   0    0    0    0    0    1    0    0    0    0    0    0    0    0   17

   0    1    1    1    1    1    0    1    1    0    1    0    0    1    0
   0    0    0    0    0    1    0    0    0    0    0    0    0    0   18
ENTER GROUP RATING DIMENSION( EXCH,PROT,INST,POWR,GAPP)
(I.E.,GROUPS WILL BE ORDERED BY:)
GAPP
THE ORDERED GROUPS (HIGHEST-LOWEST):
CC
SB
COC
RC
SOR
LWV
ZB
RP
CD
ZC
COG
OTH
THE RATING VALUES FOR EACH LEADER:
   1   49
   2   70
   3   49
   4   52
   5   21
   6   49
   7   52
   8   49
   9   52
  10   49
  11   70
  12   28
  13   24
  14   24
  15   28
  16   39
  17   49
  18   49
```

NUMBER OF GROUPS REPRESENTED:
7
ORDERED LIST OF GROUPS REPRESENTED:
CC
COC
RC
LWV
CD
ZC
COG
ENTER NO. OF TOP GROUPS TO DECIDE

7
NUMBER OF LEADERS IN TOP GROUPS:
18
PROFILES:

CS	RE	TO	SC	SO	DO	EX	IE	AC	URN	URE	URT	LRN	LRE	LRT
CC	ZR	ZC	CD	SR	RC	SOB	OTH	COC	LWV	RP	COG	---	---	NUM
1	1	1	0	1	1	0	1	1	1	0	0	0	1	0
0	0	0	0	0	1	0	0	0	0	0	1	0	0	1
1	1	1	1	1	1	0	1	1	0	0	1	0	1	0
1	0	0	0	0	0	0	0	1	0	0	0	0	0	2
1	1	0	0	1	1	0	1	1	1	0	0	1	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	3
1	1	0	0	1	1	0	1	1	1	0	0	1	0	0
0	0	0	0	0	1	0	0	1	0	0	1	0	0	4
1	1	1	0	1	1	1	1	1	0	1	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	5
1	1	0	0	1	1	1	1	1	0	1	0	0	1	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	6
1	1	1	1	1	1	1	1	1	0	1	0	0	1	0
0	0	0	0	0	0	0	0	1	0	0	0	0	0	7
1	1	1	1	1	1	0	1	1	0	1	0	0	1	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	8
1	1	1	0	1	1	0	1	1	0	1	0	0	1	0
0	0	0	0	0	1	0	0	1	0	0	0	0	0	9
1	1	1	1	1	0	1	1	1	0	1	0	0	1	0
0	0	0	1	0	1	0	0	0	0	0	0	0	0	10

```
1   1   1   1   1   1   0   1   1   0   1   0   0   1   0
1   0   0   0   0   0   0   0   0   0   0   0   0   0  11

1   1   1   1   1   1   0   1   1   0   1   0   0   1   0
0   0   0   1   0   0   0   0   0   0   0   0   0   0  12

1   1   1   1   1   0   0   1   1   0   1   0   0   1   0
0   0   1   0   0   0   0   0   0   0   0   0   0   0  13

1   1   1   0   1   1   0   1   1   0   1   0   0   1   0
0   0   1   0   0   0   0   0   0   0   0   0   0   0  14

1   1   1   1   1   1   0   1   1   0   1   0   0   1   0
0   0   0   1   0   0   0   0   0   0   0   0   0   0  15

1   1   1   0   0   1   0   1   1   0   1   0   0   1   0
0   0   1   0   0   0   0   0   0   1   0   0   0   0  16

0   1   1   0   1   1   0   1   1   0   1   0   0   1   0
0   0   0   0   0   1   0   0   0   0   0   0   0   0  17

0   1   1   1   1   1   0   1   1   0   1   0   0   1   0
0   0   0   0   0   1   0   0   0   0   0   0   0   0  18
THE EMERGENT LEADER IS NUMBER:
5
PROFILE:
  CS   RE   TO   SC   SO   DO   EX   IE   AC   HRN  HRE  HRT  LRN  LRE  LRT
  CC   ZB   ZC   CD   SB   RC   SOB  OTH  COC  LWV  RP   COG  ---  ---  NUM
  1  1  1  0  1  1  1  1  1  0  1  0  0  1  0
  0  0  0  0  0  0  0  0  0  0  1  0  0  5
THE DECISION IS:
      REZONE
.....
```

```
        LEADERS CHOOSE OPTIONS
SITUATION DESCRIPTION?
NO
ENTER GROUP RATING DIMENSION( EXCH,PRST,INST,POWR,GAPP)
(I.E.,GROUPS WILL BE ORDERED BY:)
GAPP
THE ORDERED GROUPS (HIGHEST-LOWEST):
CC
SB
COC
RC
SOB
LWV
ZB
RP
CD
ZC
COG
OTH
THE RATING VALUES FOR EACH LEADER:
    1   49
    2   70
    3   49
    4   52
    5   21
    6   49
    7   52
    8   49
    9   52
   10   49
   11   70
   12   28
   13   24
   14   24
   15   28
   16   39
   17   49
   18   49
NUMBER OF GROUPS REPRESENTED:
7
ORDERED LIST OF GROUPS REPRESENTED:
CC
COC
RC
LWV
CD
ZC
COG
```

```
ENTER NO. OF TOP GROUPS TO DECIDE
1
NUMBER OF LEADERS IN TOP GROUPS:
2
PROFILES:
  CS   RE   TO   SC   SO   DO   EX   IE   AC  HRN  HRE  HRT  LRN  LRE  LRT
  CC   ZB   ZC   CD   SB   RC  SOB  OTH  COC  LWV  RP   COG  ---  ---  NUM
   1    1    1    1    1    1    0    1    1    0    0    1    0    1    0
   1    0    0    0    0    0    0    0    1    0    0    0    0    0    2

   1    1    1    1    1    1    0    1    1    0    1    0    0    1    0
   1    0    0    0    0    0    0    0    0    0    0    0    0    0   11

THE EMERGENT LEADER IS NUMBER:
2
PROFILE:
  CS   RE   TO   SC   SO   DO   EX   IE   AC  HRN  HRE  HRT  LRN  LRE  LRT
  CC   ZB   ZC   CD   SB   RC  SOB  OTH  COC  LWV  RP   COG  ---  ---  NUM
  1  1  1  1  1  1  5  1  1  0  0  1  0  1  0
  1  0  0  0  0  0  0  0  1  0  0  0  0  0  2
THE DECISION IS:
       REZONE
.....
```

APPENDIX B

```
      )LOAD MODEL2
SAVED  17:29:44 17-MAY-76 7K
      DOCUMENT
    ∇ CMPLMNT←COM F
[1]   CMPLMNT←1-F
    ∇

    ∇ CNTRTE←CON F
[1]   CNTRTE←F*2
    ∇

    ∇ DINDX←DECIDERS A;POWERV;DPOWERV;LBGRP;TGRPS;DN
[1]   POWERV←GPOWER
[2]   DPOWERV←GRANK POWERV
[3]   'THE ORDERED GROUPS (HIGHEST-LOWEST):'
[4]   GRPS[DPOWERV;]
[5]   LBGRP←A[;2;∊GROUPS]
[6]   LBGRP←LBGRP×(⍴LBGRP)⍴POWERV
[7]   DINDX←⌈/LBGRP
[8]   DINDX←(2,⍴DINDX)⍴DINDX,⍳⍴DINDX
[9]   LBGRP←LBGRP=⍉(⌽⍴LBGRP)⍴⌈/LBGRP
[10]  DHERE←GPRESENT LBGRP
[11]  LBGRP←+/LBGRP×(⍴LBGRP)⍴⍳¯1↑⍴LBGRP
[12]  TGRPS←(DPOWERV∊DHERE)/DPOWERV
[13]  'THE DMG REPRESENTS THE FOLLOWING GROUPS (ORDERED AS ABOVE):'
[14]  GRPS[TGRPS;]
[15]  'HOW MANY OF THE TOP GROUPS WILL DECIDE?'
[16]  DN←⎕
[17]  DN←(LBGRP∊TGRPS[⍳∊DN])/⍳1↑⍴A
[18]  'NUMBER OF LEADERS IN TOP GROUPS:'
[19]  ⍴DN
[20]  'MEMBER NUMBERS:'
[21]  A[DN;1;NUM]
[22]  DINDX←A[DN;;]
    ∇

    ∇ DECISION A;SAFEA;NEUTRALA;RISKYA
[1]   SAFEA←LOW A
[2]   NEUTRALA←MED A
[3]   RISKYA←HIGH A
[4]   →(SAFEA>NEUTRALA)/DAG
[5]   →(RISKYA>NEUTRALA)/DAU
[6]   →(RISKYA>SAFEA)/TAU
[7]   →(RISKYA=SAFEA)/DAMBIG
[8]  TAG:'THE TENDENCY IS FOR THE GROUP TO MAINTAIN +'
[9]   'THE STATUS QUO.  HOWEVER,'
[10]  →DAMBIG
[11] TAU:'THE TENDENCY IS FOR THE GROUP TO TAKE'
[12]  'THE UNCERTAIN OPTION.  HOWEVER,'
[13] DAMBIG:'THE SITUATION IS AMBIGUOUS, INDICATING'
```

```
[14]    'THE LIKELY ADDITION OF A THIRD OPTION ←'
[15]    'TO THOSE GIVEN.'
[16]    →DECOUT
[17]   DAG:'THE GROUP CHOOSES THE GUARANTEED OPTION.'
[18]    'THAT IS, ',AG
[19]    →DECOUT
[20]   DAU:'THE GROUP CHOOSES THE UNCERTAIN ALTERNATIVE.'
[21]    'THAT IS, ',AU
[22]   DECOUT:'........'
     ∇



     ∇  DILATE←DIL F
[1]     DILATE←F⋆0.5
     ∇

     ∇  ENACT A;DP;PD;PC;PCS;PDS;AU;AG;RELATION
[1]     'IT IS ASSUMED THAT A CHOICE IS TO BE MADE'
[2]     'BETWEEN TWO OPTIONS. THE OUTCOME OF ONE'
[3]     'IS GUARANTEED, THE OTHER UNCERTAIN.'
[4]     'PLEASE ENTER THE GUARANTEED OPTION:'
[5]     AG←⍞
[6]     'PLEASE ENTER THE UNCERTAIN OPTION:'
[7]     AU←⍞
[8]     'IS THE EXPECTED PAYOFF OF THE UNCERTAIN'
[9]     'OPTION LESS THAN THE GUARANTEE?'
[10]    RELATION←⍞
[11]    RELATION←2⍴RELATION
[12]    RELATION←(∧/RELATION='NO'),((∨/RELATION≠'NO')∧(∨/RELATION≠'YE')),
       (∧/RELATION='YE')
[13]    'THE DMG CONTAINS THE FOLLOWING PROFILES:'
[14]    PROFILE A
[15]    DP←OSS DECIDERS A
[16]    →((⍴⍴DP)≠3)/CHOICE
[17]    'THE OPTION SELECTOR SUBGROUP CONTAINS THE FOLLOWING MEMBERS:'
[18]    DP[;1;NUM]
[19]    DP←RISKY DP
[20]    PD←DP[1;]
[21]    PC←(+/PD)÷⍴PD
[22]    PC←RELATION/0,(COM PC),1
[23]    PCS←1↑PCS←GRANK(LOW PC),(MED PC),(HIGH PC)
[24]    PDS←((PCS=1)×(DIL PD))+((PCS=2)×PD)+((PCS=3)×(INT PD))
[25]    DP←(+/PDS)÷⍴PDS
[26]   CHOICE:DECISION DP
     ∇
```

```
    ∇ EXECUTE;A;ANS;ASWER
      '........'
      'ROAR'
      '........'
      'A CATS PRODUCTION.'
      'THIS IS THE MODEL OF LAND USE DECISION-MAKING DEVELOPED'
      'FOR THE COUNCIL FOR ADVANCED TRANSPORTATION STUDIES.'
     REDO:'PLEASE ENTER THE COLLECTIVE TITLE OF THE D-M GROUP:'
      A←∊A←⎕
      'PLEASE ENTER THE NUMBERS OF THE PARTICIPATING MEMBERS'
      'OF THIS GROUP FOR THIS DECISION:'
      ANS←∊ANS←⎕
      'THANK YOU.'
     AGAIN:ENACT A[ANS;;]
      'WOULD YOU LIKE THE SAME GROUP TO DECIDE ANOTHER ISSUE?'
      ASWER←3ρASWER←⎕
      →(ASWER='YES')/AGAIN
      'WOULD YOU LIKE TO DEFINE A NEW GROUP?'
      ASWER←3ρASWER←⎕
      →(ASWER='YES')/REDO
      'GOODBYE, THEN, AND THANK YOU FOR COMING.'
    ∇

    ∇ GPWR←GPOWER
      'ARE THE REPRESENTED GROUPS TO BE RATED ACCORDING TO EXCHANGE'
      'VALUE(EXCH), PRESTIGE(PRST), INSTITUTIONAL IMPORTANCE(INST),'
      'POWER(POWR), OR GENERAL APPLICABILITY(GAPP)?'
      GPWR←⎕
      GPWR←GRESOURCES+.×RATINGS[∊GPWR;]
    ∇

    ∇ GPINDX←GPRESENT A
      GPINDX←(∨/⍉A)×∊GROUPS
    ∇

    ∇ GINDX←GRANK A
      GINDX←⍒A
    ∇

    ∇ HGH←HIGH F
      HGH←0.5×(1+2○○(1+F))
    ∇

    ∇ INTNSFY←INT F
      INTNSFY←((F≤0.5)×2×CON F)+(F>0.5)×COM 2×CON COM F
    ∇
```

```
    ∇  LIKE←LIKABLE F;A
[1]    →((ρρF)=3)/LIOK
[2]    F←(1,ρF)ρF
[3]   LIOK:A←(3,1↑ρF)ρ0
[4]    A[1;]←⌊/F MUHIGH RE,AC,SO
[5]    A[2;]←⌊/F MUMED RE,AC,SO
[6]    A[3;]←⌊/F MULOW RE,AC,SO
[7]    LIKE←A
    ∇

    ∇  LW←LOW F
[1]    LW←0.5×(1+2○○F)
    ∇

    ∇  MD←MED F
[1]    MD←(0.5)×(1+2○○(1+2×F))
    ∇

    ∇  MHGH←I MUHIGH F;SCR;MX;RATIO
[1]    →((ρρI)=3)/MHOK
[2]    I←(1,ρI)ρI
[3]   MHOK:SCR←I[;1;F]
[4]    MX←(ρSCR)ρMSCORE[F]
[5]    RATIO←SCR×÷MX
[6]    MHGH←HIGH RATIO
    ∇

    ∇  MLW←I MULOW F;SCR;MX;RATIO
[1]    →((ρρI)=3)/MLOK
[2]    I←(1,ρI)ρI
[3]   MLOK:SCR←I[;1;F]
[4]    MX←(ρSCR)ρMSCORE[F]
[5]    RATIO←SCR×÷MX
[6]    MLW←LOW RATIO
    ∇

    ∇  MMD←I MUMED F;SCR;MX;RATIO
[1]    →((ρρI)=3)/MMOK
[2]    I←(1,ρI)ρI
[3]   MMOK:SCR←I[;1;F]
[4]    MX←(ρSCR)ρMSCORE[F]
[5]    RATIO←SCR×÷MX
[6]    MMD←MED RATIO
    ∇

    ∇  OS←OSS A;PAR;LIK;RSY;LMEN;PMEN;RMEN;GMEN
[1]    →((ρρA)=3)/OSOK
[2]    A←(1,ρA)ρA
[3]   OSOK:PAR←PARTICIPATE A
```

```
[4]    LIK←LIKABLE A
[5]    RSY←RISKY A
[6]    LMEN←LIK[H;]>LIK[M;]
[7]    PMEN←PAR[H;]>PAR[M;]
[8]    GMEN←LMEN∧PMEN
[9]    RMEN←RSY[H;]>RSY[M;]
[10]   →((+/GMEN)<1)/NOGMEN
[11]   OS←A[GMEN/⍳1↑⍴A;;]
[12]   'BASED UPON LIKABILITY AND PARTICIPATION.'
[13]   →OSOUT
[14]  NOGMEN:→((+/LMEN)<1)/NOLMEN
[15]   OS←A[LMEN/⍳1↑⍴A;;]
[16]   'BASED UPON LIKABILITY.'
[17]   →OSOUT
[18]  NOLMEN:→((+/RMEN)<1)/NORMEN
[19]   OS←1
[20]   'BASED UPON THE PRESENCE OF A RISK-TAKER.'
[21]   →OSOUT
[22]  NORMEN:OS←0
[23]   'SINCE THERE ARE NO RISK-TAKERS PRESENT.'
[24]  OSOUT:OS←OS
     ∇

     ∇ PART←PARTICIPATE F;A
[1]    →((⍴⍴F)=3)/PAOK
[2]    F←(1,⍴F)⍴F
[3]   PAOK:A←(3,1↑⍴F)⍴0
[4]    A[1;]←⌊/F MUHIGH DO,FX,CS,AC
[5]    A[2;]←⌊/F MUMED DO,FX,CS,AC
[6]    A[3;]←⌊/F MULOW DO,FX,CS,AC
[7]    PART←A
     ∇

