AN ANALYSIS OF URBAN TRAVEL AND THE SPATIAL STRUCTURE OF URBAN ACTIVITIES

by

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ABSTRACT

AN ANALYSIS OF URBAN TRAVEL AND THE SPATIAL STRUCTURE OF URBAN ACTIVITIES.

George Charles Hemmens

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This thesis is a study of the relationship of the spatial structure of activities to the physical form of the city. Urban activities are defined in terms of the daily travel of persons in urban areas. Persons make trips in order to accomplish specific purposes. These purposes are usually to participate in particular land-based activities such as work and shopping at the trip destination. The pattern formed by these purposive linkages constitutes the spatial structure of activities.

The thesis consists of an analysis of urban travel behavior and of experiments relating travel behavior to urban form. In the first part of the thesis we examine the rationality of urban travel, the spatial structure of activities, and the comparative locational advantage of sub-zones in the Buffalo, New York area using linear programming techniques. In the second part of the thesis we use linear programming to examine some of the implications of alternate urban forms on the spatial structure of activities. The principal criteria used are the efficiency with which activity linkages can be established and the equity with which locational advantage is distributed. Alternate urban forms are derived first from experimental rearrangement of the location of non-residential activities in the Buffalo area, and second from a hypothetical city form.

Some of the major conclusions about travel behavior and the spatial structure of activities are: (1) that the principal linkages from each zone are rational since they approximate the travel requirements of travel minimizing behavior; (2) the spatial pattern of activities is different for each activity examined; and (3) the urban area is organized into focal subregions which divide it into semi-independent areas. Some of the major conclusions about the impact of alternate urban forms on the activity structure are: (1) that changes in the transportation system have relatively little effect on the efficiency or the activity linkage pattern of alternate urban forms; (2) changes in the residential pattern also have relatively little effect on the efficiency or the activity structure of alternate urban forms; (3) the location and intensity of non-residential activities have a marked effect on the relative efficiency and the activity linkage pattern of alternate urban forms; and (4) in our experiments the most efficient urban form with a given transportation system has the greatest equity of locational advantage.

"Thesis Supervisor: Aaron Fleisher
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INTRODUCTION

The perplexing problem of the urban planner is to understand the spatial structure of activities in urban areas and its relation to the physical pattern and form of the community. The distinction we make between urban form and urban structure is simple. Urban form is the spatial arrangement of the physical elements of the community -- the residences, workplaces, shopping centers, recreation areas, etc. Urban structure is the pattern formed by the connection of these elements in the daily activity of the area's residents. The way in which people use the urban area -- going to and from workplaces, shopping centers, recreation areas -- establishes the spatial structure of activities.

Urban structure implies an allocation rule. Given a pattern of land uses the connections between them -- from home to work, from home to shopping -- must be established. Another way of making the distinction between urban form and the spatial structure of activities is to say that urban form describes the static physical setting of the city, and that urban structure describes the dynamics of a particular physical setting. The nomenclature is arbitrary but the distinction is necessary.

The connections between places in the urban area established by persons in the conduct of their daily activities can be thought of as lines of varying thickness. The thickness of the lines is determined by the number of person linkages between any two places. In effect this is a traffic flow map. The spatial structure of activities can be summarized in terms of the boundaries (or lack of them) established by the pattern of linkages. In a large urban area it is quite unlikely that all places will be connected with all others. So the linkages of activities may divide or partition the urban area into sub-areas between which there is little or no activity linkage. Even if all places are linked with all others, variations in the strength of the linkages may establish divisions in the urban area.

An example of an activity structure will clarify our concept. Imagine an urban area composed of a large number of small zones. There are residences in each zone, but not the same number of residences in each zone. Two of the zones contain shopping centers. The only activity in the urban area is shopping. One member of each household goes to one shopping center each day. And for convenience assume that they always select the same shopping center. Linkages are established from each zone to the shopping center zones. If all persons select the nearest shopping center the boundaries of the linkage pattern will establish distinct market areas for each shopping center. The variable strength linkages and the boundaries of the two sets of linkages comprise the spatial structure of shopping activity.

There are many ways to describe the activity which goes on in urban areas and the way in which residents make use of the urban area in the conduct of their activities. We limit our analysis to activity as defined by the trips of residents of the urban area for particular purposes. The purposes for which the trips are undertaken are thus the activities we consider; and the origins and destinations of persons for these purposes at different places in the urban area defines the spatial structure of activity.

Urban trips are primarily purposive land use connections. Trips are made from one land use to another for a particular purpose. Usually the purpose is to engage in the land-based activity at the trip destination. An accounting of urban travel, as is done in a contemporary origin and destination survey of urban traffic, thus provides a picture of spatial interaction in terms of the purposive behavior of the occupants of the urban area. The exceptions to this norm are the relatively few week-day trips which are recreational in character -- the pleasure ride -- , and the trips made by auto driver and his passengers to serve a fellow passenger.

We define trips as one-way linkages between two stops -- an origin point and a destination. If an individual requires two or more such trips to reach his ultimate destination, as an auto driver who drives first to a fellow worker's house to pick him up and then to work, each segment of the total journey is considered a separate trip.

In summary we are exploring the spatial structure of activities defined as the purposive connections of land uses by person trips in the urban area, and the relation of this activity structure to the physical form of the community. As we have defined it the spatial structure of activities is one element of the functional organization of the community. Other major elements of functional organization are the movement of goods between urban sites and communications of information, such as telephone messages, which do not require physical transfer of persons or goods.

The urban planner's job is to devise a physical form of the city -- a land use pattern -- which provides an efficient framework for the functional organization of activity in the area. He is particularly concerned with propinquity and proportion, or mix of land uses. The planner seeks to place together land uses which have common bonds in the activity structure, in site requirements, or in nuisance character. Similarly the concern for the mix of land uses reflects the planner's concept of the activity structure. In using the neighborhood unit, for example, the planner attempts to create a spatial unit which has a counterpart in the activity structure.

Our approach is to analyze the activity structure and to use this analysis for evaluating urban form. The activity structure is rooted in and reflects the spatial pattern of land use.

Related Studies

Historically most urban analysts have concerned themselves with the spatial pattern of land development. In recent years there have been several studies outlining approaches to the study of urban activity systems. In a very general sense this study is an outgrowth of these writings. Some ideas have been borrowed from these writings, and in some instances they have provided support for our ideas. A brief review of these works follows.

Richard Meier, in his book A Communications Theory of Urban Growth, pictures the modern city as a communications system.[1] He represents interaction among persons as information flow and argues that the aim of society must be to conserve information. By conservation of information he means that "information accumulation must proceed at least as rapidly as the average rate of attrition."[2] In his view the advancement of society is related to the growth of its fund of information.

Meier's analysis is of interest to us primarily because of the emphasis he places on communications linkages between persons as the key to understanding urban development. Unfortunately his approach is of little direct help to the planner concerned with organizing the physical pattern of the city. Except for a brief analysis of spatial organization he makes no connection between the physical form of the city and the communications process.

He concludes his analysis of urban spatial organization with the statement, "The allocation of space is closely linked to the use of time for passenger transportation."[3] Since person movements are not communications in his sense of information transfer he does not relate the allocation of space to the communications process. Elsewhere he says, "It is Adam Smith's unseen hand that organizes the metropolis, and it is the pattern in the communications that affords us a glimpse as to how it operates."[4] He gives no attention to the possibility that the pattern of communications may influence the spatial organization of the community. Adam Smith's "unseen hand" is actually a body of information and the communication of that information. The information concerns conditions of supply and demand and access to that information is highly prized in a competitive market.

Melvin Webber, in his essay on the "Urban Place and the Nonplace Urban Realm", attacks much the same problem we do.[5] He seeks to match "metropolitan processes" to "spatial form" and presents "a dynamic portrait of metropolitan form in action."[6] He deals with cities as "functional processes" by focusing upon "linkages expressed as interactions," and as "structural forms" of buildings, roads, and land uses. His aim is "a clearer conception of the urban communities as spatially structured processes."[7]

Webber's analysis of the city as a communications system leads him to the argument that "cohabitation of place" is no longer a necessary or sufficient condition of community. He argues that social interaction on an interest basis defines community, and that accessibility is the key to development and maintenance of community. He calls these interest communities urban realms.

He argues that persons inhabit several of these non-spatial realms. As a person shifts roles (from research chemist to coach of the Little League team) he shifts realms. The realms have spatial connotations quite similar to the planner's traditional hierarchy of urban spatial organization. As manager of the Little League team his realm is largely the local residential neighborhood, and as a member of a local service club his realm is city-wide. In his profession his realm is nation-wide and world-wide.

In Webber's view the spatially defined city is a special and relatively unimportant community. He says, "...the place-community represents only a limited and special case of the larger genus of communities, deriving its basis from the common interests that attach to propinquity alone."[8] He suggests that urban planners should "free themselves from the obsession with placeness", and should "view the urban communities as spatially extensive, processual systems in which urbanites interact with other urbanites wherever they may be."[9]

Because he concludes that access of interest groups rather than spatial propinquity is the necessary condition of community Webber's original aim of linking functional process and spatial form is not achieved. His prescriptions for planning for the spatial structure of metropolitan areas do not follow from his analysis of urban communications. They simply reflect his recognition that the fact of spatial organization of activities must be dealt with by the planner.

Chapin defines urban activity systems as "behavior patterns of individuals, families, institutions, and firms which occur in spatial patterns that have meaning in planning for land use."[10] He argues that land use patterns are the outcome of urban activity systems, and that a land use plan must be based on the interaction within the metropolitan area.

Chapin defines interaction as having two components -- activities and communications. Activities are called "within interaction" and communications are called "between interaction." As their names imply communications are the flows to and from activities, and activities, or "within interaction" occur at "particular adapted spaces."

Location behavior is seen as the link between daily activities and the spatial organization of the urban area. He says, "It may be helpful to think of daily activities as a basic form of behavior in the urban social system, and location actions as an instrumental form of behavior prompted by the basic form."[11]

Chapin identifies three general activity types: productive activities, general welfare activities, and residential activities. The agents who conduct these activities are, respectively, firms, institutions, and households and individuals. With this general framework Chapin sets out to identify activity patterns. He has conducted field surveys of residential activities which are designed to identify the time budgets of households, the spatial patterns of household activities, and variables that are likely to alter activity patterns.[12] These surveys are the only attempts made by any of the authors to empirically relate activity patterns to the physical form of the community.

Our approach to the spatial structure of activities is quite similar to the general model Chapin outlines although it was developed independently. The present study concentrates on a small element in Chapin's scheme. In his terms we are examining the linkage patterns of those household activities which occur away from the home. Our study differs from Chapin's in that we deal with trip data aggregated by purpose for zonal subdivisions of the urban area. Chapin pursues a micro-analytic study of individual households.

One additional work deserves comment. Some stimulus for the present study came from the concept of urban complex analysis.[13] As conceived by Isard, urban complex analysis is a cost analysis of alternate patterns of metropolitan organization. This organization includes both a functional and a spatial dimension. Urban complexes are defined as metropolitan activities which have strong linkages affecting their costs and revenues. Isard asserts that, "A metropolitan pattern consists of an hierarchical structure of urban complexes, where the number of urban complexes in each order and their sizes, activity mix, and locations are specified." He proposes that the planner identify several such patterns and then evaluate their costs through an input/output analysis of interactivity relationships. Some of the costs to be considered are transportation, labor, and land costs. Urbanization, scale, and spatial juxtaposition economies are to be calculated. The metropolitan pattern with the least cost (for a given level of output) is considered the best.

Isard only sketches his proposal in general terms. We follow his lead only in accepting the concept that the interactions among activities in metropolitan areas must be evaluated in order to evaluate the spatial pattern. His prescription that urban complexes must be hierarchical is arbitrary. Like the planner's neighborhood based hierarchy, an activity hierarchy is appealing because of its simplicity and neatness; but there is no proof that the world is so neatly organized as are theoreticians' minds.

Outline of the Study

The scale at which we shall conduct our study is the metropolitan area. An entire metropolitan area, rather than some municipality or other local governmental unit within it is the appropriate subject for the simple reason that such boundaries have little influence on daily travel patterns. The entire metropolitan area is available to residents of it and, in a sense, each person is a resident of the entire metropolitan area since he is likely to use the entire area over time.

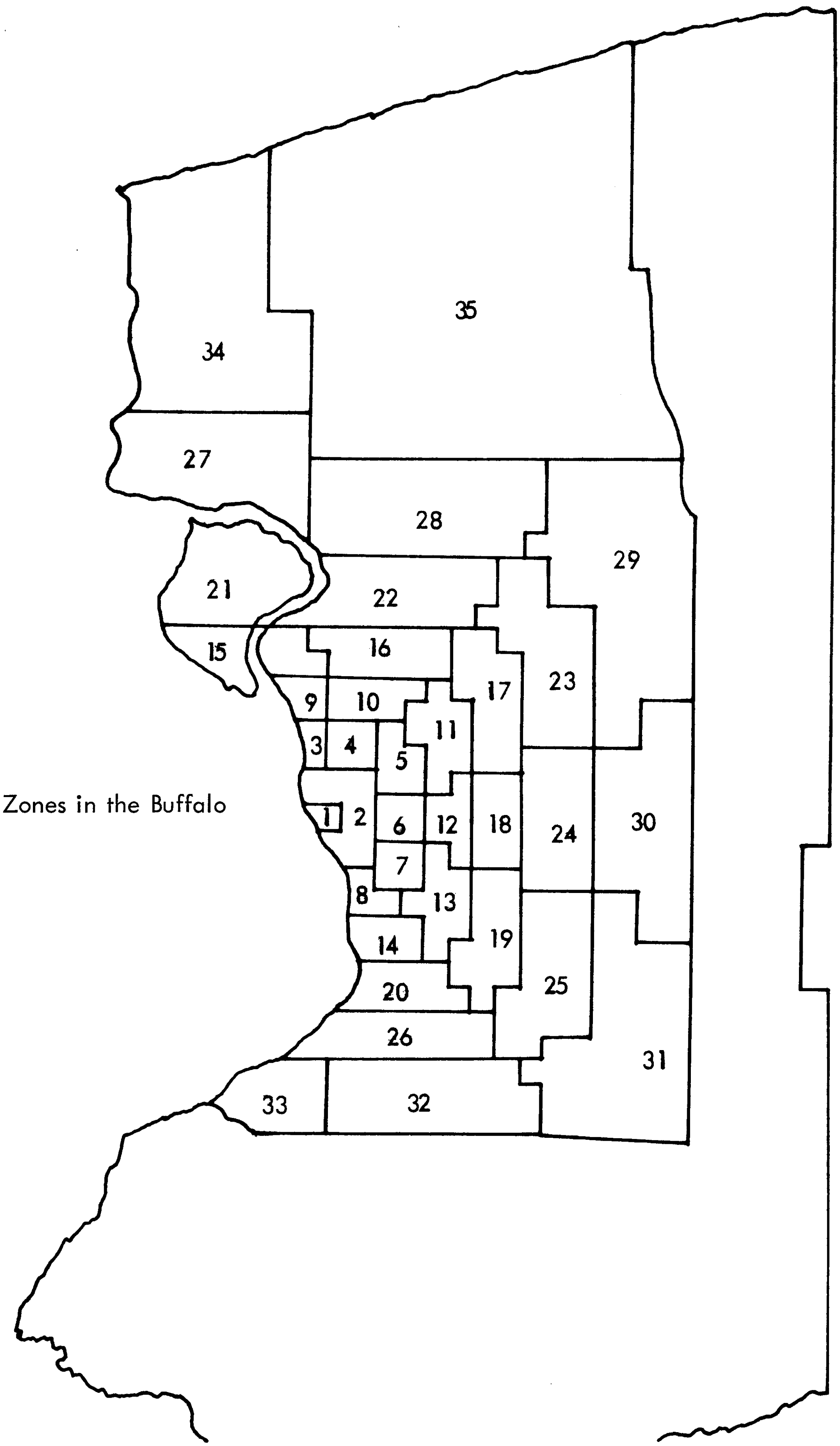
The Buffalo, New York metropolitan area will be the subject of most of our analysis. Travel data on which the analysis will be based is drawn from a home interview survey conducted in the Buffalo area in 1962 by the Niagara Frontier Transportation Study. The survey area contained about 400,000 dwelling units and had a population of about 1,220,000 at that time. Four percent of the dwelling units, selected by a systematic sample, were interviewed. Sample results were then expanded to represent the entire population. The special tabulations required for this study were provided by the Niagara Frontier Transportation Study.

We deal with only three trip purposes, or activities. These are trips to work, to shopping, and to social-recreation activities. In each case we treat the activity as homogeneous. We do not distinguish between different types of retail establishments, or different types of social-recreation activities. And we do not differentiate the tripmakers by taste, income, occupation, other personal characteristics, or household characteristics.

Our interest is in the spatial patterns of activity which results from the trip making behavior of individuals, rather than in the relationship between trip making behavior and the personal characteristics of the tripmaker, or detailed characteristics of the activity. Aggregation of data of trip making behavior into broad classes of activity is necessary in order to define and examine the general pattern of activity. The limited resources available for this study and the difficulties of data manipulation have prevented us from experimenting with a more detailed definition of activities.[14]

Analysis of spatial linkages requires that the urban area be subdivided into small zones. Ideally a separate zone should be established for each establishment capable of sending or receiving trips. Each household, each store, each factory should be separately identified. This is, of course, impractical. So we establish zones which are agglomerations of individual establishments, land parcels, city blocks, etc., and we account for trips in terms of the zone boundaries.

Since we are using data collected by the Niagara Frontier Transportation Study, we must use the zonal definitions established by the Study. We have chosen to use the Study's thirty-five traffic analysis districts for our analysis. They are shown in Map I. Hereafter they will be called zones. The use of these zones is an admittedly uneasy choice between the conflicting objectives of making zones as small as possible to achieve accurate travel accounts, and keeping the number of zones small enough for economical analysis. However we must consider that the data are drawn from a systematic sample of the population, and aggregation into fairly large zones to hedge against sample bias is a reasonable procedure. We



Map 1.
Analysis Zones in the Buffalo Area.

must also be aware that the results of analysis of trip data are influenced to some undetermined extent by the zoning system used. Thus in this case a different definition of zones would probably produce somewhat different empirical evidence.

We pursue our investigation of the spatial structure of activities in two ways. First we examine the travel patterns of persons to establish the spatial linkage patterns of activities and to evaluate the rationality of travel. Secondly we investigate some of the consequences of alternate urban forms on the spatial structure of activity and the efficiency of alternate urban forms under special conditions.

In Chapter 1 we define the standard of rational travel as the selection of linkages so that total travel time of all tripmakers is minimized. The selection of origin-destination linkages to achieve this standard is accomplished by a linear programming allocation of person trips. The rationality of actual travel is established by comparing actual travel time with the travel time required by the interchange pattern selected in the optimal allocation. If the actual trips require no more travel time than the trip pattern selected by the linear programming allocation travel time is conserved. We define conservation of travel as the selection of trip destinations so as to minimize total travel time.

In Chapter 2 we examine the spatial structure of activities established by actual trips to work, shopping, and social-recreation activities in the Buffalo area. And we examine the spatial structure of activities which is established by the linear programming allocations of these trips.

From the dual of the linear programming allocation of trips we are able to establish the comparative locational advantage of zones as places from which to originate trips. In a sense this is a measure of the relative desirability of each zone as a residence location under conditions of optimal, time conserving travel. This analysis is described in Chapter 3.

In Chapter 4 we turn our attention to the linkage of activities. Using data from Chicago and Pittsburgh we evaluate the linkage of such activities as work, shopping, social-recreation and personal business established by person trips. This is done by relating the purpose or activity from which the trip originated to the purpose for which it is destined and linking together all person trips made over a twenty-four hour day.

In Chapters 5 and 6 we use the results of our analysis to develop a method for evaluating alternate patterns of urban development under conditions of travel minimization. We use a linear programming allocation of trips to establish the trip linkages between alternate patterns of homes, workplaces, and shopping centers. We then evaluate these alternate patterns in terms of the travel time required to establish the minimal pattern of linkages, the spatial structure of activities established by these linkages, and the locational advantage of zones as residential locations. In the first instance we are evaluating the alternate development patterns in terms of their potential efficiency in establishing necessary activity linkages, and in the third instance in terms of the equity with which the potential for efficient satisfaction of activity linkages is distributed among residential sites. The spatial pattern of activity linkages (the second item in the evaluation) is a description of the spatial organization of activity under conditions of minimum travel. In Chapter 5 we conduct some experiments with alternate distributions of workplaces in the Buffalo area. In Chapter 6 we conduct some experiments with a hypothetical urban area.

In Chapter 7 we consider the implications of our findings for metropolitan planning.

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1. Richard L. Meier, A Communications Theory of Urban Growth (Cambridge, Mass.: Joint Center for Urban Studies of the Massachusetts Institute of Technology and Harvard University, 1962).

2. Ibid., p. 150.

3. Ibid., p. 59.

4. Ibid., p. 177.

5. Melvin M. Webber, et. al., Explorations Into Urban Structure (Philadelphia: University of Pennsylvania Press, 1964), pp. 79-147.

6. Ibid., p. 80.

7. Ibid.

8. Ibid., p. 111.

9. Ibid., p. 147.

10. F. Stuart Chapin, Jr., Urban Land Use Planning (2d. ed. rev.; Urbana, Illinois: University of Illinois Press, 1965), p. 224.

11. Ibid., p. 225.

12. F. Stuart Chapin, Jr., and Henry C. Hightower, "An Experimental Study: Household Activity Patterns and Land Use" (mimeo).

13. Walter Isard, Methods of Regional Analysis (New York: John Wiley and Sons, Inc., 1960), pp. 673-679.

14. To stratify activity as defined by trip purpose into finer classifications would require linking trip purpose data with detailed descriptions of the land use at the destination of the trip. This is a large, but manageable data manipulation task, and is a reasonable next step to follow the investigation begun in this study.

CHAPTER 1

SPATIAL LINKAGES OF URBAN ACTIVITY

Person trips in the urban area are the raw material of the spatial structure of activities. The linkage patterns formed by the selection of trip destinations create the activity structure.

The idea that trip making by persons in an urban area is essentially rational is widely accepted. The bones of the argument are that travel is expensive, but necessary and rewarding; and persons, being sensitive to cost, attempt to accomplish needed travel in the most satisfactory way possible. A variety of interpretations of this simple argument are possible. The most obvious source of difference in interpretation is in deciding what constitutes the most "satisfactory" outcome of travel expenditures.

It can be argued that trip makers' rationality consists of selecting the least cost solution to travel; or of selecting maximum rewards; or of selecting, in Herbert Simon's term, a "satisficing" solution. Any of these interpretations implies rationality in the sense that the trip maker calculates costs and gains and on that basis decides whether or not to make a trip and selects among possible destinations.

Rational behavior in trip making is most often expressed as selection among possible destinations from a given origin. The simple argument is that given the decision to make a trip and assuming all destinations to be acceptable the trip maker selects the most convenient destination. When an operational definition of convenience is required, and when the fiction that all acceptable destinations are equally valued is dropped, the problem quickly becomes more complex, but rationality can still be inferred.

Trip making rationality can be expressed in terms of selecting trip origins -- or in terms of selecting locations in an urban area. For example, take the case of a household deciding which of several residential sites to select. For simplicity, assume that the on-site characteristics of the several sites are equally acceptable. Then the household presumably views each potential site in terms of the important connections with other places in the urban area which the household requires, and selects the site which allows these connections to be most satisfactority established. This is again an obviously oversimplified argument, and when the complexities of everyday life are entered into the picture the role of interactivity connections in location decisions is blurred.

Evidence of travel rationality can be inferred from aggregate travel data. Most urban trips are short, regardless of the purpose of the trip. The number of trips originating from any point in an urban area falls off rapidly with trip length.[1] If the cost of travel were not a relevant factor in trip making decisions, and if persons were not attempting to conserve on travel expenditures the distribution of trips by trip length would not assume this sharply declining curve.

Travel in urban areas is both necessary and costly. So clearly travel requirements and rewards are considered both in location and in trip making decisions. The important questions are: on what rule of rationality is travel behavior based, and how can travel be simulated?

Studies of Spatial Linkages

Attempts to measure the rationality of urban travel have concentrated on the journey to work. These studies attempt to relate the household's residential location decision to transportation costs when the workplace is given.

Using data on commuting patterns and on residential moves Carroll found evidence that workers' minimized the distance between home and workplace.[2] Looking at residential moves he found that when workers changed residences they generally selected residences closer to their place of employment. Looking at commuting patterns he found that factory workers' residences were concentrated around their place of employment and the number of workers' residences decreased rapidly with distance from the workplace. However he found that the residence locations of office workers were distributed in proportion to the distribution of all residences and were not clustered close to the workplace.

The outcome of Carroll's analysis is a weak hypothesis that the rule governing the allocation of journey to work travel is that residential locations are chosen so as to minimize the journey to work. It is weak because there is no clear evidence that transportation considerations entirely accounted for the residential location choices. It appears to us that the location of the workplace, income, family characteristics, and family preferences provide at least as strong an explanation of the observed patterns.

Lapin reviews the work of Carroll and others and concludes that, "the journey to work appears significant in the selection of a residential site primarily in setting an outside limit to the distance between home and work."[3] He argues that considerations of amenity, cost, schools, and neighborhood character play a more important role in residential site selection. In the analysis of Philadelphia travel data he find that workers whose jobs are located in the suburbs have short work trips and central city workers have long work trips. Lapin's analysis adds little to our understanding of travel rationality. He accepts the argument that persons attempt to minimize travel subject to other considerations, but he does not succeed in measuring the relative influence of travel considerations.

Kain addresses the question of the relative influence of transportation cost on residential location decisions by posing the household's location behavior as a trade-off between journey to work expenditures and site expenditures.[4] He assumes that households attempt to "economize on transportation expenditures,"[5] but they substitute travel cost for residential site costs to achieve "household preferences for low-density as opposed to high-density residential services."[6] His analysis of travel data from the Detroit area shows that the length of the work trip is related to location of the workplace, income, family size, and type of residential structure. Workers in the central city, or with high incomes, or with small families, or residing in one-family dwelling units make longer work trips than do those working in the suburbs, having low incomes, having large families, or living in apartments.

Unfortunately he does not test his assumption that households "economize on transportation expenditures." This study, like the others we have reviewed, leaves us with the conclusion that a large number of factors, one of which is minimization of travel, are involved in the residential location decision. The degree to which travel approaches a minimum is not clear.

Theoretical analyses of the spatial pattern of land use have suggested a variety of rules governing travel behavior. Generally they involve the minimization of costs, one of which is transportation cost. The principal analyses differ in the relative importance they assign to transportation in determining the allocation of land to various land uses, and in the degree to which travel approaches a minimum level when land is allocated.

Robert Murray Haig provided the first clear statement of the relation between the allocation of land in urban areas to various land uses and travel cost in his study of New York.[7] He advanced the hypothesis that individual firms locate so as to minimize the sum of their site rent and their transportation costs -- their friction costs. He argues that site rent and transportation costs are complementary. In-city locations which command high site rents require low transportation outlays, and suburban sites where rents are low require high transportation outlays. Haig does not argue that transportation cost alone is minimized. Each firm seeks its least cost solution considering both rent and transportation. They trade-off one against the other.

Hoover argues that transportation (transfer costs) is the main influence on land use patterns.[8] He notes that some land uses have particular site requirements and that this influences their location. But in general non-residential uses are sited on the basis of "transfer-cost" considerations. The individual firm seeks to minimize its transfer costs by finding a location which balances its procurement and distribution costs.[9] Residential location is also considered to be strongly influenced by transfer cost. In this case the daily journey to work is the influential transfer requirement. The tendency to minimize the journey to work is tempered by consideration of neighborhood amenity. "In addition to wanting to live near their work, people like to live in quiet, spacious, clean, temperate surroundings."[10]

In Hoover's scheme the individual firm achieves its low transfer cost site choice in competitve bidding by paying a higher rent than any other potential user is willing to pay for the site. Thus the influence of transfer costs is reflected in the pattern and amount of land rent. When transfer costs are minimized land rent will be maximized.

Alonso argues that Haig's cost of friction minimization hypothesis is wrong.[11] His main diagreement is with the premises of Haig's (and by inference Hoover's) argument. Alonso contends that residences do not "locate so as to minimize the costs of friction. Rather they seek to maximize satisfaction." And he argues that firms locate so as to maximize profits rather than minimize costs. Alonso develops a model of the urban land market in which land is allocated on the basis of satisfaction and profit maximization.

Like Haig, Alonso argues that rent and transportation cost are complementary. Viewing residential land as a consumption good he sees each household's location behavior as governed by the allocation of its income among rent, transportation, and all other goods and services (the composite good). Rent is a function of the quantity of land purchased and the price of land. Trade-offs within the budget limitation determine the degree to which travel is minimized.

These theoretical analyses, like the empirical studies of the journey to work, leave us with a set of inconsistent statements as to what is the rule of rationality of travel. Confusion appears to be widespread. For example, Garrison contends that "the general social aim is land use organization which will minimize this (rent plus transportation) cost."[12] Thus far he follows Haig. He argues further that, "From the firm's point of view the objective is to maximize net revenues, and this is accomplished only when transportation costs are minimized and a bid for the best possible site is successful."[13] In so doing he mixes inconsistent rules offered as an explanation of travel and location behavior.

The one thing that is clear from the materials we have reviewed is that it is unclear just what the rational content of travel is. The rationality implicit in aggregate travel data has never been examined directly.

We do not know what rule or rules of rationality underlie urban travel behavior. There are many factors involved in trip making decisions and there is no reason to believe that every person or every family makes its travel decisions on the same basis. It is obvious from the journey to work studies that the factors considered in travel decisions and the relative weight assigned to them varies with circumstances of time and place, and with personal and family characteristics.

To accurately account for the rationality of urban travel behavior it would be necessary to survey trip makers in detail and devise a variety of allocation rules to be applied to small segments of the total population. Once determined, these rules may only be valid for the time and place on which they are based. Detailed analytic studies of travel behavior promise to contribute a great deal to our understanding of urban activity systems. But they also promise to be difficult and expensive.

There is another tactic we can take in analyzing urban travel. We can use a single rule of rationality which accounts for all or a significant part of aggregate travel behavior. Our purpose in simulating travel behavior is to find a basis for decisions about urban form. We want to estimate the travel requirements of possible alternate forms of the city, and we want to know how different city forms will be used by the residents of the city in the conduct of their daily activities. An allocation rule which simulates aggregate behavior is sufficient for these purposes. And as long as aggregate travel behavior is adequately reflected by a single allocation rule we need not be concerned with the great variety of individual travel decision rules comprehended by it.

The allocation rule with which we propose to simulate the rationality of aggregate travel is that all trips be made so that total travel time of all trip makers is minimized. The allocation of trips to minimize total travel time is accomplished by linear programming techniques. Using travel data from the Buffalo area we shall evaluate the usefulness of this allocation rule by determining what portion of actual travel can be accounted for by it. In subsequent chapters we shall show how the usefulness of this rule can be extended to the analysis of urban form.

We do not offer the minimization of total travel time as a model of actual travel. The linear programming allocation rule is highly restrictive and cannot replicate the widely dispersed patterns of actual travel. The potential usefulness of this allocation rule is that it accurately reflects the rationality of trip making implicit in aggregate travel data and provides a sufficient basis for simulating the spatial structure of activities implied by alternate urban forms.

Minimization of Travel Time

We define conservation of travel as the behavior of trip makers in selecting trip destinations to select those destinations so that their travel time is small. If travel were truly conserved, trip interchanges between zones would be arranged so as to minimize total travel time. This we define as the ideal of rational travel. We shall use this definition from now on when we refer to rational travel.

Given a set of values of trip origins and destinations by zone, and a set of values of zone-to-zone travel times, the pattern of zonal interchanges which requires the minimal amount of total travel can be calculated. The mathematical statement of the problem is a form of linear programming generally known as the transportation problem. For our application the problem is stated as follows:

$$\text{find the } X_{ij} \text{ such that } \sum\sum C_{ij} X_{ij} \text{ is a minimum} \tag{1}$$

$$\text{subject to } \sum_{j=1}^{n} X_{ij} = O_i \qquad i = 1 \ldots m \tag{2}$$

$$\sum_{i=1}^{m} X_{ij} = D_j \qquad j = 1 \ldots n \tag{3}$$

$$X_{ij} \geqslant 0, \quad C_{ij} \geqslant 0 \tag{4}$$

and

$$\sum_{i=1}^{m} O_i = \sum_{j=1}^{n} D_j; \tag{5}$$

where

C_{ij} = travel time from zone i to zone j

Xij = trips from zone i to zone j

Oi = trip origins in zone i

Dj = trip destinations in zone j.

There will usually be a unique solution to the problem. Only one flow pattern will yield the optimal solution. In some instances, however, two or more solutions will be possible, each requiring the same amount of travel. The solution yields minimum travel time for the entire system. It does not necessarily minimize travel time for each individual. That is, each origin is not necessarily connected to the nearest destination. In many cases it would be impossible to link each origin with its nearest destination because any single destination point may be the nearest possible destination from several origin points. The linear programming solution can be better understood as one in which no individual can improve his position (save more travel time) without disadvantaging some other individual to a greater extent than he benefits himself (thus causing a net increase in total travel time of two individuals). It is a general equilibrium solution.

The criterion of an optimal solution for the entire system is quite different from the criteria suggested by the studies we have examined. The journey-to-work hypothesis suggests that each individual attempts to minimize his travel time. Haig's statement of location theory suggests that each firm locates so as to minimize its friction costs and the sum of these decisions is the optimal solution of the system.

We argue that the system-optimization criterion of linear programming is useful for two reasons. First, it establishes a standard against which actual travel behavior can be evaluated. Second, the quality of the system is our legitimate concern in analyzing and planning for travel and land development.

There are two major limitations in using a linear programming allocation of person trips. The mathematical solution to the transportation problem will always contain no more zone-to-zone linkages than the number of origin zones plus the number of destination zones minus one. In the Buffalo case with 35 origin and 35 destination zones the minimal solution will require only 69 linkages, or an average of two destination zones for each origin zone. Such selectivity has never been observed in urban travel, nor is it likely ever to be observed.[14] Second, it is necessary to assume that trip destinations are freely substitutable. When all person trips are taken together this is clearly a bad assumption. It allows the substitution of a steel mill for a department store, a school for a movie theater, and similar absurdities. When only trips to drugstores to purchase a package of any brand of cigarettes are considered, it is a quite harmless assumption.

Linear Programming Tests

To test the conservation of travel time we will use the system optimal solution of linear programming as a criterion against actual travel. All person trips entirely within the cordon area of the Buffalo SMSA (zones 1 to 35) for each of the three trip purposes -- to shop, to work, to social-recreation -- have been tabulated. The tabulations are in Tables ~~1~~ 18, ~~2~~ 19, and ~~3~~ 20 in the Appendix. The sum of these stratifications is taken as the universe of all person trips. Zone-to-zone travel time was obtained from a capacity restrained, minimum path assignment to existing arterial streets and expressways in the Buffalo area.[15]

The first tests are the calculation of minimum travel time for all trips, and for each trip purpose stratification -- shop, work, and social-recreation.[16] Table 1

Table 1. Travel Time for Actual and Optimal Allocations by Trip Purpose -- All Links.

Trip Purpose	Total Time Units		Minimal as % of Actual	Time Units per Trip	
	Actual	Minimal		Actual	Minimal
All Trips	66,288,077	23,053,832	35	63	22
Work Trips	30,377,798	12,508,837	41	68	28
Shopping Trips	18,834,134	6,643,274	35	61	22
Social Trips	17,076,145	6,244,251	37	57	21

gives the results. Total time units are the sum of the travel time of all trips. Time units per trip are calculated by dividing total time units by the number of trips. In this test there are 448,741 work trips, 307,851 shopping trips, and 300,754 social-recreation trips, making a total of 1,057,346 trips.

All trips taken as a class clearly do not meet our criterion of rationality. According to the criterion, total actual travel time would be equal to the travel time required by the minimal allocation. Travel time would be conserved. In fact, minimum travel time is 35 percent of actual. The sum of the optimal solution is closer to (38 percent of) actual travel for all trips than is the optimal solution to all trips as a class. This is as expected. It results from the reduction in substitutability of trip ends which occurs when each trip purpose class is individually optimized. When all trips are taken as a class, shopping destinations may be substituted for work destinations, etc. This has the effect of allowing relatively greater freedom of choice in the optimal allocation -- a freedom of choice which does not really exist if the activity connections defined by trip purpose are to be satisfied. The results are slightly better for the individual trip purpose stratifications. Work trips are the closest to a minimal solution, shopping trips are the farthest from it. In no case are they close enough to suggest that travel minimization as defined in these tests is an overpowering influence. This is partly due to the dispersion of trips in the actual case. There is wide dispersion of trips from every origin in the actual travel pattern. The highly restrictive interzonal allocations of the minimal solution are shown in Appendix Tables ~~8~~ 25, ~~9~~ 26 and ~~10~~ 27.

Work trips are on the average the longest of the three purpose trips. They are also the longest trips of the optimal allocations for each trip purpose. Shopping trips are second ranked in average duration in both the actual and the optimal case, and social-recreation are shortest in both cases. The preservation of the rank order of actual average trip length in the optimal allocations shows that the variations in average trip length are a function of the distribution of activities rather than a reflection of the behavior of trip makers.

Work trips are longest because work places are relatively few and are concentrated relative to the distribution of work trip origins. Shopping opportunities must be more widely distributed. These conclusions are sensible. They match both our general knowledge of urban land-use patterns and our intuition. But a full demonstration of the influence of the distribution of opportunities on travel patterns must be postponed until the next chapter which deals explicitly with the spatial structure of urban activities.

Although the rank order of trip length among the three trip purposes is maintained in the optimal allocation, travel for the three purposes is not equally rational. Work trips are the most rational of the three according to our criterion. And they are the longest. It is intuitively reasonable that the longest trips should be the most carefully chosen and most closely approach a minimum since travel is costly. Furthermore, as we have said, the work trip is probably the most important daily trip in a household's travel. Again we must recognize that in the case of the work trip we are witnessing the effect of residential location decisions and not simply the selection of trip destinations.[17] Few people can freely select that destination and certainly cannot change it regularly. Which location -- work place or residence -- is fixed first for a typical family is unknown. Nevertheless, our results show that once one end of the journey to work is fixed the other is selected so that on the average the work trip is more sensitive to conservation of travel time than are shopping and social-recreation trips.

Shopping trips are the least rational of the three, and social-recreation trips fall between the extremes set by work and shopping trips. However, the range in variation of travel rationality according to our criterion is small. And the range of both actual and optimal average trip lengths is small. In summary then, the test shows that there is little difference in the degree of rationality by trip purpose, although we do note that work trips are the most rational of the three. In all cases, however, actual travel behavior clearly does not approach the ideal of minimization of travel time as established by the linear programming allocation.

Principal Linkages

Since the actual allocation of all travel is not optimal we must ask if some part of it is. Let us look at the principal linkages (zone-to-zone interchanges) of each origin zone and ask if these are optimal. Principal linkages are defined as those containing the largest number of trips.

We look first at principal linkages 1 and 2. The first and second links account for 48.4 percent of all work trips, 64.8 percent of all shopping trips, and 55.5 percent of all social-recreation trips. Taken together this is a majority of all trips. The distribution of the first and second magnitude linkages of shopping and social-recreation trips is widely dispersed and approximates the distribution of all linkages. This can be seen in Tables ~~5~~ 22 and ~~6~~ 23 of the Appendix. The distribution of first and second magnitude work linkages is heavily concentrated toward destinations in zones 1 and 2 which receive one-third of the 70 principal linkages and one-third of the trips in all principal linkages. This compares with zones 1 and 2 receiving

23 percent of all work linkages. Except for the concentration of work destinations the first and second magnitude linkages both account for a significant portion of total trips and are representative of the distribution of total trips.

The optimal allocations of the trips in the first and second linkages are given in Table 2. For both work and shopping trips the minimal allocation saves only 10 percent of actual travel time. For social trips the minimal allocation saves 16 percent of actual time. The test shows that over 50 percent of all trips are very close to the minimum possible allocation. If travel time required by the minimal allocation were 100 percent of actual travel time we would have a perfect match of actual behavior with our criterion. But such perfection is unattainable because we allow substitution of trip ends in the optimal allocation. For example, one person may set out from home to shop at a supermarket and another at a department store. Since all shopping trips are taken as a class the department store shopper may be allocated by the linear programming calculation to a zone which contains only supermarkets.

This freedom of substitution of trip ends in the optimal allocation prevents the ideal of a perfect match ever being achieved. Since the exact amount of this influence cannot be calculated, any judgment on the goodness of fit of actual data with our criterion must be subjective. However, the substitution of trip ends in the optimal allocation will always result in a reduction of aggregate travel time. Given this situation we must consider the test results a very good match of the criterion. The trips in the first and second magnitude linkages of each trip purpose are rational. They conserve travel.

Table 2. Travel Time for Actual and Optimal Allocations by Trip Purpose -- Links 1 and 2.

Trip Purpose	Total Time Units		Minimal as % of Actual	Time Units per Trip	
	Actual	Minimal		Actual	Minimal
Work Trips	8,218,487	7,417,942	90	38	34
Shopping Trips	5,178,153	4,696,222	90	26	23.5
Social Trips	4,575,489	3,823,855	84	27.5	24

Several cautions about this conclusion should be considered. Only 70 linkages were tested and as we noted above there must be 69 in the optimal solution. In our evaluation of the results of the test of all trips we noted that the wide dispersion of actual linkages was one potential explanation of the poor results. In this test the use of a limited number of linkages may have had the opposite effect. The linkages actually chosen for this test present a more serious problem. We chose the linkages which contained the largest number of trips. But since trip frequency declines with trip length we have necessarily also chosen relatively short linkages. This undoubtedly influences the results. In the case of work trips one-third of the trips in the first and second linkages were destined to zones 1 and 2. This concentration limits the optimal solution. Finally, a large proportion of the first and second linkages are intrazonal. These will not be changed in the optimal allocation since they are minimum allocations from their zone of origin. This final point requires special examination.

Interzonal Linkages

Thus far we have permitted intrazonal linkages to enter the optimal solution. In all tests the amount of intrazonal linkage was, of course, markedly increased in the optimal solution. What was in actuality a reciprocal interchange between two zones was converted to intrazonal linkage within each zone. To examine the influence of this on our findings we reformulate both tests to include only actual interzonal trips and prohibit intrazonal linkage in the optimal allocations. Table 3 shows the results of optimal allocation of all interzonal trips and Table 4 shows the allocation of first and second magnitude interzonal linkages. The results are quite

Table 3. Travel Time for Actual and Optimal Allocations by Trip Purpose -- All Interzonal Linkages

Trip Purpose	Total Time Units		Minimal as % of Actual	Time Units per Trip	
	Actual	Minimal		Actual	Minimal
Work Trips	27,063,262	12,445,667	41	101	41
Shopping Trips	15,950,353	6,078,648	38	116	37
Social-Recreation Trips	14,495,641	7,303,429	50	82	39

Table 4. Travel Time for Actual and Optimal Allocations by Trip Purpose -- Interzonal Linkages 1 and 2.

Trip Purpose	Total Time Units		Minimal as % of Actual	Time Units per Trip	
	Actual	Minimal		Actual	Minimal
Work Trips	8,242,565	6,902,157	84	76	63
Shopping Trips	3,842,972	3,337,452	87	46	40
Social-Recreation Trips	3,527,266	2,956,183	84	51	43

similar to those obtained with intrazonal linkages allowed. The travel time required by the first and second interzonal linkages is only improved 13 to 16 percent in the optimal solutions. Time savings possible for all interdistrict linkages under the optimal solution is also similar to the results obtained with intrazonal linkages included. Average trip lengths are, of course, longer when intrazonal linkages are excluded. We can conclude that the inclusion of intrazonal linkages does not prejudice our test results.

Conservation of Travel

The first tests examined the distribution of all trips. The second set of tests examined the distribution of trips from the first and second magnitude linkages. If we conducted additional tests adding each time the next magnitude linkage we could construct an over-all view of how travel behavior corresponds to our criterion. Limited resources prevents us from doing this. But we can conduct one additional test using the first, second, and third magnitude linkage and from the results of this and the two previous tests approximate the results of all possible tests.

The third magnitude linkage is small. It accounts for 9 percent of total work trips, 9.3 percent of total shopping trips, and 8.3 percent of total social-recreation trips to make the percent of total accounted for by the three principal links 57.4, 74.1, and 63.8, respectively. The minimal allocation saves 20 to 30 percent of actual travel time in all cases. Table 5 shows the test results. This is a decline from the results of testing only links 1 and 2. The decline occurs because of the increased dispersion of linkages and the low probability that the added trips are at equally low travel times as the original trips.

Table 5. Travel Time for Actual and Optimal Allocations by Trip Purpose -- Links 1, 2, and 3.

Trip Purpose	Total Time Units		Minimal as % of Actual	Time Units per Trip	
	Actual	Minimal		Actual	Minimal
Work Trips	11,803,140	9,351,966	79	41	36
Shopping Trips	6,784,979	5,344,815	79	29.5	23.5
Social-Recreation Trips	6,057,003	4,275,732	71	31.5	22

For all trips, trips in the first and second linkages, and trips in the first, second, and third magnitude linkages we know the percent of actual travel time which could be saved if the trips were optimally allocated according to the linear programming criterion. If we plot the percent time savings possible in each case against the percent of all trips in each case we can construct a curve which shows the rationality of travel behavior.

Figure 1 shows these curves based on our tests. A hypothetical zero time savings point was established by considering only intrazonal linkages. If more points were calculated it is quite likely that a smooth curve would result. The slope of the curve at any point is a measure of the rationality of travel behavior at that point. Taking a small segment of the line we can calculate the ratio of time savings possible for the trips in the interval to the percent of trips in the interval. If the rate of increase in percent of trips encountered and the rate of percent of time savings is constant the slope is unity. A slope value less than unity occurs when the change in trips exceeds the change in time savings. This means that travel time is conserved for the trips in question. These trips are more time conserving than those represented by a portion of the curve whose slope is greater than unity. If the entire curve has a unitary slope it means that all trips represented by the curve are equally rational with respect to the minimum allocation.

