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ACTIVITY ALLOCATION MODELS IN TRANSPORTATION PLANNING

by

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ACTIVITY ALLOCATION MODELS IN TRANSPORTATION PLANNING

1. Introduction

Recent efforts to deal with the long-run implications of the "transportation problem" in metropolitan areas have adopted a comprehensive attack on the several dimensions of the problem by means of the metropolitan area transportation study. An essential ingredient of such studies has been a collection of models which forecast, for small areas in the study region, the numbers of people and employees, and the amounts of land use, that are generated by industrial, commercial, and residential activities carried on in the region. Traffic estimation models require such forecasts for their inputs. Evaluation procedures, which compare the developmental effects of alternative transportation policies, depend on them for their outputs.

Until recently, transportation planners generated land use forecasts which were independent of any particular transportation system. Though recognizing the association between land use and traffic, they ignored the relationship between transportation facilities and land use patterns. Since the pioneering efforts of the Penn-Jersey Transportation Study, however, major regional transportation studies have been explicitly recognizing both linkages between the two systems. It is now clearly understood that the pattern of traffic in an urban area derives from the spatial disposition of urban activities in the area, and conversely, that the transportation system which serves this area in turn has a strong influence on the geographical location of these activities. In this respect, transportation systems both serve and shape a metropolitan region.

The operational linkages between the various components of a typical metropolitan transportation study's sequence of analytical models are illustrated in Figure 1. Beginning with a set of assumptions about possible parametric changes that are expected to occur during the forecasting period (e.g., in technology, in birth rates, in productivity, in the state of the national economy), an aggregate forecast of population and employment in the study area is made by a set of models which may be collectively referred to as the Regional Growth Models. These provide expected totals of population, disaggregated by cohort, and employment, disaggregated by sector. These outputs are then entered into a collection of land use or, more precisely, Activity Allocation Models which distribute the forecasted population and employment totals over space. Drawing on this projected spatial pattern of urban activities, the Traffic Estimation Models forecast the generation and interchange of traffic produced by this activity distribution and indicate the characteristics of the transportation system that will be required to serve this travel demand. Finally, the Evaluation Models attempt to assess the total social costs and benefits of this particular mix of model outputs and seek to provide decision makers with the information necessary for enlightened policy formulation.

In this paper, we shall be concerned only with the contents of the second box in Figure 1. We begin by reviewing the fundamental conceptual approaches that have been adopted by theorists in intraurban spatial structure. Next, we describe the variables which have been identified by location theorists as having an important influence on the locational decision making of urban activities. Finally, we outline a particularly simple, yet useful, matrix model of activity allocation which in its generalized form includes several of the more popular land use models currently in use.

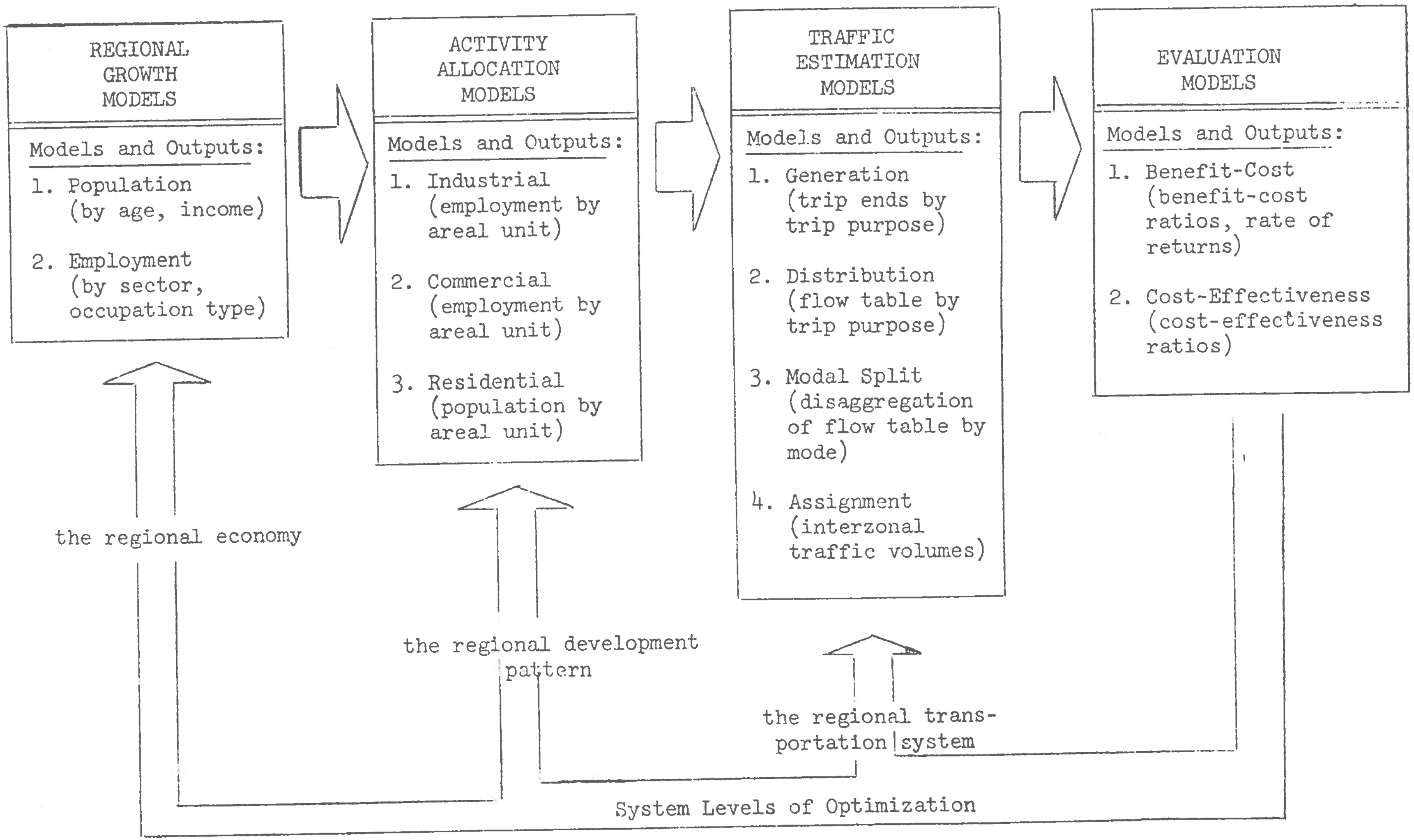

FIGURE 1.--THE MODEL SEQUENCE IN REGIONAL TRANSP[illegible]ATION STUDIES

2. Theories of Intraurban Spatial Structure: The Space-Economic Setting

The theory of urban spatial structure is concerned with the disposition of human socioeconomic activities in urban areas. Its goals are to discover, explain, and ultimately predict the regularities that exist in man's adaptation to city space. Contributions toward its development have suggested a number of distinct orientations and approaches, each of which attempts to provide a framework of empirically sound and logically consistent propositions.