     ∇ PROFILE A;V;MTRX;I;J;RWS;ITEM
[1]    RWS←⍴∊MEASURES
[2]    MTRX←((1↑⍴A),(3×RWS))⍴'   X'
[3]    →LSET
[4]   LSTRT:I←0
[5]   PSET:I←I+1
[6]    MTRX[I;3×(V[I;]/⍳RWS)]←ITEM
[7]    →(I<1↑⍴A)/PSET
[8]    →J+⌶26
[9]   LSET:V←(A MUHIGH∊MEASURES)>(A MUMED∊MEASURES)
[10]   ITEM←'H'
[11]   J←5
[12]   →LSTRT
```

```
[13]   V←(A MULOW∊MEASURES)>(A MUMED∊MEASURES)
[14]   ITEM←'L'
[15]   J←9
[16]   →LSTRT
[17]   V←((A MUMED∊MEASURES)>(A MUHIGH∊MEASURES))∧(A MUMED∊MEASURES)>(A
      MULOW∊MEASURES)
[18]   ITEM←'M'
[19]   J←13
[20]   →LSTRT
[21]   RWS←1↑ρA
[22]   MTRX[;1]←RWSρ'         11111111112222222222'
[23]   MTRX[;2]←RWSρ'12345678901234567890123456789'
[24]   '  CS RE TO SC SO DO EX IE AC RSK'
[25]   MTRX
[26]   'H = HIGH     M = MODERATE'
[27]   'L = LOW      X = NONDESCRIPT'
     ∇

     ∇ RSKY←RISKY F;A
[1]    →((ρρF)=3)/RSOK
[2]    F←(1,ρF)ρF
[3]   RSOK:A←(3,1↑ρF)ρ0
[4]    A[1;]←⌊/F MUHIGH IE,RSK
[5]    A[2;]←⌊/F MUMED IE,RSK
[6]    A[3;]←⌊/F MULOW IE,RSK
[7]    RSKY←A
     ∇
```

```
      )VARS
AC        CC        CD        CF        CJ        CO        COC       COG       CS
CV        DHERE     DMG       DO        EXCH      EX        GAPP      GRESOURCES
GROUPS    GRPS      H         IE        INST      KT        L         LE        LW
LWV       M         MC        MEASURES            MM        MSCORE    NUM       OTH
PO        POWR      PRST      RATINGS   RC        RE        RESOURCES           RP
RSK       RV        SA        SB        SC        SO        SOR       SS        ST
TO        VALUES    X         ZB        ZC
      )FNS
COM       CON       CURVES    DECIDERS            DECISION            DIL       DOCUMENT
ENACT     EXECUTE   GPOWER    GPRESENT            GRANK     HIGH      INT       LIKABLE
LOW       MED       MUHIGH    MULOW     MUMED     OSS       PARTICIPATE         PROFILE
PAT       RISKY

      GROUPS
CC,ZB,ZC,CD,SB,RC,SOB,OTH,COC,LWV,RP,COG
      ⍳⍴GROUPS
1  2  3  4  5  6  7  8  9  10  11  12

      RESOURCES
KT,MC,MM,CJ,CV,CO,SA,SS,PO,ST,CF,LE,RV
      ⍳⍴RESOURCES
1  2  3  4  5  6  7  8  9  10  11  12  13

      VALUES
EXCH,PRST,INST,POWR,GAPP
      ⍳⍴VALUES
1  2  3  4  5

      MEASURES
CS,RE,TO,SC,SO,DO,EX,IE,AC,RSK
      ⍳⍴MEASURES
1  2  3  4  5  6  7  8  9  10

      GRESOURCES
 1 1 0 1 1 1 1 1 0 1 1 1 1
 0 0 0 0 0 0 1 1 0 1 0 1 1
 0 0 0 0 0 0 1 1 0 1 0 0 1
 1 0 0 0 0 0 1 0 0 0 0 1 1
 0 1 0 1 1 1 1 1 1 1 0 1 1
 1 1 0 1 0 1 1 0 0 1 1 0 1
 0 1 0 0 1 0 1 0 0 1 1 0 1
 0 0 0 0 0 0 0 0 0 0 0 0 0
 1 1 0 0 1 1 1 0 0 1 1 0 1
 0 0 0 0 1 0 1 0 1 1 1 0 1
 0 0 0 0 1 0 1 1 0 0 1 0 1
 1 0 0 0 0 0 0 0 0 0 0 1 1
```

```
      RATINGS
 9  7  7  6  3  1  5 ¯1 ¯3 ¯7 ¯7 ¯8 ¯6
 3  3  2  2  2  1  2  1  3  3  1  2  1
 2  2  3  1  3  1  2  2  2  2  2  3  2
 3  3  3  2  3  2  3  2  2  2  2  3  2
 8  8  8  5  8  7  7  5  7  7  5  8  5

      DMC[⍳5;;]
  8       12       4       3       7      19       1      14      11       0.5
          0        1
  0        0       0       0       0       1       0       0       0       0
          0        1

  6       17       4       6       8      18       3      13       8       1
          0        2
  1        0       0       0       0       0       0       0       1       0
          0        0

  7       14       5       4       9      11       5      12       9       0.5
          0        3
  0        0       0       0       0       1       0       0       0       0
          0        0

  9       14       4       4      12      17       3      13      10       0.5
          0        4
  0        0       0       0       0       1       0       0       1       0
          0        1

 11       15       8       2       9      15      11      13      10       0.5
          0        5
  0        0       0       0       0       0       0       0       0       0
          0        1
```

EXECUTE

....

ROAR

....

A CATS PRODUCTION.
THIS IS THE MODEL OF LAND USE DECISION-MAKING DEVELOPED FOR THE COUNCIL FOR ADVANCED TRANSPORTATION STUDIES.
PLEASE ENTER THE COLLECTIVE TITLE OF THE D-M GROUP:
DMG
PLEASE ENTER THE NUMBERS OF THE PARTICIPATING MEMBERS OF THIS GROUP FOR THIS DECISION:
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
THANK YOU.
IT IS ASSUMED THAT A CHOICE IS TO BE MADE BETWEEN TWO OPTIONS. THE OUTCOME OF ONE IS GUARANTEED, THE OTHER UNCERTAIN.
PLEASE ENTER THE GUARANTEED OPTION:
DENY REZONING PETITION
PLEASE ENTER THE UNCERTAIN OPTION:
GRANT REZONING PETITION
IS THE EXPECTED PAYOFF OF THE UNCERTAIN OPTION LESS THAN THE GUARANTEE?
UNKNOWN
THE DMG CONTAINS THE FOLLOWING PROFILES:

	CS	RE	TO	SC	SO	DO	EX	IE	AC	RSK
1	X	H	M	M	M	H	L	H	H	M
2	H	H	M	H	M	H	L	H	H	H
3	M	H	M	M	H	M	M	H	H	M
4	H	H	M	M	H	H	L	H	H	M
5	H	H	H	L	H	H	H	H	H	M
6	H	H	M	M	M	H	X	H	H	H
7	H	H	H	H	M	H	H	H	H	M
8	H	H	M	H	M	H	X	H	H	L
9	H	H	M	L	H	H	L	H	H	H
10	X	H	H	H	M	M	M	H	H	M
11	X	H	M	M	M	H	X	H	H	M
12	M	H	L	M	H	H	X	H	H	H
13	H	H	H	H	H	M	M	H	H	M
14	H	H	H	M	H	H	X	H	H	M
15	H	H	H	H	H	H	L	H	H	M
16	M	H	H	M	M	H	L	H	H	M
17	M	M	H	M	H	M	L	H	H	M
18	M	H	H	H	H	H	L	H	H	M
19	M	M	L	L	M	H	X	H	H	H
20	M	H	H	H	M	M	L	H	H	M

H = HIGH M = MODERATE
L = LOW X = NONDESCRIPT
ARE THE REPRESENTED GROUPS TO BE RATED ACCORDING TO EXCHANGE VALUE(EXCH), PRESTIGE(PRST), INSTITUTIONAL IMPORTANCE(INST), POWER(POWR), OR GENERAL APPLICABILITY(GAPP)?