An individual curve may be convex or concave in shape or approximate a straight line. The shopping trip curve of Figure 1 is an example of a convex curve. Both the work and social-recreation trip curves approximate a straight line. When interpreting the shape of these curves we must remember that the percentage of trips axis is ordered by magnitude of the actual linkages. The convex curve can be

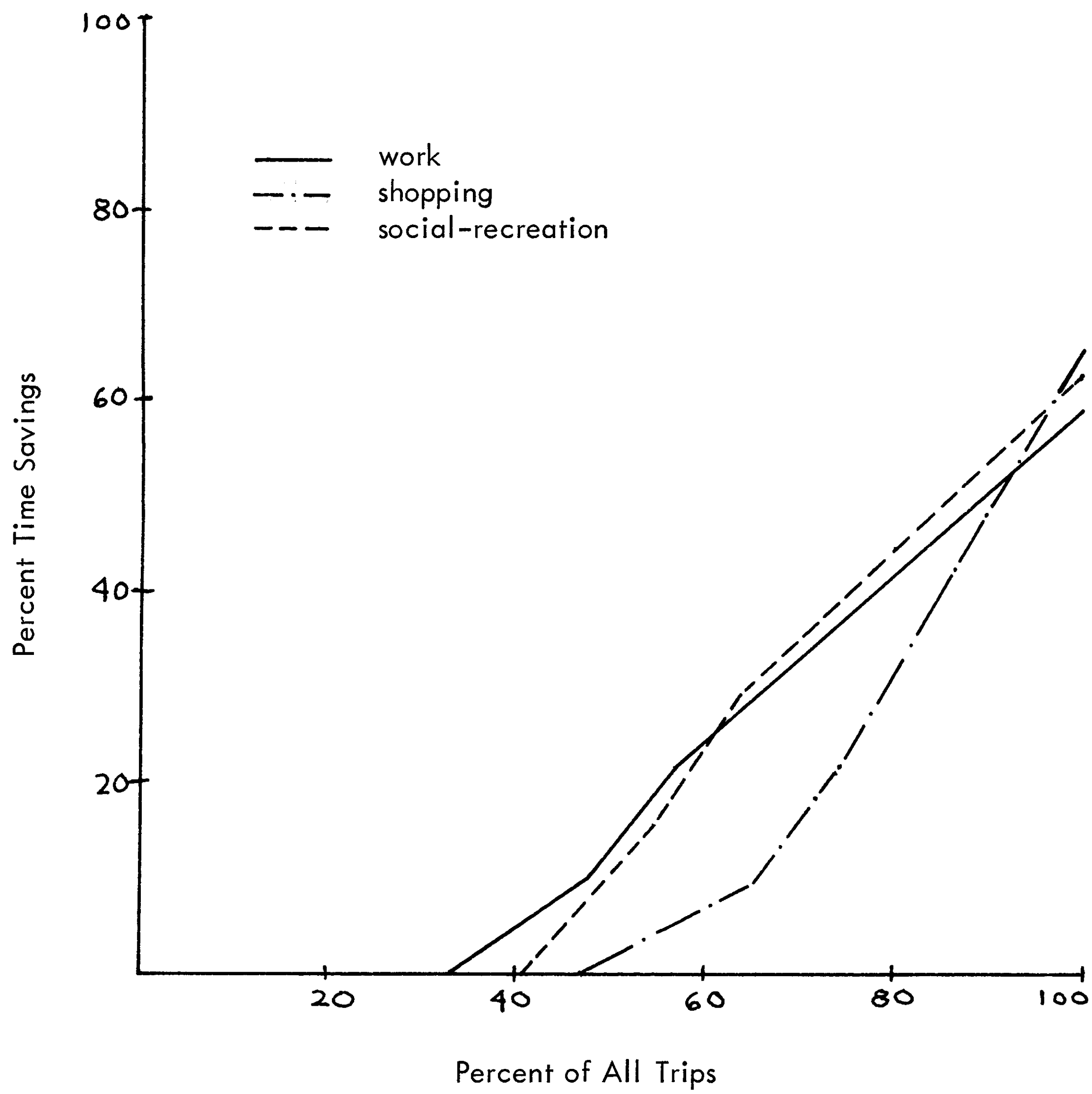


Fig. 1. Travel Time Savings Possible by an Optimal Allocation of Trips in Relation to the Percentage of All Trips Included.

interpreted to mean that trips in the largest actual zonal interchanges are more time conserving than trips in the smaller actual zonal interchanges, and that in general the degree of time conservation varies with the strength of the linkage. A straight line is interpreted to mean that the degree of time conservation is constant; it is unaffected by the strength of the linkage. A concave curve would be interpreted to mean that stronger linkages were least influenced by the conservation of travel time.

Since the social-recreation and work trip curves are quite similar and approximately straight, it appears that travel time conservation is not affected by the strength of the linkage, but is constant. The convex curve of shopping trips indicates that travel conservation is related to the strength of the linkage. Another way to interpret this is that from a given zone of origin the more frequent (or more probable) shopping trips conserve more travel time than less frequent trips.

Summary

We posed two questions about urban spatial linkage patterns. Is there an identifiable structure of activities overlying the spatial structure of land use? Is the travel involved in creating these linkages in some sense rational? The analysis of this chapter is devoted to the second question -- the rationality of travel.

Investigation of either question requires that we define what we mean by trips and activities. The definitions we choose will, of course, influence both the direction of our inquiry and the results. We use the simplest possible definition of a trip. A trip is the one-way travel between two points -- an origin and a destination. This definition is, in a sense, the least common denominator of the various possible trip definitions. A trip as we define it is often a segment of a journey from an origin to an eventual destination via intermediate stops. Typical examples of a journey are the travel paths of a car-pool driver going to work, the route of a salesman, and the housewife's round-trip shopping expedition. We define activities simply as the consummation of the trip purpose. Thus a trip made for the purpose of going shopping is a unit of shopping activity at the destination of the trip. Activity description of the trip destination will often coincide with the usual classification of the land use at the trip destination, as in the case of a shopping trip to commercial land. In some cases the activity and land-use classification will not match well, as with a work purpose or social-recreation purpose trip to commercial land.

We have defined travel rationality essentially as the conservation of travel. Travel rationality can be examined in two senses: (1) in selecting among alternate trip destinations given a trip origin, and (2) in selecting among origins. The first of these is concerned with trip-making behavior. Given an origin and two alternate trip destinations of equal desirability but requiring unequal travel expenditures, the rational decision is one which elects to make the trip requiring the least travel. Travel rationality in the selection of trip origins is simply the selection among possible locations as a base for activity and travel in the region so as to conserve an aggregate travel required. This may be a household selecting a residence or a manufacturing firm selecting a plant location.

We have tested travel rationality in the first sense -- of trip making -- with information about person trip making in the Buffalo, New York, metropolitan area.

The tests consist of comparing actual travel with the minimum travel requirements of the activity pattern of the region. The model for minimum travel requirements is a linear programming allocation of trips. Quite simply, the model accepts the actual distribution of trip origins and trip destinations and reallocates trips so as to minimize aggregate travel time.

The principal conclusions from the tests are:

1) Total travel does not conform with the criterion of aggregate minimal travel time for any of the three trip purposes.

2) Trips in the principal linkages from each origin zone for all trip purposes exhibit a high degree of rationality in that actual travel time is quite close to that obtainable with a linear programming allocation.

3) Travel rationality varies with the activity destination or purpose of the trip, and with trip length.

Since the first and second magnitude linkages constitute a majority of all trips, and since they are time conserving according to our minimization criterion, we conclude that the bulk of travel is rational. In the case of shopping trips this evidence of rationality can be partly explained by trip length. The principal linkages are the shortest since trip frequency is related to trip length. But the degree of conservation of travel of work and social-recreation trips appears to be independent of trip frequency and trip length.

We have noted that the distribution of activities -- of trip destinations for the three trip purposes -- influences the potential for time savings. The next chapter examines the spatial pattern of activities in detail.

1. See for example, Chicago Area Transportation Study, *Study Findings, Vol. I: Final Report* (Chicago: The Study, 1959), Figure 17, p. 38.

2. J. Douglas Carroll, Jr., "Some Aspects of the Home/Work Relationships of Industrial Workers," *Land Economics*, XXV, No. 4. (November, 1949), pp. 414-422.

3. Howard Lapin, *Structuring the Journey to Work* (Philadelphia: University of Pennsylvania Press, 1964), p. 152.

4. John F. Kain, "The Journey to Work as a Determinant of Residential Location," *Papers and Proceedings of the Regional Science Association*, Vol. 9 (1962), p. 137.

5. *Ibid*, p. 139.

6. *Ibid*, p. 137.

7. Robert Murray Haig with Roswell C. McCrea, *Major Economic Factors in Metropolitan Growth and Arrangement*, Vol I: *Regional Survey of New York and Its Environs* (New York: Committee on the Regional Plan of New York and Its Environs, 1927).

8. Edgar M. Hoover, *The Location of Economic Activity* (New York: McGraw-Hill Book Co., Inc., 1948), pp. 128-141.

9. *Ibid.*, p. 29.

10. *Ibid.*, p. 130.

11. William Alonso, *Location and Land Use* (Cambridge., Mass.: Harvard University Press, 1964), pp. 102-105.

12. William L. Garrison, *et. al.*, *Studies of Highway Development and Geographic Change* (Seattle: University of Washington Press, 1959), p. 186. Material in parenthesis added.

13. *Ibid.*

14. A solution to this problem would be to formulate the mathematical problem so that a constraint equation could be written for each Xij. Unfortunately we know of no method to do this.

15. Chicago Area Transportation Study, *Data Projections*, Vol. II, *Final Report* (Chicago: The Study, 1960), pp. 104-108, gives a description of a capacity restrained assignment. Travel time is measured in 12-second time units.

16. Computations were performed on an IBM 7094 computer at the Harvard University Computing Center. The program used is a modified version of SHARE # 1328, SOTRCO.

17. We can assume that the work trip origin is at the trip maker's home since on the average 70 to 80 percent of work trips in metropolitan areas begin at home. See Chapter 4.

CHAPTER 2

THE SPATIAL STRUCTURE OF URBAN ACTIVITIES

In the last chapter we examined the linkages of urban activities formed by person trips for work, shopping, and social-recreation purposes among zones in the Buffalo area. We evaluated the efficiency of these linkages by comparing the total travel time of existing linkages with the total travel time which would be needed if the same linkage requirements were met (that is if all origins and destinations were satisfied) in such a way that total travel time was minimized.

As we have seen each zone is connected to almost every other zone in the urban area by person trips. But most of the connections or linkages from any one zone to other zones are quite weak since they are composed of relatively few person trips. In the last chapter we showed that the majority of trips from any zone are contained in the first and second magnitude linkages from that zone to other zones. These principal linkages were shown to be efficient in that the total travel time of the trips making of these linkages was little more than the travel time required by an optimal allocation of these trips.

In this chapter we shall examine the spatial patterns of these principal linkages. Our purpose in doing this is to determine the spatial organization of activity in the urban area. The linkages show which zones are interconnected for a particular activity such as shopping. Interconnected zones may be considered a closed activity system or subdivision of the urban area. To illustrate this imagine that we have ten sequentially numbered zones. Suppose there are linkages formed by shopping trips to and from each of zones one through five, and to and from each of zones six through ten, but no linkages from any of zones one through five to any of zones six through ten. Then the urban area is organized into two distinct subregions for shopping activity. It is as if there were a wall between the first five and the last five zones. The question we ask in the first part of this chapter is are such walls or boundaries formed by the principal linkages, and if so, are the boundaries similar for different activities?

By concentrating on the principal linkages we limit our analysis to only part of the spatial organization of activity. But since these linkages account for a majority of all trips and since the remaining trips from each zone are widely dispersed through many linkages of relatively small magnitude, we argue that the principal linkages form the basic spatial pattern of activities. In what follows we shall briefly examine the spatial pattern of the successive linkages.

Finally we will examine the spatial organization of activity formed by the optimal allocation of all trips. Since the principal linkages are efficient, we want to know whether or not the spatial organization of activity which they form is similar to the spatial organization of activity formed by an optimal allocation of all trips. If this is so, then an optimal allocation of all trips can be used to simulate the actual organization of activity.

Spatial Structure of Principal Linkages

Figures 2, 3, and 4 show the principal linkages of work trips, shopping trips, and social-recreation trips between zones. The numbered circles represent the zones,

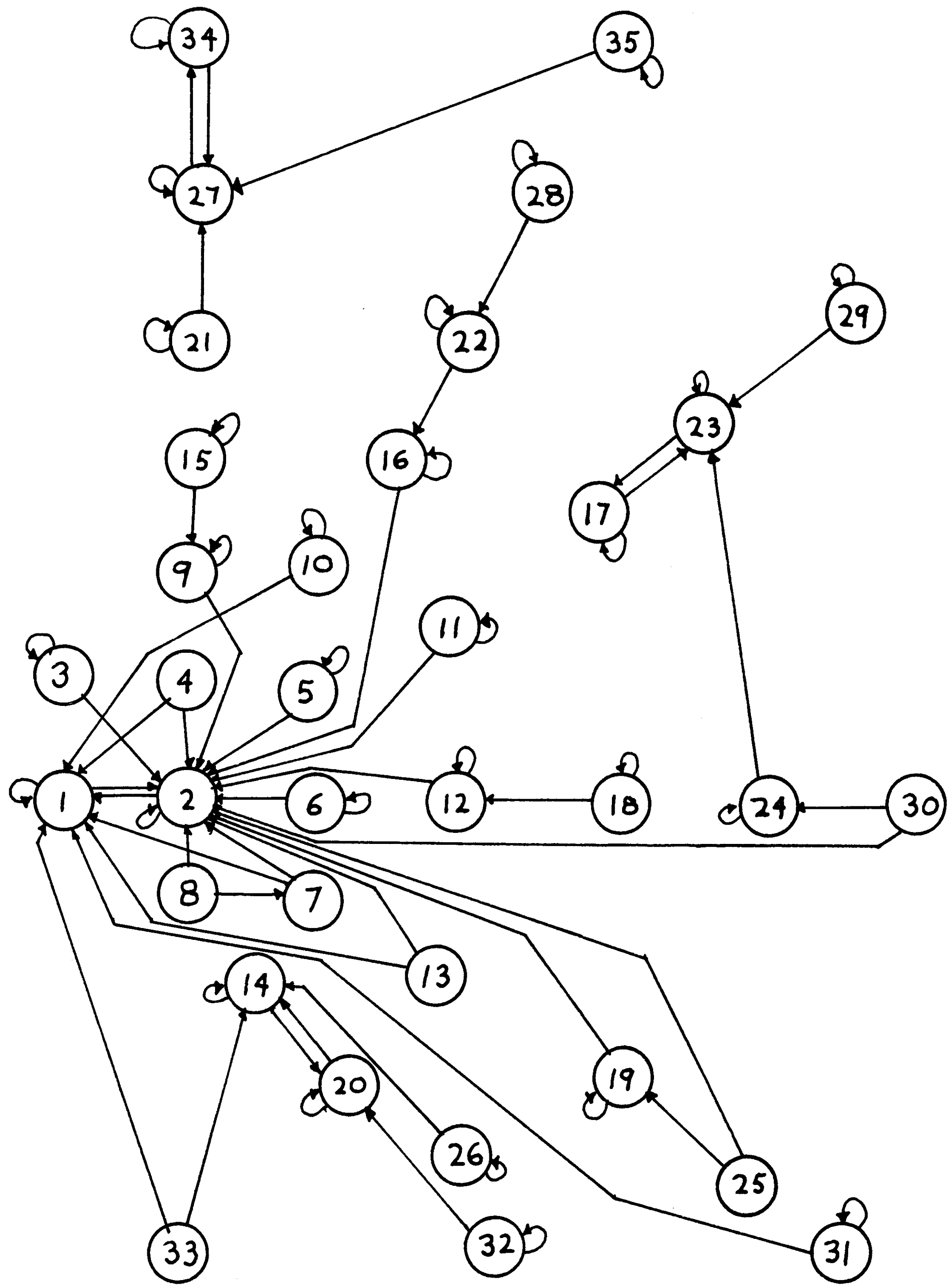


Fig. 2. Structure of Principal Work Linkages.

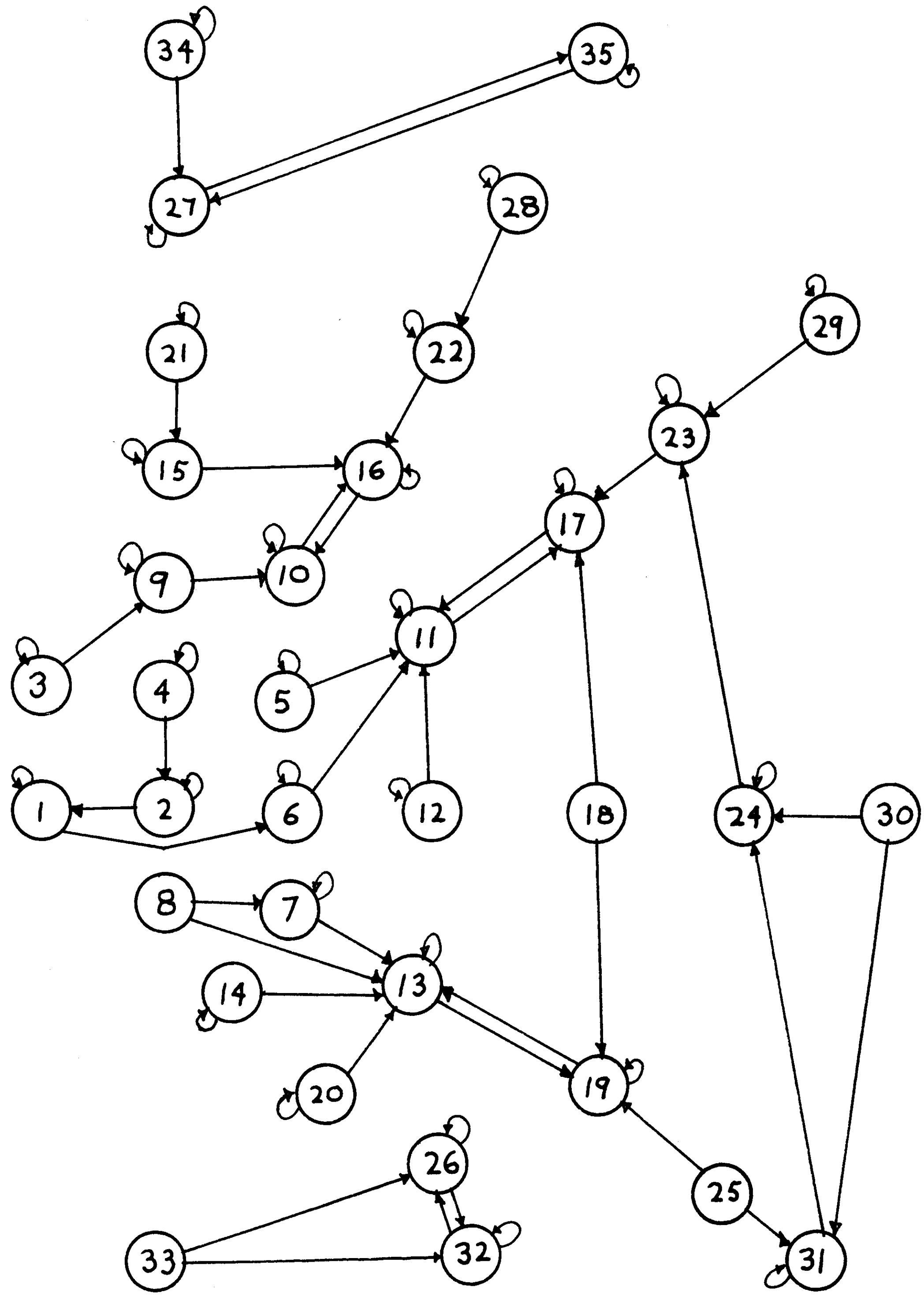


Fig. 3. Structure of Principal Shopping Linkages.

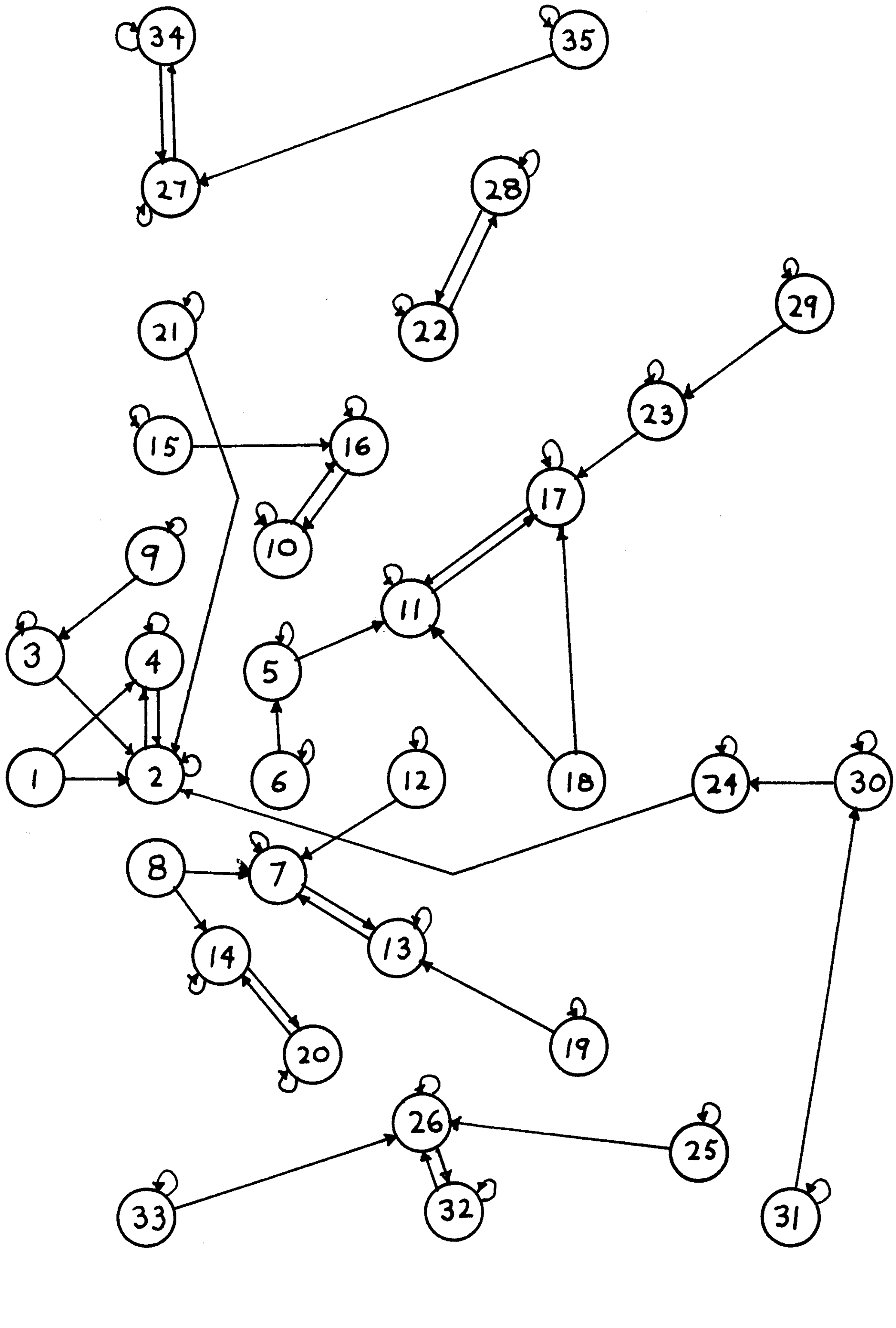


Fig. 4. Structure of Principal Social-Recreation Linkages.

and the arrows represent the linkages. A loop, an arrow from a zone to itself, means that one of the principal linkages of that zone is self-linkage. The numbered circles are arranged on the page in accord with the actual geographic relationship of the zones but the spacing between them has been altered to permit drawing the linkages.

The figures show that the principal linkages divide the zones into groups or clusters of zones. In Figure 2 for example, zones 21, 27, 34, and 35 are linked together but are not joined with other zones. There is a wall between these zones and the rest of the urban area or a boundary around them. Zones 26, 32, and 33 form a similar cluster in the plot of principal shopping linkages (Figure 3), and so do zones 1, 2, 3, 4, 9, 21, 24, 30, and 31 in the plot of principal social-recreation linkages.

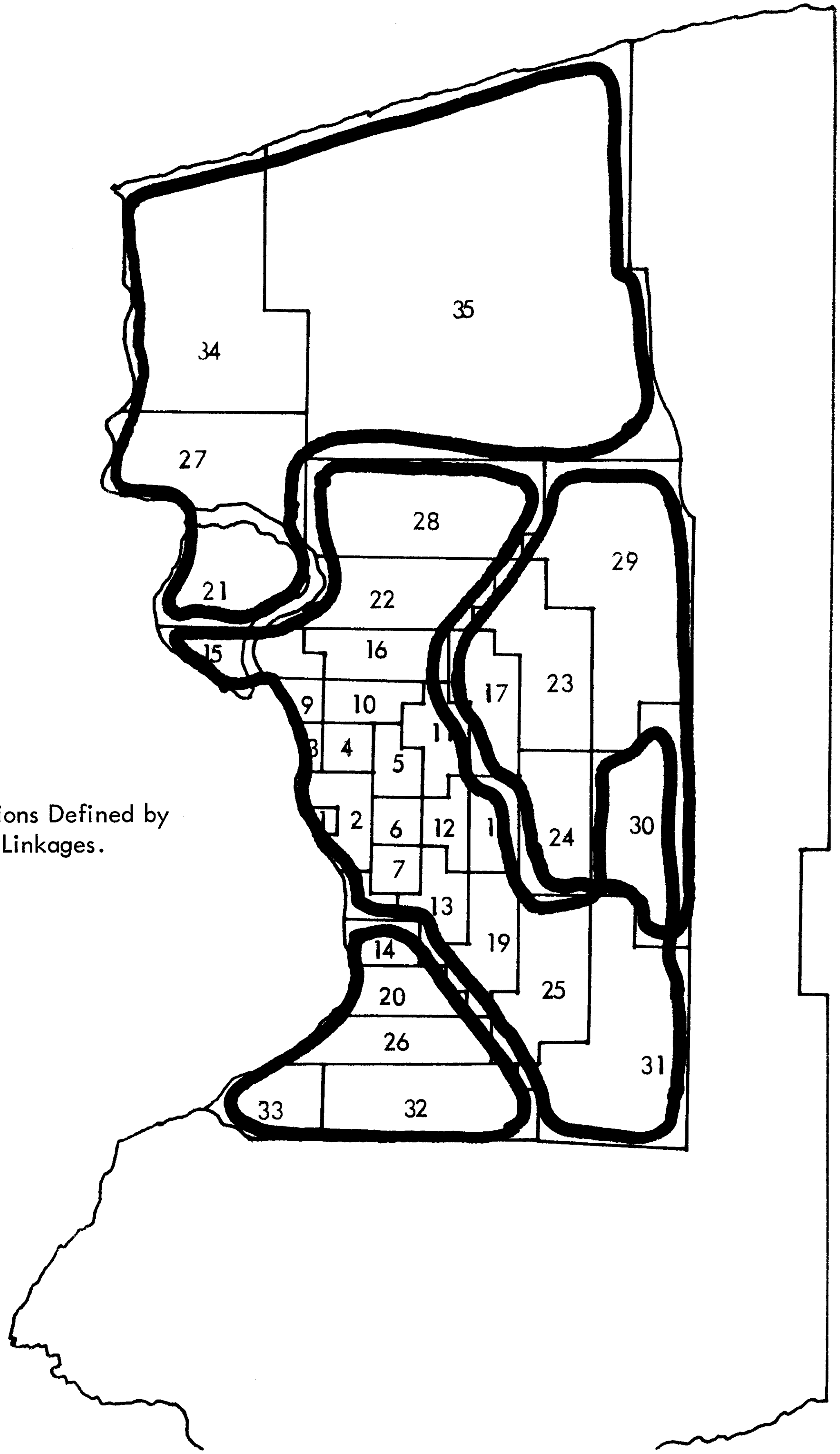
There are also clusters of zones which are joined to each other by one or more zones which send a principal linkage to each cluster. The trips from these zones which are common to two clusters are like a group of people which cannot make up its mind which way to go and so splits up and goes both ways. Zones 18 and 25 in the plot of shopping linkages are examples of common zones. They connect two clusters of zones. These two clusters of zones can be considered independent since there is no interchange of trips between them. That is, it is not possible to trace a path from a zone in one cluster, such as zone 11, to a zone in the other cluster, zone 13 for example. In effect these two clusters of zones have overlapping boundaries.

For each of these clusters or groups of zones there is a center. This center consists of two zones which exchange principal linkages. In the plot of shopping linkages in Figure 3, zones 11 and 17, 10 and 16, 13 and 14, 27 and 34, and 26 and 32 are the focal axes of the five groups of zones.

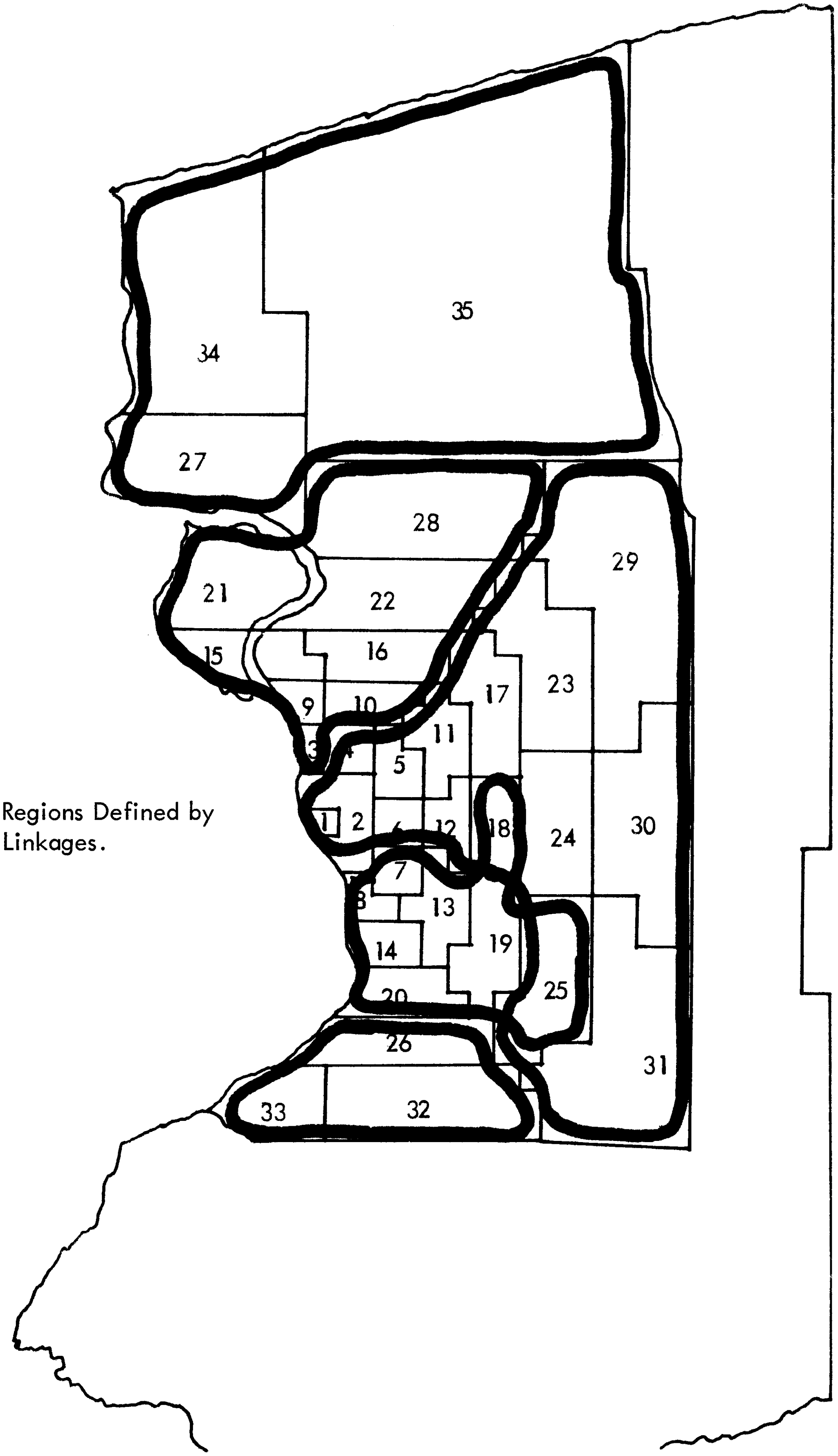
The spatial organization of activities shown by the plots of principal linkages is a focal pattern. Zones are grouped about a central focus. The delineation of zones tributary to the central focal zones divides the urban area into subregions. Each of these subregions is a self-contained locus of activity. Thus we see that in terms of principal linkages of activity there are walls within the urban area. Activities in the urban area are not organized so that the entire area is connected either by linkages which connect all the zones together like a string of beads or by linkages from each zone to one or two zones which serve as a center for the entire area.

It is apparent from the plots of principal linkages that the three activities have different subregional boundaries. Maps of the spatial organization of the linkages illustrate the differences. Maps 2, 3, and 4 are based on the plots of work, shopping, and social-recreation activity linkages, respectively. Common zones are shown by overlapping boundaries. There are four work regions, five shopping regions, and eight social-recreation regions.

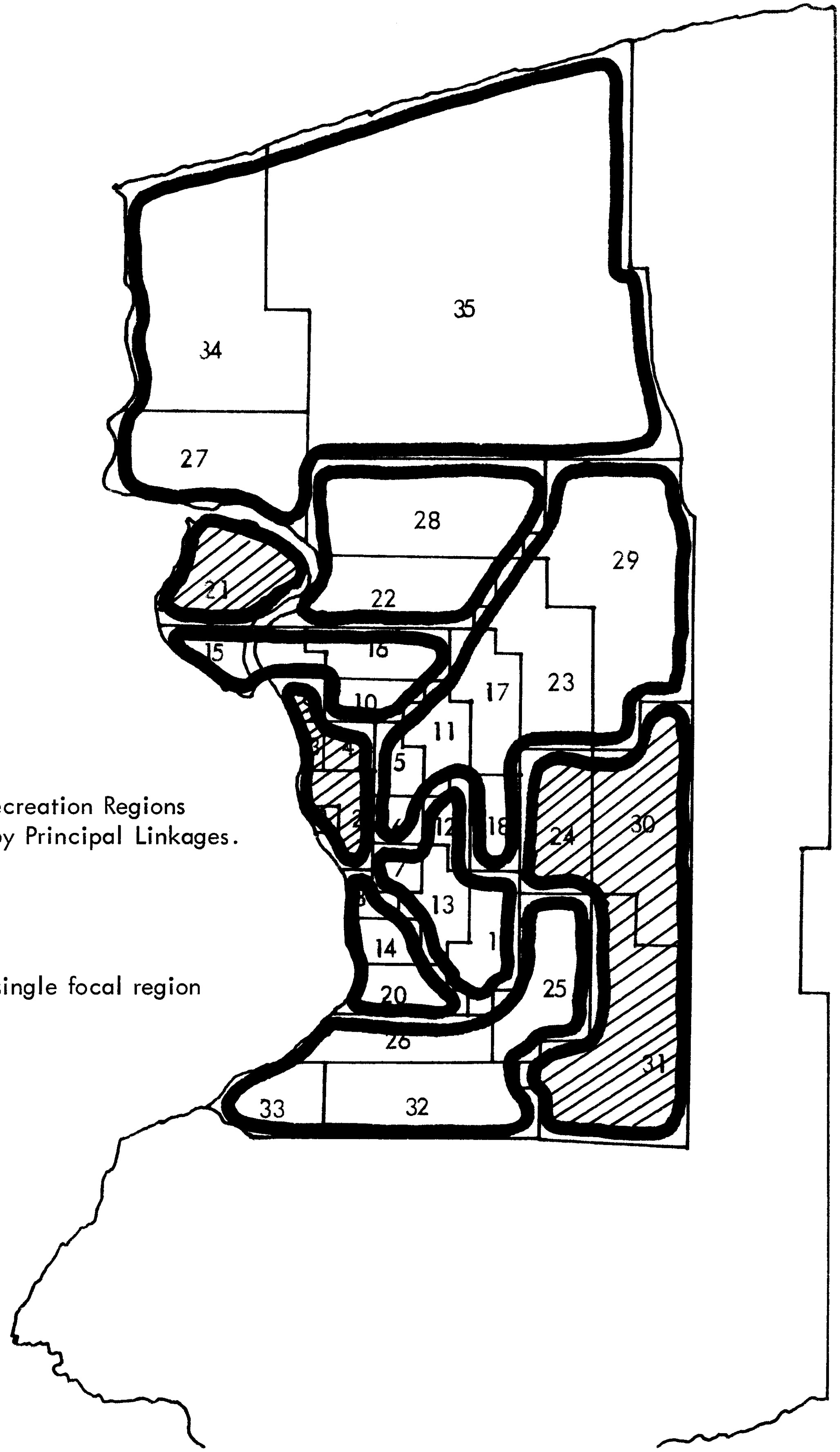
The pattern of focal regions is quite different for each activity. The eight social-recreation regions cannot be combined so that they match the four work regions or the five shopping regions. The shopping and work regions are themselves dissimilar. There is one exception to this general observation. Zones 27, 34, and 35 are combined into a single, independent region in all cases.[1] This suggests that these zones are not substantially integrated with the rest of the region, but that they are an independent region. In fact, they are essentially coterminous with Niagara County as opposed to Erie County which is the lower two-thirds of the two-county region. Zone 27 contains the city of Niagara Falls which is the historic commercial



Map 2.
Work Regions Defined by
Principal Linkages.



Map 3.
Shopping Regions Defined by
Principal Linkages.



Map 4.
Social-Recreation Regions
Defined by Principal Linkages.

= single focal region

and employment center of Niagara County. The two counties are considered integral under the definitions of the U. S. Bureau of the Census and are officially designated a single metropolitan area. They are considered a single, functional urban area in current land use and transportation planning efforts. Our findings indicate that the current metropolitan definition may considerably overstate the case.

In all cases the subdivision of the region is primarily radial about the Buffalo CBD. The region is always split along the lines between zones 28 and 29 and between zones 31 and 32. The radial pattern of the linkages themselves can be seen in Figures 2, 3, and 4. Work linkages show a strong radial orientation because of the importance of the Buffalo central business district (zones 1 and 2) as an employment center. A radial pattern also occurs in the plots of shopping linkages and social-recreation linkages. The main radial axes are along the alignment of zones 7, 13, and 19; zones 11, 17, and 23; and zones 10, 16, and 22. This radial organization of linkages reflects the radial orientation of the existing arterial street system in the Buffalo area. The influence of the Buffalo CBD varies considerably with activity type. It is a major center for work trips. In the organization of shopping trips it does not even appear as a center. It is the center of a large, but spatially discontinuous focal region of social-recreation activity.

This last case -- the spatially discontinuous focal region -- is particularly interesting. A spatially discontinuous focal region is, as observed on Map 4, one in which not all of the included zones have common boundaries. All efforts to subdivide large urban spatial structures, whether metropolitan in scale or submetropolitan or supermetropolitan, start from the premise that the larger structure is composed of parts which are spatially continuous as well as functionally integrated. These subregions are considered to be composed of a further set of smaller spatially continuous subregions.

An example of this type of spatial organization is the concept of the neighborhood based hierarchy in urban planning. This one example of a spatially discontinuous subregion suggests that the spatial structure of urban activities is more complex than is generally recognized.

Additional Linkages

Principal linkages give a clear picture of the spatial structure of activities. But we must remember that although we have accounted for a majority of trips we have accounted for only a small fraction of the actual linkage paths. The likely pattern of additional linkages can be deduced from observations of trip making behavior and from the patterns of the principal linkages. As we noted in Chapter 1 most urban trips are short. The number of trips made decreases rapidly with trip length. Trips in the principal linkages are mostly short trips. Figures 2, 3, and 4 show that these trips are primarily intrazonal trips and trips to adjacent zones. The trips in each succeeding linkage (third magnitude, fourth magnitude, etc.) will likely be longer trips, and, of course, the number of trips in each linkage will be successively smaller by definition. We should also note that each successive linkage from a zone may not go to a zone that has already received a linkage from that zone.

Since the principal linkages have preempted adjacent zones, are primarily radial in orientation, and tend to be directed toward the center of the region, it appears that successive linkages will be increasingly circumferential rather than radial in orientation, directed away from the CBD, and skip over nearby zones to more distant zones. The smallest magnitude linkages for example will likely include those few trips which traverse the entire urban area from north to south or east to west. To examine the pattern of additional linkages we will add one linkage from each zone. Following our earlier practice we will take the largest remaining linkage. We now have the first, second, and third magnitude linkages. This is the same set of linkages used in analyzing travel behavior in the last chapter. Drawing the principal linkages was facilitated by the fact that many of these linkages are intrazonal. When the third linkage is added the plot of linkages becomes quite complicated. Figures 4A, 4B, and 5 show the third linkages of work, shopping, and social-recreation activity superimposed over the principal linkages.

With the third linkage added the zones are no longer partitioned into separate clusters. The zones are not fully connected since to be fully connected it must be possible to find a path from every zone to every other zone. But all zones are connected in that there are no groups of zones which do not exchange trips with other zones outside the group.

As shown in Figure 4A many of the third magnitude work linkages go to the CBD zones 1 and 2 from zones which were originally not connected to the CBD oriented cluster. Although all of the original focal centers remain, the general spatial organization formed by the first three linkages taken together is a single focal region centered on the Buffalo CBD.

As shown in Figure 4B one-third of the third magnitude shopping linkages are radial and directed away from the Buffalo CBD. An additional one-third of these linkages are circumferential, and the remainder are mostly radial and directed toward the CBD. The third magnitude linkages of social-recreation trips also have

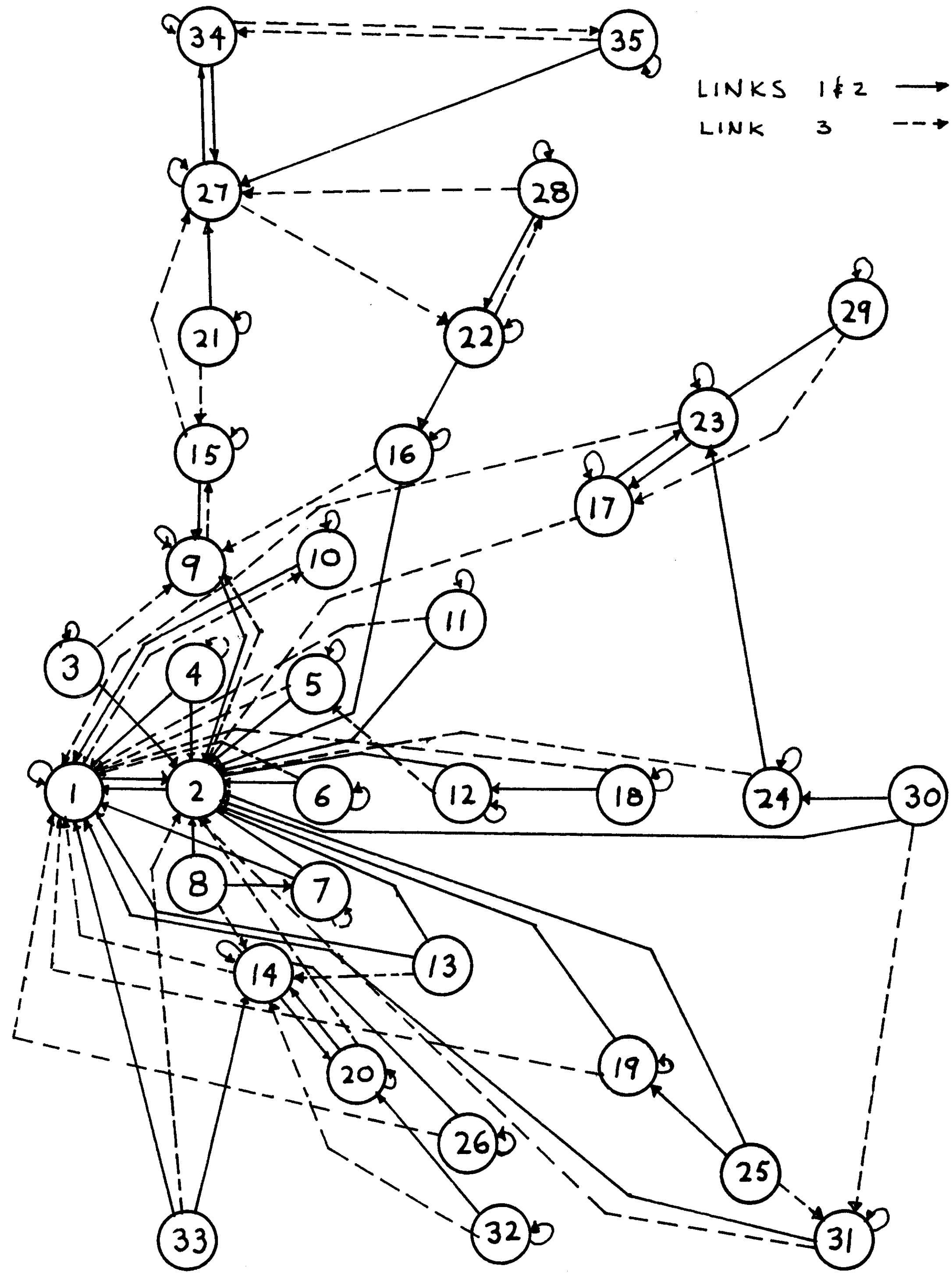


Fig. 4A. Structure of Principal and Third Magnitude Work Linkages.

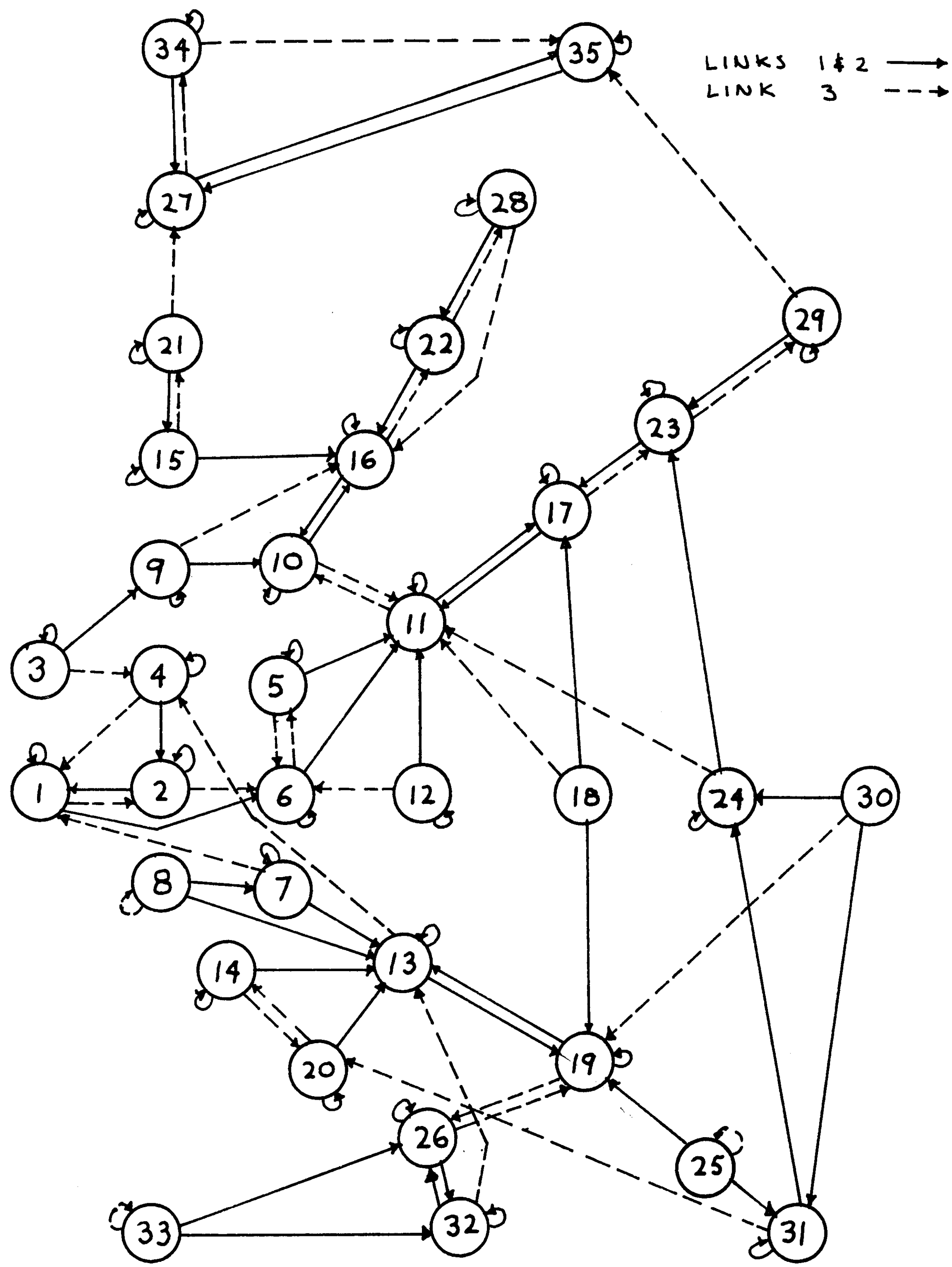


Fig. 4B. Structure of Principal and Third Magnitude Shopping Linkages.