Two main streams of thought underlie the voluminous literature on the subject. The basic distinction lies in the orientation with which the fundamental problem is approached. The first point of view is macro and market-oriented, focusing on the phenomena of urban growth and change and on the regulative economic forces acting to promote orderly development. The second, on the other hand, is micro and decision-oriented, concerning itself rather with the factors that give rise to the phenomena by their collective influence on the decision making of societal units.

A market-oriented approach toward the analysis of urban form and structure is one which interprets the spatial pattern of a city in terms of the dynamics of socioeconomic forces acting within an urban environment. The primary concern of such theories has been to describe and explain why a particular activity is carried on at a given site, and how it is spatially related to all other activities of the system. The statement of the problem is presented in a market context, and the method of analysis reflects this macro orientation. Typically the emphasis of such theories lies in the development of a set of general principles which account for the urban pattern by reference to factors that interact in the landmarket, through the medium of rents, to promote a greater efficiency in the arrangement of activities in urban space.

A decision-oriented approach, on the other hand, focuses on the events that produce growth and change in the urban development pattern. It views these events as the consequences of actions by decision makers interacting in the urban field. The active role of human volition replaces societal adaption to space as the principal referent. The locational behavior of decision units is examined as it responds to different environmental conditions. Spatial preferences, cost and profit considerations, competition, and accessibility are typical principles which are used to account for observed phenomena.

2.1. Market-Oriented Approaches

Theories dealing with the determinants of urban form and structure from a market-oriented point of view have been developed almost exclusively by economists. Thus the rationales of these studies understandably have emphasized economic motivations. The efforts have focused on classifying activities into groups and have attempted to describe their spatial distribution and interaction in terms of basic economic forces. A particular site, according to such theories, is endowed with a unique complex of space relationships by virtue of its location and thereby achieves a particular value in the competitive land market. The major attribute of a site is its accessibility to all other activities in the urban area, and its rental value is viewed as a direct consequence of this accessibility.

The theoretical structure of modern urban land economics is founded upon a highly simplified application of classical price and rent theory [20, 25]. Land economists view accessibility to the central core as the primary objective of individuals and business units seeking a location. Such units, it is asserted, strive to reduce to a minimum the sum of site rentals and transportation costs, a quantity defined as "the costs of friction." Competition for the most accessible sites then produces a land use pattern by matching available sites with activities willing to pay the rental attached to them. Transportation costs provide the connection between accessibility and rent. This conceptual scheme, aptly christened by Wendt [36] as the "Haig-Ely-Dorau-Ratcliff Hypothesis," is the touchstone of contemporary economic theory of land use. It postulates that an economic activity can derive a certain amount of utility from every parcel of land in an urban area. This utility is reflected by the amount of rent which the activity is willing to pay for the parcel. As an outgrowth of the competitive bidding process in the land market for sites offering the greatest utility, each site will be occupied by its "highest and best use." This use is one which can derive the greatest utility from the site and which, therefore, is willing to pay the most to occupy it. The result of this process is an orderly pattern of land use which maximizes the aggregate rent of the whole system.

Urban land economics is concerned with how land uses are distributed throughout the city and why. Its fundamental statements are in terms of major economic forces and do not deal in very great depth with particular determinants of land use. Recently, however, significant attempts have been made to focus analysis on the economic determinants of land use. Foremost have been the studies dealing with rent as the principal determinant [23, 26, 54].

The rent theorist's basic proposition is that rent gradients exist with respect to markets and production facilities in all areas. These are a function of accessibility to markets and local production costs. Corresponding to every parcel of land there exist several rent gradients, each reflecting a particular use of the land. The highest rent gradient determines the parcel's ultimate use.

The theory of urban land use and the theory of rent together embrace the major contributions made by economists toward explaining the spatial structure of urban areas from the market-oriented point of view. Paralleling these theoretical explorations have been the efforts, again largely by economists, to account for spatial patterns by analyzing the decision behavior of individual units which create these patterns. These are the decision-oriented theories of location.

2.2. Decision-Oriented Approaches

Virtually all of the decision-oriented theories concerned with the locational behavior of activities in an urban setting view the problem within a "space-economic" framework. Such a view emphasizes the inadequacy of conventional economic theory and introduces spatial considerations as an integral part of locational decision making. In a broad sense, this approach suggests that the essence of the phenomenon of spatial structure lies in the myriad of individual optimizing efforts of decision units and their interactions with one another, subject to the conventional resource restraints of economic theory: land, labor and capital. Each unit chooses the "best" alternative available to it, and the spatial activity pattern that results is a consequence of this optimum-seeking behavior.

Three streams of thought appear in the literature on decision-oriented theories of location. Greenhut [38] aptly has christened these: "the least cost theory of location," the "interdependence theory of location," and the "theory of maximum profit location."

The theory of least cost location, the foremost representative of which is the work of Alfred Weber, [41] subscribes to a rationale which emphasizes the minimization of total expenditures. Weber's framework for explaining industrial location in terms of the competition to locate at places of least cost has been carried on by a school of locational economists. Although a few of these have included the size of the market area as a factor, the significant features of the theory of least cost location are a focus on the search for a site offering the minimum sum of all expenditures, the disregard for the locational interdependence of competing firms, and the assumption of a market demand unaffected by the locational decision of a firm.

According to the "theory of least-cost location," the primary objective of a firm seeking a location is to establish the plant at the site where total expenditures are minimized. Here, it is asserted, the firm can achieve greater profits than at any other location. The assumption of a purely competitive system assures a horizontal demand curve for the firm's product, and thus each seller is faced with an unlimited market for his goods.

During the past forty years, a school of thought has developed which points out the shortcomings of the Weberian perfectly competitive framework led by Fetter, Hotelling, Lerner and Singer, and Smithies [18, 24, 28, 35] these theorists focus on locational interdependence and view location as being determined by the attempt to control the largest market area. Thus while the basic problem remains essentially the same as in the Weberian framework, the methodology and conclusions differ.

The theory of locational interdependence is based upon monopolistic competition. It claims that the major effect of space on economic theory is the introduction of spatial monopolies. With buyers scattered over an area, a firm by virtue of its location is able to sell its product to nearby consumers at delivered prices which are lower than those of its competitors. Thus a pattern of market areas develops, and a premium is developed for locations at which the firm can monopolize the largest number of consumers.