```
GAPP
THE ORDERED GROUPS (HIGHEST-LOWEST):
CC
SB
COC
RC
SOB
LWV
ZB
RP
CD
ZC
COG
OTH
THE DMG REPRESENTS THE FOLLOWING GROUPS (ORDERED AS ABOVE):
CC
SB
COC
RC
LWV
CD
ZC
COG
HOW MANY OF THE TOP GROUPS WILL DECIDE?
8
NUMBER OF LEADERS IN TOP GROUPS:
20
MEMBER NUMBERS:
1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20
BASED UPON LIKABILITY AND PARTICIPATION,
THE OPTION SELECTOR SUBGROUP CONTAINS THE FOLLOWING MEMBERS:
1  2  3  4  5  6  7  10  11  13  14  15  18
THE TENDENCY IS FOR THE GROUP TO TAKE
THE UNCERTAIN OPTION.  HOWEVER,
THE SITUATION IS AMBIGUOUS, INDICATING
THE LIKELY ADDITION OF A THIRD OPTION ←
TO THOSE GIVEN.
........
WOULD YOU LIKE THE SAME GROUP TO DECIDE ANOTHER ISSUE?
YES
IT IS ASSUMED THAT A CHOICE IS TO BE MADE
BETWEEN TWO OPTIONS. THE OUTCOME OF ONE
IS GUARANTEED, THE OTHER UNCERTAIN.
PLEASE ENTER THE GUARANTEED OPTION:
REJECT REZONING PETITION
PLEASE ENTER THE UNCERTAIN OPTION:
GRANT REZONING PETITION
IS THE EXPECTED PAYOFF OF THE UNCERTAIN
OPTION LESS THAN THE GUARANTEE?
```

UNKNOWN

THE DMG CONTAINS THE FOLLOWING PROFILES:

	CS	RE	TO	SC	SO	DO	EX	IE	AC	RSK
1	X	H	M	M	M	H	L	H	H	M
2	H	H	M	H	M	H	L	H	H	H
3	M	H	M	M	H	M	M	H	H	M
4	H	H	M	M	H	H	L	H	H	M
5	H	H	H	L	H	H	H	H	H	M
6	H	H	M	M	M	H	X	H	H	H
7	H	H	H	H	M	H	H	H	H	M
8	H	H	M	H	M	H	X	H	H	L
9	H	H	M	L	H	H	L	H	H	H
10	X	H	H	H	M	M	M	H	H	M
11	X	H	M	M	M	H	X	H	H	M
12	M	H	L	M	H	H	X	H	H	H
13	H	H	H	H	H	M	M	H	H	M
14	H	H	H	M	H	H	X	H	H	M
15	H	H	H	H	H	H	L	H	H	M
16	M	H	H	M	M	H	L	H	H	M
17	M	M	H	M	H	M	L	H	H	M
18	M	H	H	H	H	H	L	H	H	M
19	M	M	L	L	M	H	X	H	H	H
20	M	H	H	H	M	M	L	H	H	M

H = HIGH M = MODERATE
L = LOW X = NONDESCRIPT

ARE THE REPRESENTED GROUPS TO BE RATED ACCORDING TO EXCHANGE VALUE(EXCH), PRESTIGE(PRST), INSTITUTIONAL IMPORTANCE(INST), POWER(POWR), OR GENERAL APPLICABILITY(GAPP)?

GAPP

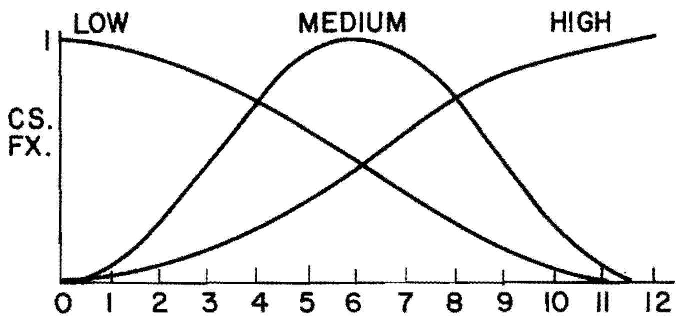
THE ORDERED GROUPS (HIGHEST-LOWEST):

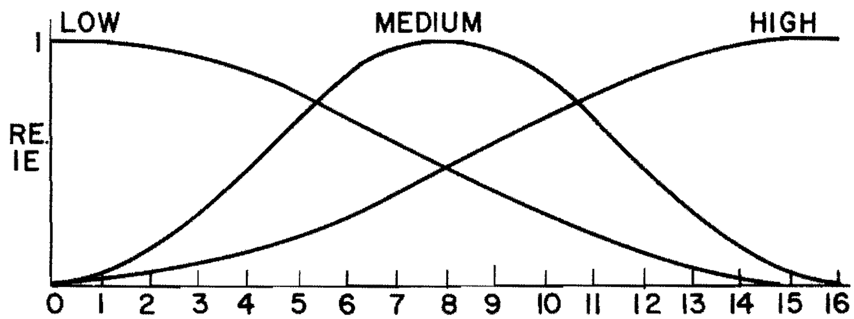
CC
SB
COC
RC
SOB
LWV
ZR
RP
CD
ZC
COG
OTH

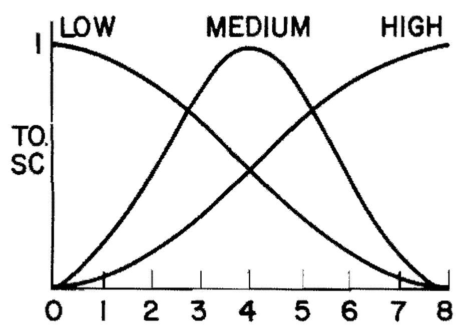
```
THE DMG REPRESENTS THE FOLLOWING GROUPS (ORDERED AS ABOVE):
CC
SB
COC
RC
LWV
CD
ZC
COG
HOW MANY OF THE TOP GROUPS WILL DECIDE?
1
NUMBER OF LEADERS IN TOP GROUPS:
2
MEMBER NUMBERS:
2  11
 BASED UPON LIKABILITY AND PARTICIPATION,
THE OPTION SELECTOR SUBGROUP CONTAINS THE FOLLOWING MEMBERS:
2  11
 THE GROUP CHOOSES THE UNCERTAIN ALTERNATIVE.
THAT IS, GRANT REZONING PETITION
........
WOULD YOU LIKE THE SAME GROUP TO DECIDE ANOTHER ISSUE?
NO
WOULD YOU LIKE TO DEFINE A NEW GROUP?
NO
GOODBYE, THEN, AND THANK YOU FOR COMING.
```

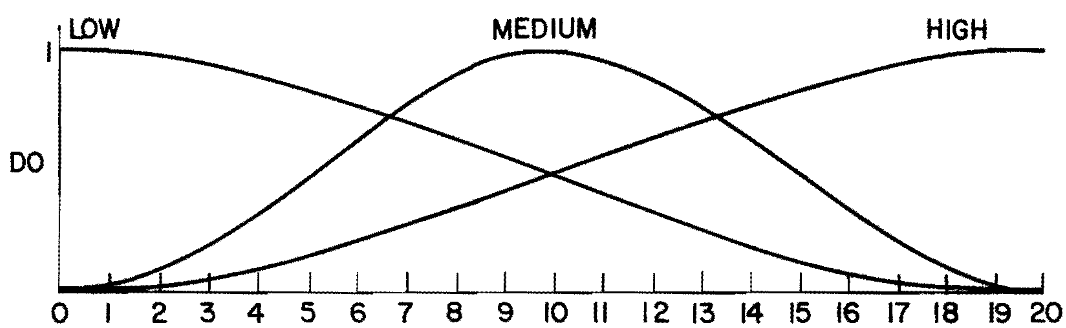
APPENDIX C

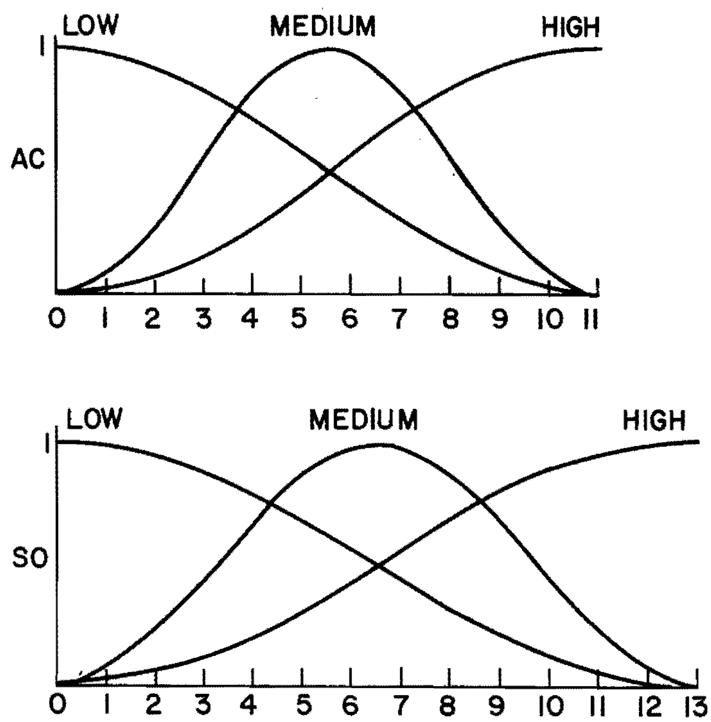
APPENDIX C: MEMBERSHIP FUNCTION CURVES







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PART III: TIME COGNITION AND ITS MODELING AND POLICY IMPLICATIONS

Pat Burnett
Donna Prestwood
Jose Montemayor

I. INTRODUCTION

Over the last decade there have been many studies of the cognized separation of points in space. All these studies, however, have been of the cognition of the physical distance between points, and the majority have been concerned with the cognized distance between home and other locations within the city.[1] Few of the investigations so far have treated cognized time as a measure of the spatial separation of points within the city.[2] Yet it has come to be a truism that time distance is more important than physical distance as an influence on the utilization of intra-urban locations. Consequently, current work on physical distance cognition is largely irrelevant for the explanation of many kinds of urban spatial behavior, including intra-urban travel.

If spatial cognition studies are to provide more than an interesting description of the perception of intra-urban spatial structures, they must

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[1] See, for examples, R. G. Golledge, R. Briggs, and D. Demko, "The Configuration of Distances in Intra-Urban Space," Proceedings of the Association of American Geographers, 1, (1969) pp. 60-65; D. Stea, "The Measurement of Mental Maps: An Experimental Model for Studying Conceptual Space," in: K. R. Cox and R. G. Golledge (eds.), Behavioral Problems in Geography: A Symposium, Evanston, Illinois: Northwestern University Department of Geography, Studies in Geography, No. 17, (1969) pp. 169-196; T. Lee, "Perceived Distance as a Function of Direction in the City," Environment and Behavior, 2, (1970) pp. 40-51; O. Lundberg, O. Bratfisch, and G. Ekman, "Emotional Involvement and Subjective Distance: A Summary of Investigations," Journal of Social Psychology, 87, (1972) pp. 169-177; R. A. Lowery, "A Method for Analyzing Distance Concepts of Urban Residents," in: R. M. Downs and D. Stea (eds.), Image and Environment: Cognitive Mapping and Spatial Behavior, Chicago: Aldine, (1973) pp. 322-337; R. Briggs, "On the Relation Between Cognitive and Objective Distance," in: W. F. Preizer (ed.), Environmental Design Research, Vol. II, Stroudsberg, Pa.: Dowden, Hutchinson and Ross, (1973a) pp. 186-192, and "Urban Cognition Distance," in: R. M. Downs and D. Stea (eds.), Image and Environment: Cognitive Mapping and Spatial Behavior, Chicago: Aldine, (1973b) pp. 361-388; R. H. Ericksen, "The Effects of Perceived Place Attributes on Cognition of Distance," Iowa City, University of Iowa, Department of Geography, Discussion Paper No. 23, (1975); David Canter and S. K. Tagg, "Distance Estimation in Cities," Environment and Behavior, 7, (1975) pp. 59-80.

[2] But see, M. T. Cadwallader, "Cognitive Distance in Intra-Urban Space," mimeographed paper, Portland State University, (1976).

obviously focus on those aspects of structures which are assessed and used in decisionmaking. This is so whether decisionmaking is concerned with residential or other kinds of site selection and hence with the behavior of structures over the long run, or whether it is concerned with short-run selection among destinations for daily activities.

This report is a study of the cognition of time distance within the city. This is not only timely for the reasons given above. It seems especially relevant for the further development of those models of trip distribution and destination choice used in transportation planning. The great majority of these models contain an independent variable representing time taken to a given destination, so that spatial choices are dependent on travel time. In operationalizing these models, the relations of cognized and objective time are of some importance. In the first part of the report, therefore, a power law is assumed to associate cognized and objective travel time, and the implications for trip distribution modelling and planning are discussed. The second part contains some empirical evidence of the existence of the power law, thus supporting the conclusions of the first section.

II. THE POWER LAW AND ITS MODELLING AND PLANNING IMPLICATIONS

THE POWER LAW

Steven's power law[3] in this context is

$$Y = aX^b \quad \text{or} \quad X = cY^d \tag{1}$$

where X is the cognized time between points in urban space, Y is the objective time, and a, b, c, and d are parameters. A reasonable starting hypothesis is that the parametric constants vary over space. This is suggested by the literature on physical distance cognition, which is analagous to time cognition (Table 1).

Before discussing the implications of the power law for modelling and planning purposes, it should be noted that the use of the power law is strongly backed by psychological theory. Stevens gives reasons why the function should hold in any relation of cognized to actual variables; the b parameter appears as a function of the sensory modalities involved, although other interpretations exist.[4] The use of the law, especially in empirical work, is therefore not 'curve-fitting for curve fitting's sake.'

AGGREGATIVE MODELS AND THE POWER LAW

The current work on urban trip distribution modelling occurs at two scales. At the aggregative level, models predict the distribution of trips from origin to destination zones. Aggregative spatial choice models therefore are concerned with the movement or urban population groups which are 'large rather than small' in some sense of those words. On the other hand, at the disaggregated level, models predict the movement of 'small groups' of the urban population, from point origins to point destinations. At the extreme,

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[3] Stevens, S. S., "On the Psychophysical Law," <u>Psychological Review</u>, 64, (1957) pp. 153-181.

[4] Teghtsoonian, R., "On the Exponents in Steven's Law and the Constant in Ekman's Law," <u>Psychological Review</u>, 78, (1971) pp. 71-80.

TABLE 1. SUMMARY OF PARAMETER ESTIMATES OF THE POWER FUNCTION FITTING OBJECTIVE TO COGNIZED DISTANCE

REFERENCE			R^2	a ($Y = aX^b$)	b ($Y = aX^b$)
Canter and Tagg (1975)	Glasgow		.27	1.54	.35
	Heidelberg		.76	1.35	.53
	London		.94	1.43	.73
	Glasgow		.85	1.52	.59
	Glasgow		.88	1.30	.79
	Nagoya		.83	1.17	.92
	Sydney		.94	1.03	.89
	Nagoya		.90	1.14	1.04
	Edinburgh		.86	1.19	1.03
	Tokyo		.90	1.27	.93
	Tokyo		.85	1.48	.82
Ericksen (1975)	Kingston, Ont.	Overall	.45	1.51	.91
		Range for Individuals		.83-5.53	.32-1.22
		Range for Location & Subject Subsets	.11-.51	1.71-1.03	1.43-.59
Briggs (1973)	Columbus, Oh.	Overall	.82	.81	.79
		Overall	.76	1.76	.57
		Range for Location Subsets	.98-.66	.91-.72	1.29-.47
		Range for Location Subsets	.89-.74	2.03-1.38	.84-.48
Lowry (197)	Baltimore	Range for Facility Types			.07-.40
		Range for Individuals			.11-2.06
Bratfisch (1969)	Europe	Range for Experiments			.58-1.08

models of individual behavior exist which bear testimony to an attempt to 'explain' larger group behavior from postulates about individual travel demand. The intention in this section is to spell out the implications of substituting cognized for objective time distance in aggregate trip distribution models.

First, a change in notation is made in the power law which allows its substitution in aggregative models to be clearer. Let ${}_pD$ be perceived or cognized time distance, and ${}_oD$ be objective time distance. Then, from (1),

$$ {}_pD = a\,{}_oD^b \quad \text{and} \quad {}_oD = c\,{}_pD^b \tag{1A} $$

Now consider the most elementary of trip distribution models, the well-known older versions of <u>The Gravity Model</u>. These were used during the fifties and sixties for planning purposes, together with growth-factor methods and the competing or intervening opportunity model, and are still widely used within the United States.[5] The basic formulation is

$$ I_{ij} = \ell \frac{A_i A_j}{{}_oD_{ij}^k} \tag{2} $$

where I_{ij} is the total number of trips between zone i and zone j, A_i and A_j are measured of the attractiveness (mass) of i and j, ${}_oD_{ij}$ is the objective time distance between i and j, ℓ is a constant, and k is the distance exponent. Substituting cognized for objective distance, we have

$$ I_{ij} = \ell \frac{A_i A_j}{(c\,{}_pD_{ij}^d)^k} \tag{3} $$

where the terms are defined as in (1A) and (2). Equation (3) is of interest for two reasons. First, it has a didactic value in that it proffers a more realistic explanation of interaction than (1). Secondly, the equation suggests one way of explaining much of the observed variation of k and ℓ in (2): it could be due to the assumed spatial variation of c and d in

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[5] Cantanese, A. J. (ed.), <u>New Perspectives in Urban Transportation Research</u>, Lexington: Heath, (1972) pp. 72-146.

(3).[6] The same kinds of argument hold for the other standard versions of the gravity model in transportation planning. For example, for a given trip purpose:

$$I_{ij} = \frac{\dfrac{A_i}{{}_oD_{ij}^{k}}}{\sum_{j=1}^{n} \dfrac{A_j}{{}_oD_{ij}^{k}}} N_i \tag{4}$$

becomes

$$T_{ij} = \frac{\dfrac{A_i}{(c\,{}_pD_{ij}^{d})^{k}}}{\sum_{j=1}^{n} \dfrac{A_j}{(c\,{}_pD_{ij}^{d})^{k}}} N_i \tag{5}$$

where T_{ij} is the number of trips in zone i which are attracted to zone j, n is the total number of destination zones, and N_i is the total number of trips produced in zone i. Also, by substitution

$$T_{ij} = \frac{N_i A_j ({}_oD_{ij}) K_{ij}}{\sum_{j=1}^{n} A_j ({}_oD_{ij}) K_{ij}} \tag{6}$$

becomes

$$T_{ij} = \frac{N_i A_j (c\,{}_pD_{ij}^{d}) K_{ij}}{\sum_{j=1}^{n} A_j (c\,{}_oD_{ij}^{d}) K_{ij}} \tag{7}$$

where "${}_oD_{ij}$ = empirically derived travel time factor which expresses the average areawise effect of spatial separation on trip interchange between zones which are ${}_oD_{ij}$ apart, (and)

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[6] Lowe, J. L. and S. Moryadas, The Geography of Movement, Boston: Houghton Mifflin, (1975) pp. 180-181. It would not be acceptable to use any reformulated aggregative model for planning purposes. For example, equation (3) implies that objective time would have to be estimated from data on cognized time; it is obviously simpler to measure objective time between zones directly.