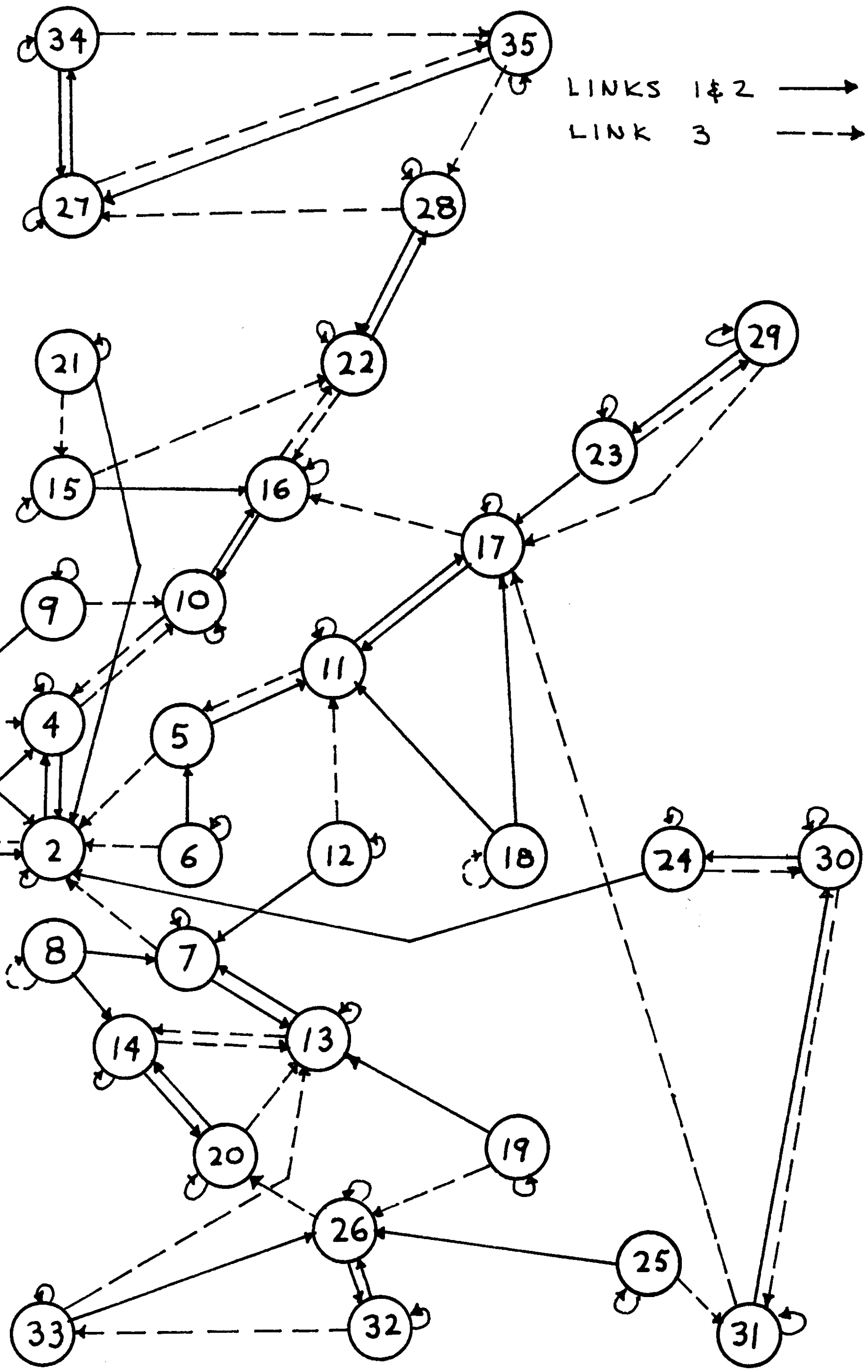


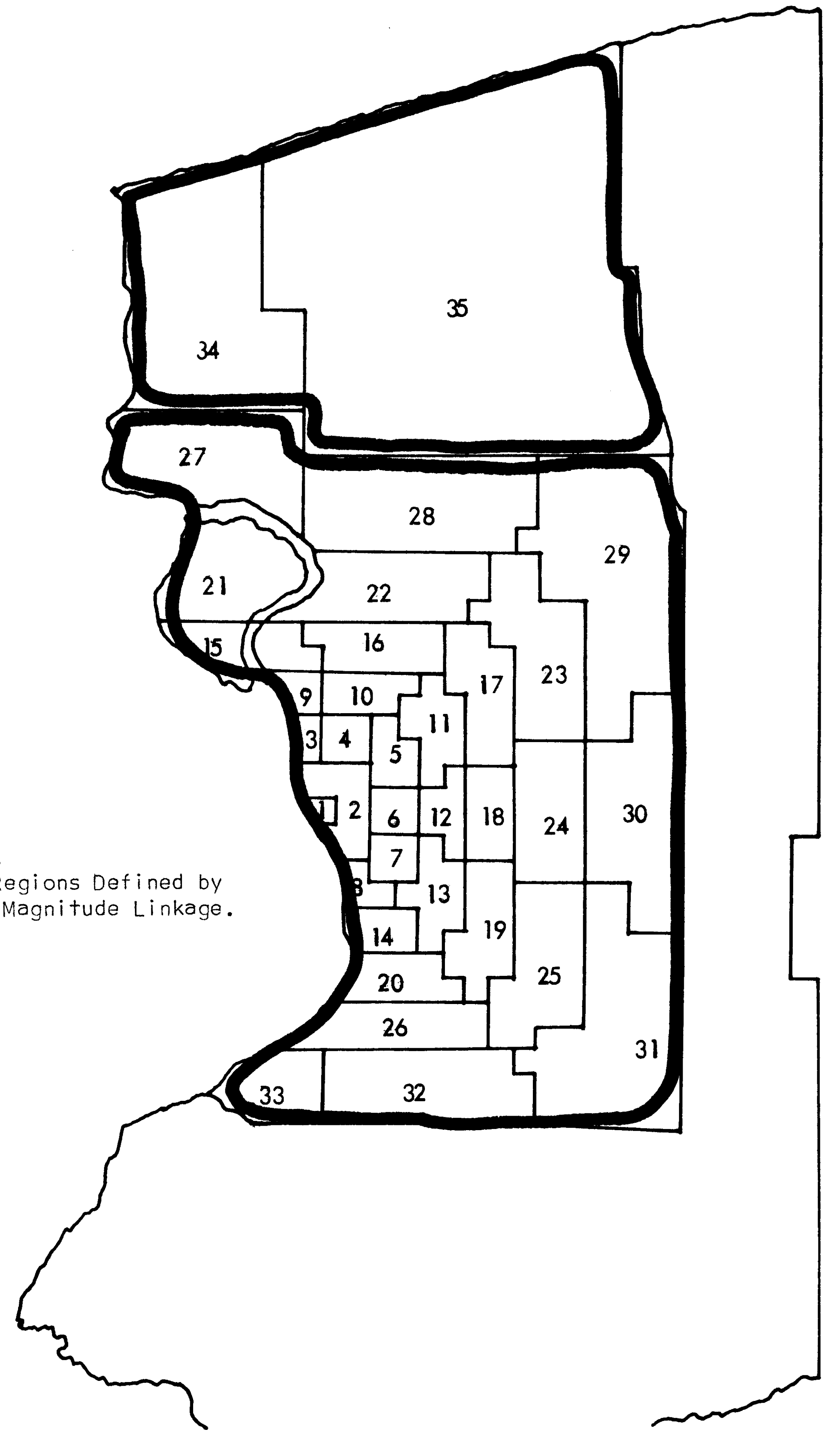
Fig. 5. Structure of Principal and Third Magnitude Social-Recreation Linkages.

a mixed pattern of radial and circumferential direction. Many of these linkages connect the original eight focal regions.

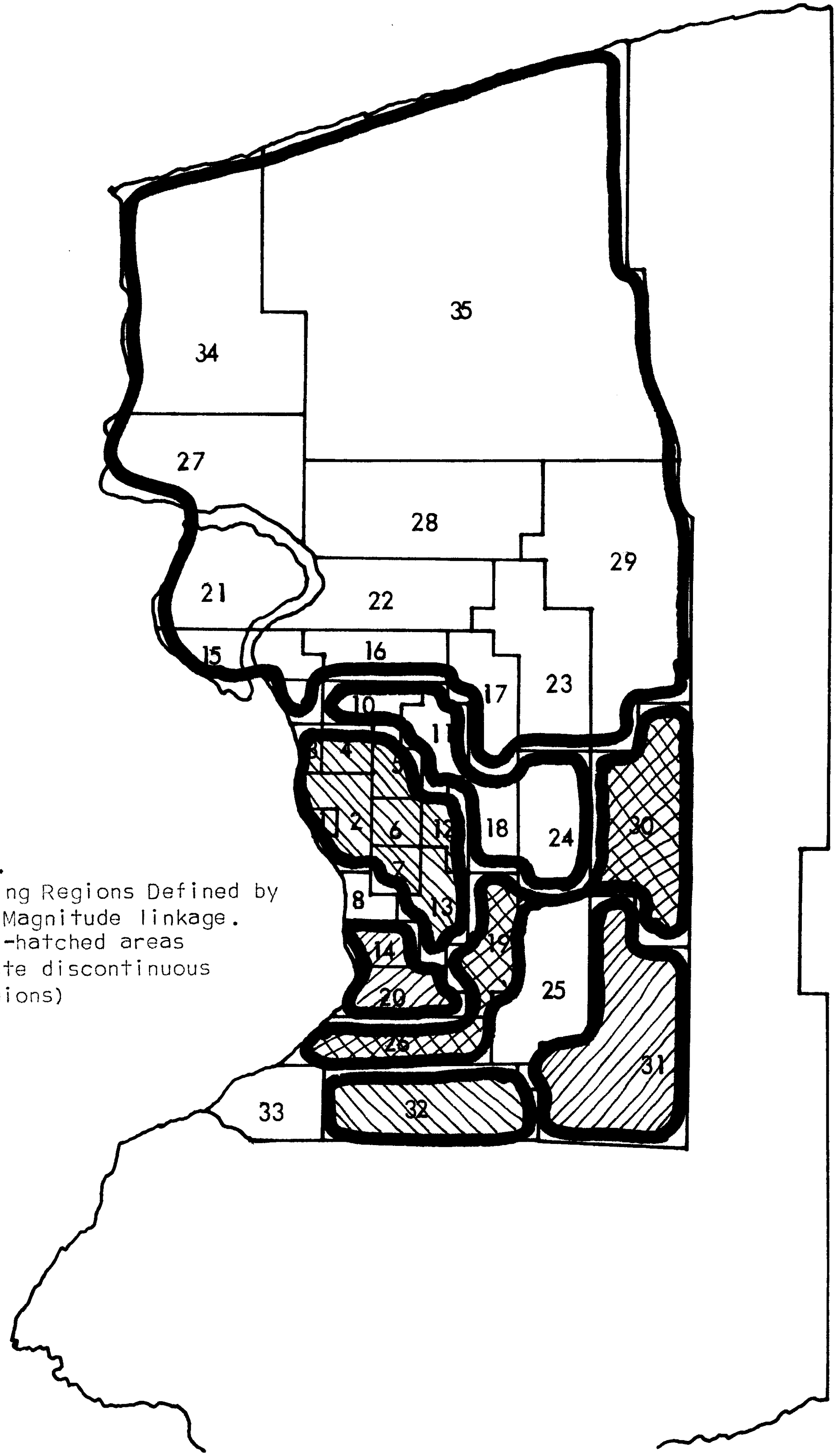
In all three activities many of the third magnitude linkages are reciprocals of the principal linkages. For example in the plot of shopping linkages there are principal linkages from zones 22 to 16 and from zone 23 to 17. There are third magnitude linkages in the reverse direction from zone 16 to 22 and from zone 17 to 23. To the extent that third magnitude linkages are reciprocals of principal linkages they reinforce the original spatial organization of activity. Another way in which third magnitude linkages reinforce the original structure is by establishing a direct linkage between two zones which were linked through intermediate zones by principal linkages. Looking again at shopping linkages for an example we see that a direct link is established between zones 28 and 16 by third magnitude linkage.

Turning our attention now to the spatial organization of the third magnitude linkages themselves we observe that like the principal linkages they partition the urban area into distinct subregions. These subregional patterns are shown on Maps 6, 7, and 8.[2] For all three activities there are fewer subregions formed by the third magnitude linkages than by the principal linkages.

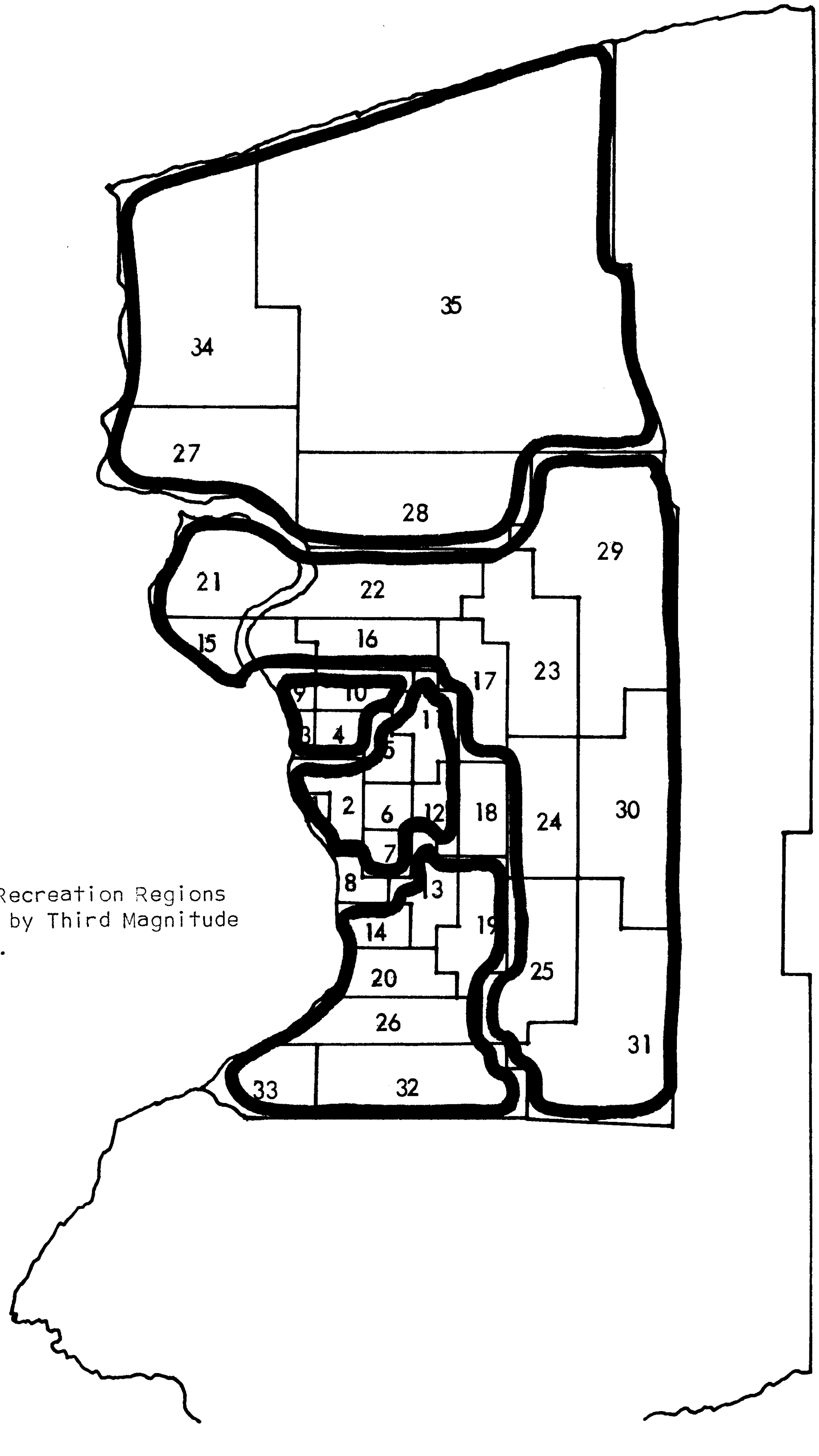
Zones whose third magnitude linkage is intrazonal are not outlined on the maps. See, for example, zones 8 and 25 on Map 7. As successive linkages are examined, it is likely that subregional patterns of organization would disappear. This would occur because each succeeding linkage from every zone would probably be to a destination zone farther away than the previous linkage. Two patterns might emerge. First, when each magnitude linkage is plotted there might be more examples of spatially discontinuous subregions. As an example, three spatially discontinuous



Map 6.
Work Regions Defined by
Third Magnitude Linkage.



Map 7.
Shopping Regions Defined by
Third Magnitude linkage.
(cross-hatched areas
indicate discontinuous
subregions)



Map 8.
Social-Recreation Regions
Defined by Third Magnitude
Linkage.

subregions are formed by the third magnitude shopping linkage. Second, the entire urban area might be linked together in a single activity structure.

It is clear that the net effect of the linkages other than the principal linkages is to over-ride the focal, subregional activity pattern formed by the principal linkages. However, the pervasiveness of this basic activity structure is demonstrated in the third magnitude linkage by the amount of reciprocal linkage and the direct linkage of zones originally linked through intermediaries.

Summary of the Existing Activity Organization

The two major findings of our examination of the spatial pattern of activity formed by principal linkages are that the spatial structure of the activities is focal and that pattern of focal subregions formed is different for each of the activities. The focal pattern we have identified consists of a division of the urban area into distinct activity locii. To the extent that the principal linkages are representative of the predominant travel patterns of all residents of the urban area, the subregions these linkages form illustrate the spatial organization of activity in the urban area. Zones within the boundaries of a subregion are held together by the predominant daily travel patterns of the residents of those zones.

The remaining trips by residents of each zone (those trips not included in the principal linkages) are widely spread throughout the urban area. Some of these trips remain within the subregions formed by the principal linkages as we have seen in examining the third magnitude linkage from each zone. Some are destined to the historic core of the urban area, the Buffalo central business district, and some transverse the entire urban area.

The test of whether or not the spatial organization of activity formed by the principal linkages is representative of the spatial organization of activity formed by all person trips is the percentage of all trips contained within the focal regions formed by the principal linkages. If a large percentage of all trips are within these focal regions, that is, if these focal regions contain most of the trips, then the subregions are largely independent. If this is true, establishing walls around the subregions to prevent trips from one subregion to another does not interfere significantly with the conduct of daily activities by the residents of the urban area.

By definition the focal regions will contain 48.4 percent of all work trips, 64.8 percent of all shopping trips, and 55.5 percent of all social-recreation trips because these are the trips contained in the principal linkages. Of all person trips 82.9 percent of the work trips are contained within the focal regions formed by the principal work linkages. Similarly 83.9 percent of all shopping trips and 65.3 percent of all social-recreation trips are contained in their respective focal regions. It is clear that the establishment of subregional boundaries by principal linkages does not disrupt the basic patterns of work and shopping activity since only 17 and 16 percent respectively of the daily trips are not accounted for. The focal regions of social-recreation activity are less inclusive of all social-recreation trips. The remaining trips, those not contained within the subregions formed by principal linkages, are spread throughout the urban area.

At this point we are in a position to comment on the importance of the core area -- the central business district -- as a locus of activity. It has often been assumed in planning for urban spatial organization that the core area is a major focal point of activity, and a frequent goal of such planning is to strengthen and preserve the core area in this role by providing easy access to it from all parts of the urban area.

It is true that the core area attracts many trips. Zones 1 and 2 which contain the Buffalo CBD and its immediate environs are among the top five of all zones for each of the three activities when zones are ranked by the number of trips destined to them. But this large accumulation of trips is mainly composed of trips from zones within the same focal regions as the core area zones. Ninety-one percent of the work trips to the core are from zones within the same focal region as the core area zones. Only nine percent of the work trips come to the core area from zones which are in other focal regions. For shopping and social-recreation trips respectively 74 percent and 60 percent of the trips to the core area are from zones within the same focal region as the core area zones. The 26 percent of the shopping trips to the core which come from outside the focal region which contains the core area zones are a very small percentage of all such trips in the urban area. The trips to the core area from zones outside the focal area containing the core area zones are respectively two percent of all work trips, two percent of all shopping trips, and four percent of all social-recreation trips.

These data suggest that the importance of the central business district as a focal point of activity for all residents of the urban area may be overstated in metropolitan planning. At least in the Buffalo area, the CBD draws trips mainly from the focal region of which it is a part and draws relatively few trips from beyond that focal region.

The pattern of spatial organization of activity which emerges from this analysis is one of distinct subregions of activity overlayed on a general background of interaction among all zones. The subregional pattern formed by the principal linkages and accounting for 83 percent of all work trips, 84 percent of all shopping trips, and 65 percent of all social-recreation trips is dominant. The background level of interaction composed of trips crossing subregion boundaries has no specific pattern. A small percentage of these background trips are directed to the central business district (two percent of the remaining seventeen percent of all work trips; two percent of the remaining sixteen percent of all shopping trips, and four percent of the remaining thirty-five percent of all social-recreation trips), but the influence of the core area as an organizing focus of the background level of interaction is clearly quite small.

Spatial Structure of Optimal Linkages

We turn now to an examination of the spatial structure of activities formed by the optimal allocation of all trips. Our purpose in doing this is to determine to what degree the optimal allocation of all trips forms a spatial pattern of activity organization that matches the focal regions of activity identified in the analysis of actual trips.

Figures 6, 6A, and 6B show all the zonal linkages selected in the optimal allocation of all work, shopping, and social-recreation trips. Again these have been plotted on a base which approximates the actual spatial relationships of the zones. Examination of the figures will show that a focal pattern of activities is formed by the optimal linkages. For example, zones 1, 14, 17 and 23 in the plot of work linkages (Figure 6) are centers of clusters of zones. The linkages do not divide the urban area into distinct subregions because there are a large number of

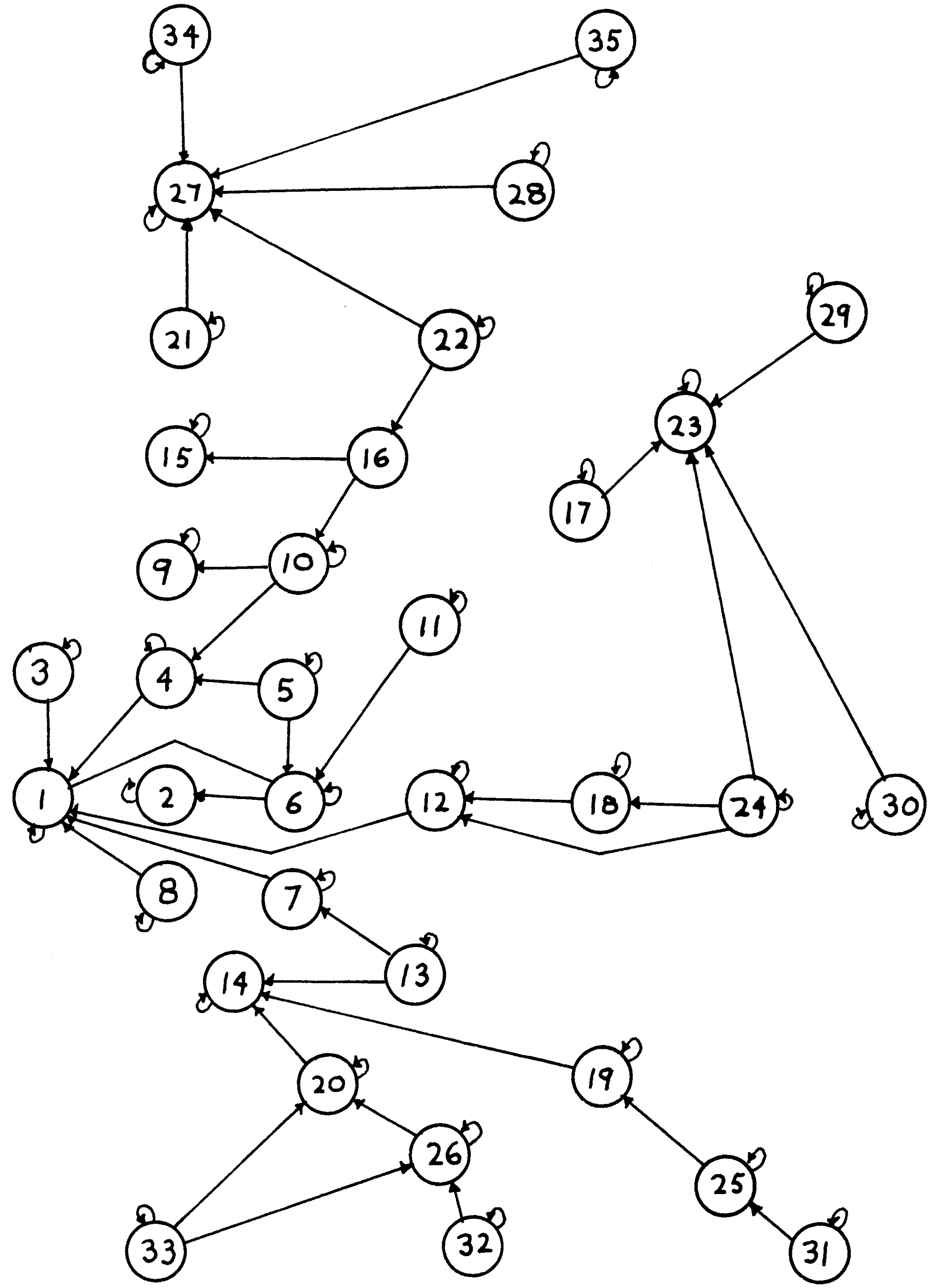


Fig. 6. Structure of Work Linkages Established by Optimal Allocation of Work Trips.

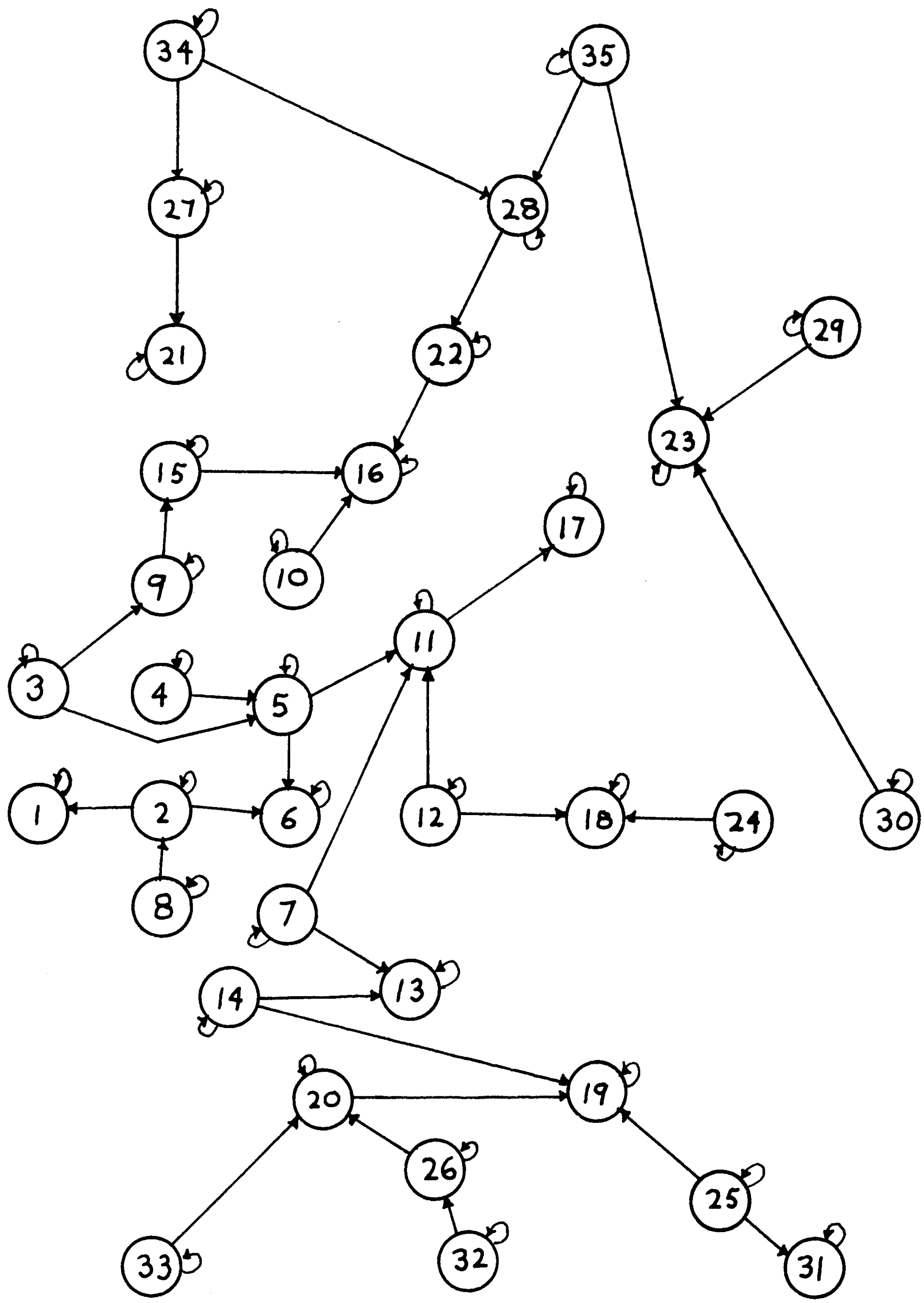


Fig. 6A. Structure of Shopping Linkages Established by Optimal
Allocation of Shopping Trips.

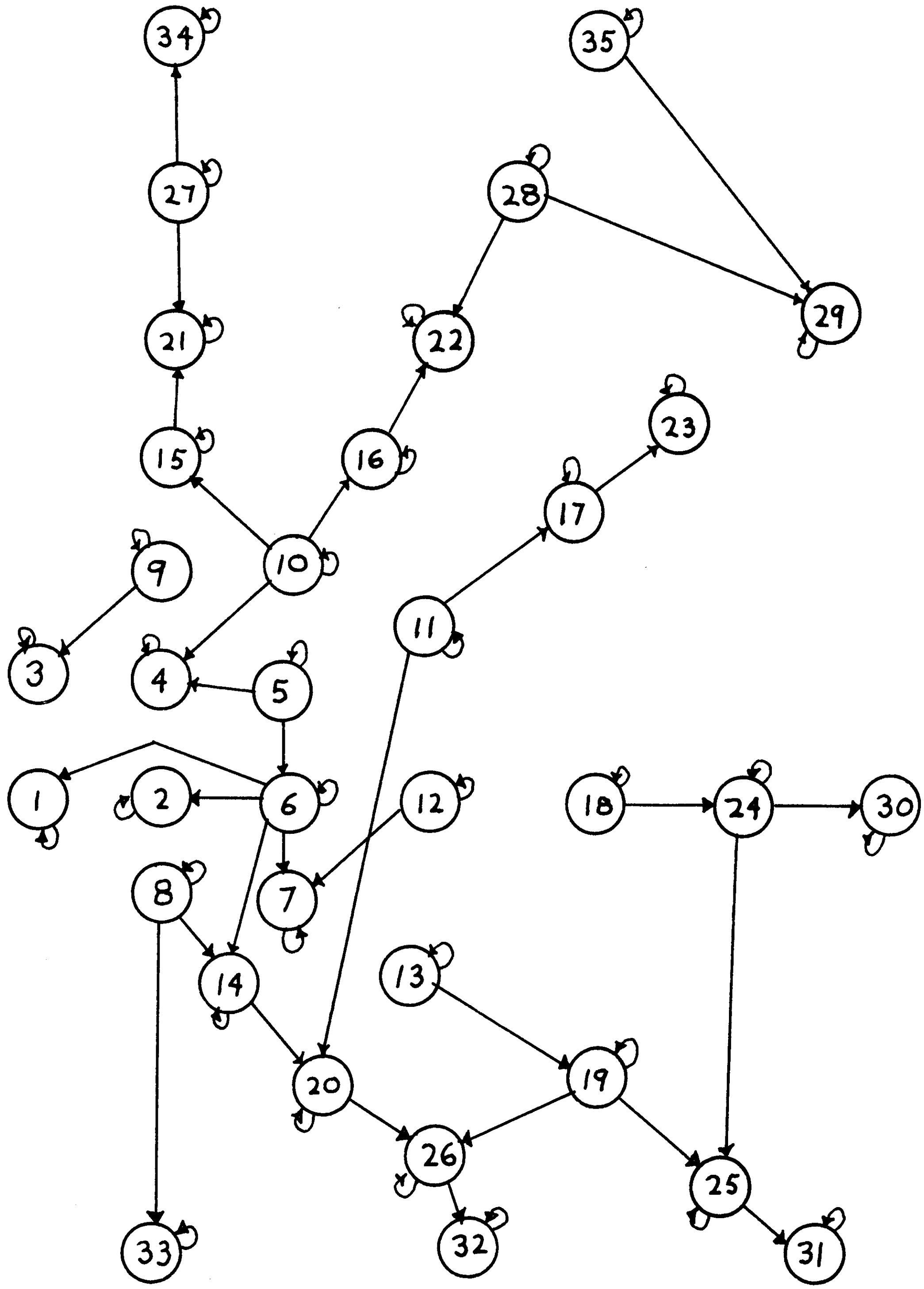


Fig. 6B. Structure of Social-Recreation Linkages Established by Optimal Allocation of Social-Recreation Trips.

common zones which are connected to two clusters of zones. For example zones 13, 22, and 24 in the plot of work linkages connect separate clusters of zones.

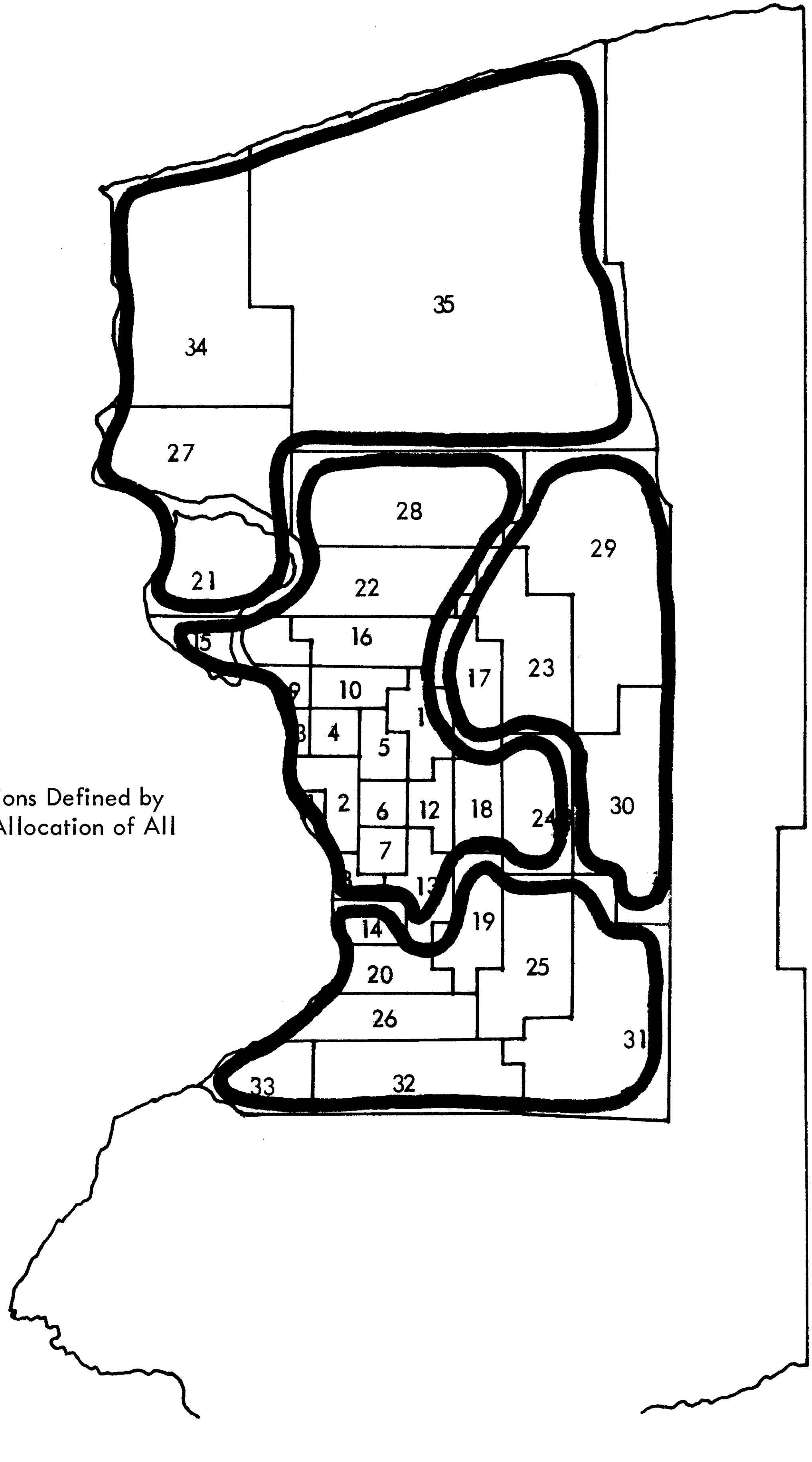
In order to map the spatial organization of activity formed by the optimal allocation of all trips we will simplify the linkage patterns by allocating common zones to one or the other of the zones to which trips from them are destined. By so doing we will divide the urban area into distinct subregions instead of the overlapping subregions which are indicated by the linkages.

The rule we will use in simplifying the linkage patterns is as follows. Zones which are connected to more than one zone by optimal linkages will remain connected (in terms of the number of trips contained in the linkage) and will be separated from other zones, except that no zone will be disconnected from all other zones. The effect of this rule is to redirect all of the trips from what we have called common zones onto the largest magnitude linkage from that zone established in the optimal allocation of all trips. This procedure will divide the urban area into distinct subregions.

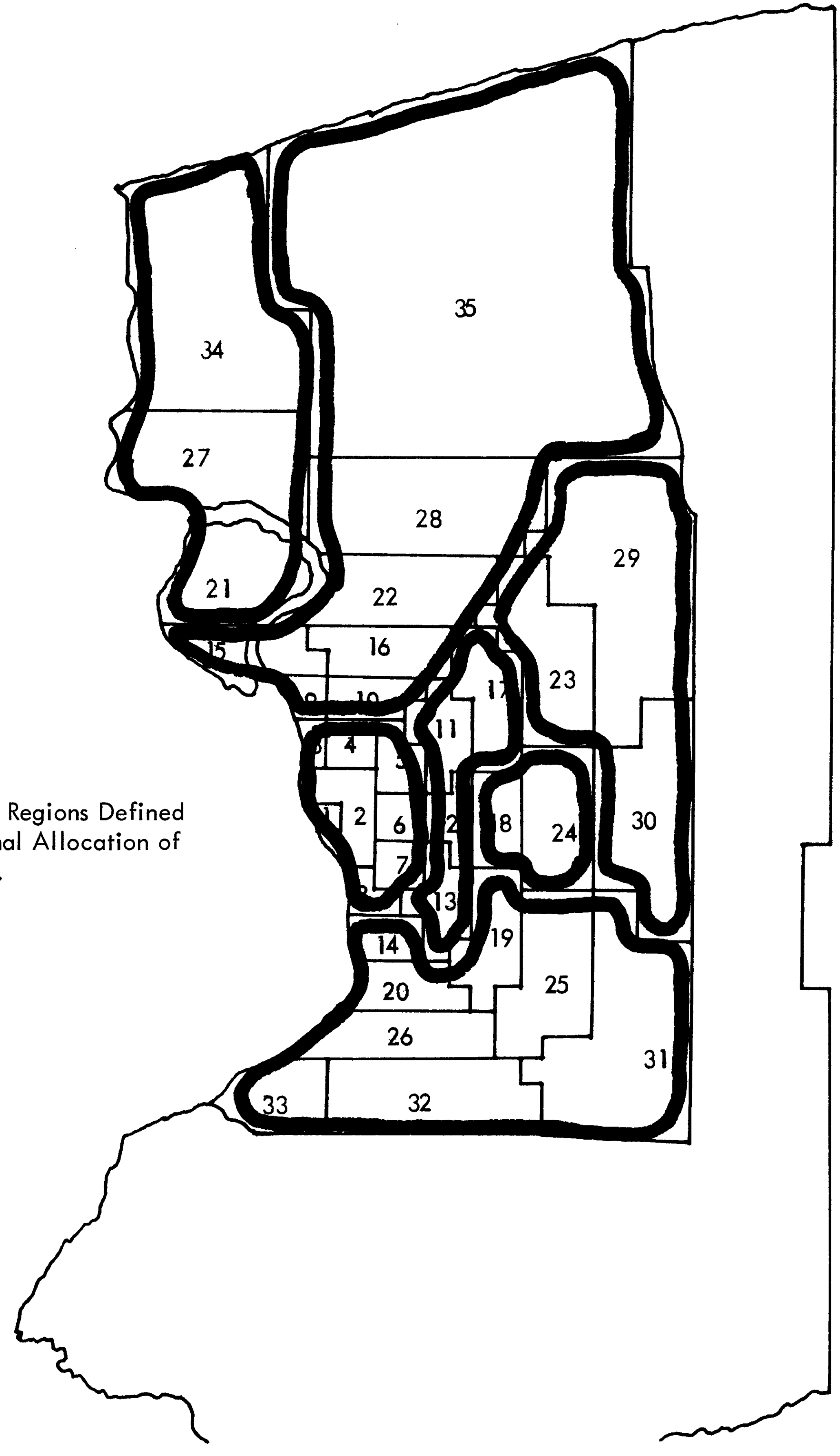
As an example of how the rule is applied, consider zone 22 in the optimal allocation of work trips (Figure 6). Zone 22 sends 1967 trips to zone 16 and 1137 trips to zone 27. Therefore the linkage from zone 22 to zone 27 will be cut and all trips from zone 22 will be directed to zone 16. This establishes zones 21, 27, 28, 34, and 35 as a distinct subregion. The next step in the process is to consider zone 16. There are 3297 trips from zone 16 to zone 15 and 6313 trips from zone 16 to zone 10. In this case the exception to the rule comes into play. Zone 15 is not separated from zone 16 since this would leave zone 15 completely disconnected. If instead of the actual situation more trips were sent from zone 16 to zone 15 than to zone 10 the linkage between zones 16 and 10 would be cut and zones 22, 16, and 15 would form a subregion. In actuality zones 22, 16, and 15 are linked to zone 10 by the simplification rule and are part of a larger subregion.

Maps 9, 10, and 11 show respectively the spatial organization of activity formed by the optimal allocation of all trips based on the rule we have used to simplify the linkage patterns. Since the effect of this rule is to redirect those trips which cross the subregional boundaries formed by the largest magnitude linkages from common zones, we take the number of trips that must be redirected to simplify the linkage pattern into distinct rather than overlapping subregions as a measure of the reasonableness of our mapping of the spatial organization of activity. If the number of such trips is small then the mapped organization of activity is a good representation of the linkage pattern. In fact only 0.3 percent of all work trips, 1.7 percent of all shopping trips and 0.9 percent of all social-recreation trips were redirected in simplifying the linkage patterns for mapping. Thus the usage of our rule simplifies but does not violate the linkage pattern.

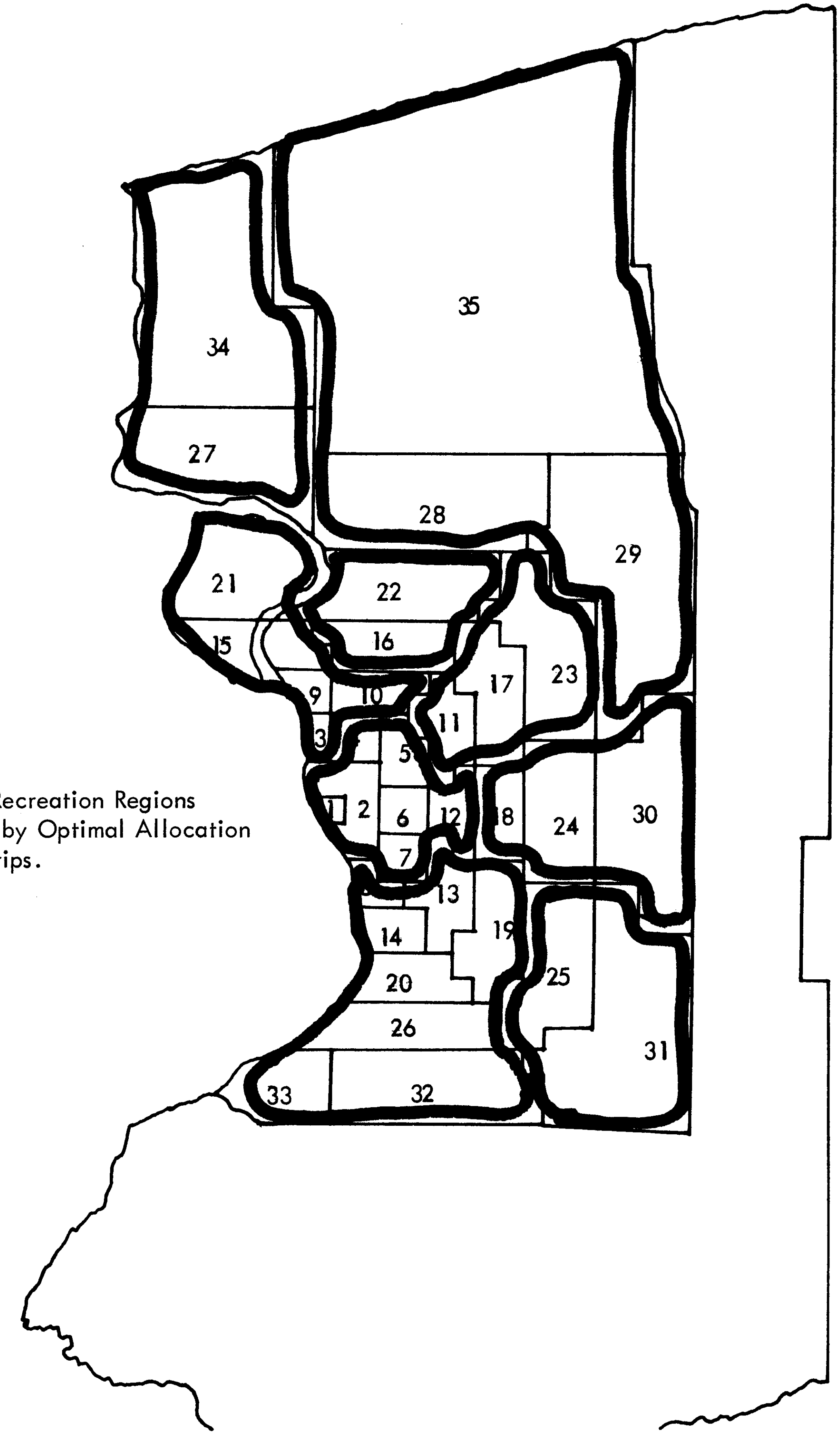
In no case do the subregional boundaries formed by the optimal allocation of all trips exactly match the subregional boundaries formed by the principal linkages shown in Maps 2, 3, and 4. The closest match occurs for work activity (Maps 2 and 9). In this case there are the same number (four) of subregions and the northern most subregion is exactly the same in both mappings. In the case of both shopping and social-recreation activities there are more subregions formed by the optimal allocation of all trips than by the principal linkages. Consequently the subregional boundaries do not match. Nor can the larger number of subregions formed by the optimal allocation be combined so that they match the subregions formed by the



Map 9.
Work Regions Defined by Optimal Allocation of All Trips.



Map 10.
Shopping Regions Defined
by Optimal Allocation of
All Trips.



Map 11.
Social-Recreation Regions
Defined by Optimal Allocation
of All Trips.

principal linkages.

As with principal linkages, the spatial organization of activity formed by the optimal allocation of all trips is different for each activity. The subregional pattern of social-recreation activity formed by the optimal allocation of trips (Map 11) is very regular. The southern half of the urban area is divided into subregions of approximately equal size which are spread in a ring about a core subregion focused on downtown Buffalo. The northern, Niagara County portion of the area is split in two subregions centered on the cities of Niagara Falls and Lockport. The subregional pattern of shopping activity defined by the optimal allocation of shopping trips is closely related to the density of population in the urban area. Subregions are small in the high-density area in the center of the region and large in the lower-density outer areas.

Requirement of an exact match of subregional boundaries formed by an optimal allocation of trips with the subregional boundaries formed by principal linkages is too demanding a requirement in evaluating whether the pattern formed by the optimal allocation replicates the pattern formed by the principal linkages because a small difference in the linkage pattern can result in marked differences in subregion boundaries. There are two questions we ask in comparing the two descriptions of the spatial organization of activity. First, what percentage of the principal linkages are replicated in the optimal allocation? Second, what percentage of the trips on principal linkages are replicated in the optimal allocation?