Perhaps the principal fault of the theory of maximum profit location is its abstraction from cost. Here it parallels the analogous abstraction from demand made by the Weberian School. In this sense it is a one-sided approach. Next we shall consider an attempt to treat both cost and demand as variable factors which influence the selection of a location. This is the theory of maximum profit location.

The theory of maximum profit location, as advanced by Greenhut [38], adopts a model which treats cost and demand as variables at all locations. It asserts that firms do not merely seek a least cost location nor one offering the largest market area. They seek, rather, the maximum profit location, a location which Greenhut defines in the following manner [38, p. 267]:

> . . . the concept of the maximum profit location . . . may be referred to as that site from which a given number of buyers (whose purchases are required for the greatest possible profits) can be served at the lowest total cost. While the lowest level of average production cost at this site may be higher than that existing at alternative ones, the monopolistic control gained over larger numbers of buyers (spread over a market area) makes it the maximum profit location at the optimum output.

In a later publication Greenhut develops his ideas further and considers the space-economy in terms of an oligopolistic market economy [19]. Perfect knowledge, mobility and several other fundamental components of the traditional theory are relaxed. Furthermore, the concepts of risk an uncertainty are introduced by way of payoff matrices. It is hypothesized that the individual locational decision maker views alternative locations in terms of a profit-risk matrix and makes a selection on the basis of some criterion (e.g., regret) and a decision strategy (e.g., max-min).

The dimensions of a decision-oriented location theory, as described above, offer a great deal of insight into the determinants of activity location. The principal analytical results suggest the following general conclusions:

1) Firms serving a single consumption center will seek the least-cost location with respect to this point and ignore the locational decisions of rivals.
2) Firms serving a scattered population will be greatly influenced in the locational decision by the location of competitors. Under these circumstances sites controlling the largest market area will be sought.
3) Firms in selecting a site will elect the location which offers the optimum profit situation.
4) Firms selling over a market area will concentrate or disperse according to factors such as freight cost, demand elasticity, marginal cost characteristics, and the degree of locational competition.

Despite its theoretical appeal, the theory of maximum-profit location is rarely used in practice. Generally a focus on cost minimization or on revenue maximization is adopted instead. The particular choice depends on the characteristics of the activity that is being analyzed.

2.3. Conclusion

The analysis of urban spatial structure has been the subject of extensive research in academic disciplines such as economics, geography, marketing, and sociology. The work has ranged from the principally empirical and descriptive studies of geographers to the sophisticated axiomatic and analytic formulations of economists. The underlying premise in most of the efforts has been that the territorial layout of activities in urban areas has a sense of order and rationality which arises out of the interplay of certain factors. The factors listed as promoting spatial order vary from theory to theory, ranging along a continuum from a tacit denial of the active role of human beings to a fundamental recognition of locational decision making as the principal force structuring activity patterns. Along another dimension, these theories can also be differentiated according to the degree of descriptive accuracy claimed. These vary from the highly empirical descriptions of uniform patterns manifesting certain natural forces which distribute human activities over urban space, to those whose concern with empirically realistic patterns is wholly incidental to their analytic preoccupation.

Brief reflection upon the two principal main streams of theoretical thought on the subject of urban spatial structure suggests that their fundamental difference rests on the way in which the phenomenon is viewed. The market-oriented approach focuses on a particular site within an overall pattern and is concerned with the forces which determine the activity which will be carried on at that location. The decision-oriented approach, on the other hand, focuses instead on a particular activity and analyzes the behavior of decision units which seek for it the appropriate location. Both approaches have provided significant insights and understanding concerning urban form and growth. The system-oriented approach, however, in its preoccupation with economic forces of change, supplies insights which are very general and does not provide the basis for quantitative prediction. The problem is viewed mechanistically. Typically, supply, demand, income, and capital are viewed as the principal factors with which spatial structure is concerned. The "behavior of the land market," and the "behavior of rent" are studied as if these are the actors influencing developments and not the human beings who act in the land market or set the rents.

> As a result, these concepts are powerless to deal with the prediction of changes resulting from changed conditions; they can in the main only assess the probabilities resulting from a continuation of trends. Thus they are not fully prepared to assist in distinguishing the effects of alternative policy decisions [21, p. 701].

Urban spatial structure is principally influenced by the locational decisions of private and public groups, and individuals. These decision units interact in the urban field and create the "events" which lead to change in the metropolitan fabric. Thus a theory which seeks to cope with the factors leading to growth and change in urban communities must ultimately deal with the behavior patterns of these individual decision units.

3. The Location of Urban Activities

Behind a city's physical structure of buildings, streets, and utility systems, lie the social, economic, and political patterns by which people organize and carry on their daily activities.[1] The institutionalization of these activities into regularly organized channels of behavior results in an orderly pattern of urban life.

> Cities, of whatever age or size, exist through the piling up of people's activities which take place in them, changes in the physical makeup of the city come about in response to changes in the organization and arrangements of those activities. The structures of the land and the subdivided land itself--streets, public utilities, open places, old areas or new--all are the result and record of the changing physical accommodations made for people's activities past and present [32, p. 1].

A comprehensive analysis of the complex interactions which are the essence of city life must take into account both the activities of urban life and the physical setting in which they take place. Neither can be fully understood without the other. The fundamental role, however, is played by activities. Their changing demands for accommodation are reflected in the physical changes of the urban environment. They are the most important single source of change of urban form, and it is their curtailment in an area of the city which ultimately produces a deterioration

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[1] The concept of an activity system is implicit in Haig's early writings; however, its first formal development as a conceptual scheme is presented in Chester Rapkin, "An Approach to the Study of the Movement of Persons and Goods in Urban Areas," (unpublished Ph.D. dissertation, Columbia University, 1953); Robert B. Mitchell and Chester Rapkin, Urban Traffic, A Function of Land Use (New York: Columbia University Press, 1954); and John Rannels, The Core of the City (New York: Columbia University Press, 1956). For recent efforts that have focused on the analysis of specific activity categories, see: Andrei Rogers, "A Stochastic Analysis of Intra urban Retail Spatial Structure," (unpublished Ph.D. dissertation, University of North Carolina, 1964), and F. Stuart Chapin, Jr., and Henry C. Hightower, "Household Activity Patterns and Land Use," Journal of the American Institute of Planners, XXXI: 3 (August 1965), pp. 222-231.

of the physical structure, as has been demonstrated by the relative decay of the "downtown." In short, the physical environment is continually responding and adjusting to changes occurring in the urban activity system.

Urban activities are performed on land and operate in establishments, a term Mitchell and Rapkin [7, p. 14] define as "individuals or groups occupying recognizable places of business, residence, government, or assembly within or upon units of land. The organization and processes of urban activities, their spatial distribution, together with the interlinkages that exist between these activities and all other activities, constitute the intraurban activity system. The analysis of the inner workings of this complex system of movement, people, and goods is the principal concern of a theory of intraurban spatial structure.