K_{ij} = a specific zone to zone adjustment factor to allow for the incorporation of the effect on travel patterns of defined social and economic linkages not otherwise accounted for in the gravity model formulation."[7]

The use of the power law has similar implications in the case of The Entropy Model. The well known basic form of the model for use in trip distribution is

$$T_{ij}^{st} = A_j^i B_j O_i^t D_j \exp(-\beta^t C_{ij}^s) \qquad (8)$$

where T_{ij} is the number of individuals moving from zone i to zone j, O_i is the total number of persons in i, D_j is the attractiveness of j, A and B are balancing factors, C_{ij} is the generalized cost term measuring the effects of spatial separation of i and j, β is a parameter of the model, s is a superscript designating type of mode and t is a superscript designating type of subgroup of the population.[8]

Make the reasonable assumption that C_{ij}^s is proportional to time distance. Then a version of the model which would allow for time cognition is

$$T_{ij}^{st} = A_i^t B_j O_i^t D_j \exp\left[-\beta^t (c_p D_{ij}^s)^d\right] \qquad (9)$$

This equation suggests that variability in the β parameter is possible not only because of variations in total expenditures on the journey to work within a population subgroup, as Wilson suggests.[9] It is also possible that parameter β changes because of variations in c and d within the population type. There are two possible reasons for this. First there might be residual variations in c and d within a population group, given that c and d could differ with direction of travel, as is the case with physical distance.[10]

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[7] Cantanese, op. cit., pp. 88.

[8] Wilson, A. G., "Some New Forms of Spatial Interaction Model #: A Review," Transportation Research, 9, (1975) p. 168.

[9] Ibid., p. 173.

[10] See, T. Lee, "Perceived Distance...," op. cit.; R. Briggs, "Urban Cognitive...," op. cit.; and R. Golledge, "On Determining Cognitive Configurations of a City, Vol. 1," Unpublished Research Report to the National Science Foundation, Department of Geography, Ohio State University, (1974).

Second, and more interesting, is the implication that the population has not been stratified properly, that is, into those population subgroups having different c and d parameters. This leads to the conclusion that studies of the relation between cognized and observed time will materially assist with the stratification of the urban population for trip distribution modelling and planning via entropy methods.

Finally, consider models for aggregate trip distribution based on Utility Theory. Following the well known formulation of Niedercorn and Bechdolt,[11] let

$$ {}_mU_{ij} = f({}_mT_{ij}) \tag{10} $$

where

${}_mU_{ij}$ = the net utility of individual m at origin i of interacting with persons or things at destination j, per unit time, and

${}_mT_{ij}$ = number of trips taken by individual m from origin i to destination j, per unit time.

Then if $f({}_mT_{ij}) = \ell n\, T_{ij}$, it can be shown that

$$ {}_mT_{ij} = \frac{{}_mM_i}{r} \cdot \frac{N_j}{\sum_{j=1}^{n} N_j} \cdot {}_oD_{ij}^{-1} \tag{11} $$

Here $\frac{{}_mM_i}{r}$ is the total distance actually travelled by individuals at origin i to all destinations per unit time, N_j is the population of destination zone j and ${}_oD_{ij}$ is the measure of spatial separation of zones i and j. Substituting cognized for observed distance, (11) becomes

$$ {}_mT_{ij} = \frac{{}_mM_i}{r} \cdot \frac{N_j}{\sum_{j=1}^{n} N_j} \cdot \frac{1}{c\,{}_pD_{ij}^{d}} \tag{12} $$

This equation suggests that, in practice, variations will occur around the distance exponent of -1 in the model, and that these will result from place

[11] Niedercorn, J. H. and B. V. Bechdolt, "An Economic Derivation of the Law of Spatial Interaction," Journal of Regional Science, 9, (1969) pp. 273-282.

to place variations in the cognized distance parameters c and d. This conclusion accords with that for the normal formulation of the gravity model.

DISAGGREGATE MODELS AND THE POWER LAW

Disaggregate models of destination choice differ from aggregate models in that a cognized distance term is sometimes included in them. This is so for Stopher's[12] version of the multinomial logit, the most widely known of destination choice models. The model is, for a given purpose:

$$P_d^i = \frac{e^{G(X_d, S_i)}}{\sum_{k=1}^{D} e^{G(X_k, S_i)}} \qquad (13)$$

where P_d^i is the conditional probability of individual i choosing destination d, D designates the set of destinations from which individual i chooses, $G(X_d, S_i)$ is a linear function of first, attributes of the destination, X_d (including cognized travel time to reach it), and second, S_i, characteristics of the individual. This kind of model can be utilized by planners only if some simple relation is found between cognized time and the variable policymakers can manipulate, that is, observed time. The power law provides such a simple relationship.

Accordingly, to make the multinomial logit operational, the parameters of the power law must first be estimated for a study region. Policymakers can then estimate the additional parameters for a model like that in (13). Then the observed time equivalent of cognized time may be substituted in the model--that is $a_o D^b$ of equation (1A) may be substituted for ${}_pD$. Similar substitutions may be made of the observed equivalents of any other cognized variable. This will allow the forecasting of different spatial choices as the travel time and other variables are manipulated by planners. It is clear that the verification of the power law is crucial to the future development of such disaggregate trip distribution models of the behavioral type.

This may also be seen in Hanson's model.[13] Although in an embryonic stage, the model also attempts to account for destination choice in terms of

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[12] Stopher, P., "Development of the Second Survey--Shopping Destination Study," Mimeograph, (1975).

[13] Hanson, S., "On Assessing Individuals' Attitudes Towards Potential Travel Destinations," Mimeograph paper read at the Transportation Research Forum, October 1974.

cognized attributes of destinations. Its distinctive features lie in the incorporation of several additional variables which the behavioral literature in geography suggests: these variables are the level of familiarity of an individual with a destination and the trip type (single or multiple purpose) of the proposed journey. The model is,[14] in full

$$P^n_{ijp} = f\left(\sum_{j=1}^{m} I_{\ell j},\ L_{ij\ell}, Q_{ij\ell}, P_j,\ H_j,\ T^b_n\right) \tag{14}$$

where

P^n_{ijp} = probability that the ith destination is chosen by the jth individual on the nth trip for purpose p.

f = the approximate functional form

m = the number of individuals

$I_{\ell j}$ = importance of the ℓth destination attribute to the jth individual (for example, the importance of cognized time)

$Q_{ij\ell}$ = amount of attribute ℓ (for example, cognized travel time) that the jth individual perceives i to have

$L_{ij\ell}$ = level of information jth individual has about the ℓth attribute of the ith destination

P_j = personal characteristics of individual j (age, sex, income, occupation)

H_j = household characteristics associated with individual j (income, car ownership)

T^b_n = trip type of the nth trip for purpose p (single or multiple purpose)

Stutz's model[15] of social travel is a third behavioral model which requires at least the verification of the power law to become operational. His model is

$$R = u(IT^{-1} - \ell_p D) - v(oT^{-1} - \ell_p D) \tag{15}$$

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[14] Ibid., pp. 11-12.

[15] Stutz, F. P., "Distance and Network Effects on Urban Social Travel Fields," Economic Geography, 49, (1973) pp. 134-144.

where

R = expected net reward from social interaction governing trip making

I = expected interaction reward per trip unit

T = duration of interaction

ℓ = travel cost per distance unit

${}_pD$ = cognized travel time between participants[16]

o = expected opportunity costs foregone

and u and v are subjective weights based on preference between travel time and site characteristics. The model is more useful for policymaking if ${}_pD$ is replaced by a_oD^b, the power law, assuming a and b have been calculated for a sample population.

Finally, there remain several disaggregate models of trip distribution which do not contain cognized travel time. The first is a second version of the multinomial logit: in this version the X_d of (13) are observed rather than cognized attributes of destinations. Such a version of the multinomial logit model has been operationalized with some success by Ben Akiva,[17] and Kostyniuk.[18] Time substitution of c_pD^d of (2) for observed travel time is of didactic value only here.

Finally, there remains Burnett's linear learning model[19] applied to shopping travel. This model is

$$\begin{aligned} V_{t+1}\big|V_o &= \alpha + \beta V_t \quad \text{if a given destination is visited at } t \\ V_{t+1}\big|V_o &= \alpha + \lambda V_t \quad \text{if any other destination is used} \end{aligned} \tag{16}$$

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[16] Stutz does not state whether his spatial separation measure is in cognized or observed time units. However, since the model is advanced as a behavioral one, it is here assumed to incorporate the variable cognized time.

[17] Ben Akiva, M., "Structure of Passenger Travel Demand Models," Mimeographed paper presented at the 53rd Annual Meeting of the Transportation Research Board, January (1974).

[18] Kostyniuk, L., A Behavioral Choice Model of Urban Shopping Activity, unpublished Ph.D. Dissertation, State University of New York at Buffalo, Buffalo, New York (1975).

[19] Burnett, K. P., "Toward Dynamic Models of Travel Behavior and Point Patterns of Traveler Origins," Economic Geography, 52, (1976) pp. 30-45.

Here V_o is the probability of an individual choosing a given destination on the first trip in a sequence.

V_t is the probability of choosing the destination chosen at time t

V_{t+1} is the probability of choosing a given destination at time t+1

α, β, λ are parametric constants.

It is assumed that $f(V_o)$ is the probability distribution of V_o over the population, from which an individual with a given V_o is randomly sampled. In this model, cognized distance of individuals from the given destination will affect $f(V_o)$. However, because a spatial separation term does not appear in the model, no direct substitution of the power law is possible.

Throughout the preceding discussion, it has been assumed that the power law does not relate cognized and objective time, and that there are spatial or other variations in its parameters. It remains to demonstrate that such assumptions are true of travel behavior in cities.

III. TIME COGNITION: AN EXPERIMENT

DATA

The distribution phase in travel behavior modelling involves allocating trips generated at a given origin to destinations in a study region. A pilot study was devised to collect measures of cognized time in a corresponding framework. Drivers leaving the Dallas-Fort Worth Regional Airport were interviewed using the questionnaire in Table 2. This was part of a larger survey examining the impact of the new airport on the surrounding region. The questionnaire elicited from each respondent simple estimates of the driving travel time to his or her destination. The type of destination, the route followed to it, and some basic characteristics of the respondent (age, income) were also elicited.

The destinations were next plotted on a large scale map of the Dallas-Fort Worth area which showed objective travel times by route segment. This information was supplied by the North Central Texas Council of Governments, which measured travel times for all road segments in the Dallas-Fort Worth area in order to prepare the comprehensive Transportation Plan for the cities. Using this information, objective travel times were calculated between the airport and each respondent's destination. The result was 200 pairs of cognized and objective travel time distance.

ANALYSIS

Power functions of the form $Y = ax^b$ (where Y equalled cognized and x equalled objective time) were fitted to the data using linear regressions with a natural logarithmic transformation. These functions were estimated for different subsets of the data, namely subsets describing (1) direction away from the airport, (2) destination type (primarily home and work), (3) age of the respondent, and (4) income of the respondent. These subsets were used so that the impact of the four factors on cognized time could be explored.