To answer the first question we add up the number of principal linkages which are replicated in the optimal allocation and divide by the total number of principal linkages. Fifty-six percent of the principal linkages of work trips, 66 percent of the principal linkages of shopping trips, and 59 percent of the principal linkages of social-recreation trips are replicated in the optimal allocations. To answer the second question we sum up the number of trips on principal linkages which are replicated in the optimal allocation of all trips and divide by the total number of all trips on principal linkages. Seventy-two percent of principal linkages work trips, 87 percent of principal linkage shopping trips, and 81 percent of principal linkage social-recreation trips are on linkage paths selected in the optimal allocations of all trips.

This analysis shows that the spatial structure of activity formed by the optimal allocation of all trips is only a fair match for the spatial structure of activity formed by the principal linkages since only one-half to two-thirds of the principal linkages are replicated in the optimal allocations. However the high percentage of principal linkage trips accounted for by the replicated linkages shows that the most important principal linkages (as measured by the number of trips on the linkage) are selected in the optimal allocations.

These results must be interpreted with caution because intrazonal linkages account for a large number of principal linkages and will always be replicated in an optimal allocation. We can examine the impact of intrazonal linkages on our findings by holding intrazonal interchange constant as we did in evaluating travel rationality in the last chapter. To do this we consider the percentage of principal interzonal linkages and the percentage of principal interzonal linkage trips that are replicated in an optimal allocation of all interzonal trips. The optimal allocations of principal interzonal trips are given in Tables ~~14~~ 31, ~~15~~ 32, and ~~16~~ 33 in the Appendix.

Thirty-seven percent of the principal interzonal work linkages, and 56 percent of both the shopping and social-recreation principal interzonal linkages are replicated in the optimal allocations. Thus the match of the spatial structure of activity formed by the optimal allocations with the spatial structure of activity formed by principal interzonal linkages is less satisfactory than with principal linkages which include intrazonal trips. Looking at trips, 47 percent of all principal interzonal linkage work trips, 66 percent of all principal interzonal linkage shopping trips, and 71 percent of all principal interzonal linkage social-recreation trips are on principal interzonal linkages which are replicated in the optimal allocations of all trips. Thus once again we see that the most important linkages (as measured by the number of trips on the linkage) are replicated.

The conclusion from this analysis is that the spatial structure of activity formed by a linear programming allocation of all trips for a given activity is only a fair match of the spatial structure of activity formed by principal linkages. This rather unimpressive result can be modified somewhat by noting that the most important principal linkages are replicated in the optimal allocations.

Conclusion

The spatial organization of activity formed by the principal linkages is focal in that the urban area is divided into distinct subregions by person trips to work, shopping, and social-recreation activities. And the subregions are different for each activity.

Reviewing our findings we see that the spatial organization of activity in the urban area has two major components. First, there is widespread interconnection of each zone with all other zones. Trips are sent from almost every zone to a large number of other zones for each activity. Most of these linkages contain relatively few trips. We have interpreted this as a background level of activity organization. Within this background level there are many trips to the historic core area of the region. Core area zones receive more trips than other zones, but this large accumulation of trips to the core zones results primarily from trips sent from nearby zones. The connection to the core area is a relatively weak one for most zones. Second, rising above both the widespread background level of activity and the flow to the core area, there is a strong focal pattern of activity which divides the urban area into subregions.

We undertook the analysis of the spatial organization of activity formed by the optimal allocations of all trips to test the degree of correspondence with the spatial organization of activity formed by principal linkages. We had previously found that the trips on principal linkages are rational in that a linear programming allocation of these trips so as to minimize total travel did not produce a significant benefit in time savings. The idea that the spatial patterns formed by the optimal allocations of all trips should match those formed by the principal linkages is based on the reasoning that since the principal linkages appear to be rationally selected, they should be replicated by the optimal linkages.

As we have seen the optimally selected linkages are only a fair match of the principal linkages, but the most important principal linkages are replicated in the optimal allocations. An additional factor complicates the comparison of the two sets of spatial patterns. We simplified the linkage patterns of the optimal allocations in order to map them. With the linkage patterns of the optimal allocations simplified the spatial organization of activity formed by the optimal allocations is also composed of distinct subregions, and the subregion patterns are different for each of the three activities.

Several implications for planning can be drawn from this analysis. The planner in planning for the arrangement of land uses and for transportation systems is directly concerned with the spatial organization of activity. His concern is two-fold. The planner is concerned that land uses be so arranged and transportation facilities provided so that the demand for activity linkages is met efficiently. And he is also concerned with the possible effects of the arrangement of land uses and the location of transportation facilities on spatial patterns of activity since these may influence trip destination decisions.

Our findings conform with the generally accepted view that the planner must satisfy the two dimensions of focality and dispersion in meeting the demand for the spatial connection of activities. If there is more than one focal center, these may be conflicting requirements.

In current transportation planning practice the possible conflict between the requirements of focality and dispersion is avoided by treating the central business district of the major city in the urban area as the hub of activity and considering the entire area a single, integrated focal region. Transportation system designs then are largely based on provision of easy access to the CBD from all parts of the urban area. Our findings show that the assumption of area-wide integration is unwarranted in the Buffalo area. The central business district does not provide a satisfactory focal point in the design of a transportation system to meet the needs of the entire urban area. If the spatial organization of activity in the Buffalo area is typical of other metropolitan areas, then it appears that the role of the CBD is over-emphasized in contemporary transportation planning.

The wide dispersion of trips which comprise the background level of interaction in the Buffalo area suggest the need for uniform transportation service. But a system of transportation service which provides this might tend to break down rather than reinforce the over-riding focal character of activity organization, and it might well be prohibitively expensive. The ability to travel with equal ease in any direction which would result from a system of uniform transportation service would remove one of the two elements forming the focal organization of activity -- the influence of the transportation system. The second element, the tendency for activities to be concentrated, is at least in part dependent on the transportation system since the transportation system defines nodal points in the region. A system of uniform transportation service might be prohibitively expensive because the opportunities to design individual facilities for specific traffic service functions would be decreased, and considerable excess capacity might have to be supplied. On the other hand, a system of transportation facilities designed primarily to serve a focal pattern, perhaps something like spokes emanating from subregional centers, might serve this need but make widely dispersed travel quite expensive.

Finally we should observe that since the subregional pattern of activity is different for each of the three activities we have examined, the planner's task is complicated by the need to serve these different demand patterns. Again considering the transportation system, it is unlikely that any single pattern of transportation facilities would provide optimal service for all the different activities. It is more likely that a unique system of transportation facilities will be found best suited to serve each of the activities. The planner's problem then is to combine these in such a way that all activities are well served and none is penalized. At the same time the planner will need to consider whether rearrangement of land uses can ease the potential conflict between the different spatial patterns of activities.

The burden of these comments is that in order to do his job well the planner must be able to formulate and evaluate trade-offs between different land use arrangements and different systems of transportation service in meeting the demand for activity linkages efficiently. To do this the planner needs to know the relative importance of changes in the physical elements of land use and transportation facilities on the spatial organization of activity and on travel requirements. So the planner must be able to experiment with alternate urban forms. In Chapter 5 and 6 we will attempt some experiments of this kind using a linear programming allocation of all trips as a simulator of rational trip-making behavior to evaluate the efficiency of activity linkages and spatial organization of activity of alternate urban forms. But first we must consider the second of the requirements identified above -- that all activities are well served and that none is unduly penalized. To examine the extent to which parts of the urban area or particular activities may be at a relative disadvantage in the daily conduct of activities in an urban area we turn next to a consideration of comparative locational advantages.

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1. This excepts the minor complication that zone 21 is combined with them in the work structure. It is a minor complication because the flow 21 is exceedingly small and can reasonably be ignored without damaging the argument.

2. Map number 5 is not used. It originally was used for an illustration which was deleted after all subsequent maps had been prepared, numbered and printed.

CHAPTER 3

URBAN STRUCTURE AND LOCATIONAL ADVANTAGE

Everyone benefits from travel minimization in that the total travel bill of society is less than it would otherwise be. But some individuals will benefit more than others because of their locational advantage. A zone has a locational advantage if persons making trips from that zone for a particular purpose are able to select a suitable destination at less travel cost than are persons making similar trips from other zones when the location of activities and the transportation system are fixed. Some individuals may suffer a net loss from travel minimization. This could occur if the average length of trips from a zone were greater in the optimal allocation than in actuality. In effect these individuals would be paying a high price for society's benefit.

The Benefits of Travel Minimization

There are significant variations in the average travel time of persons making trips for a particular purpose from the 35 zones used in the earlier analysis of travel time. There are also significant differences in the accrual of benefits from travel minimization to the various zones. If we look at the distribution of these benefits among the zones we have a measure of the degree to which persons originating trips in the various zones tend to conserve on travel time as a function of their origin location. The potential percent of time savings is such a measure. It is defined as

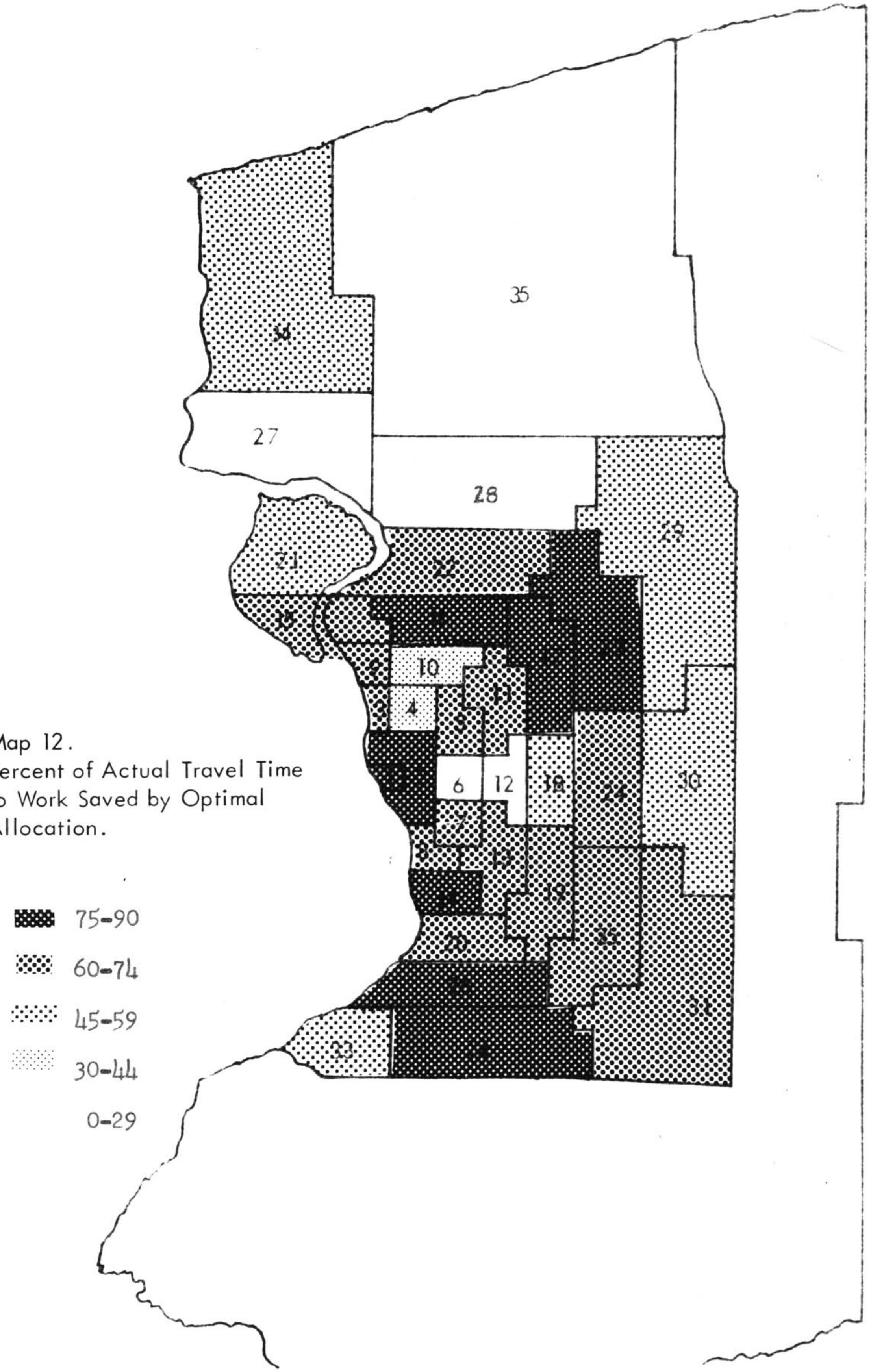
$$\frac{\text{Actual Total Travel Time Units} - \text{Minimum Total Travel Time Units}}{\text{Actual Total Travel Time Units}} \times 100$$

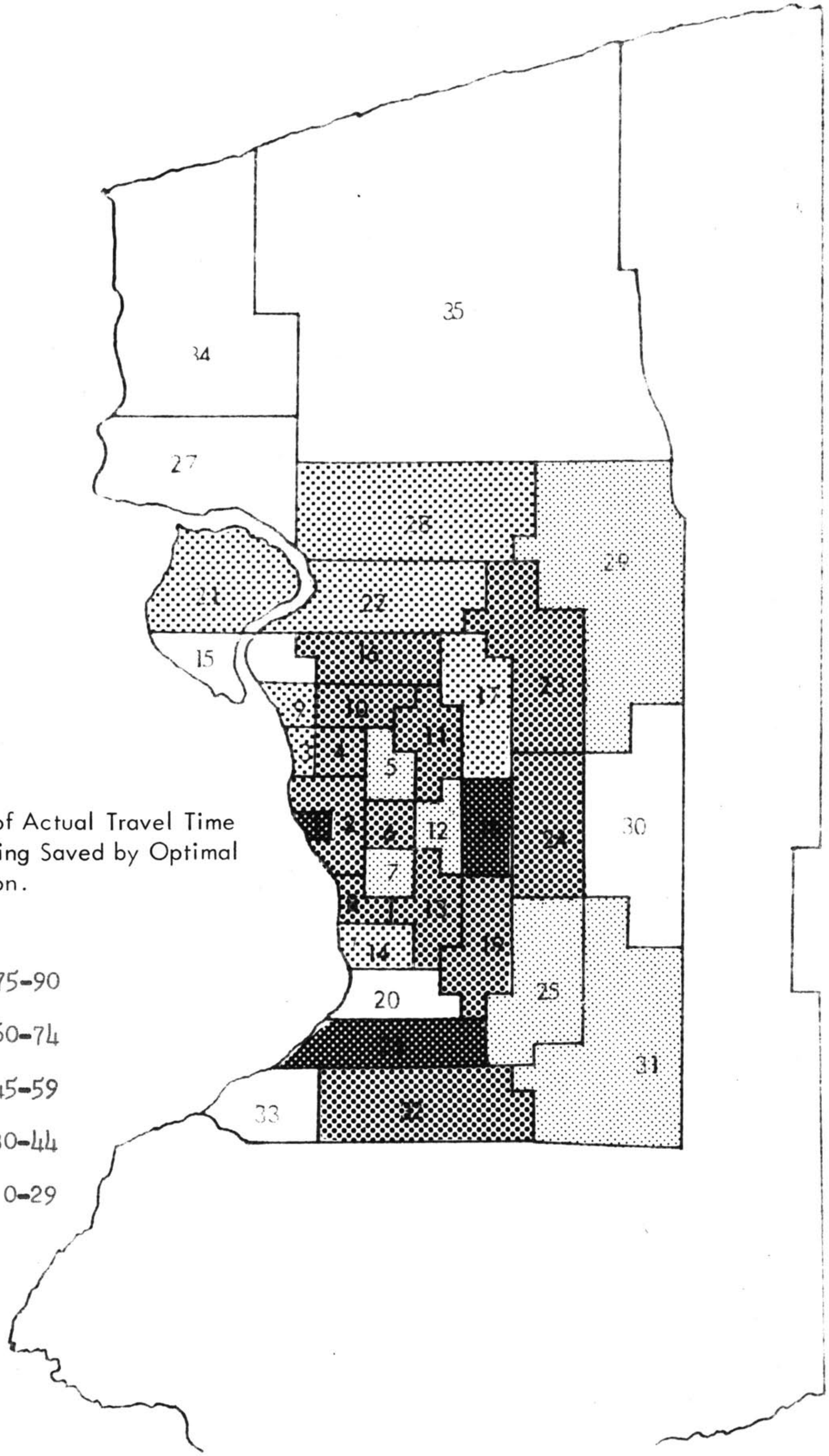
for each zone. Zones in which actual travel time is equal to that obtained through the optimal solution obviously receive no further benefits. As the minimum travel time becomes very small relative to actual travel time the potential time savings for the zone approaches 100 percent. Once again the minimum travel time from a zone is based on the optimal allocation solution to the linear programming formulation of the zonal interchange problem. The set of linkages selected is such that aggregate travel time is minimized for the system as a whole.

Maps 12, 13, and 14 show the zonal distribution of potential time savings for work, shopping, and social-recreation trips respectively. A familiar conclusion of the previous analysis both of travel time and spatial structure is immediately apparent. Except for zones 27, 34, and 35 there is little similarity in pattern among the three types of activity mapped. The distribution of benefits is different for each activity both in terms of the distribution of values among zones and in the time savings value of particular zones. Zones 27, 34, and 35 at the top of the map are low benefit zones in all cases. This means that their current travel behavior is quite close to the minimum available to them. Thus their actual linkage pattern should be similar to the optimal linkage pattern. We have already seen that this is so. These zones are strongly connected to each other by actual linkages and weakly connected with the rest of the metropolitan region. The optimal linkage pattern joins these zones together and separates them from the remainder of the region. Thus these zones comprise a well-organized region within the metropolitan area.

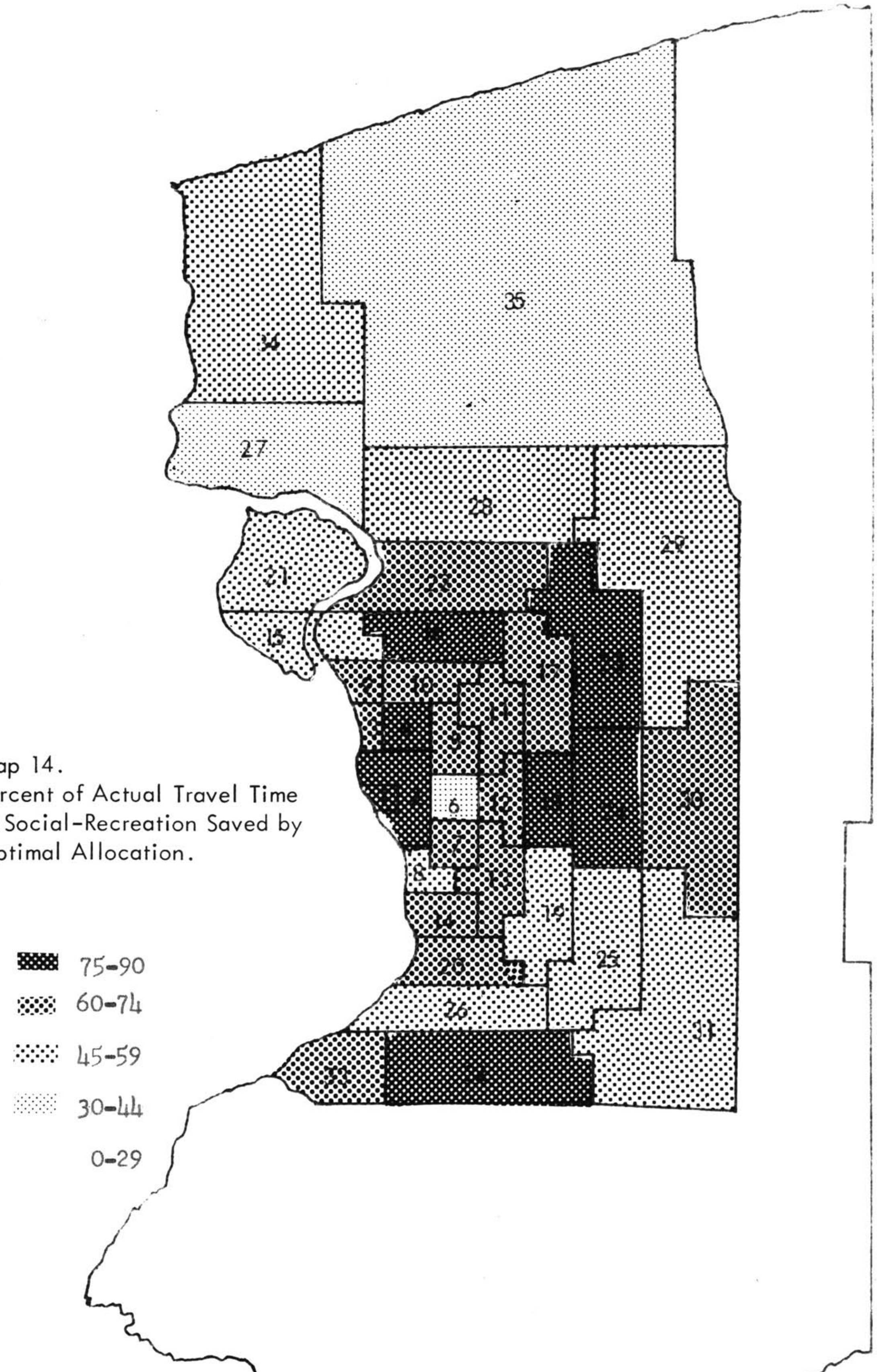
The lack of any additional subregions which serve to organize all three activities in other parts of the metropolitan region is evidenced by the considerable

Map 12.
Percent of Actual Travel Time to Work Saved by Optimal Allocation.





Map 13.
Percent of Actual Travel Time to Shopping Saved by Optimal Allocation.



Map 14.
Percent of Actual Travel Time to Social-Recreation Saved by Optimal Allocation.

variation in potential time savings of the remaining zones.

Turning now to the question of the variation in travel time conservation by zone of origin we note that a small pocket of zones in the geographic center of the lower half of the map and the outer, east tier of zones show the most consistent conservation of travel time. Trips originating from these zones actually require, on the average, less than 50 percent more time than required by the minimal allocation.

The principal offending zones -- those with high potential, savings, or "irrational" travel -- are the Buffalo CBD, zones 26 and 32 on the south, and a group of zones northeast of the CBD centering on zone 17. In all cases the large middle ground of the metropolitan area shows the opportunity for significant time savings while the periphery shows less on the average.

It is clear from these maps that in addition to differences in the benefits to each zone there are significant differences in the range and amount of time savings by activity type. This can be seen in Figure 7 which plots actual values of time savings per person trip available to zones. The distribution of potential time savings for social-recreation is most peaked. This means that the time savings available through travel minimization is most uniformly distributed for social-recreation activity. In fact 27 out of the 35 zones have potential time savings between 35 and 50 travel time units (or 7 to 10 minutes) per person trip. The distribution of potential time savings for shopping travel is less peaked and the average savings is less. In contrast the time savings available to work travel is very irregularly distributed with respect to frequency of occurrence and time savings per trip.

Dual of the Travel Minimization Problem

The degree to which persons making trips do so in accord with the rational

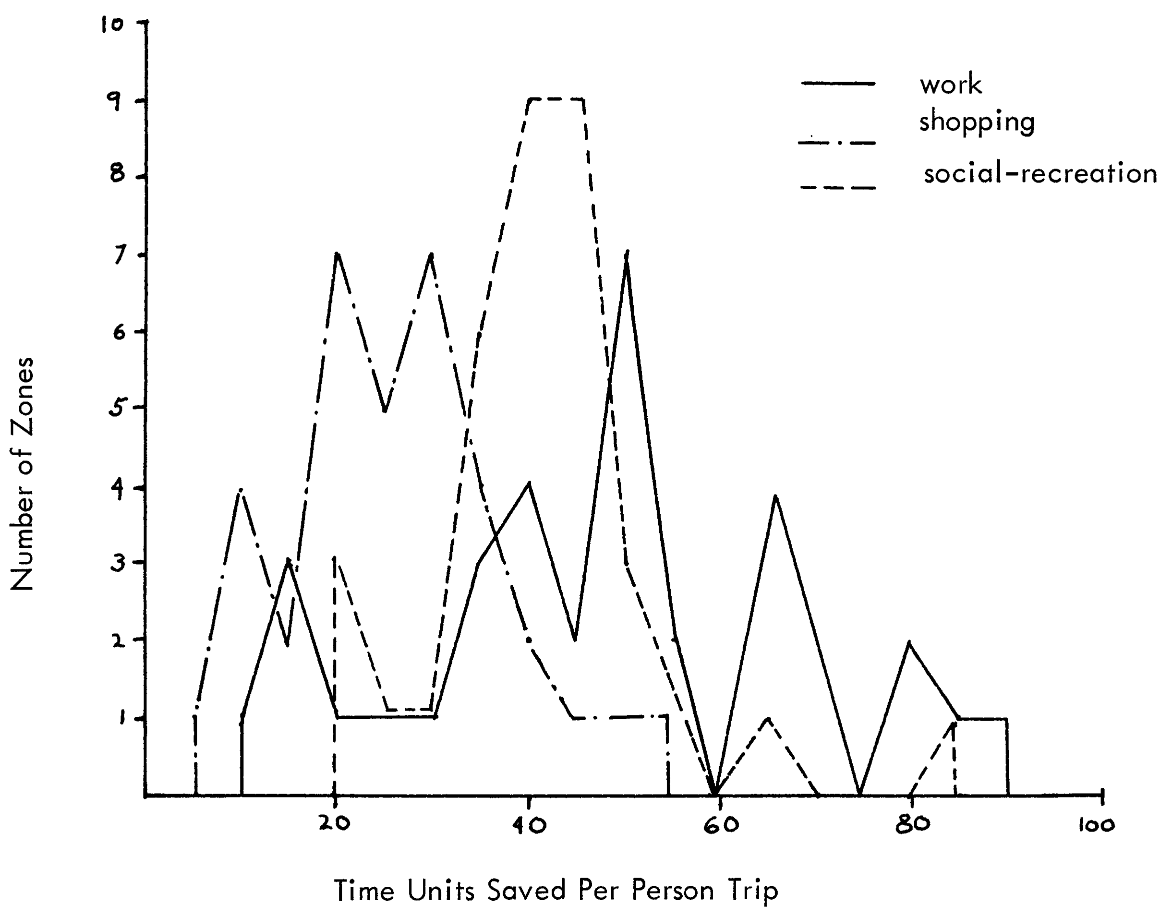


Fig. 7. Distribution of Time Savings from Optimal Allocation of Trips by Trip Purpose.

travel allocation of the linear programming criterion varies considerably with the location at which the trips originate. The distribution of potential time savings shows which locations benefit most from an optimal allocation of all trips.

Locational advantage of a zone relative to other zones is a function of the transportation system and the distribution of opportunities. Opportunities are defined as the trip destinations for a given activity. A zone has a locational advantage over other zones if persons making trips from that zone for a particular purpose are able to accomplish that purpose (select a suitable destination) at less travel cost than are persons making similar trips from other zones. The dual problem of the linear programming allocation of all trips provides a measure of comparative locational advantage of zones. First we will formulate the dual problem and then discuss its meaning.

The dual problem of a linear programming problem is in a very general sense the obverse of the original problem.[1] So the dual of our minimizing problem is a maximizing problem. The coefficients of the original problem (travel time in our case) become the constraints of the dual problem, and the original constraints (origin and destination capacities in our case) become the coefficients of the dual problem. These are defined as:

s_i = trips sent from zone i

r_j = trips received at zone j

c_{ij} = travel time units from zone i to zone j

The variables of the dual problem are u_i and v_j. The formal statement of the dual of our original problem then is:

$$\sum r_j v_j - \sum_i s_i u_i = \text{maximum}$$

where the constraints are:

$$v_j - u_i \leq c_{ij} \qquad i = 1 \ldots 35; \; j = 1 \ldots 35$$

$$u_i, v_j \geq 0$$

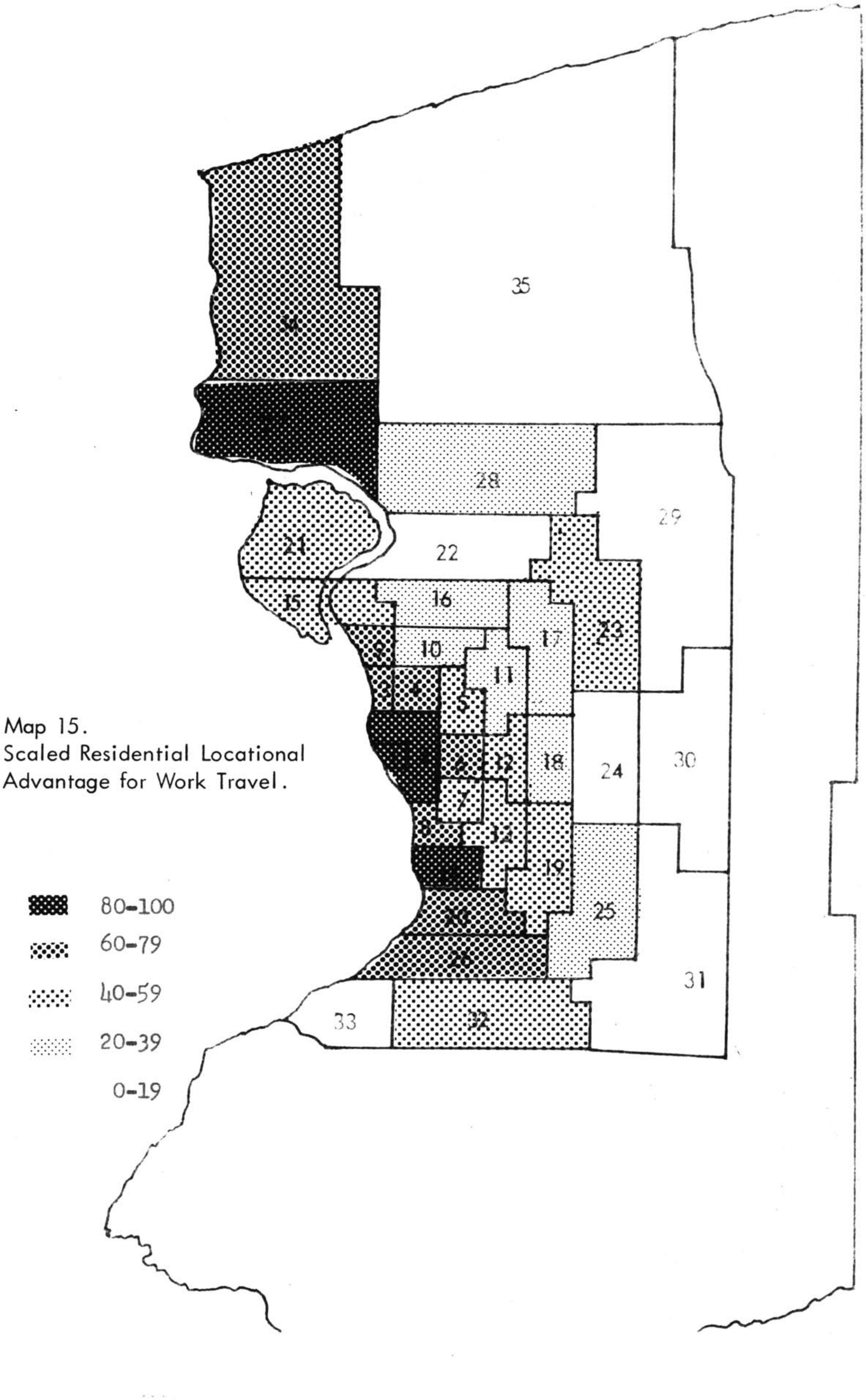
The usual meaning of the variables of the dual of a transportation problem is that they represent the price or imputed value of the item shipped. The function being maximized is the excess of total value at the destination over the total value at the origin. The constraints require that the difference between the value at a given destination zone and the value at a given origin zone be no greater than the cost of transportation between those zones. In the solution to the problem the differences in value will equal the transportation cost for linkages which are included in the optimal allocation. The difference in value will be less than transportation costs for linkages not included in the optimal allocation. The values at the origin are interpreted as a measure of the comparative locational advantage of the origin zones. The value at the destination are equivalent to competitive equilibrium prices of the item being transported.[2]

In our case the item being transported, or rather transporting itself, is people going about their daily business and selecting destinations in which to accomplish it. In our problem the value of u_i is the rental value of location in zone i as an origin point for trips to a particular activity. And v_j is the value to the trip maker of the activity in zone j. The values are measured in travel time units since these are the cost data of the original problem. However these values could be expressed in other terms, such as dollars, if the cost data of the original problem were so expressed. The rental value of a site is a measure of its attractiveness as a location point. A high rental value means that the zone has a relatively advantageous location. The value to the trip maker of the activity at a particular destination is the sum of his rental cost at the origin plus his transportation cost to the destination.

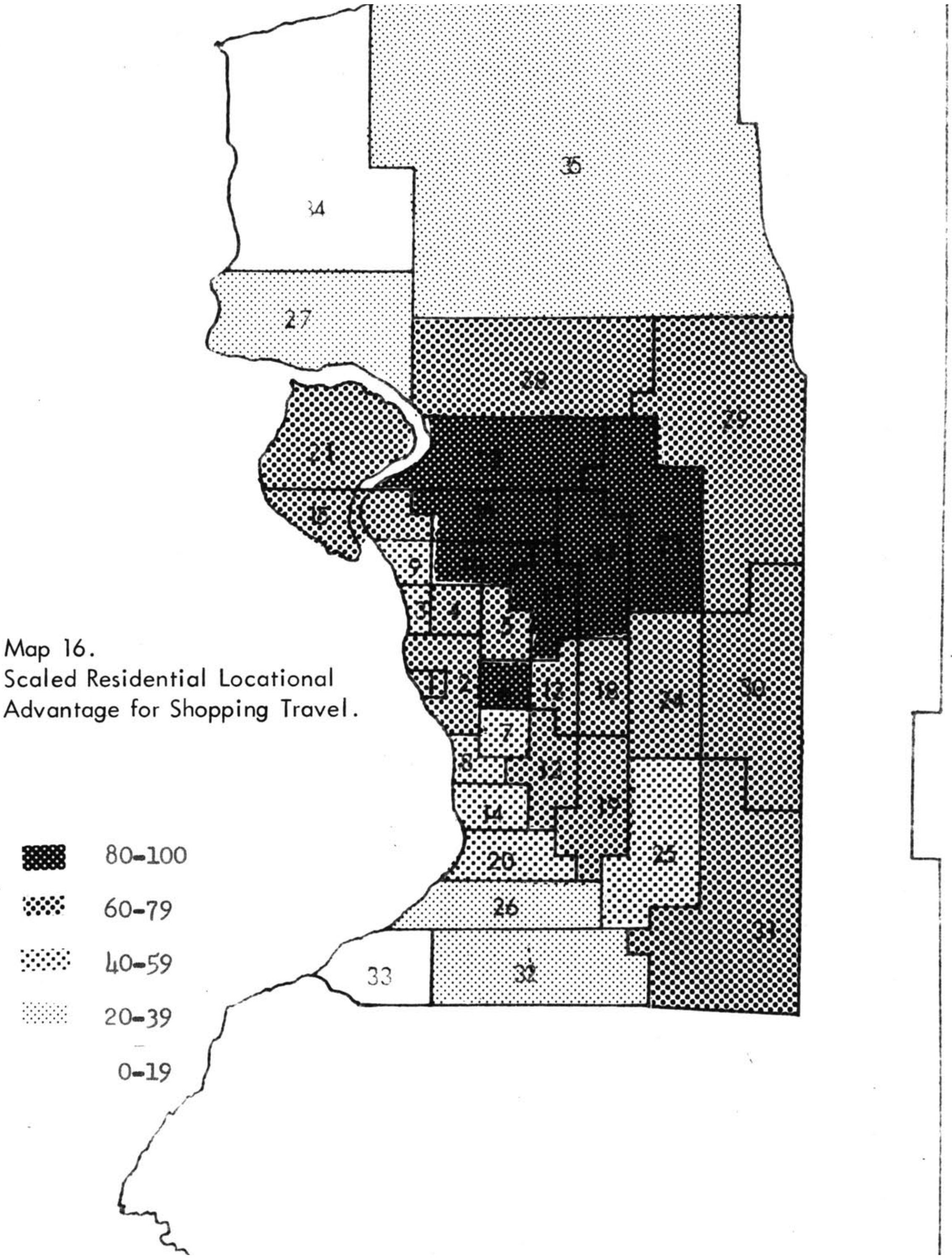
We must remember that the selection of linkages in the solution to the original problem and the values assigned to the zones in the dual are based on the minimization of total travel time in the system. The values assigned to the origin zones in the solution to the dual problem, then, measure the comparative locational advantage of the zones when persons in the region select linkages so that total travel time is conserved.

Comparative Locational Advantage

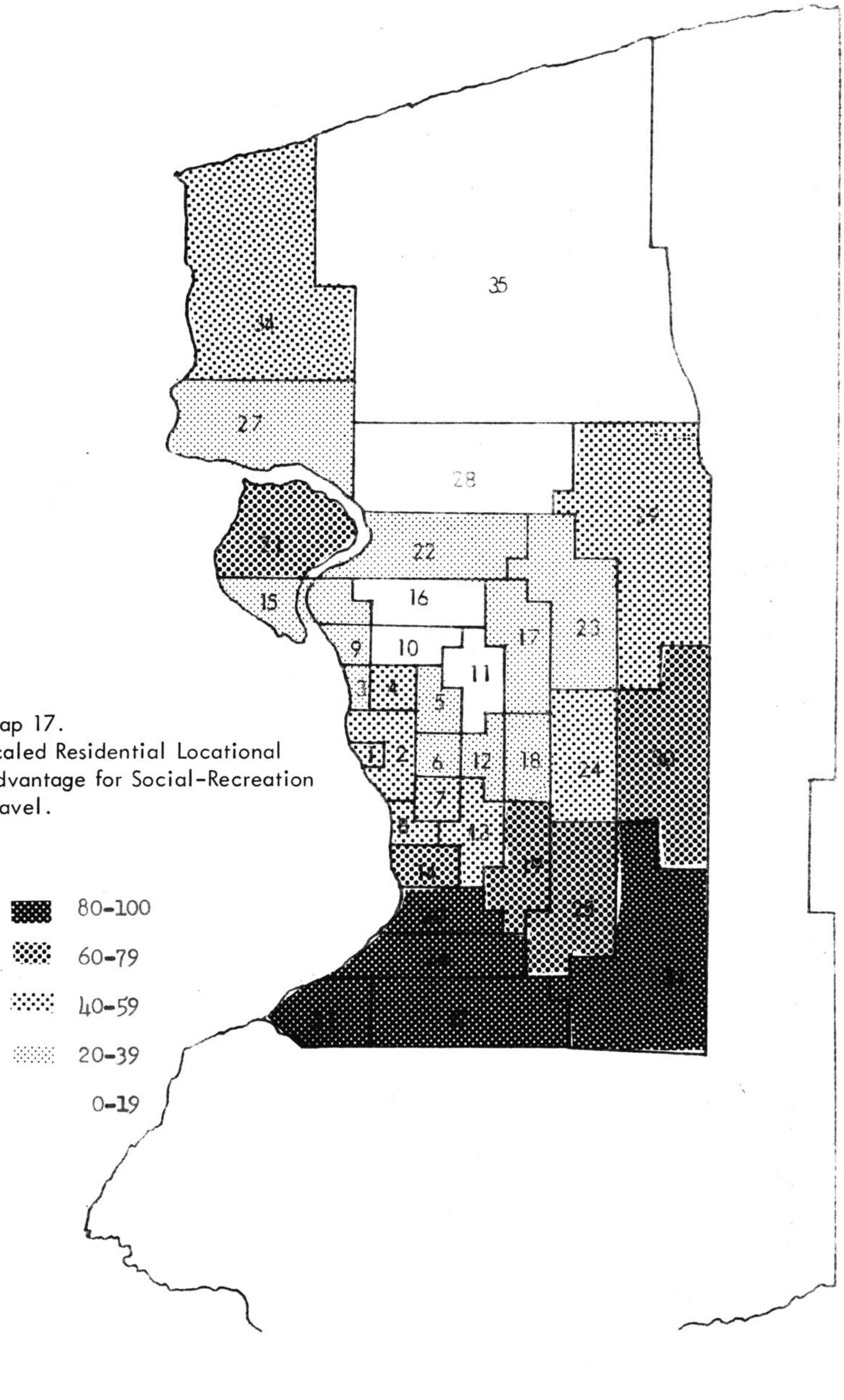
We turn now to an examination of comparative locational advantage of zones as "residence sites" based on the solution to the dual of our original travel minimization problem. The values assigned to the origin zones varies considerably with trip purpose. The values for work trips range from a maximum of 125 (travel time units) to zero; for shopping trips from 175 to zero; and for social-recreation trips from 159 to zero. To make the zonal advantage for different trip purposes comparable the u_i values were scaled to an index from 100 to zero. In each case the highest zone value was indexed at 100 and all others were reduced proportionately. An index value of 100 equals maximum comparative advantage. Maps 15, 16, and 17 show the distribution of scaled values of comparative advantage for each zone for work linkages, shopping linkages, and social-recreation linkages respectively.



Map 15.
Scaled Residential Locational
Advantage for Work Travel.



Map 16.
Scaled Residential Locational
Advantage for Shopping Travel.



Map 17.
Scaled Residential Locational Advantage for Social-Recreation Travel.

A high index value of comparative locational advantage is interpreted to mean that the zone is a relatively advantageous position for a person to base himself. There he has an advantage over others in selecting among the activity defined opportunities of the region.

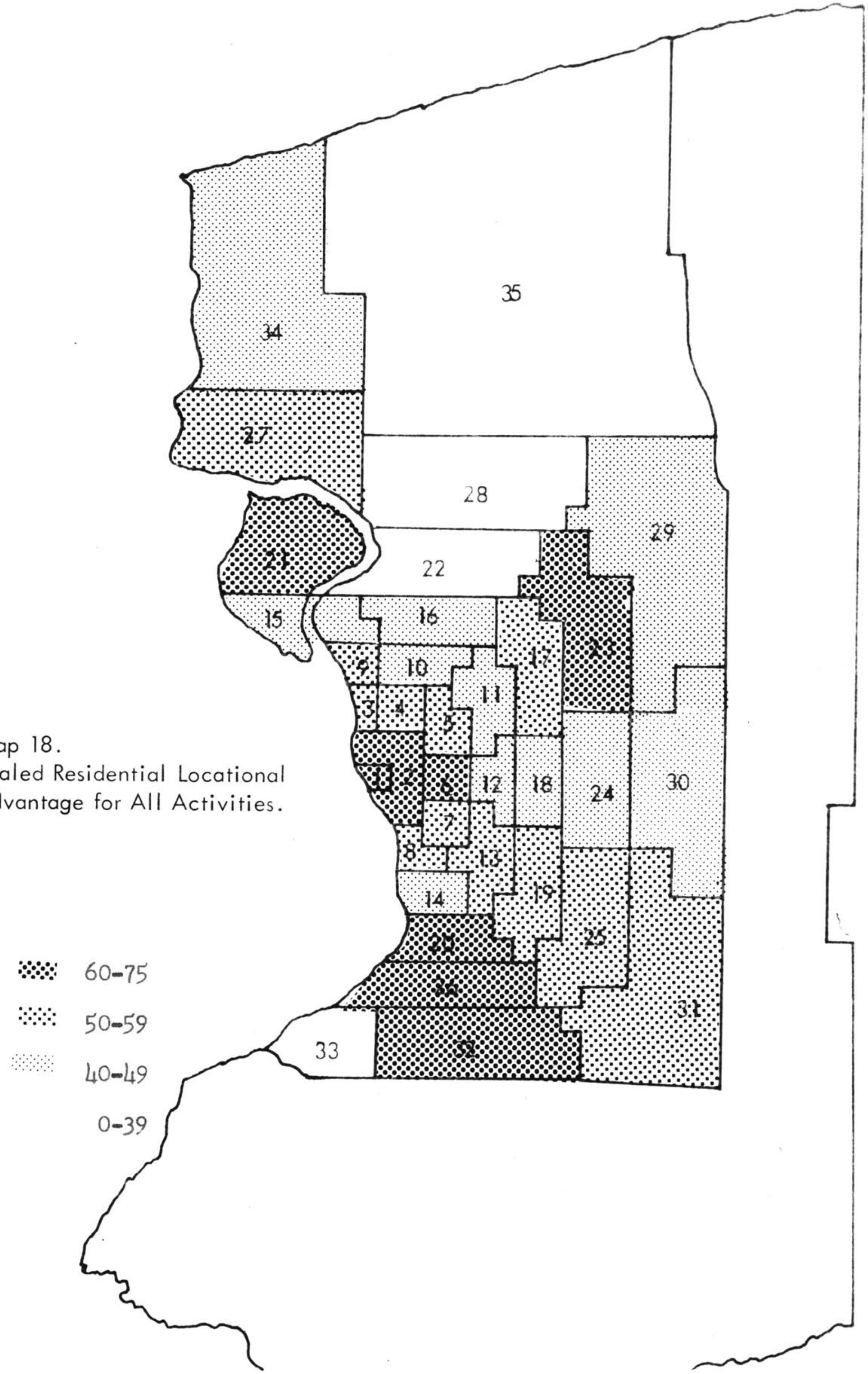
Once again the patterns are quite different for the three types of activity. A zone which has the highest ranked locational advantage for one activity is never the highest ranked for either of the other activities. Quite simply, comparative locational advantage varies with the activity considered since it is a function of the distribution of those activities as well as a function of the transportation system. Nor does any zone, whether advantageously or disadvantageously located, have the same relative rank for all activities.

The zones of greatest comparative advantage are quite tightly clustered in all cases. For work trip purpose they are strung along the lakeshore on the western edge of the region. For shopping they are clumped in the geographic center of the region. And for social-recreation they are spread across the bottom of the region. Differences in the distribution of values of comparative locational advantage are also apparent. A large number of zones have relatively advantageous positions for shopping and a large number of zones have relatively disadvantageous positions for the journey to work. This simply demonstrates that the distribution of potential shopping locations is widespread while the spatial distribution of work locations is relatively concentrated. Thus it is, in effect, difficult to be in a disadvantageous location for shopping. Put differently, this suggests that if the journey to work and the availability of shopping facilities were equally weighted in selecting a base location the appropriate strategy would be to place primary emphasis on selecting a desirable journey to work location.

In putting these separate maps together into a compositive picture of locational advantage it would be necessary to weight the three activities in terms of their relative importance. Since there is no factual basis on which to do this we will weight the activities equally as an example of a composite map. Map 18 results from summing and averaging the individual index values. Four areas stand out -- the Buffalo CBD, the island northwest of the CBD, zone 23 to the northeast, and zones 20, 26 and 32 to the south. Next in significance is the band of zones running diagonally through the region from the northwest to southeast. Perhaps the most striking feature of this measure of multiple-activity locational advantage is the strength of the CBD and its immediate surroundings as a base (or residential) location. The other high advantage locations are distributed uniformly about the CBD.

As we have seen the values assigned in the dual solution to origin zones can be interpreted as a measure of comparative locational advantage. Now we must ask whether we can give a useful interpretation to the values assigned to destination zones in the dual solution.

The value assigned to a destination zone in the dual problem is the value to the trip maker of activity in the destination zone. For linkages selected in the optimal allocation the destination zone value equals the rental cost to the trip maker of his location in the origin zone plus his transportation cost to the destination zone. The rental value of a zone as an origin point for trips is an imputed value. It is a rental which the trip maker would be willing to pay because of the benefits of location in that zone. We can interpret the values assigned to the



Map 18.
Scaled Residential Locational
Advantage for All Activities.

destination zones as imputed prices. They are the price the trip maker would be willing to pay for participating in a given activity in a particular zone. We can interpret this as the value of the activity at its location in the destination zone.

In the usual transportation problem the origin zones and the destination zones are unique. A single zone is not both a sender and receiver. In our case, when all trips are considered, all zones are both senders and receivers. And a single zone may ship to itself since self-linkages are permitted. Thus the variables of the dual problem describe the relative position of a zone in alternate roles -- as sender and as receiver.