Perhaps the most important feature of the concept of an urban activity system lies in its implicit focus on decentralized decision making. The system involves thousands of interacting components--decision units--which influence each other by their fundamental patterns of behavior. These behavioral patterns are reflected by the observable courses of action which are taken by actors within the activity system. Their attitudes and motives shape the production, spending, pricing and locational decisions which structure the disposition of urban activities in space. Thus, for example, the decisions of consumers concerning where to shop and what and how much to buy are some of the fundamental stimuli which determine the responses of producers regarding where to locate, what to produce or sell, and how much of an inventory to carry. The total collection of such decisions, and their interaction, are reflected in the patterns of behavior which constitute the urban activity system. The activity system, in turn, manifests its demands for accommodation in the size and spatial disposition of establishments in urban space.

In summary, the size and spatial disposition of establishments in urban areas is the physical manifestation of a myriad of decisions made through time by consumers and producers of goods and services acting within the institutionalized processes of the urban activity system. This activity system, organized around establishments and carried on through interlinkages, by its demands for space and location shapes the urban spatial pattern. Implicit in the concept of an activity system is the focus on the decision behavior of units within it; units which have been identified as consumers and producers of goods and services. In the following sections, we investigate the locational demands of the urban activity system by analyzing the behavioral patterns of the principal actors within it. Thus the behavior of the entity is accounted for by the behavior of its constituent parts, i.e., by the aggregate locational behavior of industrial, commercial, and residential establishments.

3.1. Industrial Location Theory

The locational decision of an industrial establishment is usually the result of an entrepreneur's conscious decision, made after an evaluation of a large number of factors, both economic and noneconomic. The presence of competition generally forces a firm to consider economic factors as paramount, but in instances where competition is minimal, or where spatial differentials in economic advantages are small, noneconomic factors may be decisive.

Earlier we concluded that although alternate locations, in theory, are judged in terms of their relative profitability, in fact, they are more likely to be assessed in terms of the simpler ideas of comparative revenue or cost. The latter has been particularly the case in industrial location theory. Spatial differentials in expected revenues are generally assumed to be small and therefore ignored. Variations in cost, however, are examined in considerable detail, and the simpler idea of a least cost location generally replaces the more complex notion of a maximum profit location.

The comparative cost approach to industrial location focuses on essentially two major categories of cost: transfer costs and processing costs. The former consist of the costs of assembling the necessary inputs at the point of production and the subsequent distribution of the finished products to the market. The latter include those costs that are incurred at the production site itself: rent, wages and interest for the use of the factors of production. The comparative cost approach seeks a location at which the sum of these two cost components is at a minimum. Thus the geographical distribution of industrial firms in an area is accounted for by reference to spatial variations of individual cost elements and their relative importance in the total cost structure of the firm.

Not all of the factors bearing on industrial location, however, derive from the character of the industry itself; several arise as a result of external influences such as agglomeration economies and governmental activities. Although in most instances these factors have an economic impact, and may therefore be entered into the calculus of processing costs, their importance warrants a separate and more detailed examination.

3.1.1. Transfer Costs

Broadly conceived, all manufacturing activity may be described as a sequence of operations, performed on a supply of inputs, to produce a set of outputs. The costs associated with the assembly of raw materials and the distribution of finished products induce manufacturers to locate their plants close to their markets and sources of supply. Since industries rarely process only one input or produce only one output, they generally seek a location that is optimal with respect to several supply points and markets. Moreover, supplies assembled for processing commonly are not the direct product of an extractive industry, but are the outputs of another manufacturer. Thus the conditions of input supply vary a great deal from industry to industry. Finally, most markets are not point markets but span a considerable area, thereby introducing complex variations in distributional costs.

Transfer costs arise out of the spatial separation of raw materials, production sites, and markets, and consist fundamentally of direct transport costs, i.e., freight charges, and indirect transport costs such as interest payments, insurance costs and clerical expenses. For many "transport oriented" industries, variations in transfer costs outweigh variations in other cost components. These activities, therefore, generally seek a location where total transfer costs are lowest. However a growing number of modern industries are increasingly finding transfer costs to be insignificant relative to the value of their product. Their locational behavior, therefore, must be accounted for by other factors.

Although modern freight rate structures are exceedingly complex, it is possible to identify a few of their more important general characteristics. First of all, freight charges per unit of weight increase with increasing distance and in steplike increments that create zones of uniform rates. Generally they increase less than proportionally with distance because a large share of the costs of movement are incurred at terminal facilities and therefore are essentially independent of the length of the haul itself. Secondly, freight rates vary according to the commodity to be transported.

Finished products commonly are charged more per ton-mile than are raw materials. Highly perishable goods, bulky items, and commodities of high value generally receive a higher rate. Finally, freight rates vary between different transport media. In general, truck transport, in which the costs vary almost directly with distance, is more economical for short hauls. Rail and water transport, on the other hand, having large fixed costs and minor distance-dependent operating costs, is generally cheaper for longer hauls.

The transport-oriented manufacturer, searching for the least-cost location, responds to transfer costs by seeking to reduce them. He can lower his procurement costs by locating close to his input supply or reduce his distribution costs by locating close to his market. Since raw material sites and markets are generally spatially separated, the producer must weigh the advantages of locating either at his source of raw materials or at his market. Intermediate locations are generally more costly because they incur additional handling charges and do not take advantage of the relative economy of a long-distance haul. However, intermediate points may have special transfer advantages when breaks in transport (i.e., "break-of-bulk") require a transshipment anyway, or when several material sources and markets are involved.

The manufacturing process almost always leads to a change in the form, and therefore weight, of the original raw materials. Removal of waste matter, as for example in the smelting of ores, leads to a considerable reduction of volume and weight. Such processes, therefore, are most economically located close to their supply of raw materials. Orientation to raw materials is also economical when the change of form involves a reduction in perishability or handling expense, as in the manufacture of cheese. The higher transfer costs on the raw material favor a location near the source.

An orientation to markets may arise as a result of counterparts to the change in form tendencies described above. Thus a market location may be based on a "weight gain" in the manufacturing process or a higher freight cost on the finished product than on raw materials. A classic example is the production of bottled soft drinks. The addition of the ubiquitous material, water, to a relatively small quantity of other inputs, results in a product whose weight considerably exceeds that of its non-ubiquitous inputs. Rapidly perishable products, such as most dairy goods, are another example of a class of goods that require a market location.