Work on physical distance cognition suggested the use of all four factors. It has been shown that cognized physical distance is different

TABLE 2. QUESTIONNAIRE USED IN DALLAS-FORT WORTH AIRPORT IMPACT STUDY

SHORT FORM
DFW ORAL AUTO SURVEY

Surveyor Number ________ (1 2)

Time ________ AM/PM Number of CP's ________ M (3 4 5 6)
________ F (7 8)

Driver: ____ M ____ F (9)

Type of Vehicle: ____ Private car ____ Rent-a-car (10)

INTRODUCTION

1. Purpose of trip to airport? (11)

____ AP, alone ____ Visitor
____ Drop off AP ____ Other (specify)
____ Pick up AP ________
____ Business at airport
____ Pick up ticket

1. What city or town are you a resident of? (12 13 14)

____

2. 1. Number of AP's ________ M ________ F (15 16)
2. What city are AP's residents of? (17 18 19)

____

3. TRIP FROM AIRPORT

1. What is your next destination? (20 21 22 23) (24 25 26)

____

____

2. ____ Your home ____ Hotel (27)
____ Someone else's home ____ Shopping
____ Your work place ____ Other (specify)
____ Another place of business ________

3. How many miles? ________ (28 29)
4. How many minutes? ________ (30 31)
5. Route ________

____

____

____

____

4. TRIP TO AIRPORT (RESIDENTS ONLY)

1. Where did trip to airport start? (32 33 34 35)

____

____

2. ____ Your home ____ Hotel (36)
____ Someone else's home ____ Shopping
____ Your work place ____ Other (specify)
____ Another place of business ________

3. Time got to control booth: ________ AM/PM (37 38 39 40)
4. What kind of parking did you use?
____ Short-term ____ Curb

5. FREQUENCY OF AIRPORT USE:

1. Times used DFW airport: ________ times last ☐ month ☐ year (42 43)
2. Times used Love Field before DFW opened: ☐ Gen'l ☐ Comm. (44 45)
________ times per ☐ month ☐ year
3. Use Love Field now? ____ Yes ____ No (46) (47)
____ times last ☐ month ☐ year
4. How many miles to Love Field from next stop? (48 49)
________ miles
5. How many minutes? ________ minutes (50 51)
6. When Love Field was main airport, type of vehicle used most often? (52 53)
____ City bus ____ Drove own vehicle
____ Limousine ____ Dropped off by someone else
____ Taxi ____ Rent-a-car
____ Courtesy bus ____ Other
____

6. AIRLINE FLIGHT INFORMATION

1. Other airport: ________ (54)
2. Flight number: ________ (55 56 57) (58 59 60)
____ AA ____ EA ____ OZ
____ BN ____ FL ____ TI
____ CO ____ METRO ____ Other
____

3. Purpose of air trip: (61 62) (63)
____ Business/Employment ____ Visiting
____ Vacation ____ Military
____ Convention ____ School
____ Personal Affairs ____ Other
____

4. When return trip? ________ ☐ fly ☐ drive ☐ other? (64 65 66)

7. PERSONAL DATA (AP'S AND CP'S)

1. Occupation: (67)
CP ________
Position Industry
AP ________ (68 69 70 71)

2. Age: (72 73 74 75)
____ A. Under 21 ____ D. 46-55
____ B. 21-35 ____ E. 56-65 (76 77)
____ C. 36-45 ____ F. Over 65

3. Family Income: (78 79)
____ A. Under 6.5^k ____ D. 20^k - 26^k (80 81 82 83)
____ B. 6.5^k - 13^k ____ E. 26^k - 32^k
____ C. 13^k - 20^k ____ F. Over 32^k (84 85 86 87)

towards points located downtown from those away from downtown.[20] In addition, Lowrey[21] investigated the difference of cognized and physical distance and suggested variations by destination type. Finally, Burnett and Briggs[22] recognized that "organismic factors" such as age and income could affect length of residence, experience and mobility and hence physical distance cognition. It seems a reasonable starting hypothesis that cognized travel time as a spatial separation measure may be affected by the same variables as cognized physical distance, an analagous spatial separation measure.

RESULTS

The destination of all respondents are shown in Figure 1. Although the majority of destinations are in Dallas, there is a pleasing scatter by direction and distance over the metropolitan area. This permits the estimation of the power function over a good range of actual and cognized travel times.

The power function fitted the data on cognized distance well (Table 3). Statistically significant R^2 values appeared for each subset of the data. The b parameters were either less than or approximately equal to 1.0, demonstrating that cognized time increased at a decreasing rate. The a parameters are consistently greater than 1. All of these findings accord with empirical studies of the cognition of distance, as shown in Table 1.

Figures 2 to 5 show the plots of the power function for each data subset (direction, destination type, age and income). Significant differences appear to exist between the population groups (Table 3). The least difference is shown between the plots and the a and b values for the destination type categories (Figure 3) and the age categories (Figure 4), respectively.

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[20] Golledge, R. G., R. Briggs, and D. Demko, "The Configuration...," op. cit.; T. Lee, "Perceived Distance...," op. cit.; R. Briggs, "On the Relation...," and "Urban Cognitive...," op. cit.; R. G. Golledge, "On Determining...," op. cit.; pp. 216, 337-340; and R. H. Ericksen, "The Effects of Perceived...," op. cit.

[21] Lowrey, R. A., "A Method for Analyzing...," op. cit.

[22] Burnett, K. P. and R. Briggs, "Distance Cognition and Intra-Urban Movement," Paper presented at the West Lake Meetings, Association of American Geographers, Carbondale, Illinois (1975).

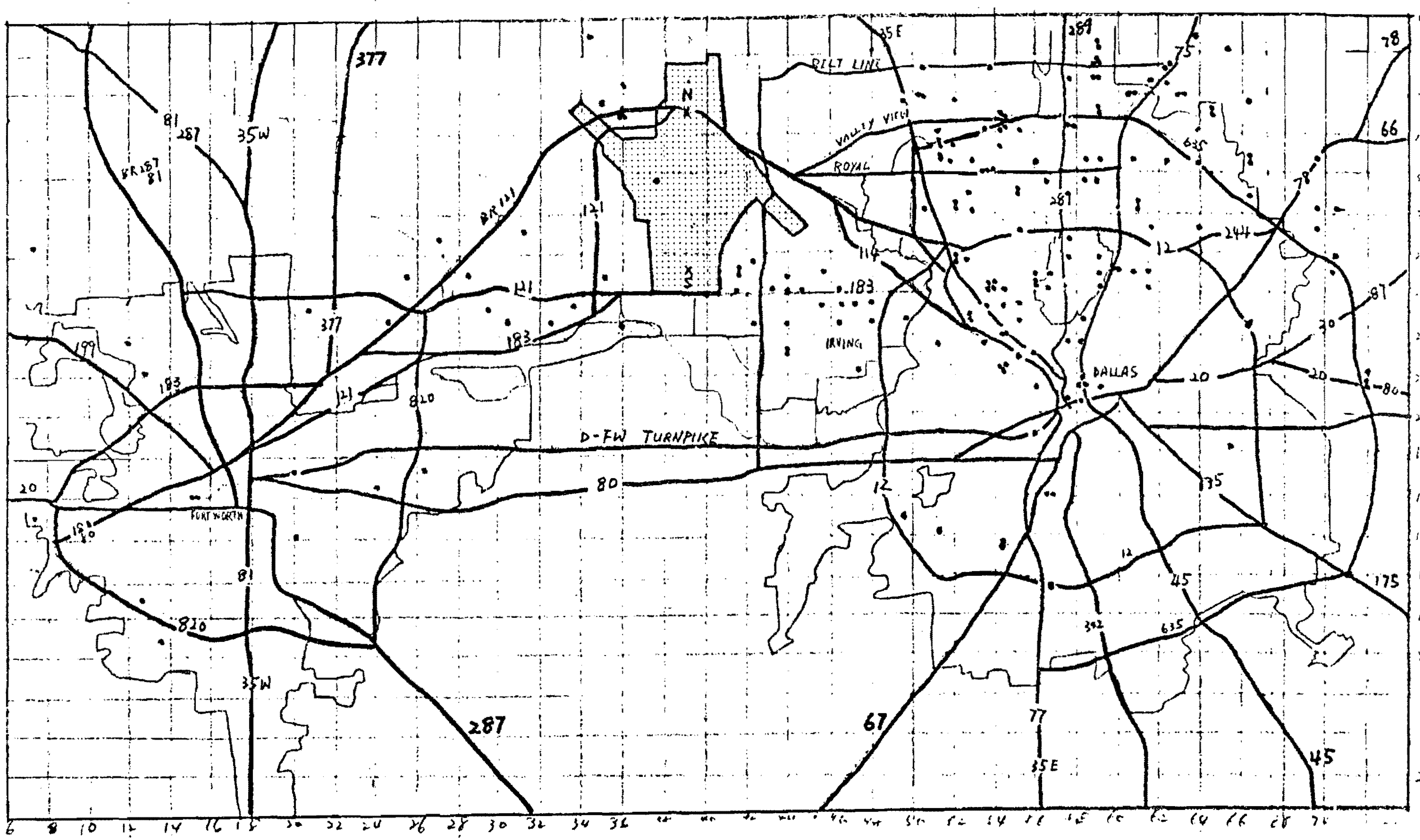

Figure 1. The Study Region and Location of Trip Destinations

TABLE 3. PARAMETER ESTIMATES FOR THE POWER FUNCTION $Y=aX^b$ RELATING COGNIZED TO OBJECTIVE DISTANCE

	TIME		
	R^2	a	b
Direction in City			
Quadrant I	.72	2.59	.69
Quadrant II	.52	3.65	.60
Quadrant III	.84	.94	1.01
Destination Type			
Work	.73	2.11	.76
Home	.84	1.84	.83
Hotel, Shopping	.72	2.64	.67
Age			
21-35 years	.77	2.63	.71
36-45 years	.73	1.74	.84
46-55 years	.71	2.08	.74
Income			
<$20,000	.79	2.77	.70
$20-32,000	.77	1.42	.89
>$32,000	.72	1.31	.88

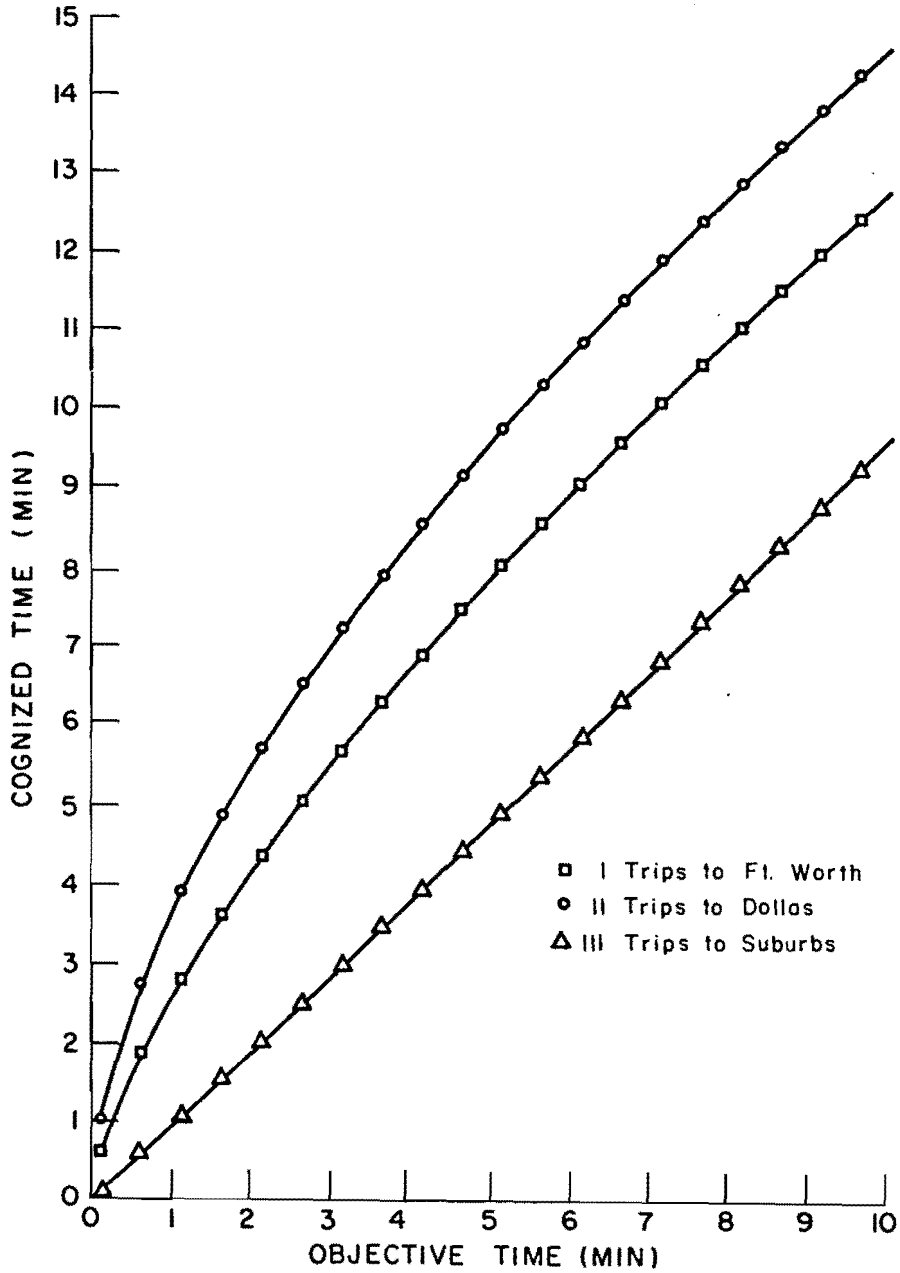

Figure 2. Time Estimates by Direction of Travel

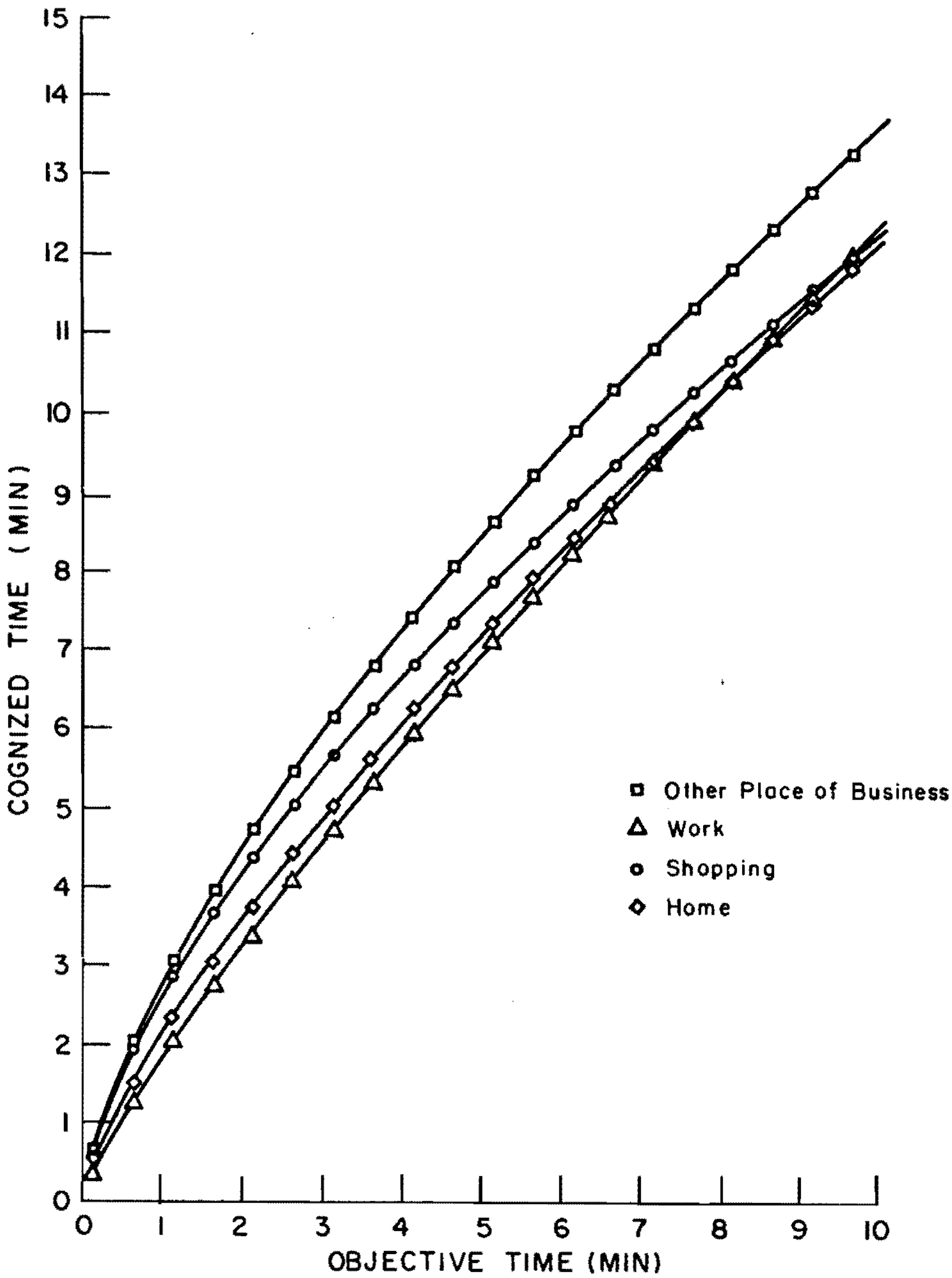

Figure 3. Time Estimates by Destination Type

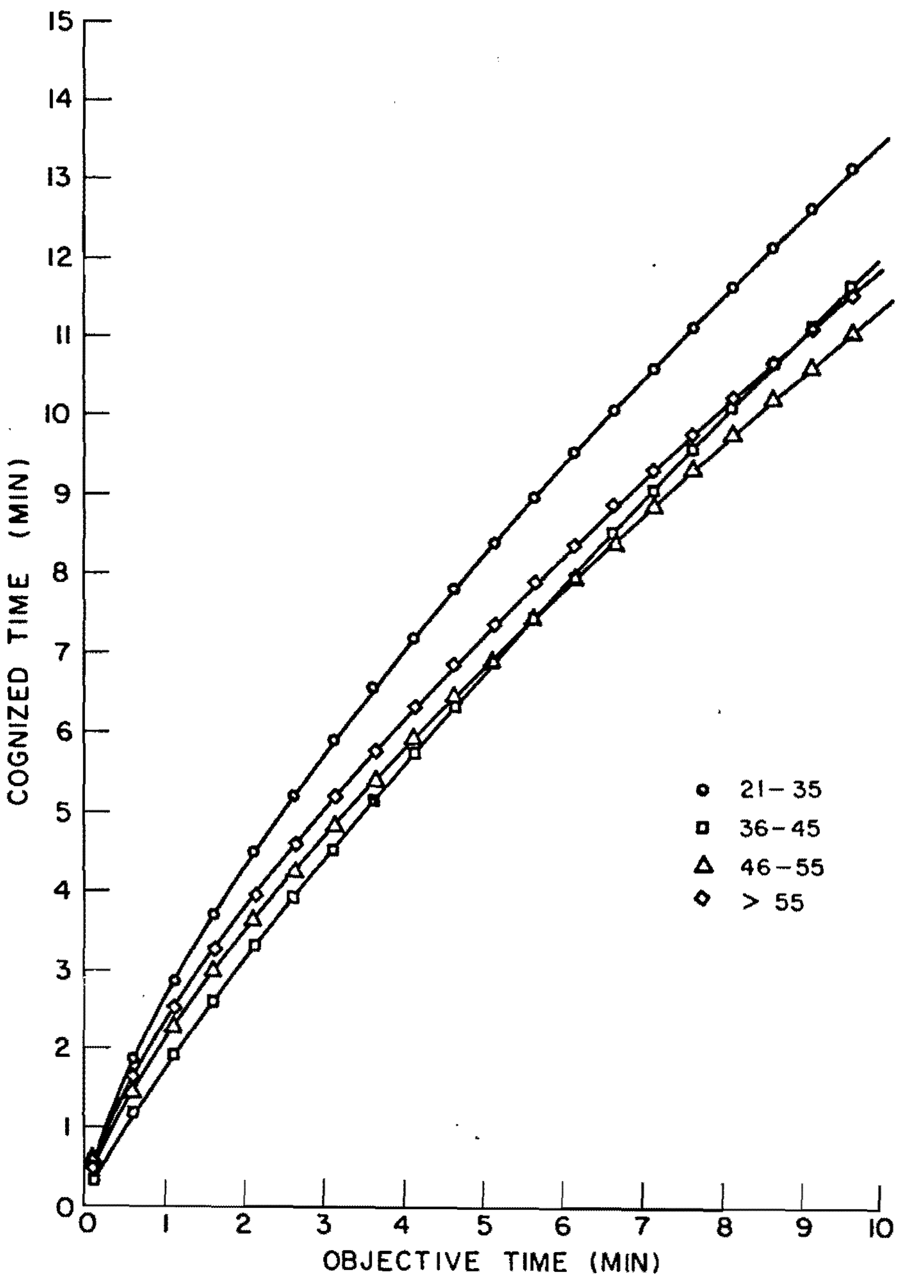

Figure 4. Time Estimates by Age Category (Years)

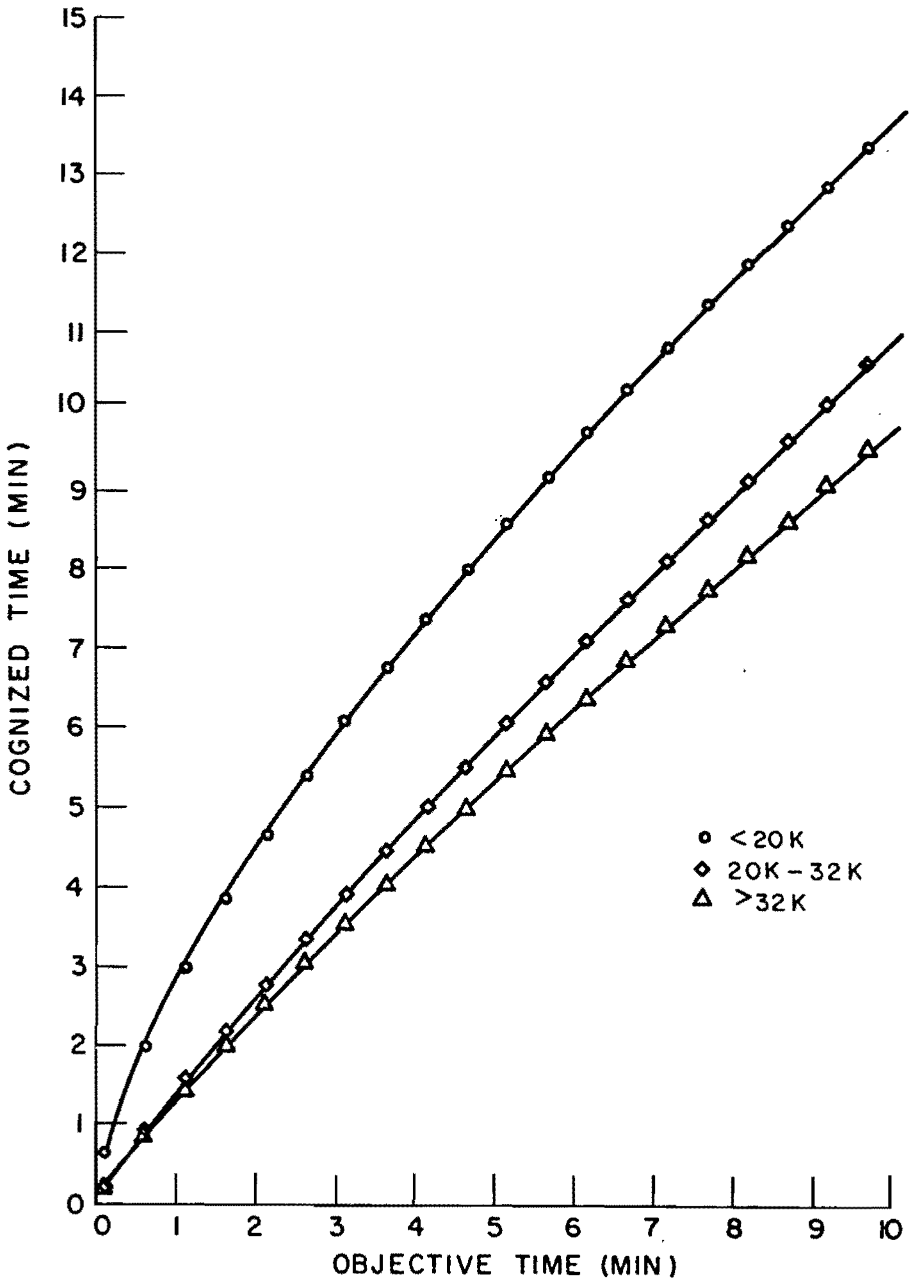

Figure 5. Time Estimates by Income Group

To determine whether the differences between regression lines were significant, Smillie's F tests of comparison between regressions were used.[23] These tests determine first, whether any pair of regression lines are coincident, and, second, whether any pair of regression lines are parallel. Given that lines are neither coincident nor parallel, the alternative that they are significantly different may be accepted. The results of these tests are shown in Table 4.

First, significant differences exist between the regression lines for various directions. Cognized travel time is high for Dallas, intermediate for Fort Worth and lowest for Suburban Areas: perhaps the "big city" environment of Dallas results in the accentuation of travel times. This finding implies that variations in the parameters of the power law will exist between any two population groups; unless there are controls over direction, differing proportions of the population will be travelling in different directions for the same trip purpose. Secondly, significant differences appear in the regression lines for low and high income groups. This supports the common practice of segmenting by household income in the application of trip distribution models. Both findings imply that there will be differences in the a and b parameters for different study regions as well as within a single area. This is because spatial variations will exist in the proportions of the study populations in different income groups and travelling in different directions.

The fact that there is little difference between many of the regression lines shows that there may be greater stability in the regression parameters for cognized travel time than for cognized physical distance. This in turn implies that only a few population segments need be utilized in the application of models of urban travel behavior. Of course, not all relevant segments will have been identified by this pilot study. Also, this study did not independently control for the factors which were hypothesized to affect cognized travel time. Consequently, a cancellation effect may operate. At a more disaggregate level, variability in cognized travel time may be more apparent and of greater importance.

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[23] Smillie, K. W., An Introduction to Correlation and Regression, London: Academic Press, (1966) pp. 72-73.

TABLE 4. RESULTS OF SMILLIE'S F TESTS FOR COMPARISON OF REGRESSION LINES

DATA SUBSETS	No. Obs.[a]	LINES COINCIDENT Y=Yes N=No	LINES PARALLEL Y=Yes N=No
DIRECTION			
1. Fort Worth, Dallas	20,110	Y	Y
2. Fort Worth, Suburbs	20,70	Y	Y
3. Dallas, Suburbs	110,70	N	N
DESTINATION TYPE			
4. Home, Work	123,47	Y	Y
5. Home, Other[b]	123,19	Y	Y
6. Work, Other	47,19	Y	Y
AGE			
7. 21 to 35 years	87	Y	Y
36 to 45 years	50		
8. 21 to 35 years	87	Y	Y
46 to 55 years	43		
9. 36 to 45 years	50	Y	Y
46 to 55 years	43		
INCOME			
10. Under $20,000	80	Y	Y
$20-32,000	69		
11. Under $20,000	80	N	N
Over $32,000	37		
12. $20-32,000	69	Y	Y
Over $32,000	37		

[a]The total of observations does not add to 200 because of the deletion of incomplete questionnaires.

[b]Because of the limited number of other trips than those to work or home, all other trips were combined into a single category

IV. CONCLUSIONS

This report has discussed the relation between objective and cognized travel time. Sufficient evidence has been presented to support a simple power law form of the relation, with the parameters of the law showing spatial and other kinds of variation. The implications of these findings have been examined for models of travel behavior. For aggregative models, the law has a didactic value in that it enables a more realistic explanation of spatial interaction. In addition, variations in the parameters of such models appear to result at least in part because of variations in the parameters of the law. For important disaggregative models, the existence of the law is necessary to make them operational, although there are several for which this does not hold true. Finally, it is clear that this report is exploratory rather than definitive, and that the cognition of time awaits further research.

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PART IV: DATA PROBLEMS IN THE APPLICATION OF CONJOINT MEASUREMENT TO RECURRENT URBAN TRAVEL

Pat Burnett

Jose Montemayor

I. INTRODUCTION

Over the past few years, some interest has been shown in the decomposition of space preference functions.[1] It is desirable to recover the part-worths of different attributes of spatial alternatives in the choice process. The rationale for this interest is that it is necessary for practical purposes to predict the degree to which an attribute must be altered in order to achieve a desired spatial choice effect. It is necessary, for example, to be able to predict the spatial choice effects of a deliberate alteration of the attributes of shopping destinations, such as price, quality of goods or convenience. It is also necessary at times to predict the effects of uncontrolled alterations in some attributes of destinations. A good example is the alteration of the convenience of shopping destinations as a byproduct of major investments in transportation facilities. Further, because of the combinatorial quality of data collection designs, relatively few attributes of alternatives can be presented for judgment in a choice experiment. It is useful to be able to predict responses for many combinations of the attributes of alternatives where only the part-worths of a few combinations are known.

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[1] Lieber, S. R., "A Comparison of Metric and Non-Metric Scaling Models in Consumer Research," Paper presented at The Symposium on Multidimensional Scaling at the Annual Meeting of the Association of American Geographers, Atlanta, April 1973; Louviere, J., "After MDS or the Role of Mathematical Behavior Theory in the Analysis of Spatial Behavior," Paper presented at The Symposium on Multidimensional Scaling at the Annual Meeting of the Association of American Geographers, Atlanta, April 1973; Rushton, G., "Decomposition of Space Preference Functions," Paper presented at The Symposium on Multidimensional Scaling at the Annual Meeting of the Association of American Geographers, Atlanta, April 1973 (Revised Version, December 1974); Stutz, F., "Environmental Trade-Offs for Travel Behavior," Paper presented at the Annual Meeting of the Association of American Geographers, Milwaukee, April 1975.

The development of conjoint measurement permits the recovery of part-worths of attributes for all of these applications.[2]