When self-linkage exists, zones which have a comparative locational advantage as a residence site are also an advantageous place for the conduct of the given activity. The self-linkage transportation costs of a zone will always be less than the cost of linking the zone with any other zone, or of any other zone linking with it. Then if u_i is large, v_j must also be large, and if u_i is small, v_j must also be small since the difference between them is small. Since there is a large amount of self-linkage in the optimal allocation of all trips the distribution of scaled zonal values of v_j for work, shopping, and social-recreation assigned to the zones as destination zones in the dual solution are a close match of the patterns showing the values of the zones as origin zones.

Conclusion

In this chapter we have introduced the measurement of comparative locational advantage of zones in the urban area. A zone has a locational advantage if, under the conditions of rational travel in a linear programming allocation of all trips, all person trips from a zone for a particular purpose are made at less total travel cost than are all similar trips from other zones. Comparative locational advantage as measured by the dual of the travel minimization problem is a function of the transportation system and the distribution of opportunities. Locational advantage is calculated from the viewpoint of the zone as an originator of trips, and measures the relative advantage of a zone as a trip-making base.

The distribution of potential time savings available to zones through the optimal allocation of all trips is a measure of the incidence of non-rationality of travel behavior. Although the spatial patterns of potential time savings are different for each of the three trip purposes, there is a common thread running through them. The downtown core area of Buffalo (zones 1 and 2 on the maps) is a locus of large potential time savings in each case. After this the area containing the next largest potential time savings is the suburban ring outside the built-up area. The inner ring between the core area and the suburbs, and the fringe area have relatively low potential time savings. The net result is like a series of waves of decreasing amplitude outward from the center. In general, minimization of travel would bring the highest benefits to persons located at the center of the region and lowest benefits to persons located at the fringe.

In summary, potential time savings measures the behavior of trip makers, and locational advantage measures a characteristic of the distribution of activity and the transportation network taken together. When the zonal pattern of potential time savings is compared with the zonal pattern of locational advantage we have an indication of the degree to which persons utilize locational advantage. Comparing Maps 12, 13, and 14 with Maps 15, 16, and 17 it is clear that the patterns of travel rationality shown by potential time savings do not match the patterns of locational advantage. Many zones with high locational advantage are also zones which would receive large benefits from travel minimization. This is particularly true for shopping trips. Map 16 shows that locational advantage for shopping is concentrated in the geographic center of the urban area. Map 13 shows that the zones in the center would receive major benefits from travel minimization. Zones at the top and bottom of the maps would benefit least from travel minimization, and they have a relative locational disadvantage. Looking at work travel, only one zone, zone 27, of those with high locational advantage also has low potential time savings. The remainder of the high locational advantage zones have high potential time savings.

Comparison of the maps of potential time savings and locational advantage shows that persons who originate trips from zones which are locationally favored often ignore their advantage when selecting trip destinations. On the other hand persons who originate trips from zones that are at a locational disadvantage often select destinations so that their travel time approaches that required by a minimal allocation.

We offer the following hypothesis to explain this behavior. Persons making trips from zones which have high locational advantage use that advantage to select destinations freely rather than to save on travel expenditures. Because of their position they are able to select fairly widespread destinations at relatively low cost. Persons making trips from zones that are relatively disadvantaged find widespread travel to be costly, and select destinations nearby. According to this interpretation locational advantage is utilized for freedom of choice in selecting trip destinations.

Some evidence to demonstrate the possible validity of this hypothesis can be obtained by comparing the average travel time of persons making trips from zones having both high locational advantage and high potential time savings with the average travel time from zones having low locational advantage and low potential time savings. If persons utilize locational advantage to travel widely, then their actual average travel time should be no greater than the average travel time of persons making trips from zones with low locational advantage and selecting destinations so that their average travel time is close to that available from travel minimization. A plausible explanation of such behavior is that budget constraints of trip makers are such that the average amount available for transportation expenditures is about the same for all trip makers when aggregated by zone. If so, then persons who have an opportunity to save on transportation expenditures and substitute expenditures on other personal or household budget items for transportation choose instead to use up their full transportation budget.[4] The average time per trip from zones with high locational advantage and high potential time savings is 51 time units. The average time from zones with low locational advantage and low potential time savings is 62 time units. So it is clear that persons who are, in effect, ignoring their locational advantage are able to accomplish their travel at an average cost which is no greater than persons who are minimizing their travel from zones with low locational advantage. It also appears that as suggested above trip makers do choose to travel widely and make longer trips when they can do so within some average transportation budget constraints rather than shift expenditure from transportation to other personal or household budget items.

Considerable additional research is needed to validate the hypothesis that locational advantage is utilized for freedom of choice in selecting trip destinations. This research should proceed on two fronts. First activities should be disaggregated into a larger number of classes so that the varieties of shopping and social-recreation activities, and specific occupation groups are independently analyzed. This is necessary to determine whether the observations from our aggregate data are found for detailed activities. Secondly, since our analysis of aggregate data does not reflect characteristics of the trip makers -- their tastes, incomes, or personal or household characteristics -- analyses should be made of individual activity patterns to determine whether our observations can be explained in part by trip maker characteristics. Unfortunately we are not able to pursue either of these kinds of analysis at this time because we do not have data at this level of detail.

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1. We follow the exposition of the transportation problem given in Robert Dorfman, Paul A. Samuelson, and Robert M. Solow, _Linear Programming and Economic Analysis_ (New York: McGraw-Hill Book Co., Inc., 1958), Chapter 5.

2. _Ibid_, pp. 125-126.

3. This interpretation follows that applied by Dorfman, Samuelson, and Solow to an example problem dealing with international trade. See Dorfman, Samuelson, and Solow, _op. cit._, p. 127.

4. I am indebted to Professor Aaron Fleisher for this interpretation.

CHAPTER 4

STRUCTURING ACTIVITY LINKAGES

Most trips to work, to shop, and to social-recreation activities are trips from residential land to non-residential land uses because most such trips begin at the trip maker's home. Indeed most person trips in urban areas are residentially based in that either the origin or destination of the trip is the home of the trip maker. Recent home interview surveys have shown that 87 percent of all person trips in the Chicago area are home based, as are 80 percent in the Philadelphia area, 84 percent in the Baltimore area, and 76 percent in the Boston area.[1] Both the origin and destination of the remaining trips is other than the home of the trip maker. But these non-home-based trips may also be to or from residential land. A trip from a person's place of work to the home of a friend is an example of this.

We cannot estimate the proportion of trips to work, to shop, and to social-recreation activities that originate on residential land because these data are not available in the published tabulations from the origin-destination surveys. But data are available on the proportion of such trips that originate at the home of the trip maker. In the Chicago area 81 percent of all trips to work are from home, 74 percent of all trips to shopping are from home, and 73 percent of all trips to social-recreation activities are from home.[2] The comparable figures for the Pittsburgh area are 76 percent, 80 percent, and 80 percent, respectively.[3] And for Boston they are 65 percent, 56 percent, and 74 percent, respectively.[4]

As these figures indicate, our analysis of trips to work, to shop, and to social-recreation activities in Chapter 1 is also an analysis of trips from the trip maker's home to non-residential land uses. In that analysis we showed that the principal linkages were essentially optimal in that they required about the same amount of travel as an optimal allocation would require; and we showed that these linkages accounted for a sizeable percentage of all such trips. The question now arises, what proportion of trips from home are accounted for by these three purposes?

In the Chicago area 69 percent of all person trips from home are to work, to shop, and to social-recreation activities.[5] In Pittsburgh the comparable proportion is 66 percent, and in Boston the comparable proportion is 61 percent.[6] Since these proportions have proven to be fairly constant in all comparable inventories of person travel in urban areas we can reasonably conclude that our analysis of activity linkages in the Buffalo area accounts for about two-thirds of all trips from home. Since there is almost perfect symmetry of the number of person trips for a particular purpose at the destination of the trip with the number of trips from an origin at which that purpose was the activity carried on, we can also argue that the analysis accounts for about two-thirds of all linkages to and from home.[7]

Since trips between work, shop, and social-recreation activities and home account for about two-thirds of home-based trips, and home-based trips are usually from about 75 to 85 percent of all person trips within a metropolitan area, trips between work, shop, and social-recreation activities and home account for slightly more than half of all person trips. In fact trips to these three activities from home and return account for 61 percent of all trips in the Chicago area, 58 percent of all trips in the Pittsburgh area, about 53 percent of all trips in the Philadelphia area, about 50 percent of all trips in the Boston area, and about 55 percent of all trips in the Baltimore area.[8] The remaining trips are divided between other home-based trips and non-home-based trips. The proportion of these that are home-based ranges from one-third to one-half.

The evidence of symmetry of trip purpose of home-based trips -- the fact that there is an almost equal number of trips from home for a particular purpose and from that purpose to home -- suggests that most trips are elements of round trips which start and end at home. This is supported by the fact that over a 24-hour day relatively few trips are non-home based. If all trips were part of a triangular journey, that is, if each trip sequence started at home, went to some other land use, then to another, and then returned home, exactly one-third of all trips would be non-home based. In fact, only 15 to 25 percent of all trips are non-home based in the several metropolitan areas reported on above.

The general pattern of person flows is evident from data on trip purpose. Most trips are elements of single round-trip sequences or journeys which start from home for a single purpose and return to home when that purpose is accomplished. Two-thirds of these home-based trip sequences are for work, shopping, or social-recreation purposes.

Functional Linkages of Urban Activities

Now we shall examine more carefully the pattern of trip flows by trip purpose in order to establish the significance of home-based round trips versus other kinds of journeys and to examine the pattern of association among trip purposes of non-home-based trips. First, let us define a journey. A trip is defined as a one-way movement between two locations for a single purpose. A journey is a sequence of trips beginning and ending at the trip maker's home. A little reflection will show that all person trips within an urban area are parts of a journey.[9]

The tabulations of person trips which we are examining intend to account for all travel over a 24-hour day. Since people reside only at home, the first trip of the day of every person must begin at home, and the last must end at home.[10] If the person does not return home until the end of the day all his trips are parts of a single journey. Typically a person will leave home, return, leave again, return, leave, and return, and so on. If every trip made was part of a two-trip journey for a single purpose the number of journeys would be one-half the number of trips. When viewed in this way each trip can be related back to home and forward to home, and is one leg of a journey.

The fact that all trips can be linked through other trips to the home of the trip maker has important consequences for our analysis. Table 6 shows internal person trips over a day in the Chicago area to and from six selected trip purposes. It has often been noted of tabulations of this kind that there is near-perfect symmetry of the number of trips from a particular purpose with the number of trips to that purpose.[11] And so it should be. For if all journeys begin and end at home, the number of trips from home must equal the number of trips to home. And similarly the number of trips to any purpose must equal the number of trips from that purpose. If this were not so some people would never get home again at the end of the day. There are several reasons why the corresponding row and column sums are not equal. First, we are dealing with sample data. Second, coding and other errors in data manipulation do occur. And finally, some persons indeed do not go home. They

Table 6. Internal Person Trips by Trip Purpose at Origin and Trip Purpose at Destination for Selected Purposes in the Chicago Area.

(in 000's)

Trip Purpose at Origin	Trip Purpose at Destination						
	Home	Work	Shop	School	Social-Recreation	Personal Business	Total
Home	--	1,652	405	182	924	753	3,916
Work	1,581	290	28	3	27	42	1,971
Shop	432	5	55	1	23	24	540
School	159	7	1	1	5	2	175
Social-Recreation	1,042	3	17	1	160	36	1,259
Personal Business	689	26	38	1	99	145	998
Total	3,903	1,983	544	189	1,238	1,002	8,859

Source: Chicago Area Transportation Study, Survey Findings; Final Report, Vol 1 (Chicago: The Study, 1960), Table 4, p. 37.

might spend the night at a friend's home, or somewhere else. However, the model of the data is a closed system of home-based journeys, and we can consider the data in this way.

Simulation of Journeys

In order to examine the composition of journeys and the association among trip purposes we need to simulate actual journeys over a typical day. The key to simulating journeys is the coefficient of linkage of trips from one purpose of activity to another. The linkage coefficient is simply the ratio of person trips from an origin trip purpose to another trip purpose to the total trips from the origin purpose. In a matrix table such as Table 6 the linkage coefficient of any cell is found by dividing the person trips in that cell by the sum of the row in which it lies. The ratio is expressed as

$$LC_{ij} = \frac{X_{ij}}{\sum_{k=1}^{n} X_{ik}}$$

where: X_{ij} = trips from purpose i to purpose j

$\sum_{k=1}^{n} X_{ik}$ = all trips from purpose i

The matrix of linkage coefficients is a stochastic matrix since each row sums to one and is composed of non-negative elements. And the linkage coefficient can be interpreted as a measure of the probability of a trip from a given purpose being destined to a particular purpose or activity. An example will clarify the procedure. In Table 6, we see that 1,581,000 of all the person trips from work are to the home of the trip maker, and 42,000 of all the person trips from work are to personal business. When each of these is divided by the total 1,971,000 trips from work we see that 80 percent of person trips from work are destined to the trip maker's home and 2 percent are destined to personal business activity. Or, in probability terms, 80 out of 100 times a person trip from work will be destined to the trip maker's home, and 2 out of 100 times a person trip from work will be destined to personal business when all trips are considered.

In our analysis of activity linkages we will examine the person trip patterns among trip purposes in both Chicago and Pittsburgh. Unfortunately, similar data for the Buffalo area were not available for this analysis. Table 7 gives the person trip data for the Pittsburgh area. Tables 8 and 9 give the computed linkage coefficients for the Chicago and Pittsburgh data, respectively.

Using the linkage coefficients we can estimate the number of each type of journey made by trip makers in the two urban areas. First, we will restate the definition of journeys used here. A journey is a sequence of trips starting from the trip maker's home and ending at the trip maker's home. The first trip of the sequence starts at home and the last trip of the sequence ends at home. It is assumed that since all the trips represented by the data were made during a single weekday and since all trip makers were in the cordon area during the entire day, the first trip of each trip maker began at home and the last ended at home. Thus every trip is part of a journey and every journey is a circular sequence of trips from and to home.

The simplest journey consists of two trips -- from home to some activity,

Table 7. Internal Person Trips by Trip Purpose at Origin and Trip Purpose at Destination for Selected Purposes in the Pittsburgh Area.

(in 000's)

Trip Purpose at Origin	Trip Purpose at Destination						
	Home	Work	Shop	School	Social-Recreation	Personal Business	Total
Home	--	366	136	121	125	199	947
Work	350	70	9	1	5	12	447
Shop	148	2	18	0	8	9	185
School	107	1	1	1	3	3	116
Social-Recreation	138	1	7	0	20	6	172
Personal Business	195	8	15	1	10	37	266
Total	938	448	186	124	171	266	2,133

Source: Pittsburgh Area Transportation Study, Final Report, Vol. 1 (Pittsburgh: The Study, 1959), Table 30, p. 92.

Table 8. Linkage Coefficients for Trip Purposes of Person Trips in the Chicago Area.

Trip Purpose at Origin	Trip Purpose at Destination						
	Home	Work	Shop	School	Social-Recreation	Personal Business	Total
Home	--	.422	.103	.047	.236	.192	1.000
Work	.802	.147	.014	.002	.014	.021	1.000
Shop	.800	.009	.102	.002	.043	.044	1.000
School	.908	.040	.006	.006	.029	.011	1.000
Social-Recreation	.828	.002	.013	.001	.127	.029	1.000
Personal Business	.690	.026	.038	.001	.099	.146	1.000

Table 9. Linkage Coefficients for Trip Purposes of Person Trips in the Pittsburgh Area.

Trip Purpose at Origin	Trip Purpose at Destination						
	Home	Work	Shop	School	Social-Recreation	Personal Business	Total
Home	--	.386	.144	.128	.132	.210	1.000
Work	.783	.157	.020	.011	.027	.002	1.000
Shop	.800	.011	.097	.000	.043	.049	1.000
School	.921	.009	.009	.009	.026	.026	1.000
Social-Recreation	.802	.006	.041	.000	.116	.035	1.000
Personal Business	.733	.030	.056	.004	.038	.139	1.000

and from that activity to home. A three-trip, or three-leg journey consists of a trip from home to an activity, a trip from that activity to another activity (or the same activity at another location), and a trip from the second activity to home. A four-trip journey contains two trips between non-home activities; a five-trip journey contains three trips between non-home activities; and so forth.

Since every journey starts from home, there obviously can be no more journeys than there are trips from home. Looking at Tables 6 and 7 it is also obvious that the data are imperfect and thus our attempts to estimate the pattern of person journeys will be imperfect. To clarify this point, remember that all journeys must begin and end at home. Therefore, there should be the same number of trips to home and from home. Similarly, every column sum should be equal to the corresponding row sum. The corresponding row and column sums are not equal in the reported data, but the differences are small. There is, for example, less than one percent difference in the total trips to and from home in both Chicago and Pittsburgh. The differences in the reported data probably occur from incomplete trip reports in some home interviews and errors in coding and manipulation of the sample data. These errors are probably magnified in the factoring of the sample data to represent the universe of all person trips.

Method of Calculating Journeys

To calculate an estimate of the number and type of multiple trip journeys we treat our matrix of linkage coefficients as an absorbing Markov chain. Markov chains consist of states and steps, or transitions, between states. The Markov chain process has been aptly described in terms of a frog jumping from one to another of a group of lily pads.[12] Each of the lily pads can be considered a state, and the steps are the frog's jumps from one lily pad to another. The probability that the frog will land on any of the lily pads when jumping from the lily pad he currently occupies is described by transition probabilities. These probabilities depend only on which lily pad the frog is occupying before he makes the jump.

The frog moving from one lily pad to another is comparable to the urban resident journeying from one activity to another. The activities are states and the transition probabilities of moving from a particular activity to another are given by the linkage coefficients.

"A Markov chain is absorbing if (1) it has at least one absorbing state, and (2) from every state it is possible to go to an absorbing state (not necessarily in one step)."[13] An absorbing state is one which once entered cannot be left. It terminates the process. In our case there is one absorbing state -- home. When a journey reaches home it is ended. There is also only one starting state -- also home. Each journey must start at home.

A major assumption of the Markov chain process is that each step, the probability that the process moves from a given state to another, depends only on the state that it occupies before the step is made. For urban journeys this assumption means, for example, that the probability of a person going from shopping to social-recreation activity is the same for a person who had come to shopping from work as for a person who had come to shopping from home.[14]

To set up our problem as an absorbing chain, it is convenient to think of "home" as two states -- leaving home and returning home. Then the matrix of linkage coefficients can be rearranged in the standard form of an absorbing Markov chain as follows:

$$
\begin{array}{c|c}
\text{Trip Purpose at Origin} & \text{Trip Purpose at Destination} \\
\end{array}
$$

$$
\begin{array}{c}
 \\ RH \\ LH \\ W \\ S \\ Sc \\ SR \\ PB
\end{array}
\begin{array}{c}
\begin{array}{ccccccc} RH & LH & W & S & Sc & SR & PB \end{array} \\
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & X & X & X & X & X \\
X & 0 & X & X & X & X & X \\
X & 0 & X & X & X & X & X \\
X & 0 & X & X & X & X & X \\
X & 0 & X & X & X & X & X \\
X & 0 & X & X & X & X & X
\end{bmatrix}
\end{array}
\begin{array}{c}
\Sigma \\ 1.0 \\ 1.0 \\ 1.0 \\ 1.0 \\ 1.0 \\ 1.0 \\ 1.0
\end{array}
$$

where RH = return home
LH = leave home
W = work
S = shop
Sc = school
SR = social-recreation
PB = personal business
X indicates a linkage coefficient with a value less than 1.

We are now in a position to estimate journeys. We can redefine journeys in terms of the Markov chain. The probability of two-trip journey is the probability of being in state RH (return home) after two steps (trips) given that all journeys must start in state LH (leave home). This probability is determined by adding the weights of each way of being in state RH after two trips. The possible ways of being in state RH after two trips are:

Trip 1 +	Trip 2
(LH-W)	(W-RH)
(LH-S)	(S-RH)
(LH-Sc)	(Sc-RH)
(LH-SR)	(SR-RH)
(LH-PB)	(PB-RH)

If we define pr(LH-W) (W-RH) as the probability of a journey from LH to W and from W to RH then the probability of being in state RH after two trips is:

$$pr(LH-W)\ (W-RH) + pr(LH-S)\ (S-RH) + pr(LH-Sc)\ (Sc-RH) + pr(LH-SR)\ (SR-RH) + pr(LH-PB)\ (PB-RH).$$

For Chicago this expression is calculated by multiplying and adding the linkage coefficients for each of the trips as follows:

$$(.422)\ (.802) + (.103)\ (.800) + (.047)\ (.908) + (.236)\ (.828) + (.192)\ (.690) = .791$$

This result is interpreted to mean that, starting from home, the probability of returning home at the end of two trips is 0.791. In order to determine the number of such journeys we multiply the total trips leaving home (3,916 in 000's) by the probability of returning home at the end of two trips.

(3,916) (0.791) = 3,098 two-trip journeys

The total number of trips involved in two-trip journeys is, of course, 6,196.

These calculations provide answers to the question, what is the probable number of journeys of each journey type -- two-trip, three-trip, etc.? In order to answer our second question, what is the composition of the journeys of each type, we evaluate each of the terms in the above expression of the probability of two-trip journeys. For example, the probability of a two-trip journey in which the intermediate destination is work is:

pr(LH-W) (W-RH) = (.422) (.802) = .338,

and the probable number of such journeys is:

(3,916) (.338) = 1,323.

This procedure of estimating journeys will not result in an estimate of a total number of journeys which is larger than the number of journeys imbedded in the data as specified by the number of trips from home. Each trip from home is the start of a journey, and each such journey must after some finite number of steps return home where it ends. The mechanics of ending the journey consists of placing the traveller in a loop in which he goes endlessly from and to the state -- return home. This occurs because the probability of going from return home to return home is 1.0. Since this probability is 1.0, it does not affect the probability of the total journey which it concludes, and it does not generate excess trips.

It is also important to note that we do not claim that the linkage coefficients and the method are useful for estimating what the pattern of journeys would be if a larger number of journeys were made on a typical day. The method is not suitable for predicting journey patterns in the case of assumed growth in population and daily trips over time. This is because the linkage coefficients are based only on observed travel behavior at one point in time and at one place and there is no reason to believe that these coefficients would be constant over time or with change in the total number of trips made.

One other feature of the Markov chain process will be useful in our analysis. The matrix called the <u>fundamental matrix</u> for a given absorbing chain provides information on the mean number of times the process (the urban journey in our case) will be in each of the non-absorbing states and on the average number of trips which will be completed before the traveller returns home. The fundamental matrix is the inverse of the identity matrix minus the sub-matrix (of our original matrix) containing only non-absorbing states.[15] Referring back to our original matrix, this sub-matrix contains all rows and columns except that headed Return Home -- the only absorbing state.

Journeys in Chicago and Pittsburgh

The pattern of journeys in Chicago and Pittsburgh is nearly identical. The probability of returning home after a specified number of trips is given in the column headed Journey Probability Factor in Tables 10 and 11 for Chicago and Pittsburgh. These factors were calculated by the method outlined above. There are no journeys of more than six trips in Pittsburgh or more than seven in Chicago. That is, the probable number of such journeys is less than 0.5. This is determined by calculating the probability factor of a seven-trip journey in Pittsburgh (an eight-trip journey in Chicago) and multiplying this factor times the total number of trips originating at home.

The journey probability factor can be interpreted as the percentage of journeys in each category of trips per journey. In Chicago and Pittsburgh the probable percentage of journeys among the categories is nearly identical -- about 79 percent are two-trip journeys; 16 percent are three-trip journeys; 3.5 percent are four-trip journeys; about 0.7 percent are five-trip journeys; and about 0.2 percent are six-trip journeys. The probable number of journeys of each category is found by multiplying the journey probability factor by the number of trips from home. The estimated number of journeys is given in the third column of Tables 10 and 11. In

Table 10. Multiple-Trip Journeys in Chicago.

Trips per Journey	Journey Probability Factor	No. of Journeys (in 000's)	No. of Trips (in 000's)
2	0.79100	3,098	6,196
3	0.16300	638	1,914
4	0.03500	137	548
5	0.00770	30	150
6	0.00170	7	42
7	0.00036	1	7
Sum	0.99876	3,911	8,857

Table 11. Multiple-Trip Journeys in Pittsburgh.

Trips per Journey	Journey Probability Factor	No. of Journeys (in 000's)	No. of Trips (in 000's)
2	0.7950	753	1,506
3	0.1600	151	453
4	0.0350	33	132
5	0.0073	7	35
6	0.0016	2	12
Sum	0.9989	946	2,138

both cases, there is a slight underestimate of the number of journeys due to rounding. The estimated number of trips is given in the fourth column. In both cases there is a slight overestimate of trips and again this is due to rounding.

The similarity of the percentage distribution of two-, three-, four-, five-, and six-trip journeys in Chicago and Pittsburgh suggests that the journey-making behavior of residents of at least large urban areas may be independent of the size and character of the urban areas. The Chicago urban area contains, of course, more population than the Pittsburgh area. There are four times more trips on the average day in Chicago than in Pittsburgh. Chicago is physically larger than Pittsburgh and is spread across a flat plain. Pittsburgh is built over hills and valleys. So there is no physical similarity in the two urban areas which might account for the similarity in what we call the journey-making behavior of the residents of the two areas.

This suggestion is a simple extension of observations of trip-making behavior of persons in urban areas. As we discussed in Chapter 1 there are many more short trips than long trips on an average day in an urban area, and the relative proportion of short and long trips is similar for all urban areas. It also appears that there are many more short journeys than long, where length is defined in terms of the number of trips in a journey. And it appears from our very limited analysis of journeys that the relative proportions of short and long journeys is similar for different urban areas.

Although two-trip journeys are the same percent of total journeys in Chicago and Pittsburgh the composition of these journeys differs in the two areas. As Table 12 shows, 43 percent of the two-trip journeys in Chicago are to and from work, compared to 38 percent in Pittsburgh. And 25 percent of two-trip journeys in Chicago are to and from social-recreation activities, compared to only 13 percent in Pittsburgh.

Table 12. Two-Trip Journeys in Chicago and Pittsburgh.

First Trip Purpose at Destination	Chicago No. of Two-Trip Journeys	Chicago Percent	Pittsburgh No. of Two-Trip Journeys	Pittsburgh Percent
Work	1,324	42.7	286	38.1
Shop	321	10.5	109	14.5
School	168	5.3	112	14.7
Social-Recreation	764	24.7	100	13.3
Personal Business	521	16.8	146	19.4
Total	3,098	100.0	753	100.0

The journeys were estimated by the method outlined above. These differences reflect variations in what might be called the life style of the two areas. Despite these variations, the functional linkages are quite similar. Eighty percent of trips from home to shop are elements of two-trip journeys in both Chicago and Pittsburgh. Eighty-three percent of trips from home to social-recreation are elements of two-trip journeys in Chicago compared to 80 percent in Pittsburgh. The comparable percentages for work trips are 80 and 78 percent, respectively. Seventy percent of all person trips in both Chicago and Pittsburgh are elements of two-trip journeys. They are also, of course, trips for a single non-home purpose.

Table 13 gives the total triangular journeys in both Chicago and Pittsburgh. A triangular journey is composed of three trips -- from home to some activity; to another; and back home. These journey patterns were estimated by calculating the probability of each of the 25 ways of being at home after three trips and multiplying these probabilities by the number of trips from home. The importance of self-linkage among trip purposes of triangular trips is striking. Sixty-three percent of all triangular journeys in Chicago and 58 percent of all triangular journeys in Pittsburgh contain self-linked purpose trips. They are journeys for a single purpose, but utilize two destinations in accomplishing that purpose.

Single-purpose triangular journeys account for 13.6 percent of all trips in Chicago, and 12.5 percent of all trips in Pittsburgh. When these are added to the single-purpose two-trip journeys we see that 83 percent of the trips in Chicago and in Pittsburgh are elements of journeys which have a single non-home purpose. They link the home of the trip-maker to a single activity.

Table 13. Number of Triangular Journeys From and To Home in Chicago and Pittsburgh.

Intermediate Trip Purposes	Chicago	Pittsburgh
Work - Work	195	45
Work - Shop	18	6
Work - School	3	4
Work - Social-Recreation	19	8
Work - Personal Business	24	1
Shop - Work	3	1
Shop - Shop	33	10
Shop - School	1	0
Shop - Social-Recreation	14	5
Shop - Personal Business	12	5
School - Work	6	1
School - Shop	1	1
School - School	1	1
School - Social-Recreation	4	2
School - Personal Business	1	2
Social-Recreation - Work	1	1
Social-Recreation - Shop	10	4
Social-Recreation - School	1	0
Social-Recreation - Social Recreation	97	12
Social-Recreation - Personal Business	19	3
Personal Business - Work	16	5
Personal Business - Shop	23	9
Personal Business - School	0	1
Personal Business - Social-Recreation	62	6
Personal Business - Personal Business	76	21
Total	640	154

Note: Totals do not agree with those in Tables 5 and 6 due to rounding.

The most frequent second activity of the remaining triangular journeys (those with more than one intermediate purpose) is social-recreation in both cities. The second and third most frequent second activities of these triangular journeys in both cities are personal business and shopping, but they are in different order in the two cities. The intermediate activity from which the largest number of non-self-linked triangular journeys stem is personal business in both cases. The important point is that there are few of these multiple-purpose journeys. In Chicago only 8 percent of all trips are elements of dual-purpose triangular journeys. In Pittsburgh 9 percent of all trips fit this description.

In Chicago and in Pittsburgh 35 percent of the remaining trips (those contained in journeys of more than three trips) are elements of single-purpose, multiple-trip journeys. These include 4- 5- and 6-trip journeys. All single-purpose journeys in both Chicago and Pittsburgh account for 86 percent of all person trips. This adds up to a strong demonstration of the single-mindedness of urban travel. Urban journeys are usually undertaken for a single purpose or activity. When that activity is accomplished, whether it requires one, two, or more trips, the person returns home. Multiple-purpose trips are few. Those that there are primarily link up personal business and social-recreation activities with other activities.

Turning now to the <u>fundamental matrices</u> for the absorbing chains we have postulated in Chicago and Pittsburgh we find further evidence of the similarity in length of journeys in the two urban areas. Since the answer to the question what is the average number of trips in a journey depends on the state from which the process starts, and since there is only one starting state in our system -- leave home -- we are interested only in the first row of the fundamental matrix. This is the row labeled Leave Home. The values of the elements of this row of the two matrices are given below.[16]

	Leave Home	Work	Shop	School	Social-Recreation	Personal Business
Chicago	1.0	0.507	0.138	0.049	0.316	0.256
Pittsburgh	1.0	0.473	0.196	0.135	0.189	0.268

When each of these rows is summed we have an estimate of the average number of trips in a journey in the two areas. The average number of trips in a journey in Chicago is 2.266 and in Pittsburgh it is 2.261. As our previous analysis has indicated, the average journey is short -- about two and a quarter trips. And the length of an average journey is almost identical in the two urban areas.

The individual elements of the fundamental matrix are an estimate of how many times, on the average, the urban traveller will be engaged in each of the activities before the journey is ended. An average journey in Chicago for example will include half a trip to work and a quarter of a trip to personal business. To make these figures more meaningful consider 100 average journeys. The number of trips to each activity in 100 hypothetical journeys in the two areas are tabulated below.

Number of Trips in 100 Hypothetical Average Journeys

Activity at Destination	Chicago	Pittsburgh
Work	51	47
Shopping	14	20
School	5	14
Social-Recreation	32	19
Personal Business	26	27
Home	100	100
Total Trips	228	227

There are, of course, 100 trips to home in 100 journeys since each journey must end at home. The differences in journey patterns between the two urban areas which we have previously noted, and have described as differences in the life style of the two areas, is again apparent. In the 100 journeys there are only five trips to school in Chicago in comparison to 14 trips to school in Pittsburgh; there are 14 trips to shopping in Chicago in comparison to 20 such trips in Pittsburgh; and there are 32 trips to social-recreation activity in Chicago in comparison to only 19 such trips in Pittsburgh. In summary, it appears that the average journey in Chicago is less likely to include a trip to school or shopping and more likely to include a social-recreation trip than is the average journey in Pittsburgh.

Conclusion

It is apparent that the pattern of association among activities which we wished to examine is no pattern at all. It simply does not exist. The amount of interconnection of activities by person trips is so small in comparison to the amount of travel between home and individual activities that it need not be given major consideration in examining the spatial structure of activities and in planning for urban transportation and land development.

Given the single-mindedness of urban travel, the question we must ask is: Are significant linkages or associations among non-residential land uses created by people in their daily use of the urban area? The answer obviously is no. Since trips are by definition from one origin to one destination for one purpose, it must follow that if 70 percent of all trips are elements of single-purpose two-trip journeys, then 70 percent of all trips are elements of journeys from residential land to some non-residential land use and back to residential land. And to the extent that a person making a single-purpose, multiple-trip journey consistently exercises this activity on the same type of land use, then the 13 percent of all trips which are elements of single-purpose, multiple-trip journeys have a counterpart in multiple-trip journeys to a single type of land use.

As with activities defined by trip purpose, it is true that there are some non-residential land-use linkages established by person travel. But this interconnection is so small by comparison to the direct residential to non-residential to residential linkages that it also need not be a major concern in planning for urban transportation and land development.

A cautionary reminder is, perhaps, needed at this point. This analysis has dealt only with person travel in urban areas. Truck trips and other forms of goods movement in urban areas have not been examined. Hence these observations cannot be applied to commercial traffic.

In conclusion, then, we make these two points. On the basis of our limited examination it appears that the pattern of urban journeys is quite similar for all metropolitan areas. The complexity of travel as indicated by the percentage of 2-, 3-, 4-, and more trip journeys appears to be independent of the size and site characteristics of urban areas. There are differences in the composition of the journeys. In Chicago, for example, a slightly higher percentage of two-trip journeys is work oriented and a slightly lower percentage is shopping oriented than in Pittsburgh.

Second, urban travel is single-minded. Almost all journeys are undertaken for a single purpose. Since 70 percent of all trips are elements of two-trip journeys, this is obviously so. But the single-mindedness of travel goes beyond this, so that single-purpose journeys account for a sizeable percentage of other multiple-trip journeys. Consequently there is very little association or linkage established by person travel among urban activities or among non-residential land uses.

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1. Wilbur Smith and Associates, Comprehensive Traffic and Transportation Inventory (Draft), (Boston: Boston Regional Planning Project, September, 1964), Table 36, p. 135. These percentages are based on linked internal trips.

2. Chicago Area Transportation Study, Survey Findings, Final Report, Vol. 1, (Chicago: The Study, 1959), Table 4, p. 37.

3. Pittsburgh Area Transportation Study, Final Report, Vol. 1, (Pittsburgh: The Study, 1959), Table 30, p. 92.

4. Wilbur Smith and Associates, op. cit., Table B2, p. 15A. These estimates were made by linking change mode trips with home-based trips as reported. This slightly overestimates the percentage of home-based trips. Despite this the Boston figures are well below the findings of other studies for work and shopping trips. The report offers no suggestions as to why this occurs.

5. Chicago Area Transportation Study, loc. cit.

6. Pittsburgh Area Transportation Study, loc. cit., and Wilbur Smith and Associates, loc. cit.

7. In the Chicago area, for example, trips from sites where the activity had been work, shopping, or social-recreation account for 71 percent of all trips to home. Chicago Area Transportation Study, loc. cit.

8. Wilbur Smith and Associates, op. cit., p. 135.

9. It is important to distinguish between internal and external trips. The data we have been examining are limited to internal trips. Internal trips are those which lie wholly within the defined home interview, or cordon area.

10. Some exceptions to this rule occur in the accounting system of origin-destination surveys because all persons are not on the same work schedule. For example, if the start of the day is taken to be 4:00 a.m., the first reported trip of the day in a household which includes an industrial employee working the graveyard shift will likely be a trip from work to home.

11. Chicago Area Transportation Study, Survey Findings, *op. cit.*, p. 35.

12. Ronald A. Howard, *Dynamic Programming and Markov Processes* (Cambridge, Mass.: M.I.T. Press, 1960), p. 3.

13. John G. Kemeny, *et. al.*, *Finite Mathematical Structures* (Englewood Cliffs: Prentice-Hall, Inc., 1959), p. 404.

14. Whether this assumption is accurate for the urban traveller is debatable. The major weakness of the assumption would be in applying similar next step probabilities to persons who had made few previous trips in their current journey and those who had already completed many trips. As will be seen later, this problem is negligible because most urban journeys are short, and few such sharp contrasts occur.

15. Kemeny, *et. al.*, *ibid.*, pp. 404-407.

16. These computations were performed on a UNIVAC 1105 computer at the Computation Center of the University of North Carolina at Chapel Hill on a grant of time made by the Center.

CHAPTER 5

EVALUATION OF ALTERNATE URBAN FORMS

In the first three chapters we examined, in a particular instance, the spatial pattern of urban activity as defined by person trips for particular purposes. The chapters have dealt in turn with the rationality of trip based spatial linkages in terms of the conservation of travel, with the spatial pattern of trip based activity regions, and with the comparative locational advantage of zones in the region as trip base points, or "residence" locations. All of this analysis has been in terms of a given spatial distribution of person origins and destinations for each activity. And the analysis has been at one point in time. Because the analysis has been limited to particular live instances it is difficult and dangerous to draw generalizations about urban spatial structure from the results.

In the analysis of travel time and selection of origin-destination linkages we related the travel time required by actual linkages to the travel requirements of the set of linkages which minimize total travel time. We observed that travel time is conserved in principal linkages from each origin zone. We might say that "substantial rationality" exists since a sizeable percentage of all trips from a zone are quite close to the minimum travel required. Since we have defined rationality as the conservation of travel, a rational set of spatial linkages is also an efficient set of linkages. An efficient set of linkages is one which satisfies the origin and destination requirements for the least expenditure. Since people most often select linkages which conserve total travel time, the pattern of linkages (or of principal linkages) is an efficient pattern.

It would be incorrect to jump from this conclusion to the further conclusion that the spatial organization of the urban area is efficient. Such a conclusion would be incorrect because it is a conclusion about the distribution of trip origins and destinations -- about the locations of persons at the origin of trips and the spatial distribution of trip destinations for a particular activity. Our analysis deals with only one spatial distribution. The analysis has demonstrated the accommodation of a given set of locations to a given set of activities. The next, natural question is whether this particular pattern is more or less efficient than some other patterns of origins and destinations. If the actual pattern of trip ends is more efficient than any other pattern we have another kind of rationality, structural rationality.

To clarify this distinction it is useful to think of two levels of urban spatial structure. At one level we are concerned with the selection of linkages between given origins and destinations for a particular activity. At another level we are concerned with the spatial distribution of locations and activities as defined by trip origins and destinations.

We have been examining the first type of spatial structure -- the selection of linkages between given origins and destinations. In examining the rationality of linkage selection in relation to the linear programming allocation of trips we have been concerned with the degree of efficiency with which persons utilize the distribution of activities and with the distribution of benefits of an efficient set of linkages as measured by comparative locational advantage.

In looking at the spatial distribution of origins and destinations we are also concerned with efficiency. We want to know if a given distribution of origins and destinations for some activity is more efficient than some other distribution. In a sense we are concerned with the goodness of fit of the distribution of activities with the spatial distribution of the origins of trips to the activities. An efficient fit is one where the required linkages can be established for the least travel expenditure. The most efficient pattern would contain an equal number of trip origins and destinations for a given activity in every zone. Then no interzonal travel would be required. A less efficient pattern would contain all destinations for an activity in one zone while the trip origins would be dispersed. Neither of these extremes is likely to occur in an urban area, but there is a wide range of possible patterns which represent different qualities of fit.

We must distinguish the pattern of origins and destinations from the spatial structure of activities. The pattern of origins and destinations is the physical form of the urban area as measured by the number of persons who use a site for a particular purpose. Like the land use pattern which describes the amount, type, and location of developed land, it describes the amount and location of activity. The spatial structure of activities is the linkages between the pattern of origins and destinations. It is defined by an allocation rule which specifies how linkages from origins to destinations are selected.

It is possible to have efficiency of one type of spatial structure and not of the other. We may have structural rationality (congruence of origins and destinations) and not have travel rationality (efficient selection of linkages). Or the reserve situation is quite possible.

Evaluation of Urban Form

Analysis of the spatial pattern of activity is a part of the more general problem of evaluating alternate urban forms. Alternate activity patterns defined by origins and destinations of person trips for particular purposes are alternate patterns of urban form. When we look at the implications of alternate activity patterns for the spatial structure of activity and for travel requirements, or when we look at the implications of alternate transportation systems we are evaluating alternate forms of the metropolitan area in terms of their functional operation. It is a limited evaluation because it deals only with person linkages between activities in the urban area. Linkages established by the movement of goods or other communications are not included.

The linear programming allocation of person trips for specified activities can be used to evaluate alternate urban forms in terms of the implications of both alternate activity patterns and transportation systems. The inputs for evaluation are (1) alternate patterns of activity as defined by trip origins and destinations for particular purposes, and (2) alternate transportation systems. Outputs of the evaluation are (1) the minimum linkages, (2) the spatial structure of activity as defined by these linkages, and (3) the comparative locational advantage of zones as "residence" or trip origin locations.

An activity pattern is not a land use pattern. It is more nearly a description of the way urban land is used. A land use pattern would specify, for example, the acres of land or square feet of floor space devoted to retail activity in a zone. An activity pattern as we have defined it specifies the number of shopping trips to a zone. Similarly a land use pattern would specify the amount of land devoted to residential use in a zone and an activity pattern specifies the number of trip origins in a zone. If patterns of work activity are to be evaluated the activity pattern is specified as the number of work trip origins in each zone (usually one for each household) and the number of jobs in each zone.

The alternate transportation systems to be evaluated are not detailed networks of transportation facilities. Rather they are systems of transportation service. A system of transportation service is specified in terms of the travel time required to go from each zone to every other zone. Conceivably there are a variety of networks of transportation facilities which could provide the specified level of transportation service.

The distinctions between a pattern of activities and a land use pattern, and between a system of transportation service and a network of transportation facilities show how our linear programming analysis of urban spatial structure differs from conventional land use and transportation facilities analysis. What we propose is to abstract from the complex physical city the elements which are crucial for an understanding of urban spatial structure in terms of the interaction of spatially separated and physically rooted activities and the transportation system linking them. These crucial elements are the residential pattern and the distribution of activities (specified as trip origins and destinations), and the level of transportation service between residence locations and activities.

As we have seen in the last chapter most urban travel is single-minded. There is little direct linkage of non-residential activities by person travel. So we can consider the spatial pattern of each activity in relation to the residential pattern, and independent of other activities.

To translate a specified urban form into an activity structure we apply the linear programming allocation rule. We allocate all trips so as to minimize total travel time. Again this is a social welfare criterion. It is the optimum solution for the community as a whole to the linkage of residences and activities. There are two parameters to the evaluation: (1) total travel time, and (2) the comparative locational advantage of zones as residence sites.

The first parameter is an efficiency criterion. It measures the minimum cost of travel of alternate urban forms. Other things being equal an activity pattern which requires less travel than some other activity pattern when the level of transportation service is given is more desirable. The second parameter is an equity criterion. It measures the locational advantage of zones in terms of the benefits to trip makers from each zone under conditions of efficient travel. The measurement of locational advantage was discussed in detail in Chapter 3. Other things being equal, a small range of values of locational advantage is preferable to a large range of values. The ideal pattern would be one in which there was no locational advantage. In this case each residential zone would be equally well off with respect to linkage with the activity pattern. The third element of the output from the evaluation -- the spatial structure of activity -- shows how the urban area is organized into subregions by efficient travel.

A great deal of the exploratory analysis of urban structure has dealt directly or indirectly with the question of the relative influence of the components of urban form on the organization of urban activity and the spatial pattern of the city. The work of Robert Haig and of Mitchell and Rapkin summarize these efforts.[1]

In 1927 Haig advanced the hypotheses that "...the layout of a metropolis - the assignment of activities to areas - tend to be determined by a principle which may be termed the minimizing of the costs of friction."[2] The costs of friction were considered to be composed of site rent and transportation costs. In Haig's view, each activity selected locations where its total rent and transportation costs were least. He conceived of an efficient ordering of urban space through free competition among different activities. Although he considered the free market solution the most efficient allocation of space, he also recognized that an unregulated market solution might produce social costs which outweigh the benefits to individual establishments of complete freedom of location. To counter this possibility he argued for zoning as a means of controlling the allocation of land to activities.

The important point for us in Haig's analysis is his emphasis on the transportation system as a determinant of the activity pattern. In his view transportation was a constant obstacle to maximum efficiency in the organization and operation of the urban area and the allocation of space to activities was strongly influenced by it. He saw the planner's task primarily as influencing the location of activities so as to minimize friction costs when the transportation system was given.

Mitchell and Rapkin, using information on person trips in the Philadelphia area, addressed much the same problem as Haig, but their emphasis was on the generation of traffic given a land use pattern, rather than on the location of land uses. They recognized that a time lag exists between the land use pattern and the activity pattern. Establishments with favored locations attract more trips than do similar establishments with less favored locations. And different kinds of land use attract trips at differential rates.

Given the transportation demand generated by the land use pattern they see "...the adjustment of movement channels (consistent with available resources) to facilitate the activities of an urban area as much as possible; and, at the same time, to reduce as much as possible the limitations which the channels may impose on growth or change in the city's activities"[3] as a major objective. In contrast to Haig they make the transportation system a servant of the activity pattern.

But Mitchell and Rapkin also note that "changes in streets and the street system occur, nevertheless, within the framework of the existing street pattern."[4] Thus it is difficult to tame the street system into a servant role. They also note that accessibility is one of the major forces leading to changes in land use.[5] Considering all factors they argue for the interdependence of land use and transportation.

Our method for evaluating alternate urban forms has neither Haig's nor Mitchell and Rapkin's emphasis. Although both recognize the interdependence of transportation and the activity system their emphases are different. Haig would set the transportation system and let the activity system fall in place relative to it. Mitchell and Rapkin would set the activity system in place and design a transportation system to serve it. We set both the activity system and the transportation system in place, and we specify an allocation rule which links up the residential locations with the activities. We do this in order to evaluate the relative impact of changes in the activity system and in the transportation system. Our method is more nearly akin to Mitchell's proposal that land use and transportation planning be fully integrated.[6]

The point we wish to make, in reference to the evolution of thought and the current controversy about the interaction of transportation and the activity pattern, is that there is no profit in taking sides nor is there yet any compelling argument to convince us that one is wholly true and the other wholly false. As Mitchell and Rapkin recognize, what is needed is a means for evaluating the interaction. Our use of linear programming to evaluate alternate urban form was designed with this prime objective.

One final point is needed. Mitchell and Rapkin are probably too pessimistic about the pervasive influence of the existing street pattern, and Haig certainly was. With the modern urban expressway the planner has the ability, for good or ill, of cutting across the old street network with new facilities and reorienting the traffic flow on the old network. In effect he can overlay the old system with a new system of transportation facilities which will influence the operating characteristics of the old system. Equally important is the fact that, at the current and projected rate of growth of metropolitan areas, a large part of the street system with which the urban planner is ultimately concerned has not yet been built. Current and foreseeable technology and individual mobility give him a large measure of choice in proposing a network of new facilities.

Now we shall turn to the evaluation of urban form using the linear programming analysis. In the remainder of this chapter we address the specific question of rationality of spatial structure. To do this we experimentally alter the pattern of work trip destinations in the Buffalo area and compare the travel requirements, spatial structure, and locational advantage resulting from the experiments with the existing situation. In the next chapter we turn to the evaluation of alternate urban forms and transportation systems by experiments conducted with a model of a hypothetical metropolitan area.

Experiments With the Journey to Work

Currently 41.3 percent of all work trip destinations are located in the core area of Buffalo. The core area is defined as zones 1 through 8 and comprise the CBD and the adjacent tier of zones. Our experiments will consist of changing the ratio of work trip destinations in the core to work trip destinations in the remainder of the area and testing for changes in travel requirements, structure, and locational advantage. The first experiment will increase the jobs in the core to two-thirds of the total, the second will decrease jobs in the core to one-third of the total, and the third will further decrease jobs in the core to one-fourth of the total. The changes in work trip destination in individual zones within the core and fringe areas are made in proportion to the existing distribution of work trip destinations. For example if zone 2 contains 20 percent of actual work trip destinations in the core it will contain 20 percent of the two-thirds of all work trip destinations allocated to the core area in the first experiment.