The above paragraphs have identified some of the factors that a transport-oriented manufacturer must consider in deciding where best to locate his firm along the links connecting his source of inputs to his market. For the transport-oriented industries the most economic location is one at which the transfer costs of assembling the necessary inputs and distributing the finished outputs is the lowest. However, even for a transport-oriented firm, a location other than the minimal transfer cost one may be optimal. For example, a location at which processing costs are low may be preferred if the additional transfer costs are offset by savings in processing costs. We shall, therefore, now consider some of the factors that determine processing costs.

3.1.2. Processing Costs

Processing costs reflect the availability and cost of the factors of production: land (or, more generally, space), labor and capital, all of which are available to the producer at a price. The costs incurred in the use of these factors: rent, wages and interest, constitute the major portion of a manufacturer's total production costs. The imperfect mobility of these factors gives rise to spatial variations in their price which, in turn, leads to geographical differentials in the total costs that will be incurred in manufacturing a given product at alternative locations. Thus the producer seeking an optimal location presumably will look for a site where his particular combination of the factors of production may be had at minimum cost per unit output.

The "search for space" as a causative element in relocation has been identified in scores of recent surveys of industrial migration. The introduction of continuous-material flow systems and automatic controls in manufacturing processes has contributed mightily to the technological obsolescence of the existing industrial plant in most major metropolitan centers. The desire for a production layout appropriate for modern processes has generated a search for production sites which impose the least number of constraints on construction to house the production process. The astronomically high land values in the city core, problems of acquisition, and the restraints imposed by the block grid together have acted as powerful centrifugal forces.

Fundamental to any manufacturing process is an adequate labor supply of the appropriate cost and quality. Although the importance of labor considerations in locational decisions varies widely across industry groups, few manufacturers are totally indifferent to geographical variations in labor costs and productivity. Basic considerations that assume varying degrees of importance are spatial variations in labor supply, cost, and quality. Industries for which a supply of relatively high-wage skilled labor is a key factor assume a markedly different pattern from those whose location is governed by access to a pool of unskilled low-wage labor. The former are increasingly favoring suburban locations, the latter still cluster around the city centers with their supply of low cost tenement housing.

Capital costs for equipment and money are influencing factors in interregional industrial location decisions. However their impact declines in an intraregional setting since spatial variations in capital costs are virtually nonexistant at the local level. Nonetheless, the relative immobility of heavy equipment, contributes to the geographical inertia of many industrial establishments. Heavy investment in fixed capital cannot be readily "written off" before its useful term of life has been ended. Capital replacement costs therefore often act as a significant restraining force on relocation.

Besides manifesting the differential availability and costs of the factors of production, geographic differences in processing costs also reflect the imperfect divisibility of land, labor and capital. Thus the scale of production appropriate to a particular location is also a relevant consideration in location decisions. Economies of larger scale processing have to be weighed against increases in transfer costs and diseconomies of growing administrative costs. Decreasing unit costs arising from an expanding output may more than offset the diseconomies of longer hauls for example. A least cost transfer point may have a market that is too small to support an efficient sized plant.

Finally, the search for a least cost location from the point of processing costs involves, in addition to considerations of alternative locations, a consideration of alternative mixes of the factors of production. Variation in factor prices can sometimes be offset by changes in the proportion in which they are utilized. That is, the relative quantities used of each are not fixed but may vary within rather broad technological limits. Factor substitution, for example, may lead to the use of more capital per unit labor in areas where labor is scarce and expensive, or may suggest a more intensive application of labor to a piece of capital equipment when labor is cheap.

In short, the relative advantages of different possible processing locations arise out of the fact that units of land, labor and capital are imperfectly mobile and imperfectly divisible, and depend fundamentally on two things: factor prices and factor input levels per unit output. Typically prices and amounts used depend on the scale of production. Moreover, variations in factor prices may be offset by factor substitution. If a factor is scarce and expensive, it will be utilized more intensively. Thus a manufacturer seeking the least cost processing location must consider all possible combinations of land, labor and capital that could be used to produce a given output at each site, and then compare the most economical combination with that prevailing at every other alternate site. The appropriate combination at each location will depend on the relative unit factor prices, their productivity, and the scale of production that can be economically carried on at that location.

An analysis of the locational influences of transfer costs and processing costs may aid in the understanding of a region's industrial land use pattern. Transfer costs increase regularly with distance and tend to favor locations near suppliers or near markets. Processing costs do not vary in a regular way over space but, in general, are beginning to favor outlying locations over center city sites for a large class of industries. Transfer costs and processing costs interact through substitution to create a set of sites that have special locational advantages for particular industry groups.

However, other factors frequently act as significant influences on industrial location. Factors which do not fall under the categories of transfer costs or processing costs. Their importance varies from industry to industry, but their influence is present in most instances.

3.1.3. Other Factors

Not all locational behavior of industrial establishments is directly accountable for by factors internal to the firm, i.e., comparative economies in transfer costs and processing costs. Locational decisions are constrained and influenced by many noneconomic external factors such as, for example, governmental policies. Zoning ordinances and tax assessments are but two illustrations. Locational decisions also may be influenced by economic external benefits which flow from the "external economies" that arise out of concentrations of linked activities in a given area. Analyses of the locational behavior of small establishments, producing a relatively nonstandardized product, consistently are finding that such firms favor locations within clusters of linked industries in order to share in some essential goods or services. The shared use of common facilities, the need for accommodating rapidly to sudden changes in demand and technology, the importance of face-to-face contact, all have contributed to the pronounced clustering of particular industry groups in urban areas. Geographical concentration of activity allows producers to reap the benefits of economies of scale by contracting out, to a specialized firm, the manufacturing of certain necessary inputs. It allows them to share a common pool of skilled labor, and uncertainties inherent in small plant operations may be met by drawing on external sources within the cluster. Here a firm can get materials on short notice, recruit labor for brief periods, and lease additional space in fractional units. In short, by acting as a group, firms pursuing a limited scale of operations may gain many of the economies that are internal to the large multiplant firm.

The spatial affinity of linked industries is an important factor in locational decisions. Each establishment in a cluster benefits not only from the particular cost advantages of a site there, but also shares in the external economies that arise within such concentrations. Thus the locational juxtaposition of many individual firms, linked vertically or horizontally in the manufacturing process, is a feature that must be recognized in analyses of industrial location.

3.1.4. Conclusion

Analyses of the industrial patterns of metropolitan areas require an understanding of the major influences that bear on manufacturer's locational decision. Transfer cost considerations attract plants to their sources of supply and to their markets. Processing costs interact to produce sites with particular cost advantages. Factors external to the individual firm exert a significant influence on the locational behavior of smaller establishments.