Despite the apparent usefulness of conjoint analysis, few geographers have employed it so far. Brummel and Harman,[3] Lieber,[4] and Rushton[5] present introductory discussions of conjoint measurement for spatial choice, but only examine simple laboratory applications. In addition, there are alternative ways of approaching the part-worths of the attributes of alternatives via trade-off functions, such as those suggested by Louviere[6] and Stutz.[7] These methods, however, do not allow the prediction of responses to new spatial alternatives from the utilities of attributes of existing alternatives.

The use of conjoint measurement for spatial choice therefore has some support, but remains largely unexplored. This situation is exacerbated by

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[2] Johnson, R. M., "Pairwise Non-Metric Multidimensional Scaling," Psychometrika, 38 (1973), pp. 11-18; Johnson, R. M., "A Simple Method for Non-Metric Regression," Mimeo, Market Facts, Inc., Chicago, 1973; Johnson, R. M., "Trade Off Analysis of Consumer Values," Journal of Marketing Research, 11 (1974), pp. 121-127; Krantz, D. H., "Conjoint Measurement: The Luce-Tukey Axiomatization and Some Extensions," Journal of Mathematical Psychology, 11 (1964), pp. 248-277; Krantz, D. H. and A. Tversky, "Conjoint Measurement Analysis of Composition Rules in Psychology," Psychological Review, 78 (1971), pp. 151-169; Luce, R. D. and J. W. Tukey, "Simultaneous Conjoint Measurement: A New Type of Fundamental Measurement," Journal of Mathematical Psychology, 1 (1964), pp. 1-27; Tversky, A., "A General Theory of Polynomial Conjoint Measurement," Journal of Mathematical Psychology, 4 (1967), pp. 1-20; Young, F. W., "A Model for Polynomial Conjoint Analysis," in R. Shepard, A Romney and S. Nerlove (eds.), Multidimensional Scaling: Theory and Applications in the Behavioral Sciences, No. 1, New York and London: Seminar Press, 1972.

[3] Brummel, A. C. and E. J. Harman, "Behavioral Geography and Multidimensional Scaling," Discussion Paper No. 1, Department of Geography, McMaster University, 1974, pp. 49-52.

[4] Lieber, S. R., op. cit.

[5] Rushton, C., op. cit.

[6] Louviere, J., op. cit.

[7] Stutz, F., op. cit.

the fact that attributes of spatial alternatives are still commonly represented by surrogates like size, distance, and quality,[8] or are neglected altogether.[9] Consequently, it is the objective of this paper to detail problems and their resolution in an application of conjoint measurement to spatial choice. It is particularly germane to consider how both new and existing spatial choice behavior might be predicted by the technique. The use of multidimensional scaling techniques has not yet passed from descriptions to forecasts of spatial behavior.[10] The increasingly common use of conjoint analysis in analagous marketing and brand choice situations appears to demonstrate the effectiveness of the technique for forecasting purposes.[11]

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[8]Girt, J. L., "Some Extensions to Rushton's Spatial Preference Scaling Model," Geographical Analysis, 2 (1976), pp. 137-156; Rushton, G., "Analysis of Spatial Behavior by Revealed Space Preference," Annals, Association of American Geographers, 59 (1960), pp. 391-400; Rushton, G., "The Scaling of Locational Preferences," in Cox, K. and R. G. Golledge (eds.), Behavioral Problems in Geography: A Symposium, Studies in Geography No. 17, Northwestern University (1969), pp. 196-223; Rushton, G., "Decomposition...," op. cit.; White, R. W., "A Generalization of the Utility Theory Approach to the Problem of Spatial Interaction," Geographical Analysis, 8 (1976), pp. 39-46.

[9]Fingleton, B., "Alternative Approaches to Modeling Varied Spatial Behavior," Geographical Analysis, 8 (1976), pp. 95-102.

[10]As, for example, in Ben-Akiva, M., "Structure of Passenger Demand Models," Paper presented at the 53rd Annual Meeting of the Transportation Research Board, January 1975; Burnett, K. P., "The Dimensions of Alternatives in Spatial Choice Processes," Geographical Analysis, 5 (1973), pp. 181-204; Burnett, K. P., "Perceived Environmental Utility Under Alternative Transportation Systems: A Framework for Analysis," Paper presented at the American Psychologists Association Meetings, Chicago, August 1975; Golledge, R. G. and G. Rushton, Multidimensional Scaling: Review and Geographical Applications, Technical Report No. 10, Association of American Geographers, Commission on College Geography, 1972; Lieber, S. R., op. cit.

[11]Davidson, J. O., "Forecasting Traffic on STOL," Operational Research Quarterly, 24 (1973), pp. 561-569; Fiedler, J. A., "Condominium Design and Pricing," Association for Consumer Research, Chicago, 1972; Green, P. E., "On the Design of Choice Experiments Involving Multifactor Alternatives," Journal of Consumer Research, 1 (1974), pp. 61-68; Green, P. E. and V. R. Rao, "Conjoint Measurement for Quantifying Judgmental Data," Journal of Marketing Research, (August 1971), pp. 355-363; Green, P. E. and Y. Wind., "New Techniques for Measuring Consumers' Judgments of Products and Services," Working Paper, Wharton School, University of Pennsylvania, 1974; Johnson, R. M., "Trade Off Analysis ...," op. cit., pp. 121-127; Wind, Y., S. Jolly, and A. O'Conner, "Concept Testing as Input to Strategic Market Simulations," Paper presented at the 58th International Conference of the American Marketing Association, Chicago, April 1975.

II. THE CONJOINT MEASUREMENT MODEL FOR SPATIAL CHOICE

Familiar spatial choice behavior includes long-run migration decisions and those short-run destination selections of recurrent trip-making. In the interests of simplicity, this paper focuses on travel comprising the selection of one out of n destinations on each of a series of trips from a single base.[12] The paradigm example is shopping behavior, though social and recreational travel and residential search are also embraced. The conjoint measurement approach is therefore outlined for recurrent travel, largely following Johnson.[13]

Tradeoffs between attributes of alternatives govern travel behavior. For conjoint measurement, different levels of attributes act as stimuli. For example, different levels of convenience of alternatives (close, distant) influence travel. In the choice decision, combinations of stimuli are traded against each other; a higher priced, nearby store may be more acceptable than a cheaper, more distant store as price is traded-off against distance.[14] The general goal of conjoint analysis is "the decomposition of complex phenomena into sets of basic factors according to some specified rules of combination."[15] In modeling spatial choice, "the complex phenomena" are the preference rankings assigned to different spatial stimuli combinations. An example of such a preference ranking is shown in Table 1. The conjoint measurement problem is to obtain a measurement of each of the individual stimuli such that the combination of measures account for the rank order of the preferences. The combination rule may be of an additive or multiplicative variety.[16]

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[12] This assumes that destination choices are separable from other choices; for example, choice of mode. The evidence for non-separability is still sparse (see, Ben-Akiva, M., "Structure of Passenger Demand Models," Paper presented at the 53rd Annual Meeting of the Transportation Research Board, January 1975). Also, trips are considered single purpose as the modelling of multiple purpose trips has not yet advanced far.

[13] Johnson, R. M., "Trade Off Analysis...," op. cit.; Kostyniuk, L., "A Behavioral Choice Model of Urban Shopping Activity," Unpublished Ph.D. Dissertation, State University of New York at Buffalo, Buffalo, New York, 1975.

[14] Lieber, S. R., op. cit.

[15] Young, F. W., op. cit., p. 69.

[16] Lieber, S. R., op. cit.

TABLE 1

Preference Ranking of Spatial Alternatives For Recurrent Travel

Distance	Price		
	High	Medium	Low
Close	5	2	1
Middle	6	4	3
Far	9	8	7

One appropriate conjoint measurement model may be described as follows.[17] Consider the matrix X with 9 cells representing combinations of three levels of one destination attribute, with three levels of another. The matrix X is of order n x p, where in the sample case, n = 9 "objects" (cells) and p = 6 "independent" variables (levels of attributes). Let there be m individuals, and let the vector Y of length n contain an individual's preference ratings for the n combinations; there will be m matrices and vectors, one for each individual. Now consider a single unknown vector W of length p containing weights. Let XW = Z for each individual (the additive model) or $X \log_e W = Z$ (the multiplicative model). Then the conjoint measurement problem is that of finding one W so that the elements of each Z and Y have as nearly similar rank orders as possible.

The goodness of fit statistic is:

$$\theta^2 = \frac{\sum_{k}^{m} \sum_{ij} \delta_{ijk}(z_{ik} - z_{jk})^2}{\sum_{k}^{m} \sum_{ij} (z_{ik} - z_{jk})^2} \qquad (1)$$

where

$$\delta_{ijk} = \begin{cases} 1 \text{ if sign } (z_{ik} - z_{jk}) \neq \text{sign } (y_{ik} - y_{jk}) \\ 0 \text{ otherwise} \end{cases}$$

(This statistic is discussed by Johnson.[18]) The statistic has limiting values of 0 when the elements of all Z and Y are of exactly similar rank, and a value of 1.0 "if the rank order of predictions are exactly the opposite of the input data."[19] When the recovered vector W is such that $\theta^2 \simeq 0$, then the elements of the single vector W can be considered to be the utilities of the group of m individuals for each of the levels of the p destination

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[17] As far as the author is aware, this model has not been specified in the literature so far.

[18] Johnson, R. M., "Pairwise Non-Metric ...," op. cit.

[19] Johnson, R. M., "A Simple Method ...," op. cit., p. 3.

attributes, following Green and Wind,[20] among others. This is because multiplication or addition of the weights for any levels yields the preference rank of the level combinations, so that it is "natural" to interpret the weights as group utilities. (This ignores problems of the interpersonal comparison of utilities,[21] and whether it makes sense to talk of group utilities at all.)

The group utilities comprise the desired part-worths of each destination attribute. There is a group utility for all possible combinations of levels of destination attributes, whether or not there actually exists a destination described by each combination. Thus, conjoint analysis can predict the utility of changes in levels of destination attributes and of new destinations with combinations of attributes not hitherto in existence. The only caveat is that new or altered destinations must be defined by some of those combinations of attribute levels which are used in analysis.

There are three basic properties of the model which merit reiteration since they create special problems in the application of conjoint measurement to spatial choice. These are the assumption that all relevant alternatives and attributes are known, the assumption that attributes are independent, and the question as to whether the combination rule is of a multiplicative, additive, difference, or some other variety.[22] The special problems which these assumptions create will be further discussed below.

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[20] Green, P. E., and Y. Wind, _op_. _cit_., pp. 109-110.

[21] Brummel, A. C. and E. J. Harman, _op_. _cit_., p. 51.

[22] _Ibid_., pp. 57-52.

III. THE PHASE ONE SURVEY

A case study approach is adopted to explore the problems of the application of conjoint analysis to spatial choice. The intent is to highlight some of the difficulties and methods for their resolution. The shopping travel behavior of residents in Irving, Texas was selected for examination. Irving was a city of 116,000 persons in 1970, and is located just outside the border of Dallas, Texas (Figure 1).

Before conjoint measurement can be applied, the relevant shopping alternatives and their attributes must be defined. This means that, ideally, in order to use the technique, a two-phase survey approach must be adopted. The first phase involves the delineation of respondents' possible destinations and their attributes; the second involves the application of conjoint measurement itself. The need for two surveys means that applications of the technique are more expensive than other multidimensional scaling analyses, for example, the one phase use of Torsca to predict shopping travel flows from perceptions of, and preferences for, destination alternatives.[23] However, conjoint analysis yields more information about destination alternatives and the formation of utility and preference functions. It thus remains "one of the most promising avenues of scaling for behavioral geography."[24]