The experiments could be interpreted as a sequence over time of the sub-urbanization of employment opportunities. But unlike an actual sequence of sub-urbanization the number of workers in the area and the extent of residential development in the area are constant. So a related and more accurate interpretation of the experiments is as an exploration of what would have resulted if the suburbanization of job opportunities and the spread of residential development had not proceeded together as they have. We are holding the residence pattern constant and proposing alternate patterns of job opportunities.[7] Another way to interpret the experiments is as a test of the adequacy of the accommodation of the residence and job location patterns to each other. If travel requirements are less in the extreme experiments than actual requirements then the existing patterns are not well matched. If the reverse is true a good match exists.

Travel Time

Minimum travel requirements of the actual pattern of trip origin locations and destinations are 12.5 million travel time units. The results of the experiments are:

Percent Job Opportunities in the Core	Minimum Travel Time Units (in millions)
66.6	23.8
33.3	12.1
25.0	14.1

Since minimal travel requirements are greater for the experiments with two-thirds of the jobs in the core and one-fourth of the jobs in the core than for the actual distribution of jobs, we suspect that the actual distribution of residences and jobs are a good match. Figure 8 is a plot of minimum travel requirements for the experiments against the percent of job opportunities in the core. As the curve shows the actual distribution of job opportunities requires slightly more travel than the experiment with one-third of the jobs in the core. The location of the actual minimum point on the curve cannot be determined precisely from this information. It appears to be between the actual case and the case where one-third of the jobs are in the core.[8] It is quite clear, however, that the actual distribution of jobs is a good match of the residential pattern, and that the minimum travel requirement of the actual pattern is nearly the minimum that could be achieved by spatial re-arrangement of work places.

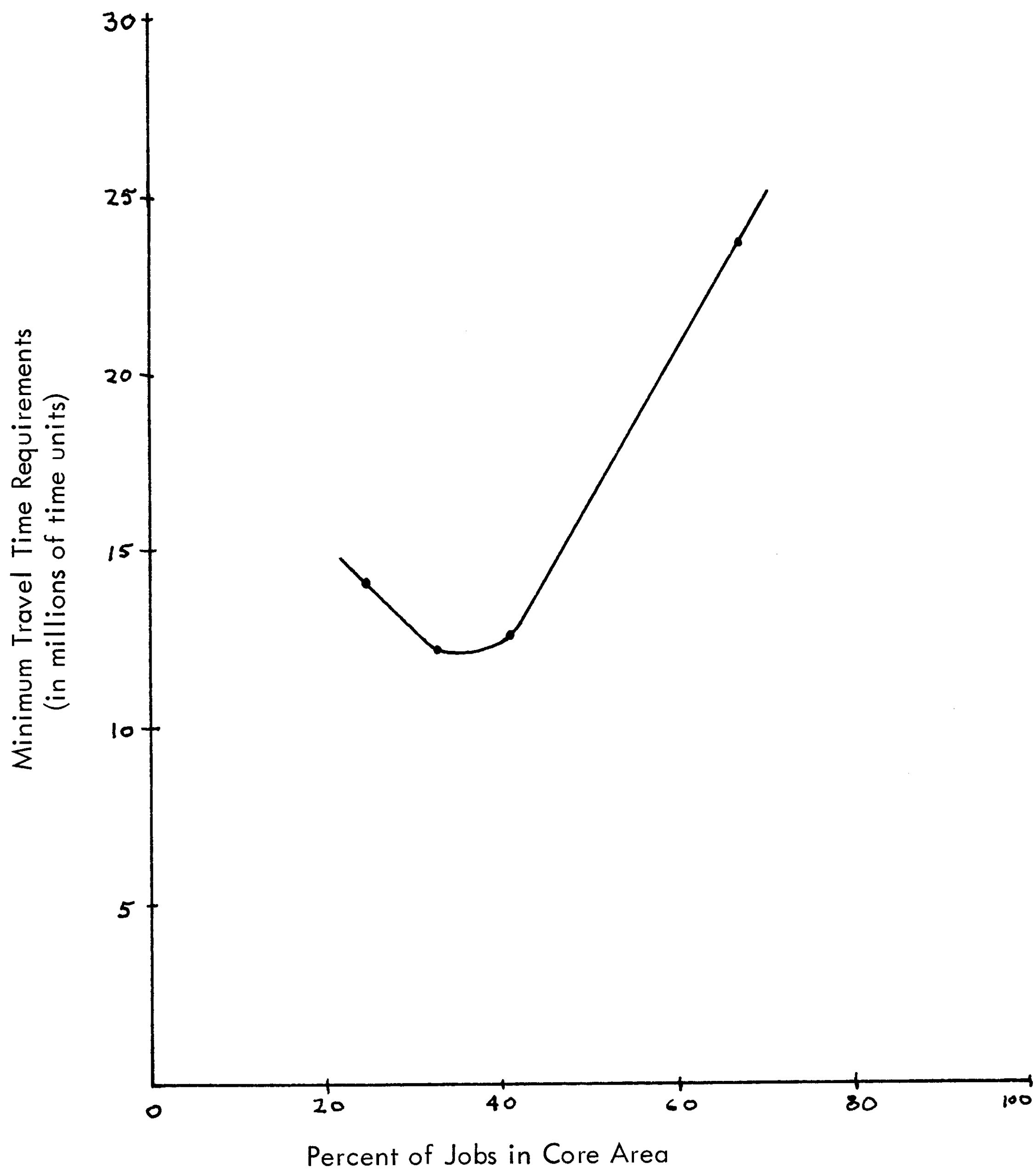


Fig. 8. Minimum Travel Requirements of Actual and Experimental Work Activity Patterns.

The test shows that structural rationality as we have defined it exists in the Buffalo area for work activity. This is so because given the existing distribution of origins of trips to work, the distribution of destinations of these trips is such that when efficient linkages are selected the total travel requirements are very nearly the minimum which could be achieved with any other distribution of work trip destinations under the conditions of the experiments. It is important to bear in mind the conditions of the experiment -- the rule we used in rearranging workplaces. If some rule for redistributing workplaces other than in proportion to the existing distribution were used the experiments would yield different results.

In our original analysis of travel rationality we showed that total travel is not rational but trips contained in principal linkages are rational in relation to the linear programming criterion. Comparing the results of our analysis of travel rationality and spatial rationality leads to this interesting speculation. The spatial structure of activities is quite rational and potentially efficient but the travel behavior of persons operating over this structure is less rational and relatively inefficient. Another, simpler way of stating the speculation is that location behavior is more rational than travel behavior with respect to conserving travel. This implies a curious contradiction. It seems that people choose locations, both to establish residences and to establish workplaces, with considerable care and a concern for their relative position with respect to the spatial distribution of activities. The net result of these individual actions is a spatial structure with a high potential for efficiency. Then these same persons ignore this potential in the selection of activity linkages in the system.

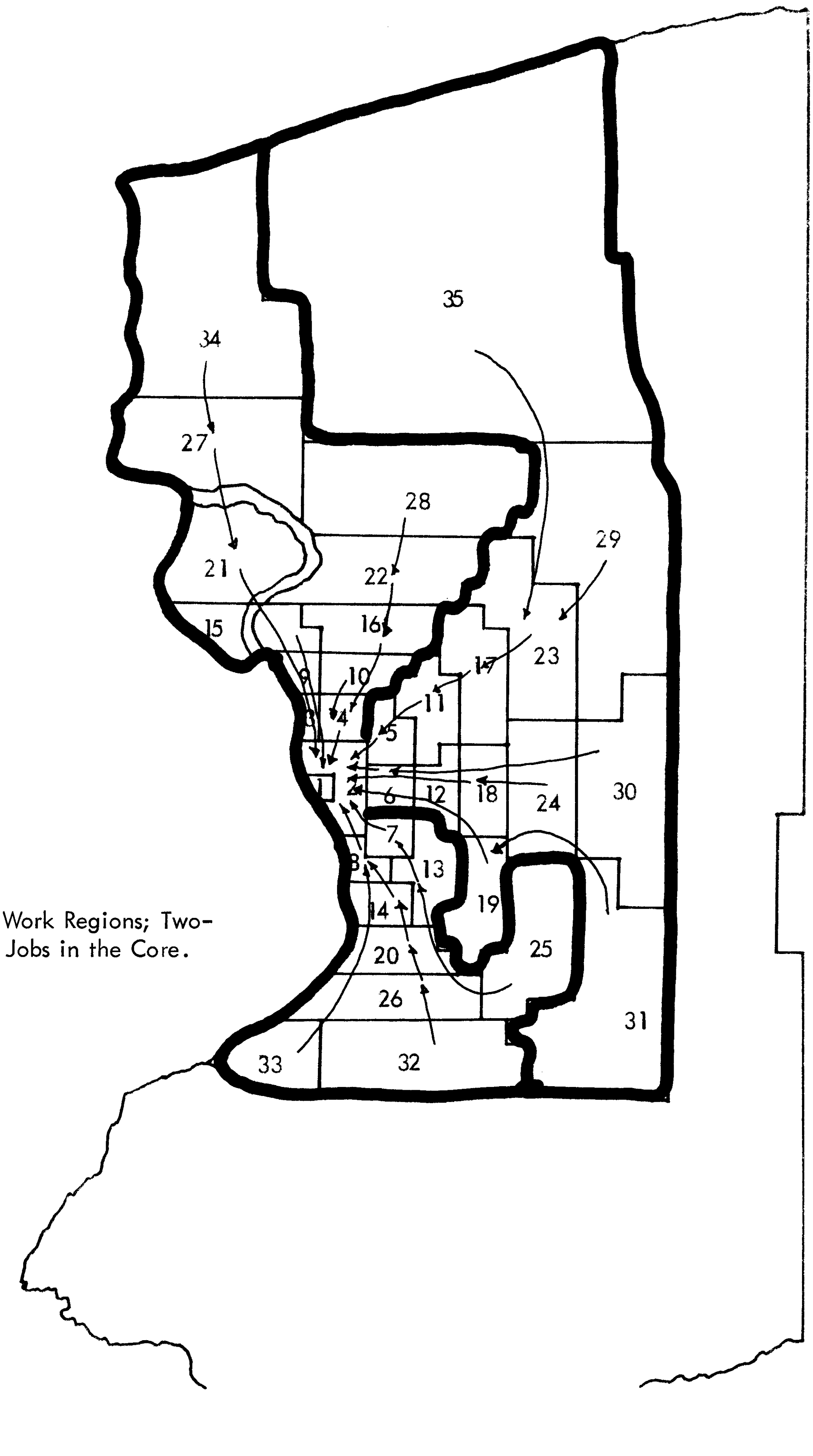
There is a plausible and very simple explanation we can offer for this apparent contradiction. If the cost of failure to conserve travel is small relative to the cost of a poor fit of the distributions of residences and activities then there is no contradiction. To clarify this notion consider the relative cost of random travel over a congruent spatial system and minimal travel over a poorly matched spatial system. If the former is less expensive then such action is more rational with respect to conservation of travel time. And an added benefit of greater freedom of choice of destination at relatively low cost is gained.

The interaction of what we have called travel rationality and structural rationality has some interesting consequences. The apparent moral is quite simple. The price of structural irrationality is the need for efficient travel behavior; or alternately, the benefit of structural rationality is the extension of choice in travel behavior.

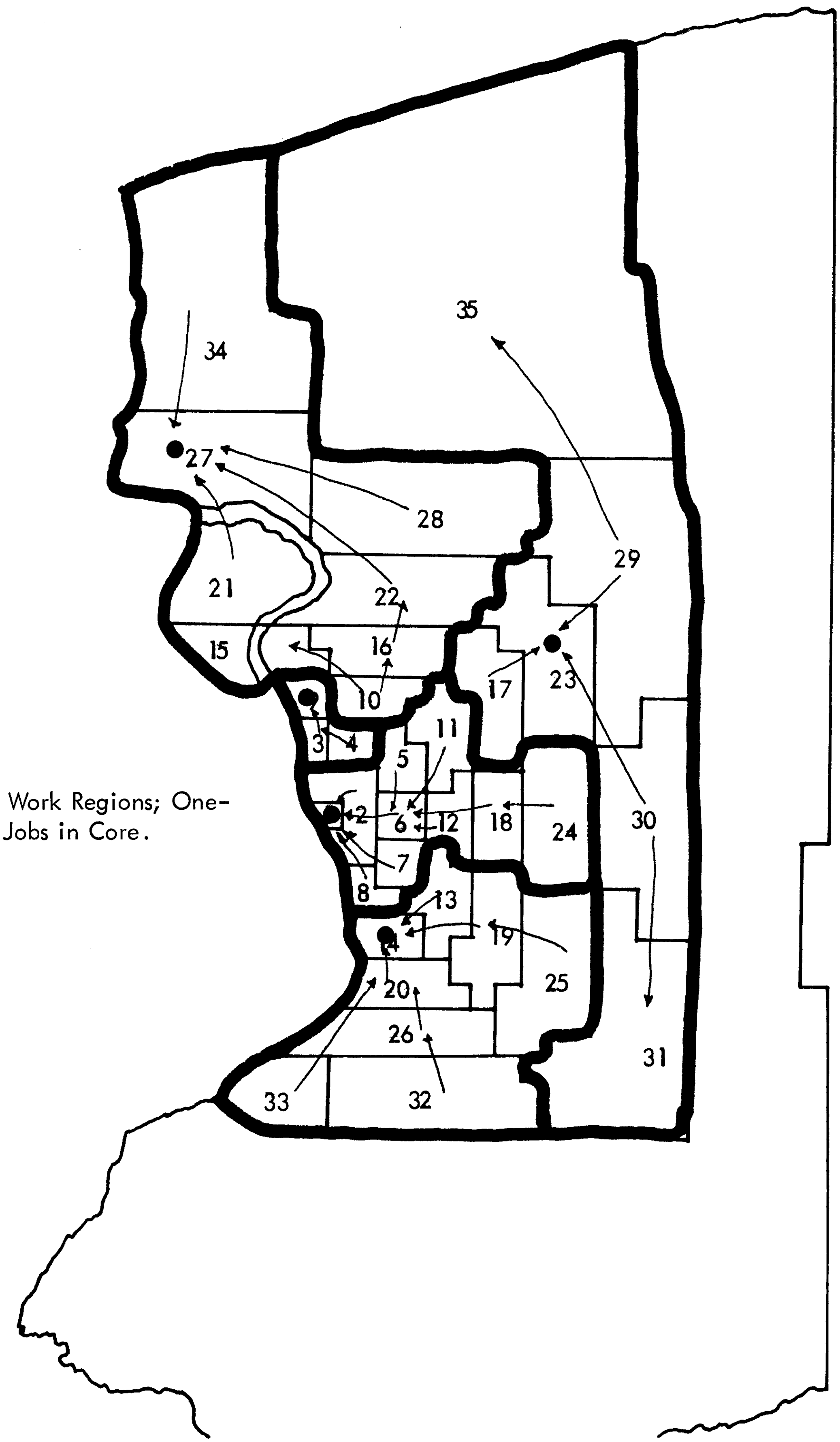
Spatial Structure

To examine the implications of rearrangement of workplaces on the spatial structure of activities we will map the linkage patterns established by the optimal allocation using the rules developed in Chapter 2 for simplifying the linkage pattern.[9]

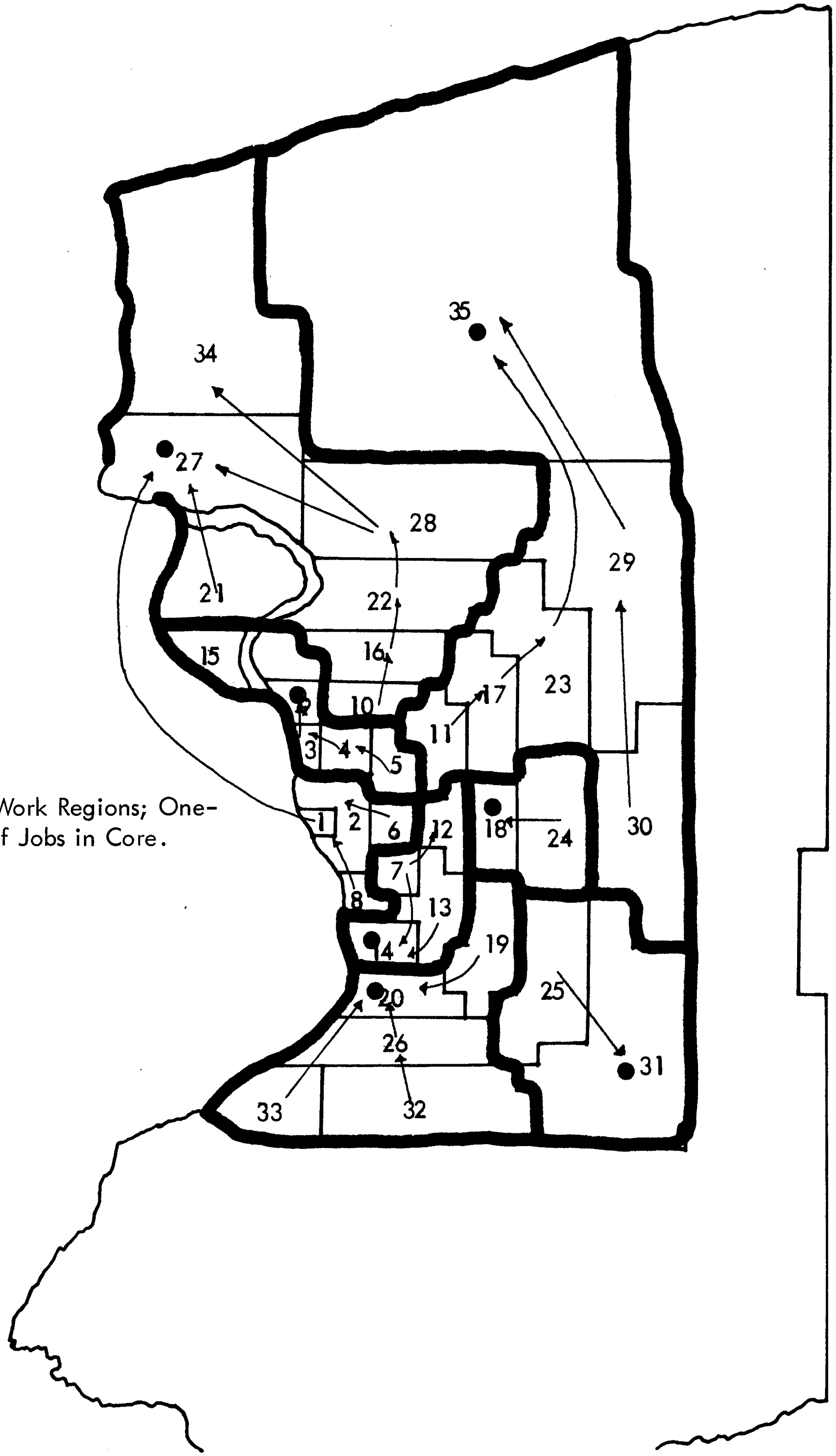
Map 19 shows the spatial structure of activity formed by the linear programming allocation for the case where one-third of the jobs are located in the fringe. Map 20 shows the activity structure formed in the case where two-thirds of the jobs are in the fringe. And Map 21 shows the activity structure formed in the case where 75 percent of the jobs are in the fringe. The spatial structure of activity formed by a linear programming allocation of trips to the existing distribution of jobs is shown



Map 19.
Optimal Work Regions; Two-Thirds of Jobs in the Core.



Map 20.
Optimal Work Regions; One-Third of Jobs in Core.



Map 21.
Optimal Work Regions; One-Quarter of Jobs in Core.

in Map 9 in Chapter 2. In each case the urban area is partitioned into focal regions. The small circle in each focal region is the focal zone of that region. It is defined as the focus or center of the region. The arrows show the orientation of zones to the focus.

The number of focal regions increases with dispersion of jobs outward from the core. In the most concentrated case -- two-thirds of the jobs in the core -- there are only two focal regions. These are centered on zone 1, the CBD, and zone 2 adjacent to and surrounding the CBD. For all practical purposes these can be considered a single focus and the urban area a single focal region. With 75 percent of the jobs in the fringe, there are seven focal regions. The urban area is quite fragmented. This fragmentation is a natural result of the suburbanization of jobs and is the outcome we expected. So the experiments appear to be a reasonable replication of reality even though the patterns produced are based on the very restrictive programming allocation.

The table below summarizes the focal centers of the maps. The definition of centers also changes with the distribution of jobs. The CBD, zone 1, is a focal center in all cases except the most dispersed. Zones 14 and 27 are focal centers in all cases except the most concentrated. Zone 23 is a focal center in the two mid-range cases. Focal centers have considerably more durability than do regional boundaries in the experiments. The spatial structure formed by the existing distribution of jobs and in the case where one-third of the jobs are in the core have virtually the same focal centers, result from relatively little difference in the distribution of jobs, but are markedly different in the definition of focal regions.

Table 14. Focal Centers in the Experimental Home-Work Activity Structures.

Percent Jobs in Core	Focal Centers (Zone Number)										No. of Focal Regions
66.6	1	2									2
41.3 (actual)	1			14			23	27			4
33.3	1		9	14			23	27			5
25.0			9	14	18	20		27	31	35	7
Frequency	3	1	2	3	1	1	2	3	1	1	18

The changing orientation of focal points within the region and of zones to focal points is of interest. When two-thirds of all jobs are in the core all linkages are oriented toward the core. They form a series of radial chain links from zone to zone to the center. In the actual case each focal point is located on the inside of its subregion towards the CBD and pendant zones point inward toward focal points and the CBD. When two-thirds of the jobs are in the fringe some of the focal points are in the center of their subregion and the orientation of zones toward focal points is no longer also toward the core of the urban area, but is often away from it. When only 25 percent of the jobs are in the core focal points are in some cases at the outer edge of their subregion and the general orientation of zones is away from the core. The net impression is of an explosion outward from the core.

The sum effect of the changing distribution of jobs from concentrated in the core to concentrated in the fringe then is a reversal from implosion to explosion. At the start the area is drawn together. At the end the area is pulled apart. The experiments have demonstrated that a relatively small change in the distribution of opportunities can have a significant effect on the spatial pattern of activity.

Comparative Locational Advantage

The third concern of our experiments is with the effect of changes in the distribution of job opportunities on the comparative locational advantage of zones for residence. In brief review, the dual problem of the linear programming selection of linkages to minimize aggregate travel time maximizes the difference in value at origin and destination of the items shipped taken over all the items shipped. In our case the item is persons shipped, or rather transporting themselves to jobs. The dual variable assigning value to items at the origin zone measures the comparative locational advantage of zones as a place from which to venture forth into the array of job opportunities. The values are in travel time units.

A large range of values as opposed to a small range of values means that location is of greater relative advantage, and disadvantage, in the former case than in the latter. As the range of values becomes very small locational advantage disappears and all zones are of approximately equal value as a residence location. As the range becomes large differences in residential location have increased significance. Figure 10 is a plot of the range of values of locational advantage against the percent of jobs in the core in our experiments and the actual situation. The shape of the curve is similar to that observed in Figure 8 when minimum travel requirements were plotted against the percent of jobs in the core.

Of the experiments conducted the range of values is smallest with the existing distribution of residences and workplaces. It appears that, at least in these experiments, the range of locational advantage is related to the goodness of fit between the distributions of residences and workplaces as measured by minimum travel requirements.

As in the examination of the influence of changes in the distribution of jobs on total travel requirements the moral which we draw is quite clear and it is similar. Variations in the distribution of jobs appear to have a marked effect on comparative locational advantage of zones as residence locations. The variations in comparative locational advantage seem to be related to the congruence or goodness fit of the distributions of residences and jobs. When the distributions are congruent the range of locational advantage is relatively small. We interpret these results to mean that

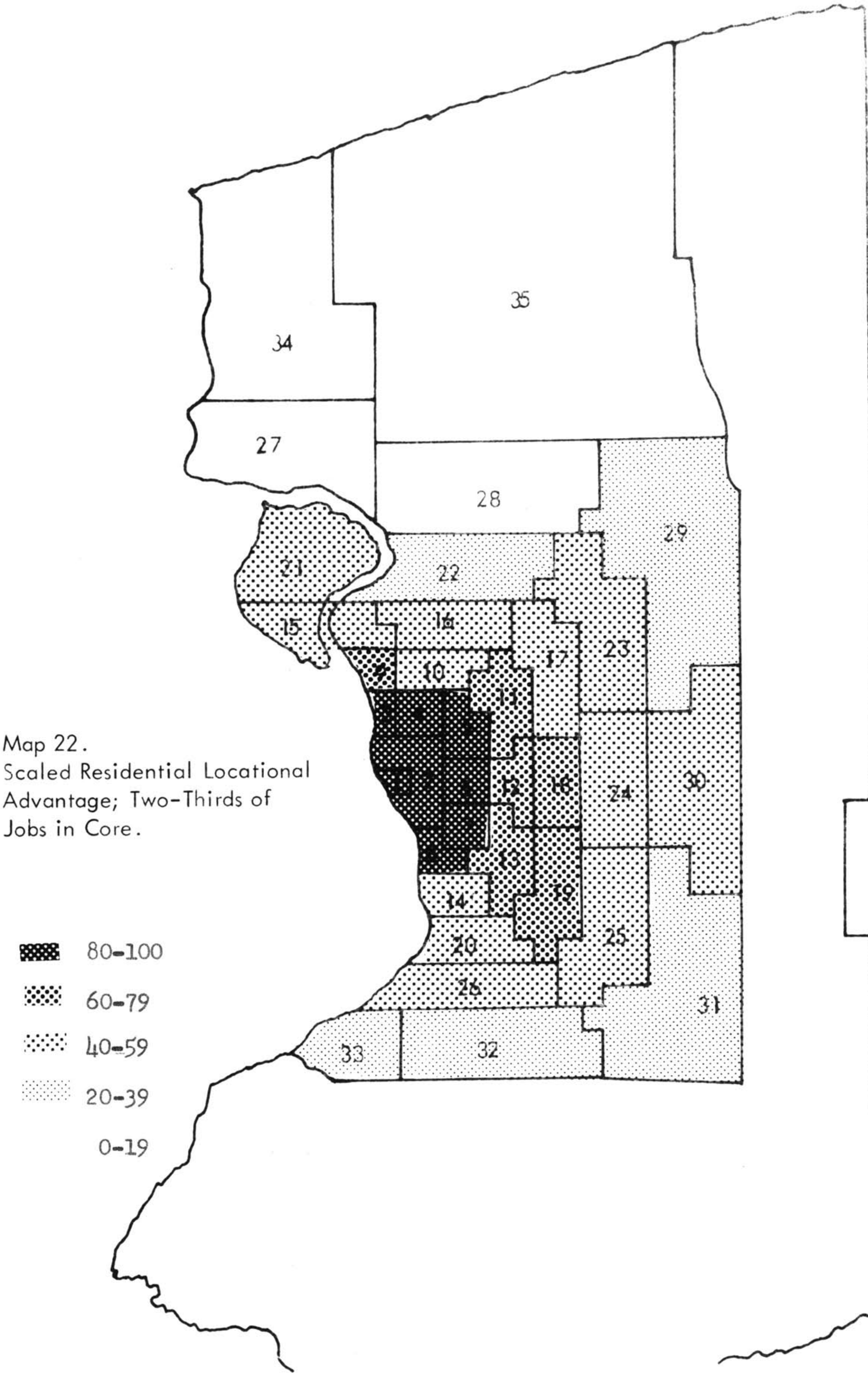
Fig. 10. Range of Comparative Locational Advantage of Actual and Experimental Work Activity Patterns.

the price paid for structural irrationality is a marked differential in locational advantage; or, alternatively, the benefit of structural rationality is relative uniformity of locational advantage.

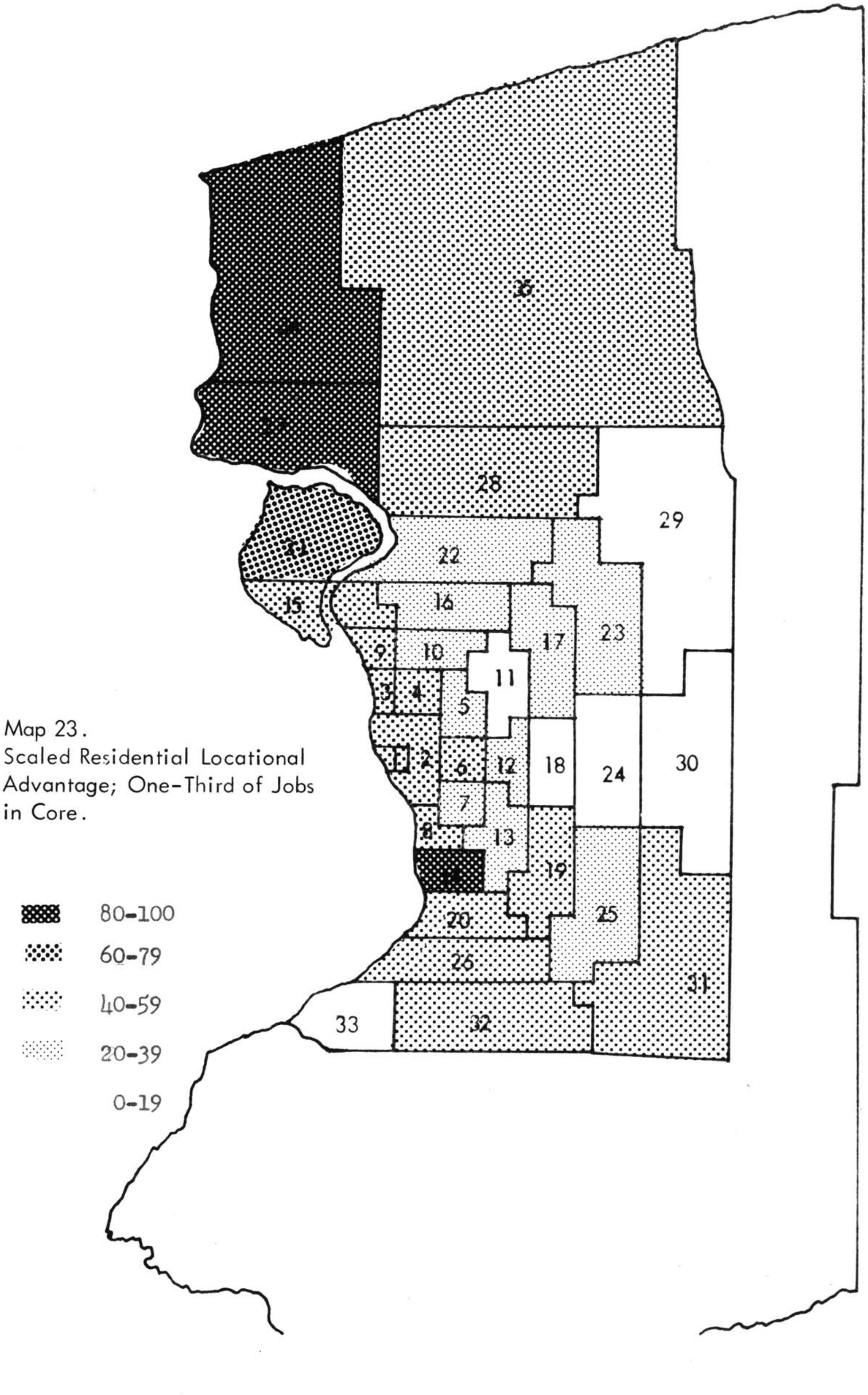
We turn now to the actual spatial patterns of comparative locational advantage produced by the experiments. Maps 22, 23, and 24 show the pattern of locational advantage when two-thirds, one-third, and one-fourth of the jobs are in the core. These maps were produced by first scaling the range of locational advantage in each case to an index with a maximum value of 100. This is the practice we followed in our original analysis and permits visual comparison of the different ranges. Map 15 in Chapter 3 shows the zonal pattern of locational advantage with the existing distribution of jobs and is not reproduced here.

When two-thirds of the jobs are in the core locational advantage is highest in the core, as expected, and declines regularly with time distance from the core. With the existing distribution of jobs locational advantage is highest along the eastern edge of the urban area and declines with time distance outward from that edge. When one-third of the jobs are in the core the high point of locational advantage shifts to the north~~ea~~west corner of the region. An area of low advantage develops in the central part of the region. It is surrounded on three sides by an area of mid-range value. Shifting 75 percent of the jobs to the fringe completes the shift of locational advantage to the northern portion of the urban area. The area of lowest advantage is spread across the center of the region.

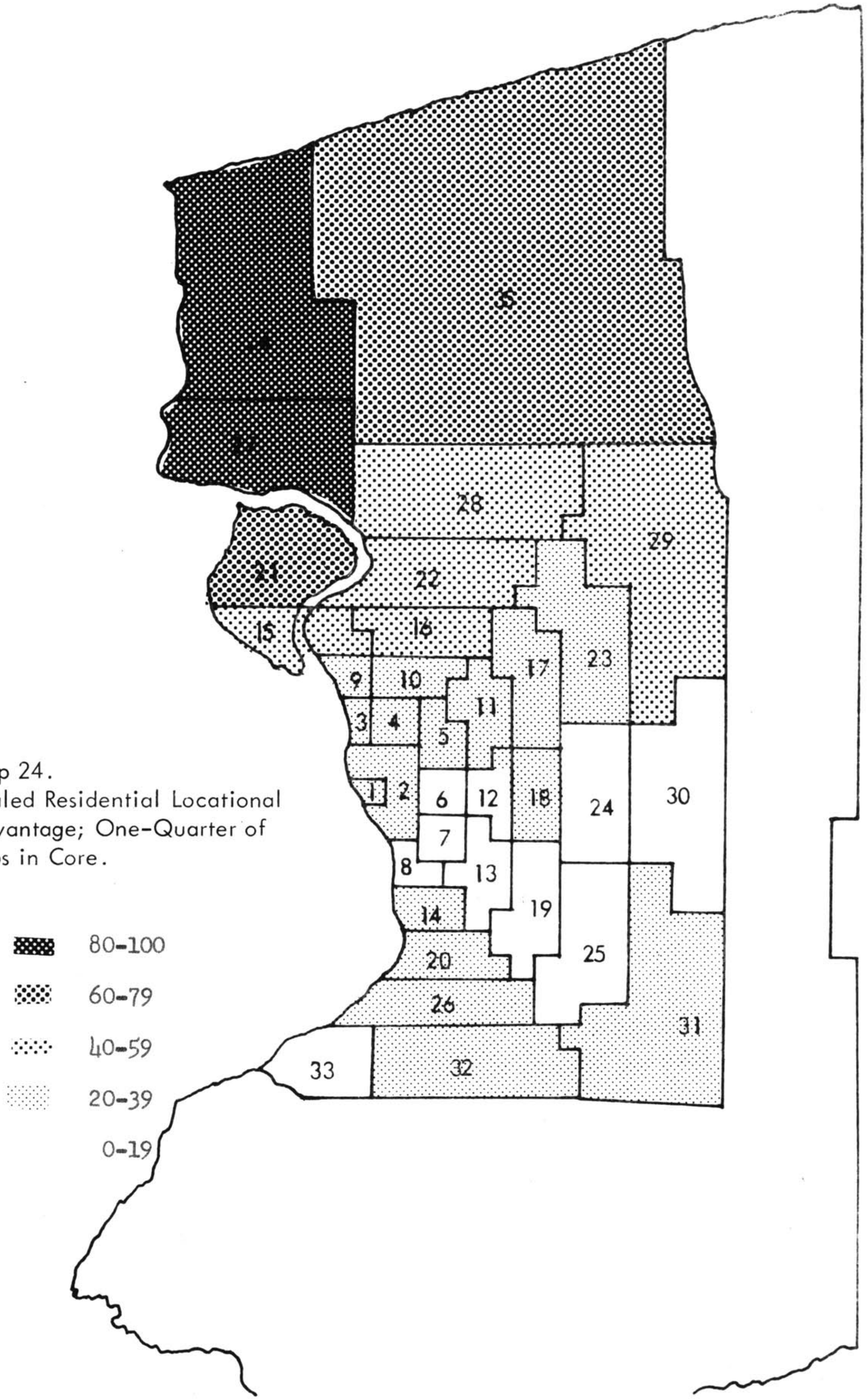
The net effect of shifting jobs from concentration in the core to concentration in the fringe area is a complete reversal of the pattern of comparative locational advantage. When two-thirds of the jobs are in the core the northern half of the



Map 22.
Scaled Residential Locational Advantage; Two-Thirds of Jobs in Core.



Map 23.
Scaled Residential Locational Advantage; One-Third of Jobs in Core.



Map 24.
Scaled Residential Locational Advantage; One-Quarter of Jobs in Core.

urban area has least advantage; and when only one-fourth of the jobs are in the core the northern half has all the advantage. The direction of shift to zones outside the core is of course influenced by the existing distribution of jobs since the experiments are based on a proportional allocation of jobs above and below the existing base. Thus zone 27 rather than some other zone or zones becomes the locus of locational advantage. In the process of the shift of opportunities the center of the region becomes an area of low advantage. The usual pattern of a city is effectively turned inside out. As in the examination of the spatial pattern of activity, the experiments have shown that a relatively small change in the distribution of opportunities can have a marked effect on the spatial organization of an urban area.

Conclusions

In this chapter we reformulated our use of linear programming to analyze travel behavior in order to evaluate alternate urban forms. We have successfully tested its use for this purpose in an examination of the spatial rationality of the existing distribution of workplaces in the Buffalo area in relation to the distribution of "residence" locations as defined by all trips to work.

We found that the existing distributions of residences and workplaces were well matched in comparison to the match of residences with our experimental rearrangements of the distribution of workplaces. The linear programming analysis provides two parameters for evaluation of alternate urban forms -- efficiency as measured by minimum travel requirements, and equity as measured by the range and distribution of comparative locational advantage. In our limited experiments different job distributions were selected as best by the two parameters. The actual job distribution results in the smallest range of comparative locational advantage. The experiment where one-third of the jobs are in the core and two-thirds are in the fringe area requires the least travel. But the difference between the two forms in both travel time and the range of locational advantage is small.

The experiments also give rise to some speculations about the validity of traditional interpretations of spatial structure. If we assume that the price of land for residence is related to its comparative locational advantage with respect to the distribution of job opportunities,[10] and if we envision an urban area in which the majority of job opportunities are located in the suburban ring, then the traditional structure of land values dictated by location theory does not occur. Instead of a core we have a doughnut and central land for residence is passed over. The assumptions, and their results are not too different from the process that has apparently been going on in older metropolitan areas in the last decade.

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1. Robert Murray Haig with Roswell C. McCrea, Major Economic Factors in Metropolitan Growth and Arrangement, Vol. I: Regional Survey of New York and Its Environs (New York: Committee on Regional Plan of New York and Its Environs, 1927); Robert B. Mitchell and Chester Rapkin, Urban Traffic: A Function of Land Use (New York: Columbia University Press, 1954).

2. Haig, op. cit., p. 39.

3. Mitchell and Rapkin, op. cit., p. 179.

4. Ibid., p. 130.

5. Ibid., p. 118.

6. Robert B. Mitchell, Metrpolitan Planning for Land Use and Transportation (Washington: USGPO, December, 1959), p. 18.

7. This is not strictly true since our data include all trips to work and not only trips from home to work. Probably 20 to 25 percent of the trips to work are from some location other than the trip maker's home. We have used this data because no more accurate data were available. We think that better data would not substantially change the results.

8. The theoretical minimum would occur when the distribution of jobs was exactly the same as the distribution of residences. Then there would be no interzonal linkage. This cannot occur except by accident since the job distribution is rearranged in proportion to the actual job distribution, and the actual job distribution and residence distributions do not match. The minimum possible travel time with these experiments will occur when interzonal linkages are minimum. In both the actual case (where 60 percent of the jobs and 66 percent of the residences are in the fringe area) and in the second experiment where 66.6 percent of the jobs and 66 percent of the residences are in the fringe area only 29 percent of all trips are interzonal. The number of interzonal trips is larger for the other experiments.

9. Simplifying the linkage pattern requires very little alteration of the optimal allocation. In the actual case only 0.3 percent of all trips are redirected in the simplification. For the experiments 1.5 percent of all trips are redirected when 75 percent of the jobs are in the fringe, 2.3 percent are redirected when two-thirds of the jobs are in the fringe, and none are redirected when one-third of the jobs are in the fringe.

10. This is reasonable since we interpret the values assigned to residence zones in the dual as the imputed rents for location in those zones.

CHAPTER 6

EXPERIMENTS IN URBAN FORM AND STRUCTURE

The experiments in rearrangement of the distribution of workplaces show that the present residential and workplace distributions in the Buffalo area are well matched since the interconnections between them can be accomplished at nearly the minimum possible aggregate travel time under the linear programming allocation. They also show changes in the focal structure of the metropolitan area and changes in residential comparative locational advantage resulting from changes in urban form. Because they were limited to variations in the distribution of workplaces, these experiments fail to provide a complete analysis of the effect on urban structure of changes in the components of urban form. We turn now to an attempt to explore this question.

The question is: What is the impact of changes in the components of urban form on urban spatial structure? In our analysis the relevant components of urban form are limited to the distribution of residences, the distribution of workplaces, the distribution of shopping opportunities, and the system of transportation service connecting the zonal subdivisions of the urban area. The elements of spatial structure in which we are interested are the travel requirements of a particular urban form, the spatial structure of activity, and the amount and distribution of locational advantage.

The distinction we make between urban form and urban structure is quite simple. Urban form is the physical arrangement of residences, workplaces, etc.

Urban structure is the pattern formed by the connection of these elements in the daily activity of the area's residents. Urban structure implies an allocation rule. Given a physical pattern of places, the connections between them -- from home to work, from home to shopping center -- must be established. Another way of making the distinction is to say that urban form describes the static, physical setting itself and that urban structure describes the dynamics of a particular physical setting. The nomenclature is arbitrary, but the distinction is necessary.

Our basic question might better be put as a series of questions. What effect do changes in the components of urban form have on travel requirements given a particular allocation rule? How does the spatial structure of activity vary with changes in urban form? What is the relative impact of individual elements of urban form on urban spatial structure? Do changes in the residential pattern have more or less impact than changes in transportation service? Is there a best combination of elements of urban form in the sense that this particular combination requires less travel than any other combination of elements? The list of questions could be continued almost indefinitely. They all add up to the same concern: Can we demonstrate the effect of changes in urban form on urban spatial structure?

In addition we want to investigate the influence of the particular allocation rule or rules used in converting form to activity structure. In our analysis we have used a linear programming model as the allocation rule. We want to know what the effect of this particular model is. Is it a useful planning tool? Does it order the structural counterparts of alternate urban forms in the same way that a less restrictive allocation rule would?

To investigate these questions we will build a simple, abstract model of an urban area in which the constituent elements can be easily manipulated within the computer.

Experimental Design

The components of the urban area model are a set of zones comprising the urban area, a set of alternate residential patterns, a set of patterns of workplaces, a set of patterns of shopping centers, and alternate systems of transportation service. The number of residences equals the capacity of the workplaces and the capacity of the shopping centers. In other words, one trip is to be made from each residence to a workplace and to a shopping center.

The hypothetical urban area is shown in Figures 11, 12, and 13. There are 37 zones of equal size. Thirty-two of these zones may contain residences. No residences are permitted in zones containing work centers. There are seven commercial centers. One is in the center of the urban area and the other six are distributed regularly around the center. There are five work centers. Again one is in the center of the urban area and the others are regularly spaced around the center. Three zones contain both work centers and commercial centers.

This is obviously a highly simplified representation of an urban area. However it does resemble the general pattern of many large urban areas. The central zone can be interpreted as the central business district. The outlying commercial centers become major shopping centers, and the outlying work centers may be interpreted as large industrial parks or historic employment concentrations. What is missing is the widespread distribution of smaller commercial opportunities, the neighborhood shopping

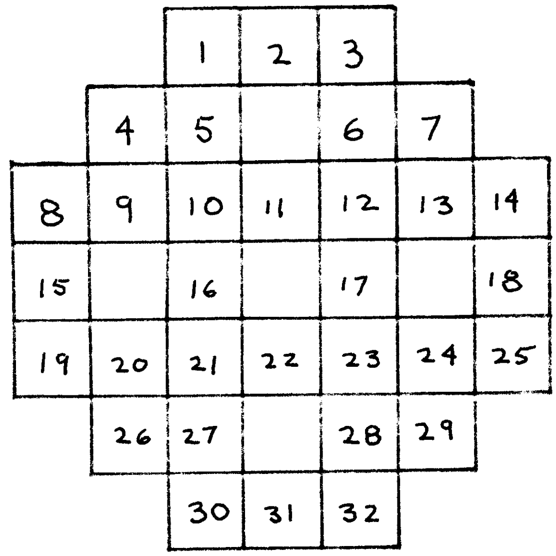


Fig. 11. Location of Residential Zones.

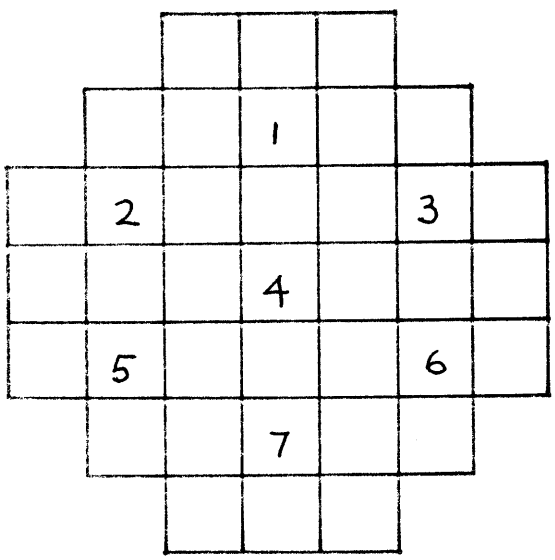


Fig. 12. Location of Commercial Centers.

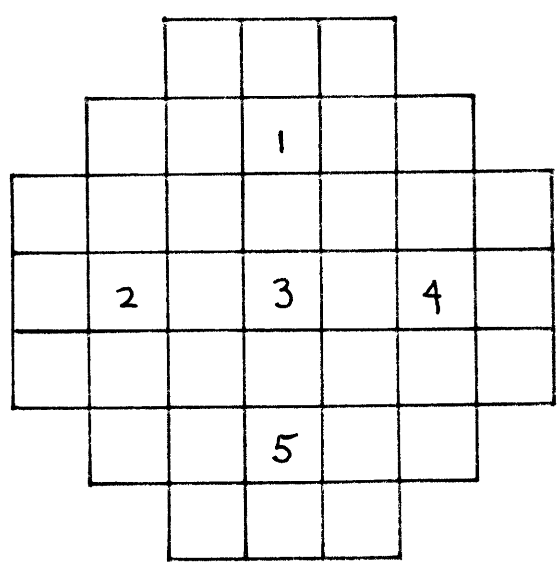


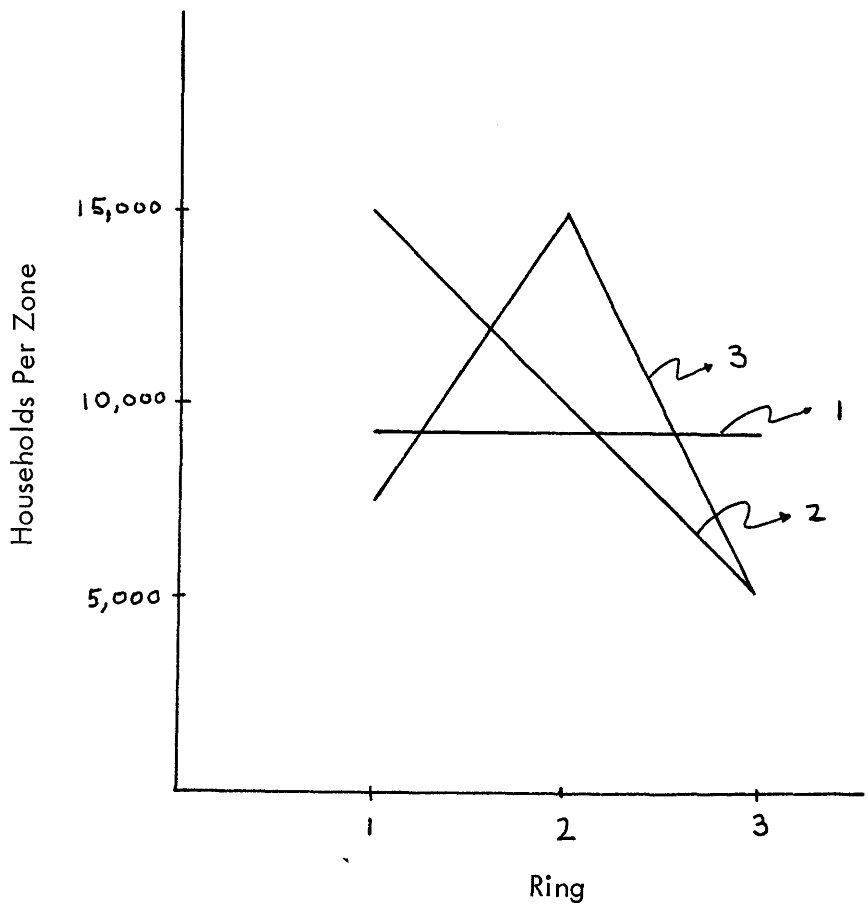
Fig. 13. Location of Work Centers.

centers and the strip commercial development; and the almost equally widespread distribution of small capacity workplaces which are typical of a metropolitan area. Also missing is the widespread distribution of jobs. For example, we are not including worktrips to shopping centers in order to keep the model simple. The model presents only the bare bones of a typical large urban area.