In recent years, however, analyses of industrial location have been severely complicated by the increasing mobility of the factors of production. Foremost has been the general decline of the initial advantages of central locations in metropolitan areas. Transportation facilities which once were unique to the city centers are now available throughout the urban area. With the decline of the barriers of distance, local differentials are disappearing. Industrial space is being offered on the suburban rental market. Labor is becoming highly mobile at the intrametropolitan level. External economies, once the monopoly of the city center, are now being found in many locations. Local variations in property tax levels are narrowing, as state and federal taxes increasingly assume a larger proportion of the total tax bill. The net result is a gradual decline of spatial differentials in attractive locations for industry. As a consequence, the analysis of industrial location within the classical framework of comparative cost, and utilizing available data, is becoming increasingly difficult.

3.2. Commercial Location Theory

Commercial location theory is concerned with the spatial behavior of retail trade and service establishments. As in industrial location theory, the locational decision of a commercial establishment may be accounted for by reference to a fundamentally economic set of influencing factors. Unlike the case in manufacturing, however, spatial variations in expected revenues are considerable and cost differentials insignificant. Consequently, the relative attractiveness of each location is measured largely in terms of revenue rather than cost. Costs are commonly assumed to be constant over space, and the maximum revenue location generally serves as a "proxy" for the maximum profit location.

The maximum revenue approach to commercial location typically associates revenue with three variables: market area, consumer expenditures, and competition. Generally it adopts the following locational rationale. A commercial establishment seeking a location in an urban area first isolates a set of alternative possible locations by eliminating clearly undesirable sites. Next, at each potential location for its activities, it evaluates the expected potential dollar volume of sales there by estimating its market area, the expected consumer expenditures for its goods within this trade area, and the possible effects of competition. Pursuing this analysis at each of a finite number of alternative sites, the establishment ultimately identifies the location that is optimal for its intended activities and locates there.

3.2.1. Market Area

Commercial activity is concerned with the distribution of goods and services to their ultimate consumers--households. Commercial establishments are business firms which perform this function for the population in the area surrounding them, i.e., their market area. This territorial delineation stems from the interaction of two components: the kinds of consumer goods and services that are being marketed, and the spatial behavior of consumers purchasing these goods and services. Their interaction defines the areal domain from which establishments are able to attract a clientele. A few theorists [43, 44] have labeled the upper limit of the radius of this domain as the "range" of a good and have combined this notion with the concept of a minimum "threshold" sales level to account for the hierarchical arrangement of retail and service centers in urban areas.

Marketing specialists typically distinguish between three classes of consumer goods: convenience goods, shopping goods, and specialty goods. The standard definitions of these terms reflect the buying habits of the consumer and typically distinguish goods on the basis of the frequency of their purchase and the role brand names play in the purchasing process.

Convenience goods are consumer goods which are bought frequently and repeatedly, and which the consumer therefore desires to purchase with a minimum of effort. Brand names, rather than price, are the principal consideration. Examples are groceries, tobacco, and drug items. Since these goods are purchased day after day, convenience and accessibility are of fundamental importance. Thus, stores carrying these goods tend to locate close to the consumer.

In contrast to convenience goods, shopping goods are generally acquired at periodic intervals: seasonally, annually, and, in some instances, only once in a lifetime. Such items commonly are unstandardized and are purchased only after considerable comparisons of quality and price have been made in a number of competing retail outlets. Furniture, shoes, jewelry, and style goods in general are prominent examples of this category of consumer goods. To satisfy the consumer's desire to "shop around" shopping goods stores tend to cluster in major retail centers.

Specialty goods are goods for whose purchase the consumer is willing to make a special purchasing effort. Price once again is not the major consideration, but plays a subordinate role to merchandise quality. Examples are expensive perfumes, watches of superior quality, and high-grade men's and women's clothing. Since consumers of specialty goods typically make a special visit to purchase them, the locational decisions of stores handling such merchandise are quite free of any restraining conditions such as are met by convenience goods or shopping goods outlets. Thus specialty goods stores may locate virtually anywhere in the urban area without seriously affecting their volume of sales.

It is quite apparent that a considerable degree of overlap exists in the above classification system. Different consumers may as a result of their buying habits treat convenience goods as specialty goods and vice versa. Thus, though most people consider groceries as a convenience good, many "shop around" for them. On the other hand, common work shoes may be treated as a convenience good and purchased at the most convenient location. These difficulties of overlapping categories are inherent in any classification system and once recognized should not seriously hamper most analytical investigations.

Probably no economic activity system is as highly dependent for its existence on the whims of the individual consumer as is the commercial activity system. Retailing is a market oriented activity and is, therefore, very responsive to changes in consumers' tastes, demands, and habits. Their desire for convenience, a wide selection of merchandise, and economy are some of the fundamental variables which have an important bearing on the operation of the activity system. Their status in terms of income and class, and their general frame of reference, act as significant influences in shaping their purchase decisions.

Empirical evidence suggests that the spatial movements of consumers to commercial centers are not arbitrary and indeterminate, but on the contrary, exhibit a rather well-defined pattern. Movements initiated from certain bases of operation proceed, by available means of locomotion, to their shopping destinations. Thus there is reason to expect that differences in movement patterns are measurable and can be related to causal factors.

Various factors appear to be associated with the spatial choices made by consumers regarding where to shop for goods and services. Implicit in the findings of several past studies is the suggestion that consumers are attracted to commercial centers in direct proportion to the size of these centers and in inverse proportion to the intervening distance that must be overcome to shop there. It also appears that this attraction to larger facilities stems, at least in part, from the attempt by the consumer to maximize the probability of having a successful shopping trip with regard to satisfying his purchase desire. The suggestion also has been made that consumer travel habits, in particular the multi-purpose shopping trip, play an important role in the selection of a shopping center. Consumer travel movements seem to reflect an attempt to minimize the costs of travel associated with shopping at alternative locations. Others have suggested the importance of "intervening opportunities" as a factor influencing spatial decisions. Finally, as was mentioned earlier, the nature of the product being purchased plays an important role. Examination of the spatial movements of shoppers reveals that food, for example, is sought in areas nearer home whereas clothing is predominantly purchased downtown.

In sum, the geographical extent of a market area is a function of the commodity being sold and the spatial behavior of consumers seeking that commodity. Since a larger market area, in general, captures more potential consumers, expected revenues at a given site increase proportionately with the size of the market area that can be commanded at that location. The character of the population that is encompassed by a market area, however, is another critical variable which influences the volume of revenues that may be anticipated. Income levels and expenditure patterns vary across population groups and vitally affect the purchasing power that a market area of fixed size can capture.