THE DESTINATION CHOICE SET PROBLEM

General Problem

In choice experiments in the laboratory there is an a priori set of alternatives to be presented to each subject.[25] The problem is to define what subsets will be presented to each subject on each choice, assuming that the subject's choices over successive presentations are stochastically

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[23] Burnett, K. P., "The Dimensions ...," op. cit.

[24] Brummel, A. C. and E. J. Harman, op. cit., p. 51.

[25] For the choice paradigm, see Atkinson, R. C., G. H. Bower, and E. J. Crothers, An Introduction to Mathematical Learning Theory, New York: Wiley, 1965, pp. 137-139.

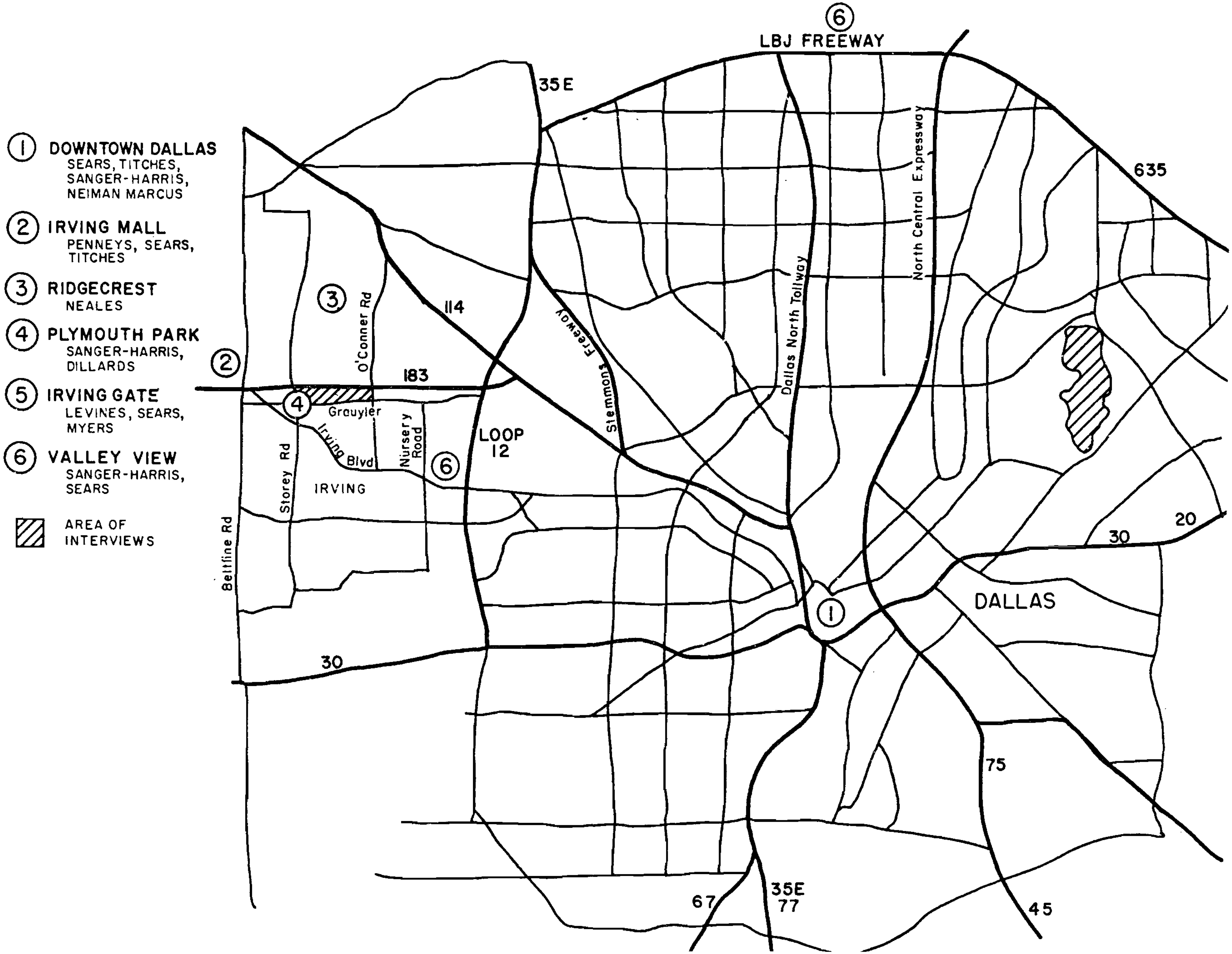

Figure 1. The Study Area

independent. In contrast, in the spatial choice situation, it is difficult to define the set of destination alternatives which each individual uses for selection. Presumably the choice set comprises that set of destinations with which a respondent is familiar for a given trip purpose. However, there needs to be some specification of the degree of familiarity which is required for a destination to be included in the choice set. For an alternative to lie within the domain of analysis, does it need to have been used, or heard about, or does some other criterion of familiarity need to be employed? There has been little exploration of this subject in the literature.

Other questions are also raised concerning the choice set. For example, the set might vary with individuals, depending on their socio-economic characteristics and their base of travel, home or work. The goods or services sought on a trip for a given purpose, and hence destinations, might also vary between individuals. In addition, there is no reason to suppose that choices from the alternatives are stochastically independent over time - the choice set might vary over successive selections as the individual learns more about the environment.

One strategy which Rushton[26] and others[27] have used to resolve some of these problems is to classify alternatives in some way such that all classes are available to each individual. One convenient scheme for shopping travel is to classify shopping centre destinations according to distance and size surrogates following central place theory. However, this is open to the now well-known criticism that the classes in the destination choice set so defined do not represent the actual stimuli to which consumers respond. Consequently, the choice set may not contain the relevant stimuli.[28] This is of importance where it is desired to predict precisely what alterations will be necessary to obtain desired spatial choice effects, as in the present instance.

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[26] Rushton, G., "Analysis of Spatial ...," op. cit.; Rushton, G., "The Scaling of ...," op. cit.

[27] Kostyniuk, L., op. cit.

[28] Brummel, A. C. and E. J. Harmon, op. cit., pp. 79-81.

Another strategy therefore appears preferable. This is to select a group of respondents from adjacent blocks within a well-established urban neighborhood. This strategy, like the first, represents an attempt to minimize discrepancies between individuals in the set of destinations for a specific trip purpose.[29] The case study investigated the ability of this solution to define the choice set.

Case Study Resolution

In the first phase survey, the blocks shown in Figure 1 were selected as the case study area. All homes within the area were approached with one callback, yielding forty-eight respondents to the phase one survey. Visits to department stores were selected as the trip purpose for investigation, since others have covered urban area shopping centre selection,[30] grocery store selection,[31] and women's wear selection[32] via multidimensional scaling. A list of fifteen possible department stores was compiled from directories and a field survey (Figure 1). Each respondent was asked whether they had heard of each store (one operational definition of familiarity), and to list others which they knew, but which had not been included. An analysis of responses is shown in Table 2.

The results show that the percentage of respondents aware of a store ranged from forty-two to ninety-eight percent, with a mode of seventy-seven percent. This seems to reveal considerable discrepancies in individuals' choice sets. Such a conclusion is also supported by the numbers of additional stores which were mentioned. These ranged from zero to four for a respondent; also, thirty-five percent of respondents listed other stores than those on the original list though these stores were different in each case. It is noteworthy that all individuals travelled from home to use department stores, so that different trip origins did not influence the

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[29] Neither strategy addresses the problem of the assumption of stochastic independence in choices over time.

[30] Stopher, P., "Development of the Second Survey-Shopping Destination Study," Unpublished Paper, Northwestern University, Evanston, Illinois, 1975.

[31] Kostyniuk, L., op. cit.

[32] Burnett, K. P., "The Dimensions ...," op. cit.

TABLE 2

Percentage of Respondents Aware of Destination

Destination	Percentage
1	76.92
2	76.92
3	76.92
4	78.85
5	98.08
6	98.08
7	96.15
8	42.31
9	88.46
10	88.46
11	78.85
12	78.85
13	75.00
14	67.31
15	65.38

choice set. It appears that selecting respondents from a single urban neighborhood does not altogether resolve problems of choice set definition, and that more research is needed on this question. Nonetheless, the fifteen stores of Table 2 were retained for later analysis by conjoint measurement, on the grounds that they seemed to offer the best choice set definition currently available.

PROBLEMS OF ATTRIBUTE (STIMULI) DEFINITION

General Problem

To apply conjoint analysis, not only does there need to be an a priori definition of the choice set, there also needs to be an a priori definition of attributes describing the set. This is because levels of attributes comprise the stimili to which individuals respond in the choice experiment, as noted in the model above. In laboratory situations and many social science applications of choice theory, attributes of alternatives are well-defined. This is not so in spatial choice behavior.

There are two widespread solutions to this problem. First, a checklist of attributes which seem applicable may be presented to respondents, and some measure of the importance of each attribute may be elicited (for example, Stutz's checklist of factors affecting destination patronage).[33] This simple method, when used alone, suffers from the fact that the checklist may not contain all the attributes to which individuals respond, and the attributes may not be defined in the manner in which they are used (for example, value for money may be used instead of price). Moreover, of course, individuals may not respond truthfully or accurately, the source of response bias. In order to avoid these difficulties, non-metric multidimensional scaling techniques are now widely used. Through applying multidimensional unfolding procedures, for example, attributes used to assess destinations may be recovered from a simple ranking of choice set members in order of preference. The naming of recovered destination attributes is however a widely recognized

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[33] Stutz, F., op. cit.

problem for which no satisfactory solution exists.[34] There is no objective means of interpreting recovered attributes without recourse to exogenous evidence on the properties of destinations.

Case Study Resolution of Attribute Definition

A combination of both solutions was used in the first phase of the case study. The method represents an attempt at a compromise solution which is applicable in a field survey where interview times must necessarily be short. This can occur both because of survey expense and because of limitations placed by respondents on interview duration (it will be recalled that the emphasis is on the recovery of attributes of alternatives from respondents in real world rather than laboratory situations).

The forty-eight respondents of the phase one survey were asked initially to check those listed attributes of alternatives which were important in their selection of a department store. They were also asked to rank order all fifteen of the stores in the choice set in order of their preference; the preference data were then scaled using Torsca 9 for analysis. The best solution was a four dimensional one in Minkowski metric two.

Two methods were employed to name the attributes (dimensions) from the non-metric multidimensional scaling analysis. First, calculations were made of the percentages of respondents who checked each attribute on the list. The results of these calculations are shown in Table 3. They indicated that price level, variety of merchandise, time to store, and prestige were the main factors in store choice. Consequently, each of the fifteen stores were rated from 1 to 7 on each attribute on a field survey, with 1 representing top scoring and 7 representing bottom scoring. The ratings were compared to the coordinate values obtained in the multidimensional scaling analysis. A high correlation suggested that a dimension could be interpreted as the attribute with which it was being compared. The results of the naming procedure are shown in Figures 2 to 4.

This procedure does not of course guarantee that the attributes describing destinations have been identified. However, a high degree of confidence

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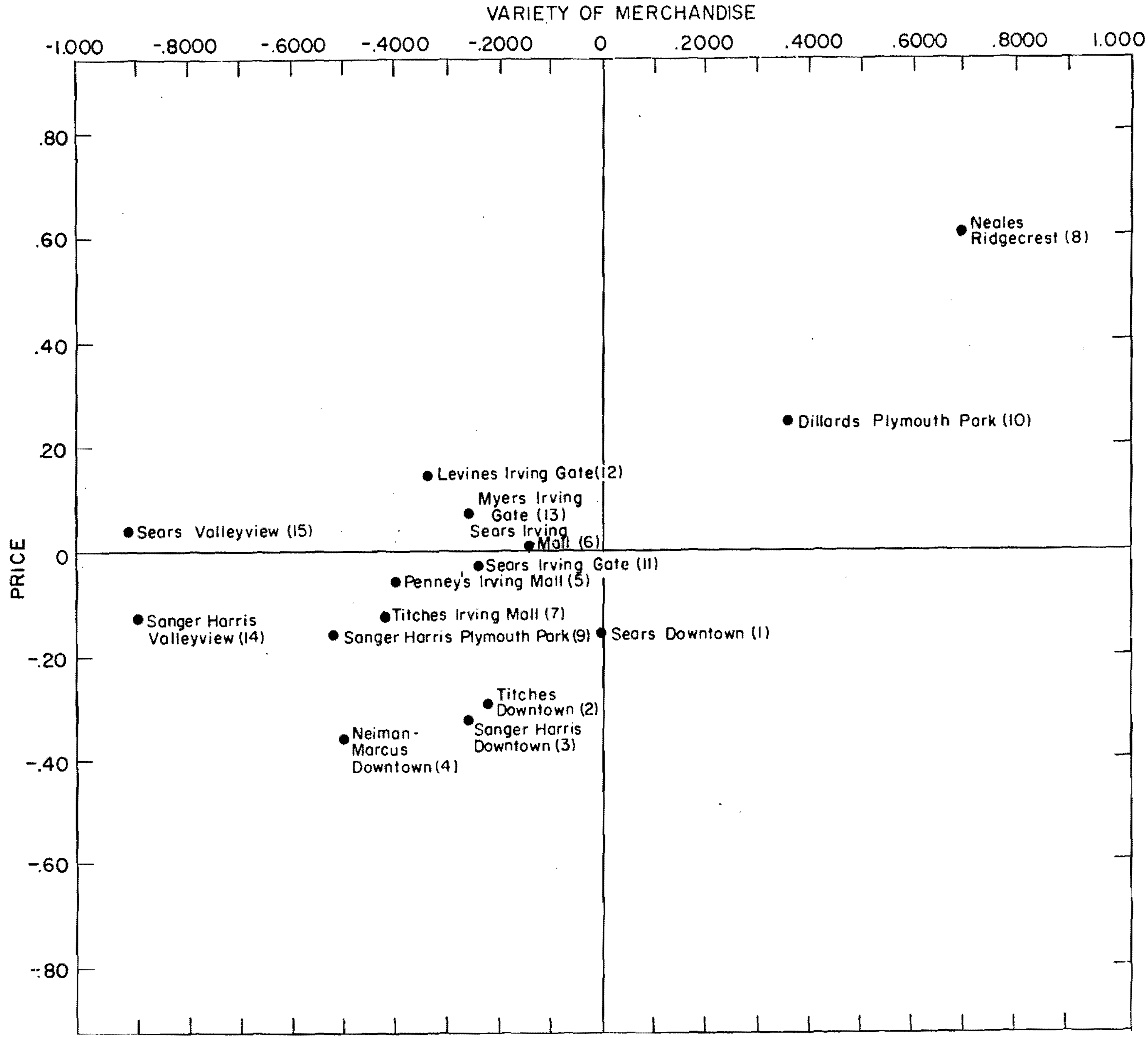
[34] Brummel, A. C. and E. J. Harman, op. cit., pp. 55-56.

TABLE 3

Percentage of Respondents Checking Attributes as Important

Attribute	Percentage
Price	*88.46
Variety of Merchandise in Store	*67.31
Number of Adjacent Stores	36.54
Parking	48.08
Time Taken to Store	*59.61
Distance to Store	51.92
Safety of Shopping Environment	26.92
Design, Layout of Store	17.31
Services	51.92
Quality of Merchandise	19.23
Prestige of Store	*75.00
Design, Layout of Shopping Centre	15.38
Advertising	15.38

*One of four highest ranking attributes


VARIETY OF MERCHANDISE
-1.000
-.8000
-.6000
-.4000
-.2000
0
.2000
.4000
.6000
.8000
1.000
PRICE
.80
.60
.40
.20
0
-.20
-.40
-.60
-.80
Neales Ridgecrest (8)
Dillards Plymouth Park (10)
Levines Irving Gate (12)
Myers Irving Gate (13)
Sears Valleyview (15)
Sears Irving Mall (6)
Sears Irving Gate (11)
Penney's Irving Mall (5)
Sanger Harris Valleyview (14)
Titches Irving Mall (7)
Sanger Harris Plymouth Park (9)
Sears Downtown (1)
Titches Downtown (2)
Sanger Harris Downtown (3)
Neiman-Marcus Downtown (4)

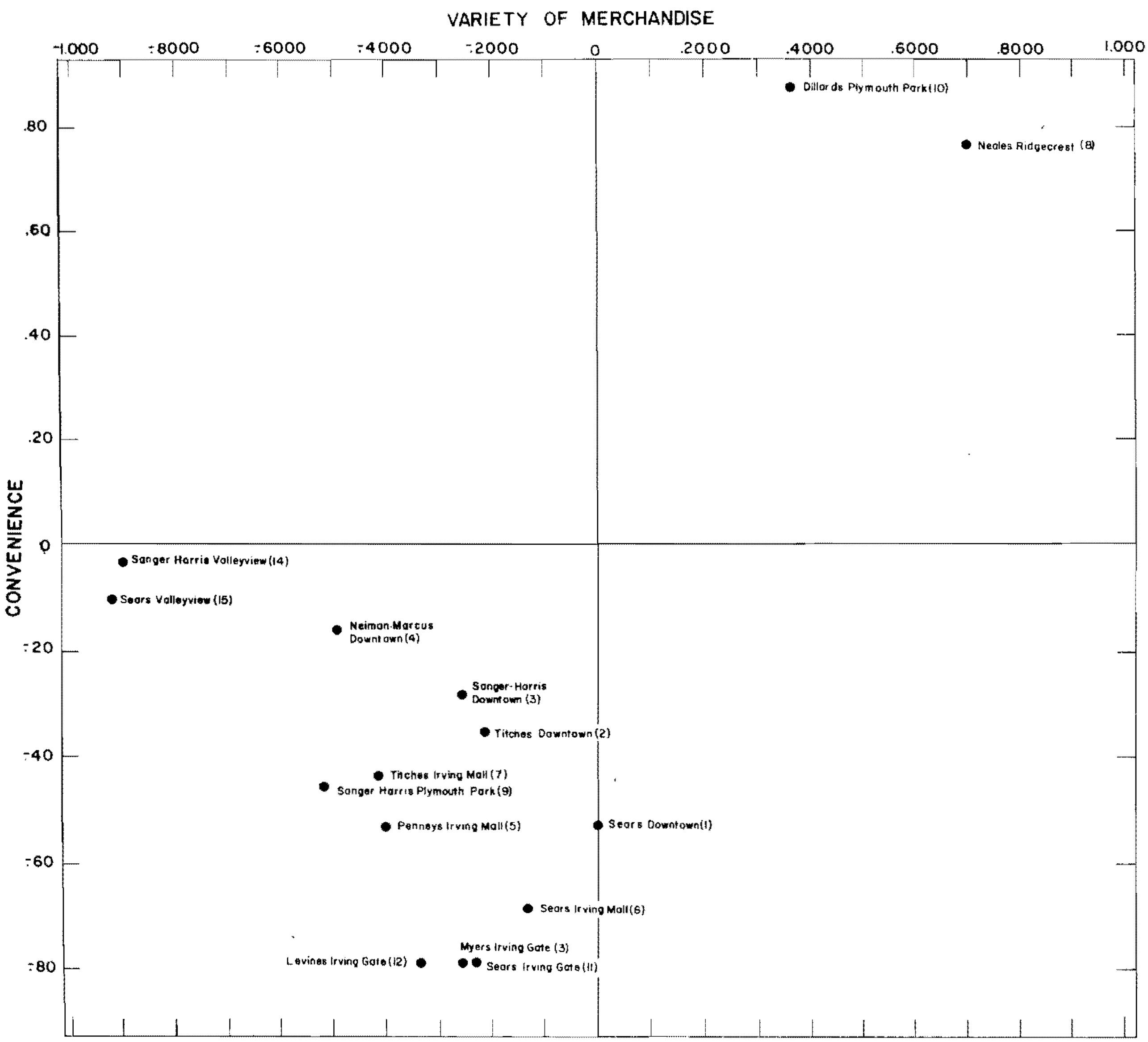


Figure 3. Store Configuration: Dimension 1 and Dimension 3

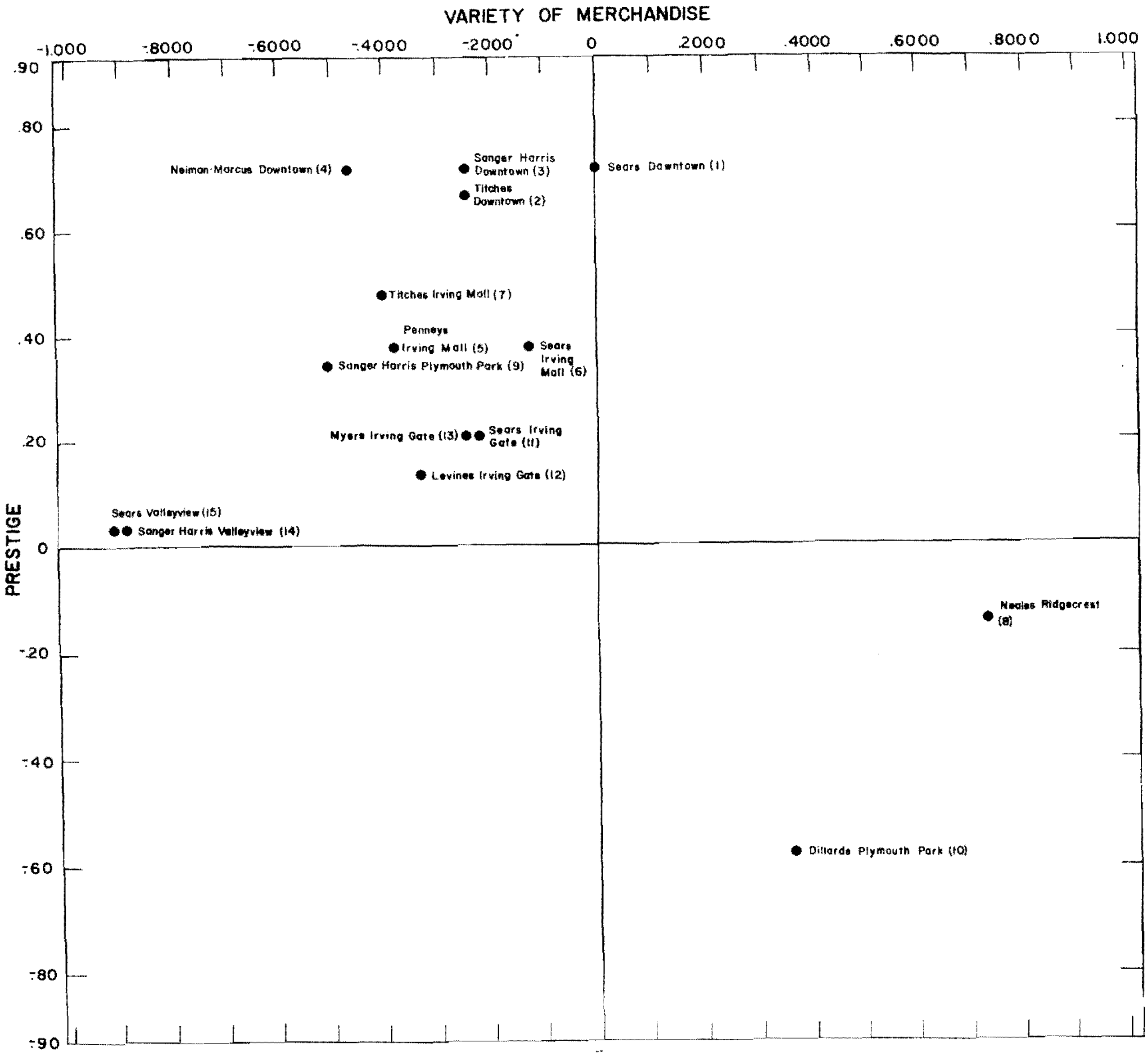


Figure 4. Store Configuration: Dimension 1 and Dimension 4

can be placed in the results; both the checklist and field survey identified attributes with a high degree of correlation with dimensions derived from multidimensional scaling.

The results are also very pleasing from the point of view of identifying the stimuli required for conjoint analysis. Each recovered dimension has a dispersion of destinations along it. Several different levels of each attribute thus act as stimuli in the case study situation, as is required by the conjoint analysis model.

IV. THE PHASE TWO SURVEY

The phase two survey comprised the application of conjoint analysis to determine the part-utilities attached to each level of destination attribute, together with the utility of the whole bundle of attribute levels defining a destination. The problems in this phase of the survey occur not only in real world spatial choice, but also in laboratory and other choice situations in general. Their resolution is therefore of widespread concern.

THE COMPLEXITY OF DATA GATHERING PROCEDURES

It has been noted earlier that conjoint analysis is used to analyze the preference rankings assigned to different spatial stimuli combinations (Table 1). The procedure is designed to reveal the utility of each level of a destination attribute relative to the utility of each level of each other attribute. In order to perform the analysis, a matrix like Table 1 is required for each possible combination of attributes: if there are n attributes of interest, there will be $\frac{n(n-1)}{2}$ matrices. A problem of complexity in data gathering thus arises if n becomes large.

There is, however, a good reason for believing that this might not be a difficulty in spatial choice situations. Previous studies[35] have shown that the number of attributes which are used to discriminate alternatives is small. In the present instance n = 4 (variety of merchandise, price, convenience, prestige), so that only six matrices needed to be presented to subjects. Each attribute was divided into three levels, and respondents were therefore required to fill in six matrices of the type shown in Table 1.