There are three alternate residential density patterns, two alternate patterns of commercial center and work center capacity, and three alternate systems of transportation service. The alternate residential density patterns are: (1) uniform density throughout the urban area, (2) high central density declining regularly with distance from the center, and (3) crested density rising from a low value in the center to a high point and then declining. The residential capacity in households of each zone is shown in Figure 14. There are a total of 300,000 residences. This places the population of the urban area at about one million persons. This size is about equal to the population contained within the cordon area of the Buffalo metropolitan area which we have examined in our earlier analysis.

The residential pattern of alternative 1 is an even sheet of development. Alternative 2 resembles the historical density pattern of large urban areas with high density at the core and low density on the fringe. The third density pattern is as atypical of actual urban areas as the first. It features both a low density core and fringe with the bulk of residential development in between. These alternatives have been selected in order to explore significant differences in urban form. A more realistic description of actual and potential changes would be accomplished by slight variations of the second alternative. Changes in the slope of the density gradient would reflect the increasing suburbanization and decline of central area

Fig. 14. Alternate Residential Density Patterns.



population typical of the trend of the past decades in many metropolitan areas. We are interested in exploring the impact of basically different urban forms. By selecting significantly different alternatives we hope to do this. Unfortunately there is no way of knowing in advance which residential forms are likely to generate the largest differences in travel requirements or locational advantage. Thus the process of learning to design critical experiments is as much a part of this endeavor as is evaluating the experiments we do make.

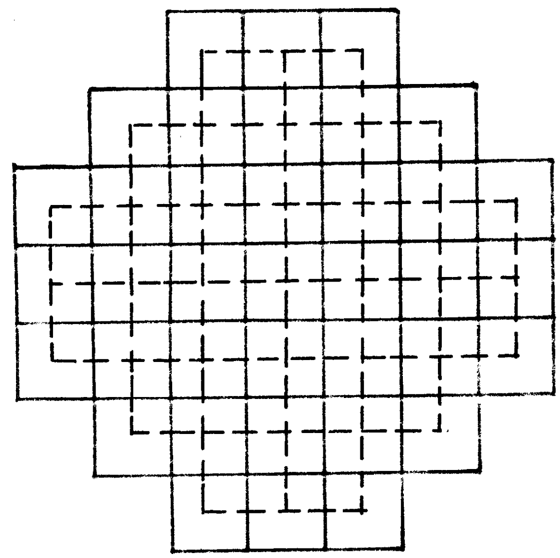
The model requires that each residence be linked with a work center and with a commercial center. Since there are 300,000 residences the capacity of work centers and commercial centers in terms of trips received must each be 300,000. There are two alternative patterns of work center and commercial center capacity, and they are similar. In the first (W1 and C1), 70 percent of the jobs and 70 percent of the shopping opportunities are in the (geographic) center zone. The remaining 30 percent of the jobs are equally divided among the four outlying work centers; and the remaining 30 percent of the shopping opportunities are equally divided among the six outlying commercial centers. The second alternative (W2 and C2) is the reverse of the first. Thirty percent of the work and shopping opportunities are in the central zone and the remaining 70 percent are divided among the outlying centers. These alternatives have obvious interpretations. In the first case there is a traditional strong metropolitan core complemented by relatively weak suburban centers. The second case depicts sharp decline in the relative importance of the core and a corresponding increase in the importance of suburban centers. However, even in the latter case the core capacity is greater than the capacity of an individual suburban center.

There are three alternate transportation systems. The transportation systems are defined as follows. The only routes permitted are in north-south and east-west directions from the center of a zone to an adjacent zone. So a diagonal path through the area is composed of zig-zag right angle links. The travel time or cost of travel from one zone to another is defined in terms of level of service provided rather than in terms of the design capacity and speed of physical facilities.

The first transportation system consists of uniform transportation service. The travel cost of all zone to zone links is given the same, arbitrary value of 2 time units. It is assumed that sufficient capacity to maintain this level of service will be provided. Since the allocation model will impose different loads on different links the network of physical transportation facilities must be differentiated. For convenience we will assume that roads are the only elements of the system and all travel is by individuals in private vehicles. Arterial streets which are designed to move traffic at an average speed of 30 miles an hour must have more capacity than residential streets on which travel is permitted at (and limited to) 30 miles an hour. Similarly, the actual facilities required to achieve a uniform service level in the model would be quite varied.

The second and third transportation systems superimpose higher service level facilities over this basic transportation surface.. In the second system north-south and east-west links through the central zone from the periphery are established at a travel cost of 1. This creates four high service level radial routes. Figure 16 shows the location of these routes. The third transportation system adds to the first and second a ring of high service level links as shown in Figure 17. Taken as a sequence over time these transportation service systems resemble the radial-circumferential

Fig. 15. Transportation Alternative 1. Travel Time on Each Link = 2



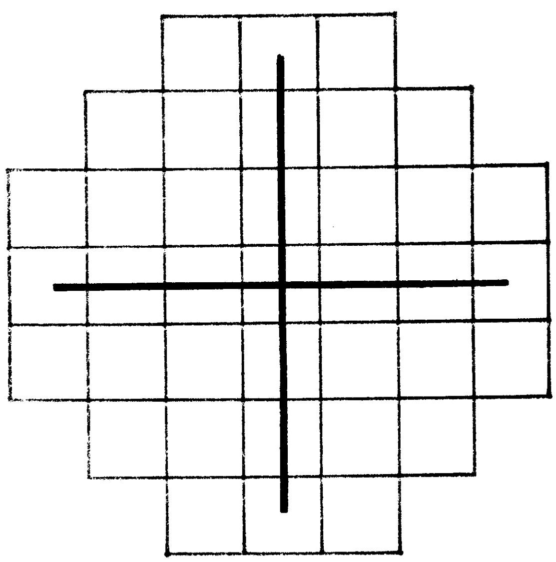
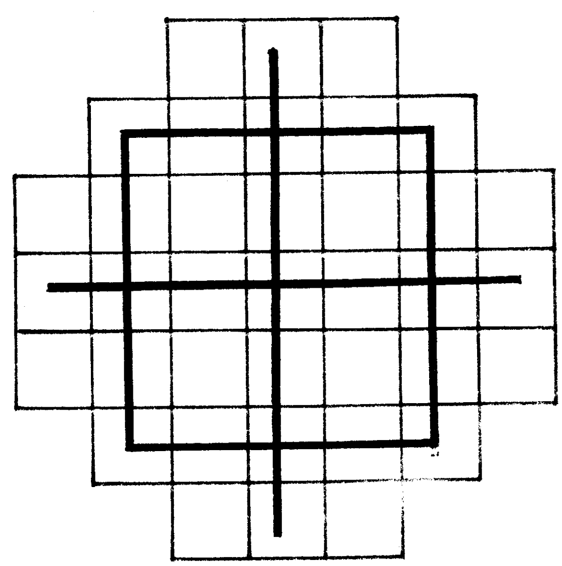


Fig. 16. Transportation Alternative 2. Travel Time on Major Links = 1; All Others = 2

Fig. 17. Transportation Alternative 3. Travel Time on Major Links = 1; All Others = 2



networks of transportation facilities which have been developed in many metropolitan areas. However, we must bear in mind that we have prescribed only the level of service to be provided and not the type of facility.

These three transportation alternatives, three residential alternatives, two commercial center alternatives, and two work center alternatives can be combined into 36 different urban forms. The paths of Figure 18 show the different combinations possible with each transportation system. To clarify the alternative urban forms possible we will give each a description. Basically all combinations with the first residential alternative are variants of a spread city. With the second residential alternative all combinations are variants on a cone shaped form which we will call a centric city. Combinations with the third residential alternative we will call variations of a ring city. The alternative forms are:

R1, C1, W1 - Spread city with strong core

R1, C1, W2 - Spread city with spread employment, but strong commercial core

R1, C2, W1 - Spread city with spread commercial, but strong employment core

R1, C2, W2 - Spread city

R2, C1, W1 - Centric city

R2, C1, W2 - Centric city with dispersed employment

R2, C2, W1 - Centric city with dispersed commercial

R2, C2, W2 - Centric city with dispersed commercial and employment

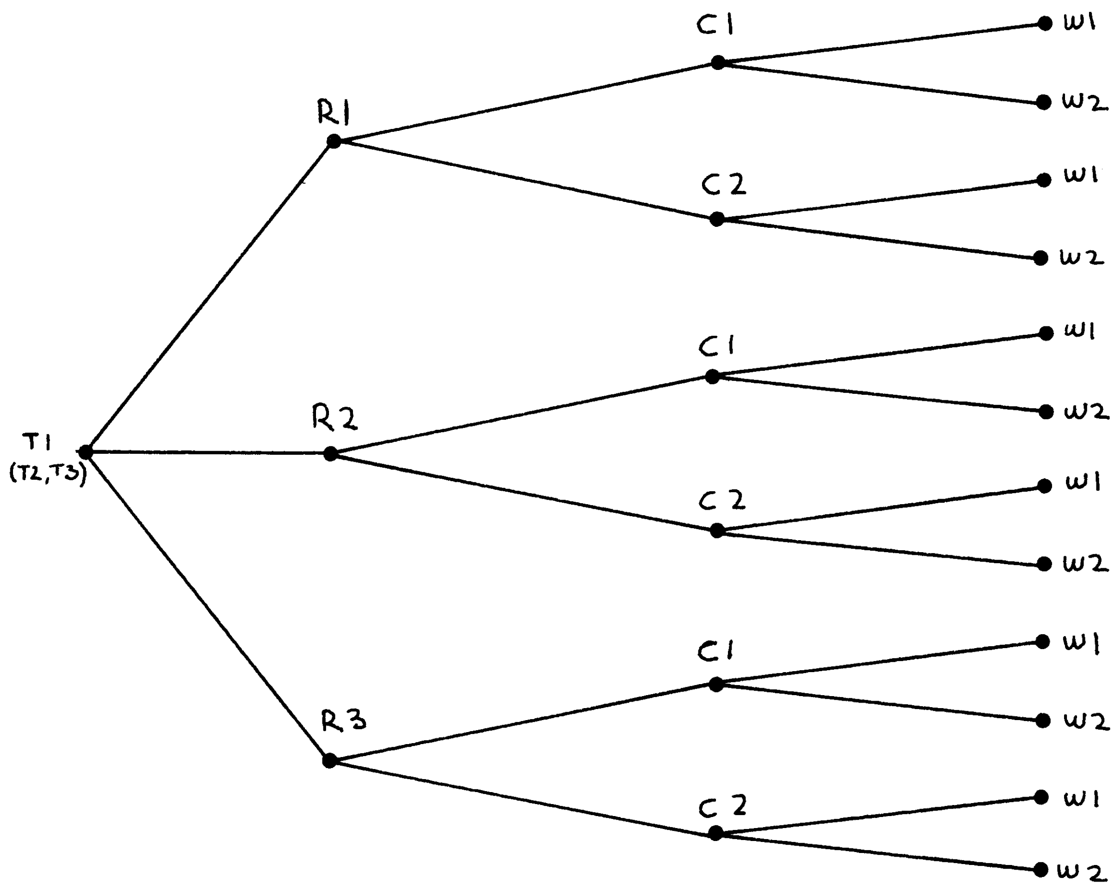
R3, C1, W1 - Ring city with strong commercial and employment core

R3, C1, W2 - Ring city with commercial core

R3, C2, W1 - Ring city with employment core

R3, C2, W2 - Ring city with weak core

Fig.18. Composition of Alternate Urban Forms.



The spread city and the centric city are the polar alternatives. In the first case all components of urban form are spread over the landscape. In the latter all components of urban form are oriented toward the geographic center of the area. All other combinations fall somewhere between these two extremes. The alternative transportation systems can be intuitively related to the alternate development patterns. The first system, providing uniform transportation service is essentially neutral. It is indifferent to urban form. We would expect the second system featuring high level radial access to the center of the urban area to be well matched with the centric city. The third system provides a high level of service through the outer ring and might be expected to best match the dispersed forms of both the spread and ring city.

The Allocation Model

The allocation rule we will use is the linear programming allocation to minimize total travel time. Separate allocations are made from residences to workplaces and from residences to commercial centers. Since commercial centers are also workplaces a joint allocation from residence to commercial centers and workplaces would be a preferable allocation model for work trips. But, since commercial center employment could not realistically exceed 20 percent of total employment, the commercial employment capacity of the outlying commercial centers would always be satisfied by intrazonal linkages in four of the six cases. In the other two cases and in the central zone the capacity would be allocated from an adjacent zone. The net effect on the outcome of the experiments of including commercial workers would be a slight, but uniform reduction of total travel requirements. The activity linkage patterns would probably not be changed since the commercial worker capacities would probably be too small to exhaust all residential origins in any one zone.

The linear programming model allocates, in effect, a person from each residence to a work center and from each residence to a commercial center in such a way that total travel costs of each trip activity are minimized. The minimizations are separate. For a given set of T, R, C, and W the work linkages are not influenced by and do not influence the shopping linkages and vice-versa. The output of the allocation model provides three kinds of information about the activity structure for a particular urban form -- the travel cost required by the minimal cost linkages; the linkage pattern selected; and from the dual of the minimizing problem, the comparative locational advantage of residential zones. We will examine each of these for some, but not all of the possible urban forms.

The Impact of Alternate Urban Forms on Minimum Travel Requirements

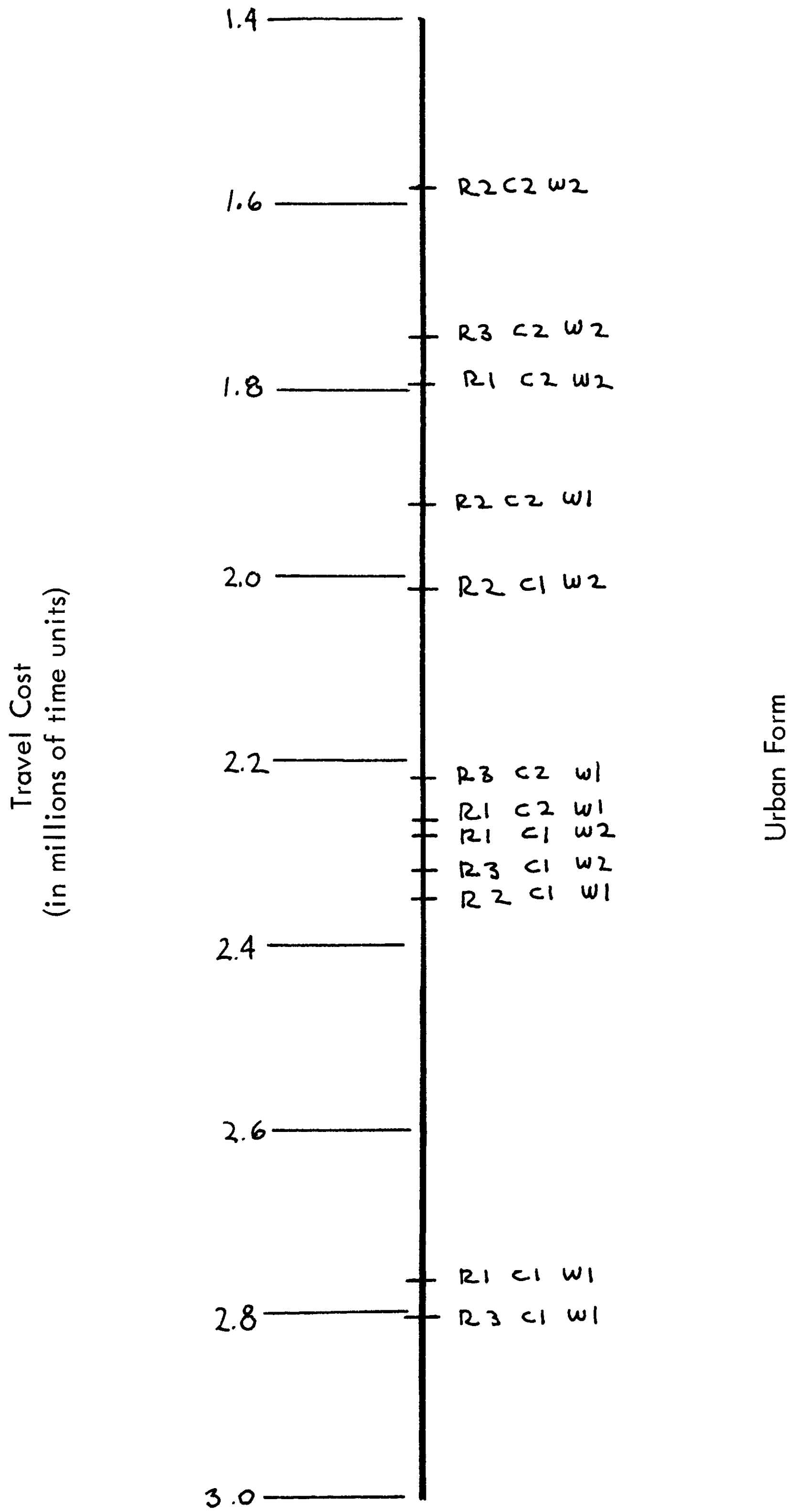
First we will look at the minimum travel requirements of alternate urban forms when the transportation system is constant. Table 15 shows the time units required for the minimal linkages in each of the 30 experiments conducted. Each experiment contains two allocations -- trips to a given distribution of workplaces and trips to a given distribution of commercial centers -- from a common residential distribution. The travel times for work and shopping trips are summed to give the total travel time for the specified urban form.

Figure 19 shows the travel requirements of all twelve possible urban forms with the system of uniform transportation service. The least cost solution is R2 C2 W2, the centric city with dispersed commercial and employment opportunities. The most costly form is R3 C1 W1 and it is closely followed by R1 C1 W1. These are,

Table 15. Time Units Required for Minimal Linkages in Urban Form Experiments.

Urban Form Experiment	Commercial	Work	Total	Rank
T1 R1 C2 W2	827,500	960,000	1,787,500	3
T1 R1 C2 W1	827,500	1,440,000	2,267,500	7
T1 R1 C1 W2	1,320,000	960,000	2,280,000	8
T1 R1 C1 W1	1,320,000	1,440,000	2,760,000	11
T1 R2 C2 W2	680,000	900,000	1,580,000	1
T1 R2 C2 W1	680,000	1,240,000	1,920,000	4
T1 R2 C1 W2	1,112,000	900,000	2,012,000	5
T1 R2 C1 W1	1,112,000	1,240,000	2,352,000	10
T1 R3 C2 W2	760,000	980,000	1,740,000	2
T1 R3 C2 W1	760,000	1,460,000	2,220,000	6
T1 R3 C1 W2	1,340,000	980,000	2,320,000	9
T1 R3 C1 W1	1,340,000	1,460,000	2,800,000	12
T2 R1 C2 W2	629,375	742,500	1,371,875	2
T2 R1 C2 W1	629,375	982,500	1,611,875	5
T2 R1 C1 W2	894,375	742,500	1,636,875	6
T2 R1 C1 W1	894,375	982,500	1,876,875	9
T2 R2 C2 W2	580,000	700,000	1,280,000	1
T2 R2 C2 W1	580,000	880,000	1,460,000	3
T2 R2 C1 W2	815,000	700,000	1,515,000	4
T2 R2 C1 W1	815,000	880,000	1,695,000	8
T2 R3 C2 W1	612,000	1,040,000	1,652,000	7
T3 R1 C2 W2	545,000	592,500	1,137,500	2
T3 R1 C2 W1	545,000	832,500	1,377,500	7
T3 R1 C1 W2	772,500	592,500	1,365,000	6
T3 R1 C1 W1	772,500	832,500	1,605,000	9
T3 R2 C2 W2	460,000	540,000	1,000,000	1
T3 R2 C2 W1	460,000	720,000	1,180,000	3
T3 R2 C1 W2	690,000	540,000	1,230,000	4
T3 R2 C1 W1	690,000	720,000	1,410,000	8
T3 R3 C2 W1	495,000	800,000	1,295,000	5

Fig. 19. Minimum Travel Requirements of Alternate Urban Forms.



respectively, the ring city with a strong core and the spread city with a strong core. In general the urban forms with a weak commercial and employment core have the lowest travel requirements and those with a strong core have the greatest travel requirements.

Looking at the individual elements we see that a change in C when R and W are the same has the greatest impact on travel requirements. Next in significance is a change in W when R and C are common. Changes in the residential pattern have the least effect on travel requirements.

Looking next at the travel requirements of alternatives of each element we see that C2 always requires less travel than C1 for the same combination of R and W. And W2 always requires less travel than W1 for any given combination of R and C. Also, any combination of C and W with R2 requires less travel than the same combination with R1 or R3.

These results suggest that, given uniform transportation service, the most efficient urban form couples dispersed employment and commercial opportunities with residential density that is high in the center and declines with distance from the center. The results also suggest that major variations in the residential pattern do not have a very significant influence on travel requirements. Changes in the pattern of shopping and employment opportunities have relatively more impact on minimum travel time.

It is difficult to evaluate these results because the differences in the alternatives of the several elements are not necessarily of the same magnitude. For example, the difference between R1 and R2 -- from uniform residential density to a regular density gradient -- does not necessarily involve the same proportional change as the differences between C2 and C1 -- a spread commercial pattern and a centrally concentrated pattern of shopping opportunities. So we must qualify the statement that changes in C have a greater influence on minimum travel time than changes in R by saying that this has been shown to be so if the changes in C and R are comparable.

Table 15 gives the minimal travel requirements for all the experiments conducted. In addition to the full 12 form combinations with T1 we have conducted experiments with 9 form combinations with both T2 and T3. The most important finding is that the general ranking of alternative urban forms by travel requirements found with T1 holds for both T2 and T3. This means that at least for the particular alternatives we have examined the system of transportation service has little influence on the relative efficiency of alternate urban forms. If this is generally true, that is if it holds for other transportation systems and other residential, commercial, and employment patterns than we have examined, it is a very significant finding.

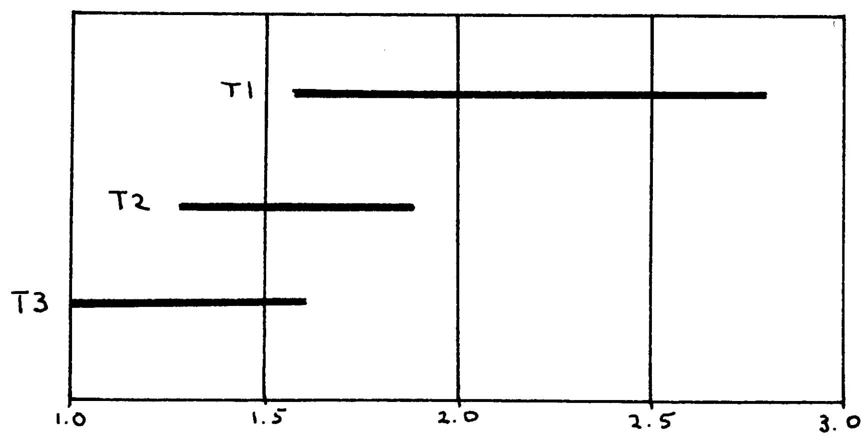
The obvious implication for urban planning is that the spatial pattern of land use and the pattern of transportation service can be planned somewhat more independently than is commonly thought. Independence is implied in a peculiar sense. The results do not imply that the land use pattern and the transportation system are not interrelated. They imply that evaluation of alternative land use patterns may be considered without reference to particular transportation systems. The reverse situation is clearly not implied. If this implication is correct then the proper order of attack on the problem of selecting an efficient urban form is to examine alternative land use patterns and then to examine alternate transportation systems to serve the selected land use pattern.

While alternate transportation systems do not significantly affect the relative efficiency of alternate land use patterns they do affect the absolute efficiency of these patterns. Figure 20 shows the range of minimum travel requirements for all the experiments with the three transportation systems. For any combination of R, C, and W the minimum travel requirements are reduced as the quality of transportation service is improved. This is not surprising. Any other result would make us suspect that the model was totally irrelevant to the conditions it is being used to examine. Two other findings are worthy of note, however. First, improvement of the quality of transportation service results in a reduction of the absolute difference in travel requirements between alternate land use forms. The total range of travel requirements is reduced. This also is to be expected. But it is interesting to note that after the first improvement, the substitution of T2 for T1, the range of travel time required is not further reduced by the addition of more high level service in T3.

The second observation is that the results of the experiments begin to suggest ways in which changes in the land use pattern can be traded off against changes in the transportation system to achieve the same level of improvement in minimum travel requirements. For example, if we start with the urban form described by T1 R2 C1 W1, the centric city with a strong core, approximately the same improvement in minimum travel requirements can be achieved by substituting T2 for T1 -- improving the quality of radial transportation service to the core -- or substituting C2 and W2 for C1 and W1 -- dispersing commercial and employment opportunities to the outer zones. The potential for this type of trade-off is shown by the areas of overlap in Figure 20.

These conclusions may seem somewhat at odds with our earlier observation of independence of the transportation system and the land use pattern. But there is no

Fig. 20. Range of Travel Requirements With Alternate Transportation Systems.



Travel Cost
(in millions of time units)

conflict. Our earlier observation was that changes in the transportation system do not appear to affect the relative efficiency of alternate land use patterns. These second observations simply show that a superior transportation system can make an inferior land use pattern as efficient as a superior land use pattern. The implication for planning is equally clear. If, for example, a level of minimum travel requirements is specified as an objective, alternate means of achieving it can be demonstrated and a clear policy choice between investment in transportation service, and control and direction of land development can be formulated.

Alternate Urban Forms and Activity Linkage Patterns

The simplest and most informative way of examining the impact of alternate urban forms on the spatial structure of activity formed by minimal linkages is to map the linkage patterns. The 30 experiments we have conducted are too many to look at easily, however. So we will select from these some critical experiments which are representative of the full range.

Examination of the impact of alternate urban forms on minimum travel requirements has shown that changes in the distribution of work and commercial opportunities have a similar effect. It is clear that they will also have a similar effect on the activity linkage pattern. So we need look at only combinations of T, R, and W or T, R, and C. For convenience we choose to look at combinations of T, R, and W. They will show the significant pattern differences. The only urban forms we cannot examine are those with C1 W2 and C2 W1. However, these fall between C1 W1 and C2 W2 in travel requirements, and will result in activity patterns between the two extremes. Therefore the full range of variation will be included in the combinations of T, R, and W. We can further reduce the number of experiments to be examined by first considering all combinations of R and W with one T alternative and then considering all variations of T and W with one R alternative. This requires examination of ten experiments. The selected experiments are:

T1 R1 W1
T1 R1 W2
T1 R2 W1
T1 R2 W2
T1 R3 W1
T1 R3 W2
T2 R2 W1
T2 R2 W2
T3 R2 W1
T3 R2 W2

The activity linkage patterns formed by the minimum allocation for these experiments are shown in Figures 21 through 30.

Since our model of an urban area is quite simple, the activity patterns must also be quite simple. This is a help rather than a hindrance because it enables us to see clearly and easily the relative impact of changes in the individual components of urban form.

Changes in the transportation system, we noted, have no effect on the relative efficiency of alternate urban forms. Now if we look at the activity patterns of T1 R2 W2, T2 R2 W2, T3 R2 W2 (Figures 24, 28, and 30 respectively) we see that changes in the transportation system also do not affect the linkage pattern. This observation holds if we change the R or W components. Figures 23, 27, and 29 show the linkage patterns of T1 R2 W1, T2 R2 W1, and T3 R2 W1 respectively. Again the patterns are quite similar. All of them are markedly different from the first set, and

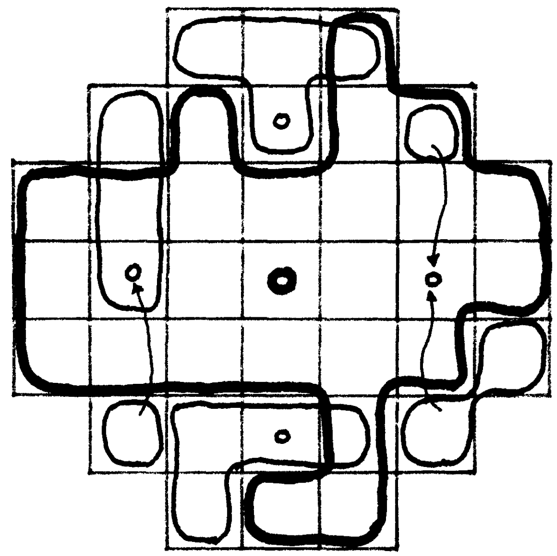


Fig. 21. Spatial Linkage Pattern for Urban Form T1 R1 W1.

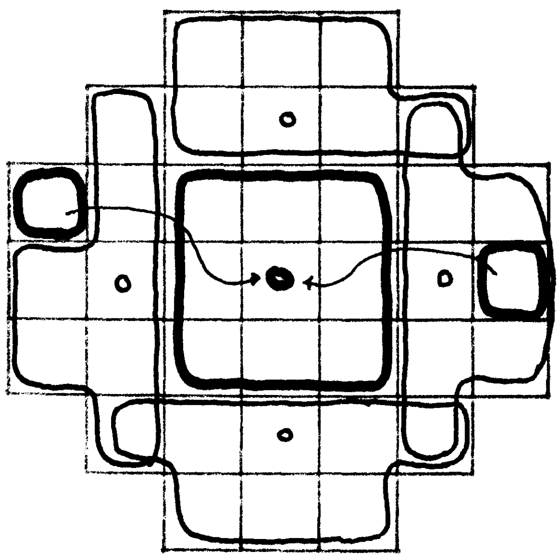


Fig. 22. Spatial Linkage Pattern for Urban Form T1 R1 W2.

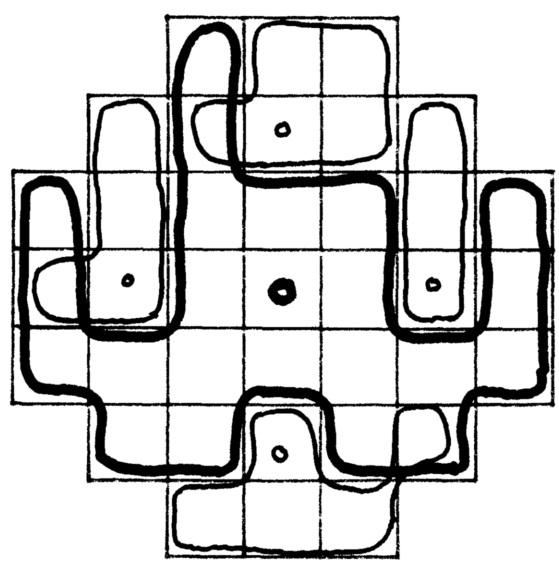
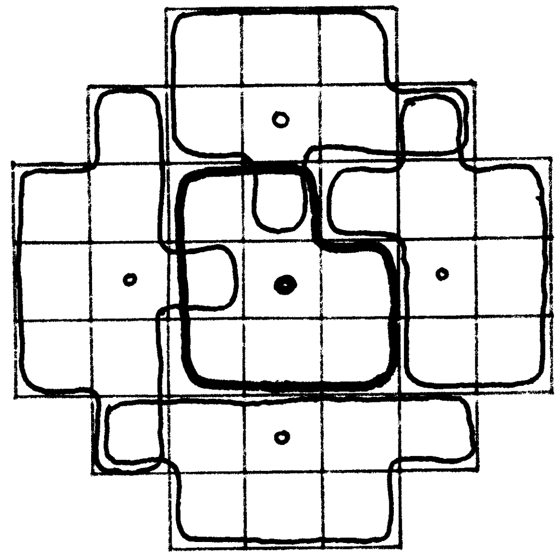


Fig. 23. Spatial Linkage Pattern for Urban Form T1 R2 W1.

Fig. 24. Spatial Linkage Pattern for Urban Form T1 R2 W2.



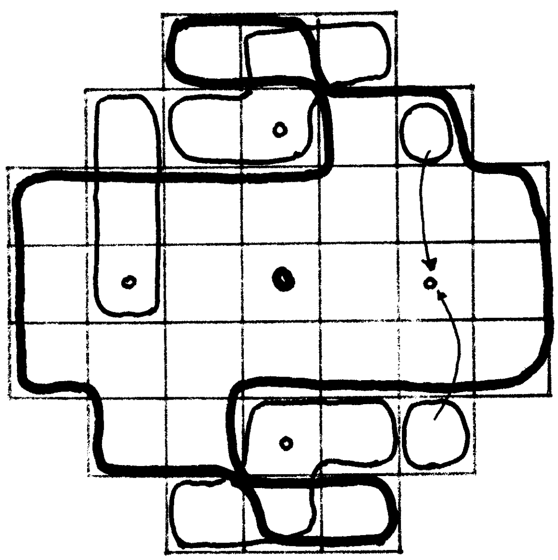
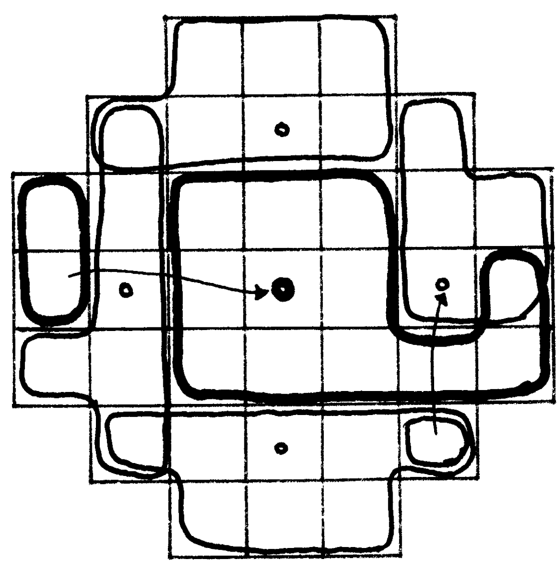


Fig. 25. Spatial Linkage Pattern for Urban Form T1 R3 W1.

Fig. 26. Spatial Linkage Pattern for Urban Form T1 R3 W2.



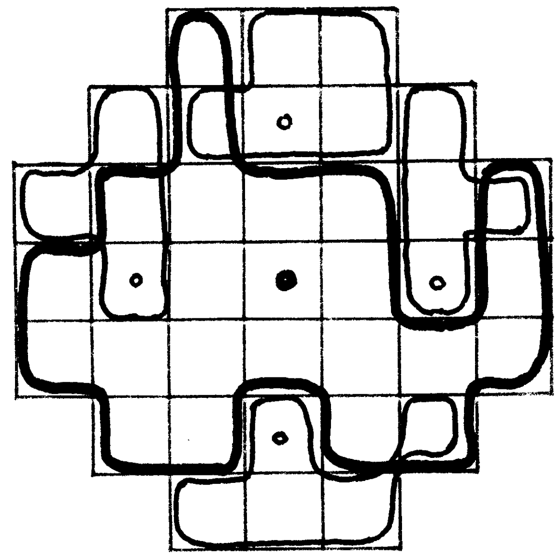


Fig. 27. Spatial Linkage Pattern for Urban Form T2 R2 W1.

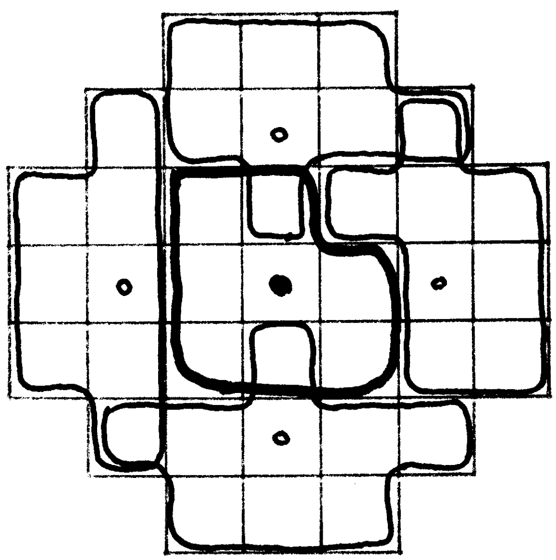


Fig. 28. Spatial Linkage Pattern for Urban Form T2 R2 W2.

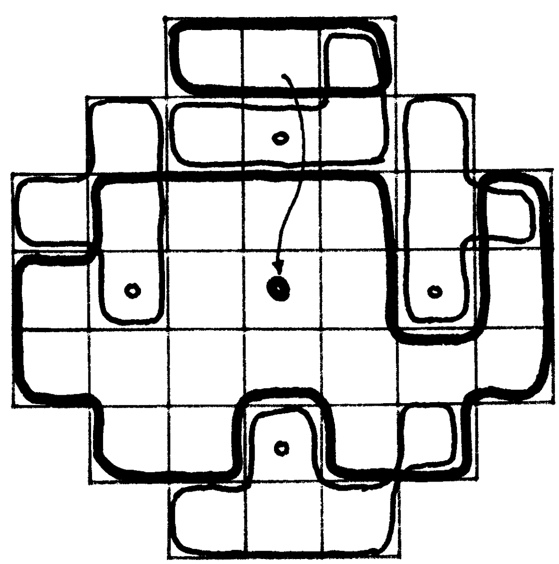
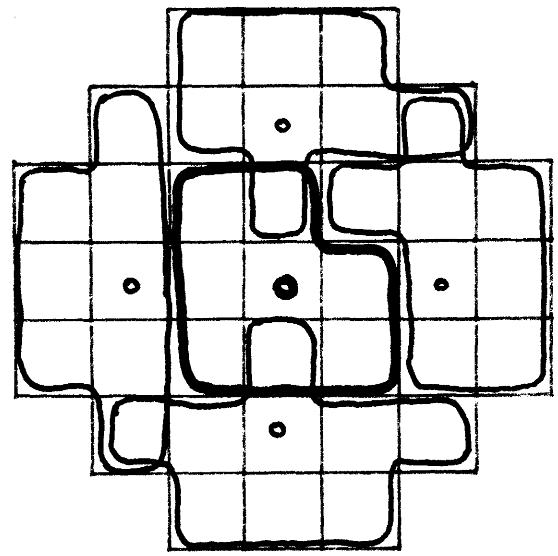
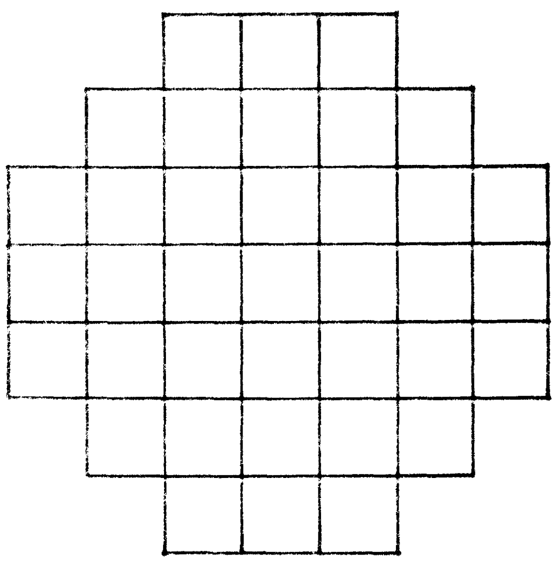
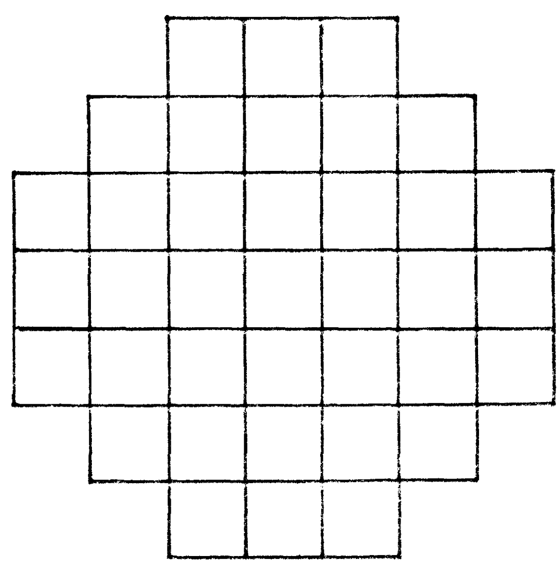


Fig. 29. Spatial Linkage Pattern for Urban Form T3 R2 W1.

Fig. 30. Spatial Linkage Pattern for Urban Form T3 R2 W2.







since the constant item that changed is the distribution of employment opportunities we may conclude that the pattern of employment opportunities has a marked effect on linkage patterns.

We previously found that changes in the residential pattern had relatively little effect on minimum travel requirements. Of the three residential patterns R2 always required less travel for any given combination of C and W than R1 or R3. Figures 22, 24, and 26 show the linkage patterns resulting from the urban forms defined by R1, R2, and R3 with T1 and W2. There is some change in the linkage pattern whith changes in R. The major change is that the focal region of the central employment zone increases in size progressively with R2, R1, and R3.

Since increases in the size of central focal region will accompany increases in total travel time for the area it is consistent with our previous findings, and reassuring, that R2 is associated with the smallest central focal region. These observations can be checked by substituting W1 for W2 in combination with T1 and R1, R2, and R3. Figures 21, 23, and 25 show the activity linkage patterns for these urban forms. Again the size of the central focal region increases progressively from R2 to R1 to R3. However, the actual increase is reduced. In the first set of experiments, with T1 and W2, three zones are added to the central focal region when R1 is substituted for R2, and three more are added when R3 is substituted for R1. In the second set of experiments, with T1 and W1, two zones are added with each substitution.

While changes in the residential pattern have an effect on the activity linkage pattern it is again obvious that the significant changes result from changes in the distribution of work (and by inference, commercial) opportunities. This can easily be seen by examining the five pairs of experiments where W is varied and R and T are constant. The pairs are shown by Figures 21 and 22; 23 and 24; 25 and 26; 27 and 28; and 29 and 30. In each case the central focal region is greatly expanded by the substitution of W1 for W2. This is an obvious, expected result. Concentration of job opportunities in the core simply extends the influence of the core outward into the urban area.

The significance of the activity linkage patterns resulting from our experiments is not in the demonstration that changes in the distribution of job opportunities have a marked effect on activity structure. The significant observation is that fairly dramatic changes in the pattern of transportation service and residential density have little or no effect on activity structure. This suggests again a greater degree of freedom in planning than is ordinarily thought to exist. If, in fact, quite different residential patterns make little difference in the efficient functional structure of the urban area, and if persons resident in the area select linkages with substantial rationality, then the different physical forms of urbanization do not have counterpart functional structures.

We might argue that differences in the physical form of residential development are almost irrelevant to the functional structure of the urban area. Since the functional structure of the urban area is a major concern of urban planning we might then suggest that far too much attention is currently given to the problem of the broad pattern of residential development. As we have seen in Chapter 1, many current efforts to develop urban land use models concentrate on the simulation of residential development and require the major commercial and employment opportunity distributions as model inputs. Then they proceed to examine the effect of alternate policies and/or assumptions on the residential pattern and on those land uses closely related to residential development. Perhaps the argument that such efforts are like "tilting at windmills" is too extreme. Certainly the evidence we have accumulated is not sufficient to verify it. But our results suggest that a re-evaluation of current emphases is worth while.

Locational Advantage as a Measure of Urban Form

Thus far our experiments have shown that alternate residential patterns have relatively little effect either on minimum travel requirements of the experimental urban forms or on the work and commercial activity structures defined by the minimum allocations. However, alternate residential patterns may nevertheless represent significantly different locational qualities for residents of individual zones. Both the examination of travel requirements and of activity structure dealt essentially with aggregate characteristics of urban form. To examine the effect of alternate urban forms on the locational qualities of individual zones we turn to an analysis of comparative residential locational advantage.

Comparative locational advantage, as previously defined, is a measure of the relative competitive position of each of the residential zones with respect to a particular locational pattern of opportunities for a particular activity. Technically, values of comparative locational advantage are derived from the dual of our travel minimizing linear programming allocation rule. The formal dual problem is the maximization of the difference between the value or price at the origin and the price at the destination. Since the difference between these prices is the cost of travel from origin to destination for linkages included in the optimal solution, the prices are given in units of travel cost.

For our analysis we will use the same ten experiments examined in the analysis of activity structure. So the activity reference of residential locational advantage will be the journey to work. Before looking at the pattern of locational advantage defined by the experiments we turn to an aggregate statistic -- the range of locational advantage.

The range of values of locational advantage is simply the difference between the highest zonal value and the lowest zonal value defined in a particular experiment. The significance of the choice of a residential zone increases with increases in the range of values of locational advantage. If the range were zero, that is if all zones had an equal value of locational advantage, there would be no reason to select one zone over another as a residential location. If the range of values were very large, the choice of a residential zone would be more significant since it would involve the potential for travel savings.

The range of values of comparative locational advantage defined by all 30 experiments conducted is given in Table 16. As expected the range of locational advantage decreases with improvements in the quality of transportation service. This is simply a result of decreases in the average travel expenditure. Alternate urban forms with any one transportation system show considerable stability in range of locational advantage. The only variations occur in the combination of W1 and W2 with T2 R2, and in the combination of C and W alternatives with T3 R2.

Turning to our ten experiments we find that the pattern of locational advantage is identical for 5 of the 6 form combinations with T1. These are T1 R1 W1; T1 R1 W2; T1 R2 W1; T1 R3 W1; and T1 R3 W2. Their common pattern is shown in

Table 16. Range of Values of Comparative Locational Advantage of Alternate Urban Forms.

Experiment	Commercial	Employment	C + W/2
T1 R1 C2 W2	6	6	6
T1 R1 C2 W1	6	6	6
T1 R1 C1 W2	6	6	6
T1 R1 C1 W1	6	6	6
T1 R2 C2 W2	6	6	6
T1 R2 C2 W1	6	6	6
T1 R2 C1 W2	6	6	6
T1 R2 C2 W2	6	6	6
T1 R3 C2 W2	6	6	6
T1 R3 C2 W1	6	6	6
T1 R3 C1 W2	6	6	6
T1 R3 C1 W1	6	6	6
T2 R1 C2 W2	4	5	4.5
T2 R1 C2 W1	4	5	4.5
T2 R1 C1 W2	4	5	4.5
T2 R1 C1 W1	4	5	4.5
T2 R2 C2 W2	4	3	3.5
T2 R2 C2 W1	4	5	4.5
T2 R2 C1 W2	4	3	3.5
T2 R2 C1 W1	4	5	4.5
T2 R3 C2 W1	4	5	4.5
T3 R1 C2 W2	4	4	4
T3 R1 C2 W1	4	4	4
T3 R1 C1 W2	4	4	4
T3 R1 C1 W1	4	4	4
T3 R2 C2 W2	2	2	2
T3 R2 C2 W1	2	4	3
T3 R2 C1 W2	4	2	3
T3 R2 C1 W1	4	4	4
T3 R3 C2 W1	4	4	4

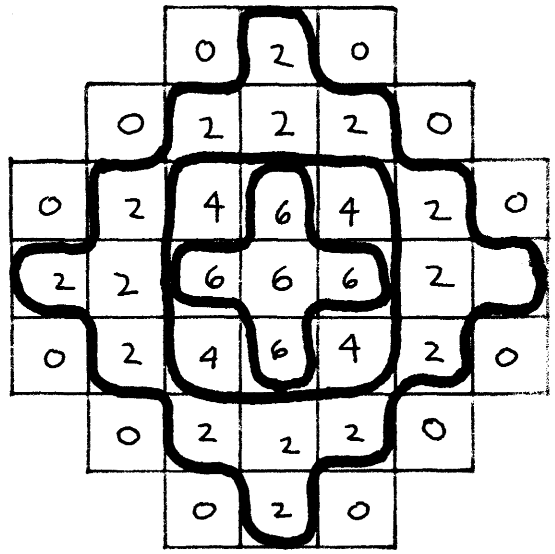
Figure 31. The exceptional pattern is T1 R2 W2. It is shown in Figure 32. The pattern of locational advantage of the remaining experiments is shown in Figures 33 through 36. Similarity of pattern of locational advantage holds with T2 and T3. So Figure 33 shows the pattern of locational advantage of T2 R1 W1; T2 R1 W2; etc., in addition to T2 R2 W1. And Figure 35 shows the pattern of T3 R1 W1; T3 R1 W2; etc., in addition to T3 R2 W1.