3.2.2. Consumer Expenditures

The volume of business which a commercial establishment can obtain at a given site is functionally dependent on the number of people in its market area and on how much money they have and are willing to spend for the type of goods carried by the establishment. A variety of factors have been identified as important influences on shopping behavior. Socioeconomic status, educational level, and occupational group are significant forces affecting the purchasing orientation of consumers. Social class position, it has been argued, is reflected in great depth in individual spending behavior. It also has been established that variations in expenditure patterns for items such as food, housing, and clothing are closely associated with variations in family size, income, and prices. Empirical data suggest that the higher the incomes of a group patronizing a store, the greater will be their dollar expenditures there. Convenience costs are becoming more important in understanding purchasing behavior. The increasing leisure time available to consumers has apparently led to a desire to minimize shopping time. Supporting evidence is the recent upsurge in catalogue and telephone purchases. The quality and selection of merchandise, salesclerk service, and the life cycle are other factors that have been identified. Finally, changes in the size and composition of the shopping party suggests that shopping is becoming increasingly a group affair. The implications of this trend have not been fully explored.

With a determination of expenditure patterns in a market area, it is possible to estimate the volume of sales available for each merchandise category by multiplying the annual per capita spending for each class of merchandise by the size of each population group. However, not all of this purchasing power need go to a single establishment. The development of a new shopping center does not generate additional sales in the area. It merely brings about a redistribution of the existing consumer expenditure pattern. Thus, the importance of evaluating the competitive "pull" of other commercial establishments is an essential step in estimating a new center's share of the market.

3.2.3. Competition

The theory of retailing and service trade describes retailing as monopolistic or imperfect competition [13, 29]. Although many features of the structure of retail markets are included in the generally accepted definitions of perfect competition, the presence of certain "imperfections" has led writers to place commercial activities in the middle ground between perfect competition and monopoly. These imperfections stem from two major sources: 1) spatial and nonspatial monopolistic influences such as favorable locations or prestige clientele; and 2) the desire of commercial firms to minimize risk and limit the area of competitive activities, such as price competition and trading stamps, that can be undertaken by other firms.

Commercial establishments continually evaluate the impact that their decisions will have on competitors and generally pay close attention to the policies of other establishments carrying similar lines of merchandise within its geographical trading area. This is in contrast to "perfect competition" where the behavior of a firm has no significant influence on market price. Also, it is frequently held that since people tend to shop around for shopping goods price elasticity of demand is much greater for shopping goods than convenience goods and, as a result, shopping goods retailing is competitive. The same point of view suggests that since consumers attempt to minimize the disutility of convenience goods shopping, and tend to purchase many convenience goods at one place, convenience goods retailing tends to be imperfectly competitive or monopolistic. This oversimplified view of the fundamental difference between the market structure of the two branches of retail trade has received some criticism. However, it does appear to have merit in explaining the spatial concentration of particular classes of retail firms and the decentralization of others.

The tendency for particular classes of commercial establishments to cluster has been noted by several theorists on the subject of intraurban commercial spatial structure. Hotelling, for example, in his classical essay on spatial competition [24], concludes that as "more and more selle[rs] of the same commodity arise, the tendency is not to become distributed in the socially optimum manner but to cluster unduly." Proudfoot [48] provides empirical evidence of this tendency, and Nelson [47, p. 179] supplies a rationale for it by his "principle of cumulative attraction." This principle holds that a group of stores carrying the same merchandise will do more business if they are clustered together than if they are widely scattered. Thus, for example, a nucleus of three shoe stores will do a larger volume of business than will the same three located several blocks apart.

Reference to the generally dispersed pattern of convenience goods outlets in urban areas also appears in much of the theoretical literature on commercial spatial structure. Ratcliff [49], for example, recognizes that certain neighborhood type establishments, such as grocery stores, do not profit from cohesion and therefore typically do not group together. Others assert that the scattered pattern of convenience goods stems from their limited "range" and the restricted market areas that they command as a result of this characteristic [43, 44, 45]. Finally, marketing researchers such as Nelson [47], note that a convenience goods establishment, in selecting a location, should be primarily concerned with accessibility and apparent freedom from future competition.

It appears then that explanations of the spatial pattern of consumer goods firms typically cite two interdependent factors as the principal contributory agents to clustering or dispersal: the nature of consumer goods, and the structure of consumer goods markets. Catering to the immediate every day needs of the consumer, convenience goods establishments have followed the urban population to the outlying areas of metropolitan communities and have assumed a spatial pattern which mirrors that of the population they serve. The day after day needs for such goods have made accessibility and proximity of fundamental importance in the purchasing process, and the hazards of competition encourage dispersion. Shopping goods establishments, however, frequently reflect the thesis that firms with a high degree of compatibility can ensure a greater volume of sales for themselves by clustering together. Their compatibility may stem from the complementary nature of their activities and products, or may occur when, though competitive, they carry goods of different quality and price. Thus, in a general sense, we may conclude that rival shopping goods establishments tend to attract one another and to cluster; whereas, competing convenience goods firms tend to repel one another and thus to assume a more dispersed spatial pattern. Establishments falling outside this dichotomous classification may be viewed as producers of specialized goods and service and may be assumed to have locational characteristics appropriate for their particular activity. Typical examples are traffic oriented activities, such as gasoline service stations, which appear to be highly dependent on the traffic flow pattern of an urban area.

3.2.4. Conclusion

In spite of the great physical changes brought about by the tremendous growth of suburban areas, the commercial spatial structure of urban areas has maintained a remarkably constant profile during the past thirty years. Commercial establishments in most major cities generally belong to one of the following classes of centers: the central business district, outlying secondary shopping districts, neighborhood business nucleations or small retail clusters, and isolated individual stores.

Commercial spatial patterns arise directly out of the locational decisions of the distributors of retail goods and services. The individual business firm operating with incomplete information regarding the urban environment seeks to serve the spatially scattered market by establishing itself at a profitable location. Analyses of the significant influences bearing on its locational decision form the body of commercial location theory.

Virtually all of the theories that attempt to analyze, interpret, and ultimately predict the spatial behavior of commercial establishments point to a common set of factors which together are held to influence the locational decisions made by such firms. These are variables having as their principal referent the consumer, the state of the urban system, or the establishment. Related to the first are factors such as the distribution of population, income, and purchasing power. Connected with the second are considerations pertaining to accessibility, site economics, and the availability of advantageous locations. Finally, falling in the third category are factors which reflect the establishment's accommodation of internal needs to the external setting, as for example, the affinity for other economic activities and the role of spatial monopoly in competition

The general rationale that emerges concerning the spatial behavior of commercial outlets is that the distribution of retail and service trade establishments in urban areas reflects the averaging of the attracting and repelling forces of linkages incident to his operation and evaluates the relative advantages and disadvantages of a particular site in light of these considerations. Accessibility to the residentially based market, exposure to vehicular or pedestrian movements, and proximity to competing and complementary establishments are typical examples of some of the fundamental considerations that appear to be present in these locational decisions.