There were one hundred respondents from whom these data were gathered on the phase two survey.[36] They were sampled from the same area as phase one respondents (Figure 1). This enabled the necessary (though questionable) assumption to be made that the subjects used the same attributes to discriminate alternatives as did the sample for the phase one survey.

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[35]For example, Burnett, K. [illegible], [illegible]

[36]Two respondents were later dropped from the sample owing to incomplete questionnaires.

THE INDEPENDENCE OF ATTRIBUTES ASSUMPTION

The application of conjoint analysis requires that the attributes used be independent of each other, that is, "there should be no interaction effects between attributes"[37] and "the attributes must all be non-redundant, or, more accurately, they all must be equally redundant."[38] In a spatial choice situation, it is by no means clear that the independence of attributes assumption will hold. For example, in the present instance, it is plausible that the extent to which a respondent prefers a low priced department store to a high priced one will not be independent of at least the prestige of the facility. It seems reasonable that low price may be someone's preferred price level for a low prestige store, while high price might be their preference for a store of high prestige. In this situation the application of conjoint analysis seems suspect.

However, it has been reasoned that the assumption is "tenable under ordinary circumstances," and that "if interactions do exist in a special set of data, they will be indicated by unfavorable values" of the goodness of the statistic.[39] The analysis of the respondents' six preference matrices was therefore carried out, using Johnson's trade-off analysis algorithm. This algorithm finds the solution to the conjoint measurement problem outlined in the first section of the paper. Table 4 shows the six θ statistics obtained by the analysis, one for each of the six matrices. In the case study, low values of the θ statistic for the additive model indicate that little interaction is present. Accordingly, although there is reason to suspect the presence of interaction in the destination choice context, the attributes of alternatives seem independent enough to yield meaningful results.

The output of the conjoint analysis program is shown in Table 5. This table contains the weights (utilities) derived for each level of each attribute, with one set of weights derived for each of the matrices in which any

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[37] Brummel, A. C. and E. J. Harman, *op. cit.*, p. 51.

[38] Johnson, R. M., "Trade Off Analysis ...," *op. cit.*, p. 124.

[39] *Ibid.*

TABLE 4

θ Statistic for the Additive Model

Matrix No.	Attributes	θ
1	Variety	.21916
	Price	
2	Variety	.28299
	Convenience	
3	Variety	.36280
	Prestige	
4	Price	.28596
	Convenience	
5	Price	.35656
	Prestige	
6	Convenience	.31929
	Prestige	

TABLE 5

Weights (Utilities) for the Additive Model

Matrix	Level of Attribute High	Medium	Low
Variety × Price	.41	.04	.19
× Convenience	.41	.004	.34
× Prestige	.63	.03	.39
Price × Variety	.10	.03	.25
× Convenience	.17	.05	.40
× Prestige	.34	.03	.58
Convenience × Variety	.21	.01	.15
× Price	.14	.00	.15
× Prestige	.56	.01	.41
Prestige × Variety	.09	.02	.03
× Price	.01	.002	.003
× Convenience	.05	.01	.01

given attribute appears. Figure 5 contains plots of the utilities for the levels of attributes which are portrayed in Table 4.

INTERPRETATION OF RESULTS

The Assumption of Additivity

One assumption underlies the presentation of results thus far. This assumption is that the additive conjoint model is preferable to the multiplicative model. In general, reasons for the assumption in practice of either the additive or multiplicative combination rule are rarely discussed in the literature.[40] Since each model yields different results, it is worthwhile briefly discussing the criteria for the use of one or other forms.

One criterion which obviously can be used is the goodness of fit statistic, θ. For the present instance, the θ statistic for the multiplicative model was higher than the θ for the additive model, for all the six matrices in the experiment. This indicates a better fit of the additive model to the original preference data. Accordingly, the additive model and its results were adopted here.

Another criterion could be the kind of relationship that may be anticipated a priori among the variables. For example, in the additive model, it is implied that the total utility of a given destination is the sum of the utilities for each level of the attributes which describe it. This implies that if one of the utilities of destination attributes is zero, then the destination will have a utility which is a sum of the utilities of the remaining attribute levels: this seems reasonable. In contrast, for the multiplicative model, the multiplication of the utilities of each attribute level gives the overall utility of a destination. This implies the unreasonable result that, if only one of the utilities is zero, the total utility of the destination is zero. Accordingly, the additive rather than the multiplicative model seems preferable for most applications, despite the fact that the multiplicative model is recommended for widespread use.[41] This is a second reason for concentrating here on the results of the additive model.

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[40] See, for example, Ibid.; Tversky, op. cit.

[41] Johnson, R. M., "Trade Off Analysis ...," op. cit.

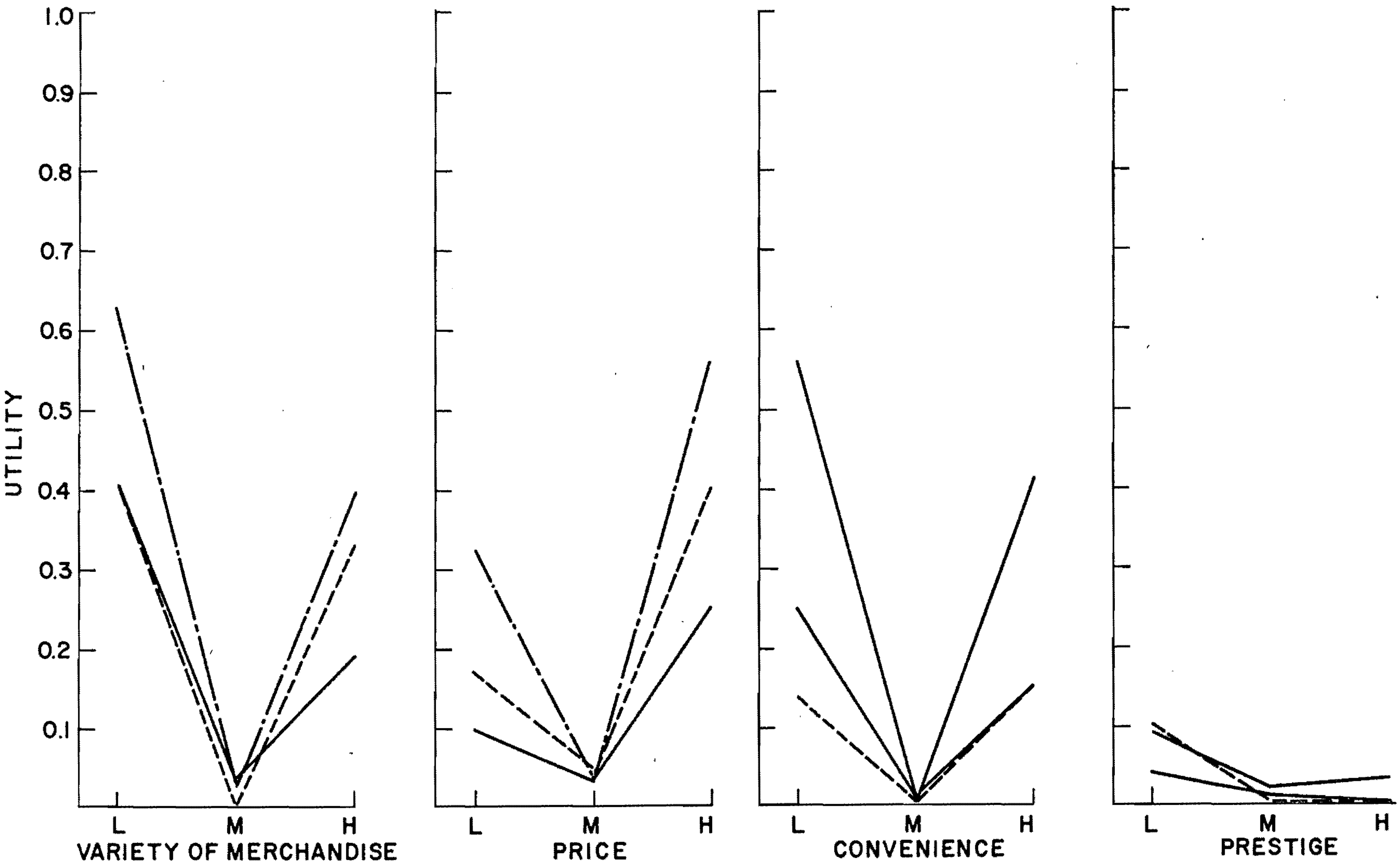

Figure 5. Utilities for Attribute Levels

Computational and Interpretive Problems

As may be seen from Table 5, each matrix in which an attribute occurs produces a different set of utilities for levels of that attribute. A question therefore arises as to which set of utilities should be used for the purpose of further computation and interpretation. This question is not discussed in the literature, although the resolution of the problem is of some importance. It may be seen from Figure 5 and Table 5 that the values for each attribute level are similar in each of the three matrices in which they occur. Consequently, the variation from matrix to matrix may reflect deviations in the utility value of an attribute level about some overall mean. The mean value of the utility of each attribute level was therefore calculated. These mean values are shown in Table 6 and Figure 6. Each attribute in these illustrations has the same pattern of utility values. Peak utility is found at the low level and the high level of each attribute. This apparently reflects the fact that, for the case study respondents, department stores with either high or low attribute levels are preferred. In other words, there is most preference for either department stores which are very convenient or low priced but which have low variety of merchandise and low prestige; or for department stores which are less convenient or high priced but which have great variety and high prestige. This is a reasonable and pleasing result. Consequently, the mean utility for each attribute level may be used for further analysis.

In particular, the overall mean utility for each store in the case study may be calculated. The sum may be found of the mean utility for each attribute level describing a destination. The problem here is to determine what levels of attributes define each destination in order to carry out the computation. Perceived levels of attributes determine behavior (for example, the perceived convenience of a destination influences its selection). This suggests that configurations of destinations like those of Figures 2 to 4 may be used to define whether choice alternatives rank high, medium or low on each attribute. In the case study, therefore, the levels of each attribute which describe a store were derived from an analysis of Figures 2 to 4. Table 7 contains the results of this analysis, and of summing the utilities of each attribute level describing a store to compute overall store utility.

TABLE 6

Average Utilities for the Additive Model

	Level of Attribute		
Attribute	High	Medium	Low
Variety	.48	.02	.31
Price	.20	.04	.41
Convenience	.32	.01	.32
Prestige	.05	.01	.01

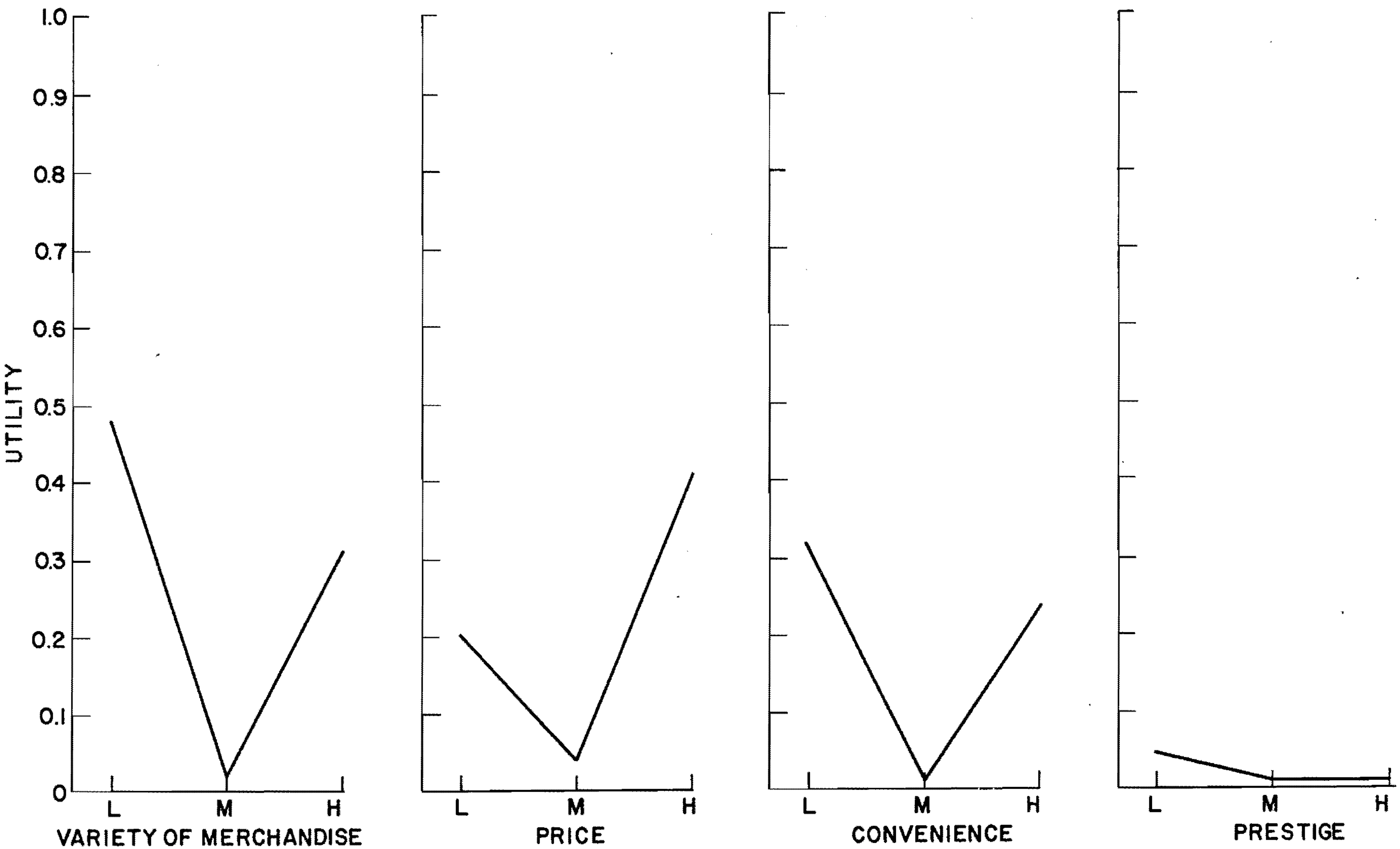

Figure 6. Average Utilities for Attribute Levels

TABLE 7

Store Utilities

Store	Attribute Level*				Total Utility†
	Variety	Price	Convenience	Prestige	
1	M	M	M	H	.12
2	M	M	M	H	.12
3	M	H	M	H	.28
4	M	H	M	H	.28
5	M	M	M	M	.08
6	M	M	L	M	.21
7	H	M	M	H	.58
8	L	L	H	M	1.05
9	M	M	M	M	.08
10	L	L	H	L	1.05
11	M	M	L	M	.31
12	M	M	L	M	.31
13	M	M	L	M	.31
14	H	M	M	M	.54
15	H	M	M	M	.54

*L = Low

M = Medium

H = High

†Utilities are calculated from Table 6.

The store utilities can now be easily related to choice probabilities; thus a model of destination choice can be generated by the conjoint analysis procedures. The utility of a destination is reflected in the probability with which it will be chosen. Let the aggregate utility U of all destinations be equal to the sum of the utilities of individual destinations, U_i. Then a destination alternative will have a choice probability of $\frac{U_i}{U}$. Table 8 contains the result of calculating the choice probabilities for the case study department stores. There is some difficulty with the interpretation of the choice probabilities derived in this fashion. Should they be interpreted as the relative frequency with which an entire group of individuals will select an alternative, so that, for example, a destination choice probability of .50 means that a group of subjects will allocate fifty percent of their aggregate number of trips to that alternative? Or should choice probabilities be interpreted as the relative frequency with which each individual selects an alternative? Since the conjoint analysis model in this paper yields only group utilities for different levels of destination attributes, the first interpretation seems preferable.

Finally, the results so far can be used to predict the utility (and hence the choice probability) of new alternatives in the choice set. For example, there may be added to the existing department stores in the case study, a new store with an image of low price, low prestige, high convenience and high variety of merchandise. The utility of the new alternative may be calculated by summing together the known utilities for each of its specific attribute levels. The entire set of choice probabilities may then be recalculated for the enlarged store set. Similarly, if the attribute levels of an existing alternative are altered, a new utility and choice probability may be calculated for it. The easy accomodation of new alternatives or changes in existing ones is the greatest strength of conjoint analysis procedures.

TABLE 8

Store Choice Probabilities

Store	Choice Probability
1	.02
2	.02
3	.05
4	.05
5	.01
6	.04
7	.10
8	.18
9	.01
10	.18
11	.05
12	.05
13	.05
14	.09
15	.09

V. CONCLUSION

This paper has discussed problems and their resolution in the application of the conjoint measurement model to real world spatial choice, with special reference to choice behavior on recurrent urban travel. The principal problems encountered are: (1) the definition of the choice set, (2) the determination of choice set attributes as stimuli for the experiment, (3) the complexity of data gathering procedures, (4) the independence of attributes assumption, (5) the additivity assumption, and (6) computational and interpretive questions. Each of these problems is examined in turn, and a case study illustrates their resolution. It may be concluded that conjoint analysis is particularly useful for examining real world spatial behavior, since the difficulties encountered do have satisfactory solutions.

Although this paper has explored some of the principal problems of using a conjoint measurement model, obviously other questions arise in its application to spatial choice. Especially, questions of sampling and difficulties in administering questionnaires have been left aside. Also, there has been no discussion of the interpretation of group weights as utilities for each attribute level. In addition, there has been no treatment of theoretical difficulties with the conversion of group utilities into choice probabilities. These are all questions which merit further research, but space precludes their inclusion here. Nonetheless, this paper seems to have fulfilled its main aim of demonstrating the usefulness of conjoint analysis in research on choice behavior.

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