What do these rather strange results mean? First we can observe that changes in the residential pattern alone do not change the pattern of comparative locational advantage because T1 R1 W1, T1 R2 W1, and T1 R3 W1 are identical. Similarly we observe that changes in the distribution of work opportunities alone do not change the pattern of comparative locational advantage because the pairs T1 R1 W1 and T1 R1 W2; and T1 R3 W1 and T1 R3 W2 are identical. Changes in the pattern of locational advantage occur only when R2 and W2 are both present.

The net effect of the combination of R2 W2 on the pattern of locational advantage is twofold. It lowers the range of values of locational advantage, and it increases the areal extent of highest locational advantage. The urban form, R2 W2 which is associated with significant changes in the pattern of locational advantage also reduces the range of values of locational advantage and thus decreases the significance of selecting a particular residential zone for potential travel savings. This urban form -- the centric city with dispersed employment (and by inference, commercial) opportunities is, of course, the urban form which has the lowest minimum travel requirements.

One further outcome of the linear allocation model should be noted. The dual problem, as we have said, calculates value or prices at both origin and destina-

Fig. 31. Comparative Locational Advantage of Residence Zones; Urban Forms T1 R1 W2, T1 R2 W1, T1 R3 W1, T1 R3 W2, and T1 R1 W1.



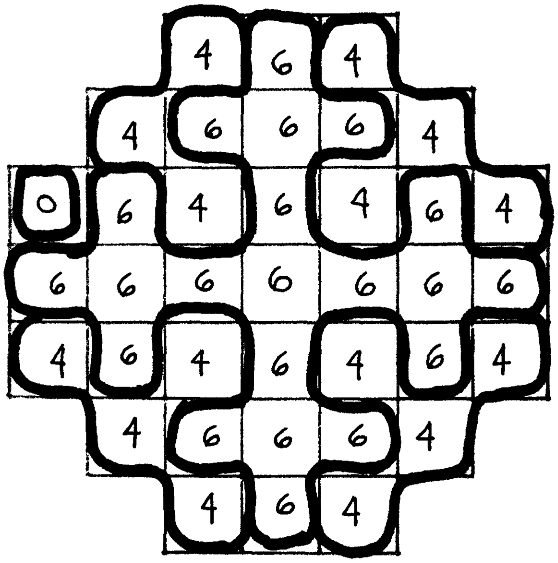
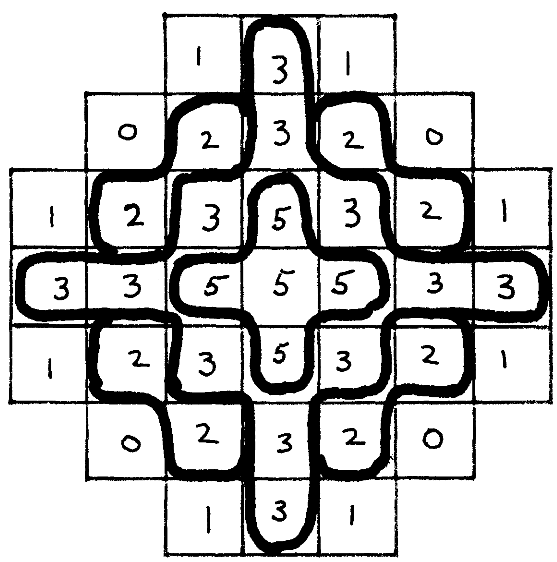


Fig. 32. Comparative Locational Advantage of Residence Zones; Urban Form T1 R2 W2.

Fig. 33. Comparative Locational Advantage of Residence Zones; Urban Form T2 R2 W1.



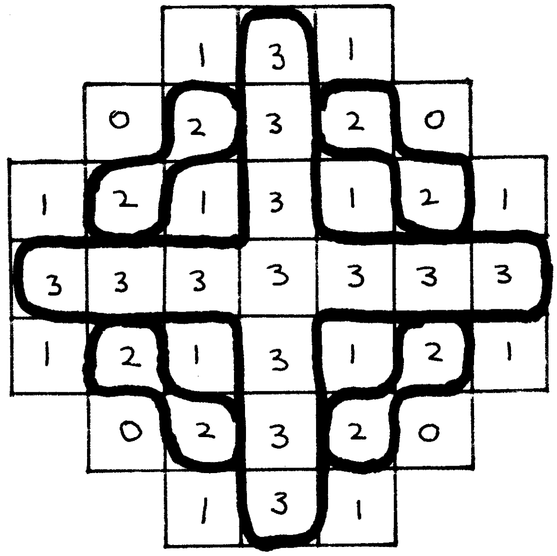


Fig. 34. Comparative Locational Advantage of Residence Zones; Urban Form T2 R2 W2.

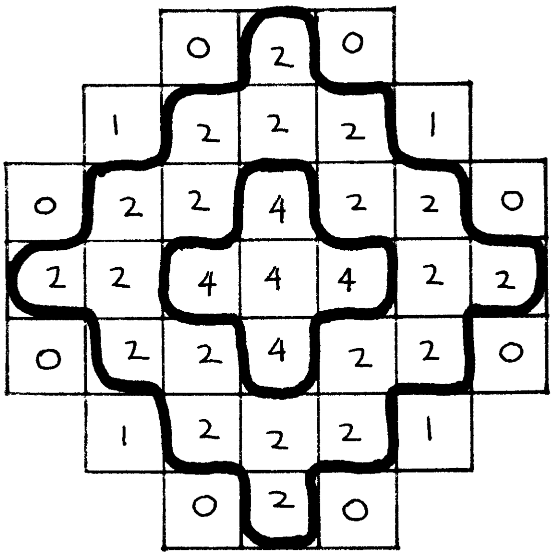
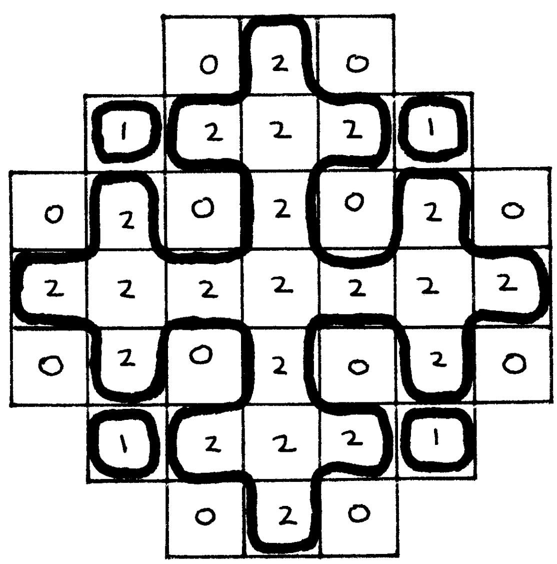


Fig. 35. Comparative Locational Advantage of Residence Zones; Urban Form T3 R2 W1.

Fig. 36. Comparative Locational Advantage of Residence Zones; Urban Form T3 R2 W2.



tion. The price at the destination is traditionally interpreted as the delivered price of the item being shipped. In our experiments the shipped item is persons transporting themselves to work. So the price at the destination may be interpreted as the input cost of labor to the several employment centers. It can be interpreted as the average price in travel time which must be "paid" by each employment center to attract its work force given the distribution of employment opportunities, the residential pattern, and the transportation system. Examination of these prices for the dual problem of all experiments conducted shows that with the urban form R2 W2 and only for that urban form the prices are equal. In other words each work place "pays" the same price for its labor input. We can interpret this to mean that the location of the employment centers is equally efficient. These findings suggest this tentative conclusion: The urban form requiring the least travel with a given transportation system is also the most advantageous from the viewpoint of residential-nonresidential activity linkages because it provides the greatest equality of locational advantage to residential sites and equalizes the efficiency of nonresidential sites.

Significance of the Allocation Rule

In our analysis of the impact of urban form on travel requirements we raised the question of the influence of the linear programming allocation model on the results of the experiments. Although we have demonstrated that substantial rationality exists in actual travel behavior, the linear allocation model is an extreme or polar rule. For an examination of its influence we will use as our allocation rule the opposite extreme -- complete indifference to travel cost.

The selection of linkages when travel time is ignored can be simulated by a simple proportional allocation. Under this rule linkages from each residential zone to the zones containing work or commercial destinations are directly proportional to the number of destinations in a particular zone and inversely proportional to the total number of destinations.[1] Mathematically the travel indifferent allocation rule can be stated:

$$X_{ij} = \frac{R_i O_j}{\sum O_j}$$

where: X_{ij} = linkages from i to j

R_i = number of residences in i

O_j = number of destinations in j

$\sum O_j$ = total destinations

The allocation rule is equivalent to a gravity model where the exponent of travel time is zero and "K" factors are equal to one. Since the minimum travel requirements of the alternate patterns of commercial and employment opportunities with the several transportation alternatives vary in a similar fashion we can evaluate the influence of the linear allocation rule with one set of combinations of alternate residential and commercial center patterns. We will use all combinations of R and C with T1.

Table 17 shows the travel requirements for the two allocation rules. Predictably the proportional allocation rule requires less travel for urban forms containing C1, core-concentrated commercial opportunities, than for C2, dispersed commercial opportunities with a given residential pattern. This occurs because the proportional allocation links every residential with each commercial center. When more

Table 17. Travel Requirements of Alternate Urban Forms With Linear Programming and Proportional Allocation Rules.

(in time units)

Experiment	Linear Allocation	Proportional Allocation
T1 R1 C1	1,320,000	1,937,140
T1 R1 C2	827,500	2,119,640
T1 R2 C1	1,112,000	1,778,000
T1 R2 C2	680,000	1,903,284
T1 R3 C1	1,340,000	1,935,000
T1 R3 C2	760,000	2,088,120

commercial opportunities are in the outlying centers, as is the case with C2, the total travel will be larger than with core concentration, as in C1, because there will be more trips criss-crossing the area. Just as C2 always requires less travel than C1 under the linear allocation rule, C1 will always require less travel under the proportional allocation rule. The fact that the difference in travel requirements between C2 and C1 with any given residential pattern is less with the proportional allocation rule than with the linear allocation rule suggests that the proportional allocation is less sensitive to the distribution of opportunities.

The conflict between the two allocation rules is in their selection of a least cost commercial and employment center pattern. There is no conflict between the allocation rules on the question of the least cost residential pattern. Both allocation rules select R2, the traditional pattern of declining density from the center, as the least cost solution. And both rules select R3 as the second best, and R1 as the most costly solution.

The real significance of this comparison however is the observation that the differences in travel requirements caused by variations in travel behavior (as simulated by the allocation rules) is much greater than the differences caused by variations in urban form. There is less difference in the minimum travel requirements of the most different urban forms, T1 R1 C1 and T1 R3 C2, than there is in the travel requirements of the minimum and proportional allocations to either of these urban forms. This leads to the simple conclusion that the activity patterns of people as measured by travel behavior are more significant determinants of the functional structure of urban areas than the spatial arrangement of physical components of urban form. A corollary of this is that the emphasis in design and evaluation of urban plans should be placed on the activity structure, its prediction and control, rather than on the physical pattern of development.

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1. For another use of this model in analyzing travel behavior see John R. Hamburg, Charles R. Quinn, George T. Lathrop, and George C. Hemmens, "Linear Programming Test of Journey-to-Work Minimization," Urban Transportation Planning Techniques and Concepts, Highway Research Record 102 (Washington: Highway Research Board, 1965).

CHAPTER 7

PLANNING METROPOLITAN ACTIVITY SYSTEMS

The fundamental concern of the urban planner is with the way in which the urban area functions. Although the materials with which the planner works in attempting to chart a desirable path for urban development are the static elements of the natural and man-made landscape, his attempts to manipulate these elements and to relate them to each other are guided by his conception of how they can and will be used by the residents of the area, and by his conception of what kind and amount of interaction between the physical elements of the urban community is required for effective and efficient functioning of the urban area.

An urban development plan then is, or should be, a structure which is given to the physical elements of the urban area distributed in space. That structure is the activity system of the urban area. It is the integration of the physical elements of the urban area into a functional whole through the daily activities of the residents of the area. Disposition of the roads and land uses in the urban area alone do not make a plan for the urban community. At best they describe the base on which the plan of the community will be built, because the plan of a community includes interaction among the physical elements of the urban area as well as their siting in space. In some instances this interaction is reflected in the spatial juxtaposition or segregation of land uses. In other cases it is not, and cannot be represented on a map of land allocation.

Webber argues much the same point as this in his description of the city as a communications system.[1] He sees the city as a "spatially structured process" which includes both the "structural form" of the city and "functional processes" which are linkage patterns of interdependencies between form elements of the city. He argues for placing major emphasis in planning on the functional relationships between persons. In effect he wants to replace the urban planner's traditional concern for what he calls a hierarchy of spaces with a communications hierarchy which has spatial connotations, but in which persons move by role rather than by foot, automobile, or public carrier.[2]

John Dyckman has perhaps come closest to the concept of an urban plan which we argue for. He says, "Planning...is bound close to the notions of <u>purpose</u>. It is difficult to define either 'community' or 'facility' without having reference to the purpose of people in congregating together or in framing institutions for providing the services..."[3] He recognizes that urban planners generally fail to connect purposive systems of activity with the form of the community.

This study was undertaken to investigate the relationship between activity systems composed of the purposive travel of persons in urban areas and the form of the urban community. The results are promising in that the analysis of actual travel has shown some regularities underlying the widespread and varied travel patterns of persons and in that we have succeeded in making measured, and, we believe, meaningful statements about the efficiency of alternate urban forms and of the impact of some components of urban form on the spatial structure of activity in urban areas.

There are many obvious limitations to this research. Chief among these is that we have dealt with actual travel behavior in only one urban area. and that we have dealt only with aggregated data on travel behavior. The study of actual travel behavior and of the spatial structure of activities in Chapters 1, 2, 3, and 5 have dealt only with the Buffalo, New York area because of the difficulty of obtaining comparable data for other urban areas, and because of the limited time and resources available. Obviously the results of this analysis must be verified by performing a similar analysis of other urban areas. Hopefully this study has demonstrated a useful approach to the analysis of urban activity patterns which can be beneficially applied to other urban areas, and hopefully, some of the findings of this analysis will be reinforced by similar studies.

Two kinds of aggregation have been used in this study. We have dealt with five general types of non-home activities -- work, shopping, school, social-recreation, and personal business. An important next step in this kind of analysis would be to develop a detailed classification of activities and examine travel behavior with respect to these activities. The definition of activities would itself be a major task since there are few precedents for this kind of analysis. Some possibilities include the division of shopping activity into separate activities based on the kind of shopping goods involved, such as convenience goods, consumer durables, etc., and the division of social-recreation activity into separate activities based on the type of activity (spectator sports, active recreation, social visiting, commercial entertainment, etc.), or the kind of facility involved. One such detailed classification of activities has been developed by Chapin.[4] Since such detailed information on activities is not currently collected in urban planning studies or in Census or other public surveys, special field studies would be necessary to extend the present analysis in this direction.

We have also dealt with an aggregation of people in the urban area. In our analysis of travel behavior and the spatial structure of activities we have treated all persons resident in a zone as homogeneous. We have not, because such data were not available, examined variations in travel behavior and the spatial structure of activities which might be attributed to such personal and household characteristics as income, race, occupation, family size, etc. The data for such a study could be obtained by extensive manipulation of the data collected in origin-destination studies of urban travel. And, in our opinion, such a study is necessary to test whether our aggregate treatment of person data is reasonable.

In relating observed travel behavior and the spatial structure of activities resulting from principal linkages to a linear programming allocation of trips we have dealt with total travel time of the trip making population. This was done because our aim has been to examine aggregate behavior and to find a means of evaluating urban form which reflects aggregate behavior of persons resident in an urban area. Thus when interpreting this study, it must be remembered that we have made no claims about individual behavior. We have not, for example, suggested that a linear programming allocation of trips is a reliable simulator of individual travel behavior. On the contrary, we think it would be a very poor simulator of individual behavior.

It is disappointing to come to the conclusion of a study like this with the realization that limitations placed on the study in the original design of the project, while necessary in order to develop a feasible project, are such that they severely limit the general applicability of the results. We suspect that at least in part this is due to our very inadequate knowledge of how urban areas are organized and how, in the daily activities of people, urban areas function. A study such as this can only be a very small exploration in a large unknown area. Nevertheless, we hope that we have demonstrated the usefulness of our particular methodology for further explorations in urban analysis; that we have developed a useful approach for examining the spatial organization of urban areas in terms of the activities of area residents; and that we have perhaps raised some issues that will prompt other investigators to consider our approach either to carry it further than we have been able, or to demonstrate that it is not so useful after all. We would now like to comment briefly on several aspects of the urban planner's task which seem relevant to our analysis of urban activities.

Spatial Organization of Activities

In planning for urban activity systems is there an appropriate system of spatial subdivision of the urban community which corresponds to the activity system? This is an extremely important question because most urban planners assume that there is an appropriate scheme of spatial subdivision of an urban area. Typically spatial organization is viewed as a hierarchy of spaces. At the lowest level of the hierarchy is the neighborhood, which is the smallest unit or building block. Several neighborhoods are combined into a community, and several communities into a larger area. This process continues, depending on the planner's definition of areal units and the size of the urban area until we reach the top of the pyramid which is the entire urban area as a unit. Even recent attempts to analyze the functional organization of urban areas accept this notion of spatial organization.[5]

It is argued that there is a functional organization of activity which corresponds to this scheme of spatial organization. That is, it is assumed that the boundaries of the spatial subdivisions are boundaries of activity systems. Each level of spatial organization is presumed to be the locus of a set of activities.

Our analysis of the spatial structure of activities showed that there are distinctly different sets of boundaries for each of the general activities we have examined. There is no single set of areas which bound even the principal linkages of the three major activities we examined.

The planner's concept of spatial organization is really based on two observations. First the historic conduct of retail trade in urban areas featured a hierarchical pattern of service areas. There were many small stores, carrying convenience items, and serving small areas. There were fewer large stores, carrying specialized merchandise, and serving larger areas. Second, family activities, particularly those centering on child care, were seen to organize activities around the home, and homes around shared child care facilities. The nucleus of the planner's neighborhood is the elementary school, and the nucleus of his community is the junior high or high school. But these patterns may no longer hold true. The housewife seldom walks to the neighborhood store. Usually there is none. And the child seldom walks to school in a suburban neighborhood.

Since our analysis has dealt with aggregated data on activities, we are not in a position to argue whether a hierarchy of spaces corresponding to a hierarchy of detailed activities of some general type such as shopping does exist. Field research on detailed activities, as outlined above, would be needed for this task. However, the fact that there are different spatial organization patterns for the general activities we have examined leads us to believe that no one spatial pattern will adequately bound the organization of different activities even though an individual activity may be disaggregated on a hierarchical basis. If this is so, and from the evidence we have obtained it seems reasonable, then the urban planner need not, and probably should not attempt to plan for all urban activities within a rigid, hierarchical system of spatial organization. Each activity may well have its own spatial pattern.

Plan Design and Plan Evaluation

The planner's task is two-fold. He must design a plan or plans for the physical development of the urban area and the facilities needed to serve that development. And he must evaluate the plan or plans he prepares so that at least some of the consequences of different urban forms and public policies may be anticipated. In the past three decades urban planners have accumulated considerable experience with the first of their tasks -- design of plans. There has been woefully little progress in the evaluation of urban plans. In part this has been due to disagreement among planners as to their responsibility for developing measured alternative urban development proposals, but it is mainly due to the complexity of the task.

There are two main components of the evaluation task which, depending on their content, either simplify the problem or make it extremely complex. These are the criteria used for evaluation and the scale, or level of detail required for evaluation. The progress made in recent years in the evaluation of alternate plans for street and highway facilities is an example of how a useful start on the evaluation of urban development plans can be made by a careful selection of criteria and content.[6] The progress has been possible because the evaluation task was narrowly conceived. A least cost criterion based on the known or estimated costs of constructing the highway system and the estimated travel cost of the system to the highway using public is the mechanism for selection among alternatives. The limitations of this type of evaluation are recognized by those who developed it. In the selection of a transportation network plan many other unquantified considerations must still be weighed along with the transportation system costs. But some progress has been made.

Evaluation of alternate urban plans including both land development and transportation components poses a similar and more complex problem. The number of possible criteria is large. They include economic productivity, social welfare, and amenity, as well as functional operation of the urban community. Our formulation of the linear programming analysis of alternate urban forms is concerned with the functional operation of the urban community. We recognize that this provides a limited evaluation of alternatives. But the functional operation of the urban community -- the interaction over space -- is a central concern of the urban planner, and it seems the proper place to start in evaluating alternate urban forms.

The criteria we use are jointly established through the linear programming analysis -- the efficiency with which required interaction can be accomplished, and the equity with which this efficiency is distributed. Ideally a third criterion should be included. That criterion is choice. The urban area should function so that the individual has a wide choice among activities and among specific locations of activity. An urban area which is arranged and operates efficiently and with equity, but restricts individual choice by a prescribed regime of spatial interaction in order to achieve those goals will hardly satisfy the more general goal of maximization of the general welfare toward which all planning efforts strive.

As we have seen, the benefit of what we call spatial rationality -- a well matched and potentially efficient spatial pattern and transportation system -- is a large measure of freedom of choice since individuals may select inefficient activity linkages at relatively low social cost. Because of this we are hopeful that our evaluation model does not restrict choice. However, a more satisfactory evaluation technique would deal explicitly with the criterion of choice.

The second component of the plan evaluation problem is scale, or the level of detail at which alternate urban forms are to be evaluated. This must be determined by the scope and purpose of metropolitan planning. Although it will vary in degree with individual urban areas, metropolitan planning is concerned with fitting together the general pattern of development and not with the detailed specification of either land development or the facilities which serve it. The evaluation of urban transportation networks is typically very detailed. The tested networks are detailed to the extent of including preliminary ramp spacing on expressways and the number of travel lanes. This is done because the purpose of the evaluation is to specify in engineering terms the type of facility required under given assumptions. At our level of concern -- fitting the transportation system and the pattern of land development together -- such detail is unwarranted. Instead we are concerned with establishing the level of transportation service to be provided. This is, in effect, a first order policy decision. For a prescribed pattern of transportation service there are conceivably a large number of different transportation networks which will provide the required transportation service.

Similarly, we are concerned with the broad pattern of location of activities and not detailed land development. Like the pattern of transportation service the general activity pattern sets a framework within which a variety of patterns of detailed land development can occur. In effect the activity pattern sets the desirable capacity for different types of land development in the zones of the urban area used in the analysis. As Isard has suggested, detailed urban complex analysis can be developed for both designing and evaluating detailed development patterns.[7] Hopefully, the linear programming analysis we have used is at the level of generality which is required and appropriate for evaluating alternative forms for metropolitan development.

In summary we return to our original point in this chapter. An urban plan should be based on the way people will use the urban area.

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1. Webber, _et. al._, _op. cit._, pp. 80-85.

2. _Ibid._, pp. 117-118.

3. _Ibid._, p. 233.

4. F. Stuart Chapin, Jr., _Urban Land Use Planning_ (2nd ed.), (Urbana: University of Illinois Press, 1965), Chapter 6.

5. Walter Isard, _et. al._, _Methods of Regional Analysis_ (New York: John Wiley and Sons, Inc., 1960), p.675; and Webber, _et. al._, _op. cit._, pp. 42 and 138.

6. Chicago Area Transportation Study, _Transportation Plan_, Vol. III, _Final Report_ (Chicago: The Study, 1962), pp. 54-63.

7. Isard, _op. cit._, pp. 673-679.

APPENDIX

Table 18. Total Internal Work Trips in the Buffalo Area by Zone of Origin and Destination.

Zone Number	Trip Origins	Trip Destinations
1	12,679	44,789
2	51,502	59,868
3	13,307	11,190
4	17,240	16,786
5	27,307	22,010
6	13,847	15,750
7	14,086	12,137
8	2,967	2,802
9	12,495	22,926
10	29,879	16,574
11	29,758	16,441
12	7,060	5,623
13	9,796	4,523
14	8,662	13,635
15	7,308	10,605
16	22,777	15,134
17	14,861	13,597
18	2,184	3,910
19	4,740	4,094
20	4,636	7,000
21	1,850	1,438
22	21,178	18,074
23	5,727	9,242
24	13,312	8,007
25	1,998	759
26	4,062	1,971
27	43,623	51,473
28	7,889	4,142
29	3,294	1,620
30	1,521	1,033
31	5,790	5,313
32	4,557	2,969
33	1,299	310
34	5,735	4,922
35	19,815	18,074
Total	448,741	448,741

Table 19. Total Internal Shopping Trips in the Buffalo Area by Zone of Origin and Destination.

Zone Number	Trip Origins	Trip Destinations
1	5,570	15,329
2	23,094	11,862
3	5,760	2,980
4	10,336	8,549
5	16,349	12,097
6	9,064	15,960
7	9,386	6,783
8	1,433	960
9	8,460	7,572
10	25,306	22,313
11	25,294	30,229
12	4,876	2,875
13	11,084	11,691
14	5,169	2,758
15	4,336	1,793
16	23,663	34,496
17	11,981	13,395
18	1,671	3,151
19	4,639	9,105
20	2,291	2,039
21	1,512	1,549
22	16,242	14,218
23	4,710	6,510
24	8,725	8,115
25	1,560	398
26	3,235	2,960
27	29,183	30,308
28	5,396	4,367
29	2,283	1,659
30	1,255	236
31	4,325	4,577
32	4,369	4,195
33	828	208
34	3,558	2,102
35	10,908	10,512
Total	307,851	307,851

Table 20. Total Internal Social-Recreation Trips in the Buffalo Area by Zone of Origin and Destination.

Zone Number	Trip Origins	Trip Destinations
1	6,458	7,230
2	27,700	28,170
3	7,614	7,838
4	10,654	13,508
5	15,776	13,233
6	8,448	6,727
7	7,939	8,723
8	1,798	1,379
9	8,168	6,290
10	21,530	16,616
11	20,854	18,859
12	4,020	3,838
13	7,679	6,864
14	7,020	7,330
15	4,353	6,992
16	17,097	17,474
17	11,228	12,688
18	1,512	1,408
19	3,593	3,070
20	3,287	3,456
21	972	1,962
22	16,196	17,677
23	3,218	3,510
24	6,667	6,507
25	1,310	1,053
26	3,139	4,094
27	33,422	31,291
28	7,734	7,122
29	2,440	2,948
30	1,174	1,420
31	4,006	4,396
32	4,195	5,812
33	1,456	1,652
34	4,449	6,144
35	13,648	13,473
Total	300,754	300,754

Table 21. Principal Zonal Linkages of Work Trips in the Buffalo Area.

Origin Zone	First Linkage Dest. Zone	First Linkage Number of Trips	Second Linkage Dest. Zone	Second Linkage Number of Trips	Third Linkage Dest. Zone	Third Linkage Number of Trips
1	2	3,821	1	3,190	10	655
2	2	1,567	1	9,002	9	3,400
3	2	2,591	3	2,243	9	1,801
4	2	3,597	1	2,555	4	2,443
5	5	5,379	2	4,881	1	3,293
6	2	2,896	6	2,614	1	1,675
7	2	3,417	1	2,442	7	2,232
8	7	585	2	548	14	535
9	9	4,037	2	1,293	15	1,043
10	10	4,674	1	4,729	2	4,006
11	11	4,715	2	4,034	1	3,677
12	2	1,012	12	822	5	646
13	2	1,634	1	1,323	14	1,187
14	14	3,823	20	1,040	1	684
15	15	2,046	9	1,190	27	686
16	16	5,185	2	2,259	9	1,808
17	17	3,338	23	1,482	2	1,481
18	18	302	12	250	1	216
19	19	936	2	680	1	522
20	20	1,634	14	1,043	2	288
21	21	519	27	469	15	214
22	22	9,918	16	1,780	28	1,400
23	23	1,458	17	774	1	395
24	24	5,029	23	1,028	2	848
25	19	284	2	241	31	236
26	14	681	26	523	1	521
27	27	38,272	34	2,170	22	643
28	22	2,283	28	1,671	27	1,413
29	29	699	23	524	17	264
30	24	313	2	262	31	211
31	31	3,432	1	473	2	412
32	32	1,435	14	572	20	571
33	1	237	14	206	2	181
34	27	3,310	34	1,752	35	353
35	35	15,999	27	1,659	34	295

Table 22. Principal Zonal Linkages of Shopping Trips in the Buffalo Area.

Origin Zone	First Linkage Dest. Zone	First Linkage Number of Trips	Second Linkage Dest. Zone	Second Linkage Number of Trips	Third Linkage Dest. Zone	Third Linkage Number of Trips
1	1	1,326	6	756	2	642
2	2	5,571	1	4,654	6	3,613
3	9	1,094	3	1,055	4	805
4	4	2,179	2	1,517	1	1,297
5	5	5,008	11	3,437	6	2,205
6	6	3,213	11	1,901	5	793
7	7	2,733	13	1,869	1	971
8	13	457	7	282	8	226
9	9	3,110	10	1,938	16	1,397
10	10	10,221	16	5,477	11	2,782
11	11	11,024	17	3,120	10	2,163
12	11	1,551	12	1,213	6	933
13	13	4,358	19	2,804	7	935
14	13	2,233	14	1,045	20	360
15	16	1,468	15	951	21	772
16	16	15,740	10	2,650	22	1,532
17	17	5,748	11	2,474	23	1,001
18	17	461	19	276	11	245
19	19	2,157	13	908	26	343
20	20	907	13	389	14	292
21	21	661	15	348	27	142
22	22	9,455	16	3,609	28	1,452
23	23	2,273	17	554	29	400
24	24	5,405	23	786	11	580
25	19	556	31	339	25	192
26	26	1,050	32	698	19	466
27	27	27,263	35	448	34	266
28	28	2,210	22	1,359	16	794
29	23	832	29	791	35	211
30	24	578	31	181	19	156
31	31	3,616	24	212	19	129
32	32	2,796	26	677	13	188
33	26	311	32	155	33	130
34	34	1,705	27	1,498	35	110
35	35	9,237	27	546	28	188

Table 23. Principal Zonal Linkages of Social-Recreation Trips in the Buffalo Area.

Origin Zone	First Linkage Dest. Zone	First Linkage Number of Trips	Second Linkage Dest. Zone	Second Linkage Number of Trips	Third Linkage Dest. Zone	Third Linkage Number of Trips
1	2	2,206	4	584	3	403
2	2	11,298	4	2,855	1	1,784
3	3	1,966	2	1,501	4	757
4	2	2,371	4	2,323	10	1,643
5	5	3,756	11	2,603	2	1,583
6	6	2,203	5	1,129	2	1,055
7	7	2,461	13	1,146	2	978
8	7	455	14	329	8	187
9	9	1,736	3	1,083	10	958
10	10	5,618	16	2,954	4	2,095
11	11	6,954	17	2,448	5	2,085
12	12	945	7	666	11	659
13	13	2,181	7	1,428	14	658
14	14	3,634	20	599	13	413
15	16	833	15	831	22	444
16	16	6,452	10	2,372	22	1,547
17	17	4,215	11	1,804	16	735
18	11	269	17	249	18	192
19	19	895	13	703	26	367
20	14	1,001	20	858	26	312
21	21	617	2	116	15	83
22	22	8,680	28	1,963	16	1,102
23	23	893	17	566	29	479
24	24	3,590	2	370	30	342
25	26	186	25	182	31	177
26	26	1,221	32	623	20	364
27	27	26,376	34	3,043	35	701
28	28	2,410	22	2,234	27	1,036
29	29	1,325	23	530	17	130
30	30	338	24	261	31	209
31	31	3,001	30	155	17	104
32	32	1,950	26	545	33	363
33	33	442	26	259	13	159
34	34	2,140	27	1,515	35	379
35	35	10,847	27	604	28	576

Table 24. Optimal Allocation of All Trips for All Purposes.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,225
Total Trips	1,057,346
Initial Allocation: Total Time Units for Permitted Routes	65,231,380
Optimal Solution: Total Time Units for Permitted Routes	23,053,832
Number of Iterations	147
Number of Passes Through Cost Data	7

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips
1	1	24,707
2	1	2,396
2	2	99,900
3	1	4,673
3	3	22,008
4	1	9,006
4	4	29,224
5	5	47,340
5	6	12,092
6	1	19,248
6	6	12,111
7	1	6,261
7	7	25,150
8	1	1,057
8	8	5,141
9	9	29,123
10	4	9,619
10	9	7,665
10	10	55,503
10	15	3,928
11	6	7,641
11	11	65,529
11	17	2,736
12	6	3,620
12	12	12,336
13	7	2,493
13	13	23,078
13	14	2,184
13	19	804
14	14	20,851
15	15	15,382
15	21	615
16	15	80
16	16	63,457
17	17	36,944
17	23	1,126
18	6	2,973
18	18	2,394
19	19	12,972
20	14	688
20	20	9,526
21	21	4,334
22	16	3,647
22	22	49,969
23	23	13,655
24	18	6,075
24	24	22,629
25	19	2,493
25	25	2,210
25	31	165
26	20	1,556
26	26	8,880
27	27	106,148
28	27	5,388
28	28	15,631
29	23	1,790
29	29	6,227
30	23	1,261
30	30	2,689
31	31	14,121
32	26	145
32	32	12,976
33	20	1,413
33	33	2,170
34	27	574
34	34	13,168
35	23	1,430
35	27	962
35	35	42,059

Table 25. Optimal Allocation of All Work Trips.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,225
Total Trips	448,741
Initial Allocation: Total Time Units for Permitted Routes	37,640,373
Optimal Solution: Total Time Units for Permitted Routes	12,508,837
Number of Iterations	133
Number of Passes Through Cost Data	7

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips	Origin Zone	Dest. Zone	Trips
1	1	12,679	19	19	2,378
2	2	51,502	20	14	2,304
3	1	2,117	20	20	2,332
3	3	11,190	21	21	1,438
4	1	12,505	21	27	412
4	4	4,735	22	16	1,967
5	4	2,864	22	22	18,074
5	5	22,010	22	28	1,137
5	6	2,433	23	23	5,727
6	1	5,481	24	12	1,306
6	2	8,366	24	18	3,910
7	1	6,915	24	23	89
7	7	7,171	24	24	8,007
8	1	165	25	19	1,716
8	8	2,802	25	25	282
9	9	12,495	26	20	4,062
10	4	9,187	27	27	43,623
10	9	10,431	28	27	4,884
10	10	10,261	28	28	3,005
11	6	13,317	29	23	1,674
11	11	16,441	29	29	1,620
12	1	4,927	30	23	488
12	12	2,133	30	30	1,033
13	7	4,966	31	25	477
13	13	4,523	31	31	5,313
13	14	307	32	26	1,588
14	14	8,662	32	32	2,969
15	15	7,308	33	20	606
16	10	6,313	33	26	383
16	15	3,297	33	33	310
16	16	13,167	34	27	813
17	17	13,597	34	34	4,922
17	23	1,264	35	27	1,741
18	12	2,184	35	35	18,074
19	14	2,362			

Table 26. Optimal Allocation of All Shopping Trips.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,225
Total Trips	307,851
Initial Allocation: Total Time Units for Permitted Routes	18,394,770
Optimal Solution: Total Time Units for Permitted Routes	6,643,274
Number of Iterations	161
Number of Passes Through Cost Data	8

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips	Origin Zone	Dest. Zone	Trips
1	1	5,570	18	18	1,671
2	1	9,286	19	19	4,639
2	2	11,862	20	19	1,321
2	6	1,946	20	20	970
3	3	2,980	21	21	1,512
3	5	1,957	22	16	3,586
3	9	823	22	22	12,656
4	4	8,549	23	23	4,710
4	5	1,787	24	18	610
5	5	8,353	24	24	8,115
5	6	4,950	25	19	910
5	11	3,046	25	25	398
6	6	9,064	25	31	252
7	7	6,783	26	20	449
7	11	2,172	26	26	2,786
7	13	431	27	21	37
8	1	473	27	27	29,146
8	8	960	28	22	1,562
9	9	6,749	28	28	3,834
9	15	1,711	29	23	624
10	10	22,313	29	29	1,659
10	16	2,993	30	23	1,019
11	11	23,880	30	30	236
11	17	1,414	31	31	4,325
12	11	1,131	32	26	174
12	12	2,875	32	32	4,195
12	18	870	33	20	620
13	13	11,084	33	33	208
14	13	176	34	27	1,162
14	14	2,758	34	28	294
14	19	2,235	34	34	2,102
15	15	82	35	23	157
15	16	4,254	35	28	239
16	16	23,663	35	35	10,512
17	17	11,981			

Table 27. Optimal Allocation of All Social-Recreation Trips.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,225
Total Trips	300,754
Initial Allocation: Total Time Units for Permitted Routes	14,347,258
Optimal Solution: Total Time Units for Permitted Routes	6,244,251
Number of Iterations	155
Number of Passes Through Cost Data	7

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips	Origin Zone	Dest. Zone	Trips
1	1	6,458	16	22	1,202
2	2	27,700	17	17	10,936
3	3	5,960	17	23	292
3	4	1,654	18	18	1,408
4	4	10,654	18	24	104
5	4	1,058	19	19	2,255
5	5	13,233	19	25	115
5	6	1,485	19	26	1,223
6	1	772	20	20	1,938
6	2	470	20	26	1,349
6	6	5,242	21	21	972
6	7	602	22	22	16,196
6	14	1,362	23	23	3,218
7	7	7,939	24	24	6,403
8	8	1,379	24	25	18
8	14	223	24	30	246
8	33	196	25	25	920
9	3	1,878	25	31	390
9	9	6,290	26	26	1,522
10	4	142	26	32	1,617
10	10	16,616	27	21	436
10	15	3,193	27	27	31,291
10	16	1,579	27	34	1,695
11	11	18,859	28	22	279
11	17	1,752	28	28	7,122
11	20	243	28	29	333
12	7	182	29	29	2,440
12	12	3,838	30	30	1,174
13	13	6,864	31	31	4,006
13	19	815	32	32	4,195
14	14	5,745	33	33	1,456
14	20	1,275	34	34	4,449
15	15	3,799	35	29	175
15	21	554	35	35	13,473
16	16	15,895			

Table 28. Optimal Allocation of Principal Linkage Work Trips.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,225
Total Trips	217,249
Initial Allocation: Total Cost for Permitted Routes	13,168,239
Optimal Solution: Total Cost for Permitted Routes	7,417,942
Number of Iterations	129
Number of Passes Through Cost Data	6

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips
1	1	7,011
2	2	24,676
3	1	3,884
3	3	950
4	1	5,505
4	2	1,007
5	2	10,260
6	2	5,510
7	1	5,859
8	1	1,133
9	3	1,293
9	9	4,037
10	2	2,576
10	4	0
10	5	3,384
10	10	3,443
11	5	1,995
11	6	2,039
11	11	4,715
12	2	1,834
13	2	2,372
13	7	585
13	13	0
14	14	4,863
15	9	1,190
15	15	2,046
16	10	1,231
16	16	6,213
17	17	4,112
17	23	708
18	2	552
19	1	322
19	12	1,072
19	19	222
20	14	1,462
20	20	1,215
21	21	519
21	27	469
22	16	752
22	22	10,946
23	23	2,232
24	2	413
24	18	302
24	24	5,342
25	19	525
26	20	1,204
27	27	40,442
28	22	1,255
28	27	1,028
28	28	1,671
29	23	524
29	29	699
30	6	575
30	30	0
31	19	473
31	25	0
31	31	3,432
32	20	49
32	26	523
32	32	1,435
33	1	237
33	8	0
33	20	206
33	33	0
34	27	1,140
34	34	3,922
35	23	1,028
35	27	631
35	35	15,999

Table 29. Optimal Allocation of Principal Linkage Shopping Trips.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,225
Total Trips	199,424
Initial Allocation: Total Cost for Permitted Routes	15,006,893
Optimal Solution: Total Cost for Permitted Routes	4,696,222
Number of Iterations	171
Number of Passes Through Cost Data	8

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips	Origin Zone	Dest. Zone	Trips
1	1	2,082	18	18	0
2	1	3,137	19	19	3,065
2	2	7,088	20	19	389
3	3	1,055	20	20	907
3	9	205	21	15	250
3	10	889	21	21	661
4	4	2,179	21	27	98
4	5	1,517	22	16	3,707
4	10	0	22	22	9,357
5	5	3,491	23	17	523
5	11	4,954	23	23	2,304
6	1	22	24	24	6,191
6	6	3,969	25	19	587
6	7	984	25	25	0
6	11	139	25	31	308
7	7	2,031	26	20	0
7	13	2,571	26	26	1,748
8	1	739	27	27	27,711
8	8	0	28	22	1,457
9	9	3,999	28	28	2,112
9	15	1,049	29	23	832
10	10	13,920	29	29	791
10	16	1,778	30	23	755
11	11	13,006	30	24	4
11	17	1,138	30	30	0
12	11	1,551	31	31	3,828
12	12	1,213	32	32	3,473
13	13	7,162	33	26	290
14	13	481	33	32	176
14	14	1,045	33	33	0
14	19	1,752	34	27	1,498
15	16	2,419	34	34	1,705
16	16	18,390	35	28	98
17	17	8,222	35	35	9,685
18	11	727			

Table 30. Optimal Allocation of Principal Linkage Social-Recreation Trips.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,225
Total Trips	166,906
Initial Allocation: Total Cost for Permitted Routes	12,878,662
Optimal Solution: Total Cost for Permitted Routes	3,823,885
Number of Iterations	165
Number of Passes Through Cost Data	8

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips
1	2	2,790
2	2	14,153
3	3	2,399
3	4	1,068
4	4	4,694
5	5	4,885
5	11	1,474
6	2	650
6	6	2,203
6	7	479
7	7	3,607
8	1	0
8	2	269
8	8	0
8	14	515
9	3	650
9	9	1,736
9	15	0
9	17	433
10	10	7,990
10	16	582
11	11	9,283
11	17	129
12	7	301
12	11	365
12	12	945
13	7	623
13	13	2,986
14	14	4,233
15	15	831
15	16	833
16	16	8,824
17	17	6,019
18	11	518
18	18	0
19	13	1,044
19	19	554
20	14	216
20	20	1,457
20	26	186
21	21	617
21	27	116
22	22	10,643
23	17	897
23	23	562
24	23	109
24	24	3,851
25	19	341
25	25	27
26	26	1,844
27	27	28,379
27	34	1,040
28	22	271
28	28	4,373
29	23	530
29	29	1,325
30	23	106
30	30	493
31	25	155
31	31	3,001
32	32	2,495
33	26	181
33	32	78
33	33	442
34	34	3,655
35	23	116
35	28	0
35	34	488
35	35	10,847

Table 31. Optimal Allocation of All Interzonal Work Trips.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,190
Total Trips	301,312
Initial Allocation: Total Cost for Permitted Routes	21,160,611
Optimal Solution: Total Cost for Permitted Routes	12,445,667
Number of Iterations	157
Number of Passes Through Cost Data	8

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips
1	2	9,489
2	1	35,828
3	9	11,064
4	2	14,308
4	3	489
5	2	6,180
5	4	2,612
5	6	13,136
6	2	11,233
7	1	2,881
7	8	2,725
7	12	2,689
7	13	3,559
8	1	2,890
9	3	8,458
10	4	11,731
10	9	2,563
10	15	8,559
10	16	1,160
10	22	1,192
11	5	16,631
11	17	7,052
11	23	1,360
12	2	2,984
12	7	3,254
13	7	6,651
13	14	752
13	19	1,429
14	20	4,839
15	9	5,262
16	10	11,900
16	22	5,692
17	11	11,523
18	12	225
18	24	1,657
19	12	1,887
19	14	1,917
20	14	3,002
21	27	1,331
22	16	8,789
22	28	2,471
23	11	203
23	17	3,207
23	29	859
24	18	3,608
24	23	3,829
24	30	846
25	31	1,868
26	14	2,700
26	20	527
26	32	312
27	21	919
27	34	3,170
27	35	1,262
28	22	1,272
28	27	4,133
28	35	813
29	23	2,595
30	24	1,321
30	31	13
31	19	1,729
31	25	629
32	14	1,441
32	26	1,448
32	33	233
33	32	1,222
34	27	3,983
35	27	3,754
35	29	62

Table 32. Optimal Allocation of All Interzonal Shopping Trips.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,190
Total Trips	163,154
Initial Allocation: Total Cost for Permitted Routes	11,877,123
Optimal Solution: Total Cost for Permitted Routes	6,078,648
Number of Iterations	197
Number of Passes Through Cost Data	10

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips
1	2	4,244
2	1	12,796
2	6	4,727
3	4	2,574
3	9	2,131
4	3	1,925
4	5	3,901
4	9	2,331
5	6	7,269
5	11	4,072
6	2	2,047
6	7	364
6	11	3,440
7	11	140
7	13	6,513
8	1	1,207
9	4	3,796
9	10	712
9	15	842
10	16	12,868
10	22	2,217
11	5	3,188
11	6	751
11	17	7,647
11	23	2,684
12	11	3,663
13	7	3,686
13	19	3,040
14	8	734
14	19	2,998
14	20	392
15	10	3,385
16	10	7,923
17	11	6,233
18	11	88
18	24	1,481
19	12	1,662
19	13	820
20	14	1,384
21	27	851
22	10	72
22	16	5,888
22	28	827
23	11	1,569
23	29	868
24	18	3,049
24	23	61
24	30	210
25	19	407
25	31	961
26	14	329
26	20	740
26	32	1,038
26	33	78
27	21	888
27	34	397
27	35	635
28	22	2,546
28	35	640
29	23	1,492
30	24	1,229
31	19	503
31	25	206
32	26	1,573
33	26	337
33	32	361
34	27	1,853
35	27	341
35	28	1,330

Table 33. Optimal Allocation of All Interzonal Social-Recreation Trips.

Number of Origins	35
Number of Destinations	35
Number of Specified Costs	1,190
Total Trips	177,696
Initial Allocation: Total Cost for Permitted Routes	11,392,010
Optimal Solution: Total Cost for Permitted Routes	7,303,424
Number of Iterations	167
Number of Passes Through Cost Data	9

Final Allocation Sorted by Origin Zone

Origin Zone	Dest. Zone	Trips	Origin Zone	Dest. Zone	Trips
1	2	6,127	17	23	1,502
2	1	6,899	18	24	1,320
2	4	1,037	19	12	1,196
2	5	1,735	19	14	1,502
2	6	4,524	20	14	583
2	7	625	20	26	1,838
2	8	1,192	20	32	8
2	12	390	21	27	355
3	4	4,616	22	10	353
3	9	1,032	22	16	2,451
4	2	4,396	22	28	4,712
4	3	3,935	23	17	2,325
5	2	104	24	12	512
5	4	5,532	24	18	1,216
5	11	6,384	24	30	1,082
6	2	6,245	24	31	267
7	12	795	25	31	1,128
7	13	4,683	26	32	1,918
8	14	1,611	27	21	1,345
9	3	1,937	27	34	4,004
9	15	4,495	27	35	1,697
10	15	1,666	28	22	3,322
10	16	8,571	28	27	1,073
10	22	5,675	28	35	929
11	5	7,742	29	23	1,115
11	17	6,148	30	24	836
12	7	2,314	31	25	871
12	24	761	31	32	134
13	7	3,323	32	26	1,035
13	19	2,175	32	33	1,210
14	20	2,598	33	32	1,014
14	32	788	34	27	2,309
15	9	3,522	35	27	1,178
16	10	10,645	35	29	1,623
17	11	5,511			

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