3.3. Residential Location Theory

A household's decision to settle at a particular site in an urban area may be viewed as a problem in consumer choice. Such a view focuses on the different attributes that a household evaluates at each of several alternative locations and then considers how these attributes are collectively weighed by the household in arriving at its locational decision.

Earlier we noted that industrial establishments tend to seek the location at which they can carry on their productive activities at minimum cost. Commercial establishments, on the other hand, were seen as searching for a site from which they could conduct their distributive activities with a command over a maximum amount of revenue. In this section, we adopt the common argument that residential "establishments" seek a location where, as consumers, they maximize their satisfaction subject to the constraints of income. Recent efforts to account for consumer behavior in the housing market have pointed, in particular, to three key variables as having a powerful influence on a household's locational calculus [5, 54, 57, 60]: accessibility, community, and the physical endowments of site and dwelling.

3.3.1. Accessibility

As Britton Harris has pointed out [55], accessibility, like density, is a constructed rather than an observed variable. And unlike density, the rules for its measurement are by no means simple or self-evident. Despite the operational difficulties of measurement, however, one intuitively accepts the notion that accessibility, however it may be quantitatively assessed, should reflect the ease with which spatially separated activities can interact with one another. Moreover, a more detailed examination reveals that accessibility has several different dimensions and that therefore its operational definition must involve several empirically observed components.

Scores of studies have documented the critical influence that accessibility to employment, shops, schools, and other activities carried on away from home, has on a household's locational decision [5, 6, 57, 58, 59, 60]. Most begin with the assumption that the principal accessibility attribute of a site that enters a household's locational decision making is the location of the site with respect to the household's place of employment. Time-distance, convenience, and cost are the characteristics of the journey to work that are most frequently cited as the relevant explanatory variables that affect residence in relation to work. And increasingly the journey to work is viewed as a radius which delineates submarkets around places of work--submarkets within which a household then considers another set of attributes before arriving at its locational decision. In recent years this radius has grown longer and longer until today a commute of an hour's length is not unusual in many metropolitan areas.

Although the journey to work is still seen as holding a dominant position in a household's transportation budget, recent empirical analyses indicate that its relative importance is declining as a consequence of the increased availability of cars and the declining share of total person trips that the journey to work accounts for. This decline has elevated the relative importance of other trip purposes in the household's overall transportation bundle. That is, as the influence of journey to work travel has declined, that of shopping, social and recreational travel has increased. However, although accessibility to nonwork activities increasingly is becoming an important consideration in locational decisions, its influence enters the locational calculus in a slightly different manner. Nonwork trips are not as frequently undertaken as work trips and, more important, are not regularly made to a fixed destination. Moreover, they typically are shorter trips and less painful since they are generally made during nonpeak hours. Thus their influence is more appropriately visualized in terms of a "potential" measure, that is, an average accessibility of a site to all activities with which the household at that site is likely to be concerned.

As transportation costs are becoming relatively less expensive or less undesirable intermediate goods, the constraints which the friction of space once imposed on the locational decision is being relaxed. This may push other considerations to the forefront in the locational decisions made by households. Social infrastructure, for example, in the form of schools, parks, and services, may wield an increasingly powerful influence. Amenity considerations, reflecting the physical endowment of a site, too may become a more important consideration for a wider range of residential locators than ever before. Housing is not only location, but is a compound goods which includes space, prestige and many other components. Thus the dynamics of residential location must take into account not only accessibility but also the changing character of consumption functions growing out of changing levels of income distribution.

3.3.2. Community

Every residential location is surrounded by a community. The notion of community is perhaps even more ambiguous, and hence less amenable to quantitative assessment, than the concept of accessibility. Nevertheless, its importance as a factor influencing residential locational decision making has been underscored by several recent studies [5, 60].

Perhaps the most important attribute of community that a particular residential area projects is that of class image--a symbolic identification of the area in terms of the socioeconomic profile of its residents. Community images are shaped by the interaction of several different factors. However, a large part of the variation between community types can be attributed to three basic variables: occupational class, income level, and age composition. Households in the same occupational class--frequently denoted by tags such as "white-collar," "blue-collar," "professional," and "business,"--seem to have a spatial affinity for one another and cluster together in the same residential communities. Income levels stratify communities according to taste and the proportion of the household budget that is allocated for shelter. And changes in the age composition of a household that are characteristic of the family cycle are accompanied by changes in the type of community that is sought. Thus, for example, families with children prefer to reside in communities which contain children of similar ages.

In addition to its impact on the preferences held by a household seeking a location, a community image wields an additional influence on locational decision making by its relation with the investment potential of a site and, more particularly a dwelling on that site. Since the market value of a house depends in a large measure on the value of the homes in the community of which it is a part, the concern for a "saleable" community image is always present in residential locational choices. That is, households not only evaluate a community with respect to their own preferences, but, in addition, take into account the resale potential of a dwelling in that community. In thus considering the preferences of the "market," households are increasingly viewing dwellings as commodities which will be resold in the future and which in the interim will function as residences for socially aspiring families [60].

3.3.3. Physical Amenities

Increases in real income and leisure time per capita, during the past two decades, have exerted a significant influence on the spatial distribution of households in metropolitan regions. Higher incomes and increased leisure are reflected in the housing market by a growing demand for more space, both on the site and inside the home, and for other physical amenities such as climate, views, and the absence of smog.

Households electing to live close to major employment centers generally are forced to give up one amenity--spacious living. Those willing to engage in a daily commute, however, can obtain larger sites and a more spacious home by trading accessibility for space. As incomes have increased, the relative costs of commuting have declined. As a result, a far larger proportion of the population can now afford to disperse spatially and demand more space inside the home, in the form of more bedrooms and activity areas, and more space outside the home, in the form of larger lot sizes and more recreation areas.

In addition to the desire for spacious living, rising incomes also have generated a demand for a host of other amenities. Desirable natural attributes of a location such as a mild climate and views, for example, are growing influences in the locational decision of a wider range of households than ever before. A recent study found that a cooler climate, a rustic atmosphere, and the absence of smog were listed as very important factors by over 70 per cent of the households interviewed in a suburb in the Los Angeles metropolitan region [60]. The same study also found that quality of construction, particularly as expressed by the phrase "more house for the dollar," was an equally important influence.

Analyses of amenities as influencing factors in residential development are relatively recent. Thus the impact of amenities on the locational decision is only beginning to be assessed. Nevertheless, it is already clear that with the steadily increasing affluence of metropolitan populations, they will wield a growing influence.

3.3.4. Conclusion

Urban planners are increasingly recognizing the limitations of traditional land use studies which focus only on changes in the effects of urban activity systems rather than on changes in the activities themselves. Chapin, for example, remarks [2]:

> Just as the analysis of movement systems has become the basis for transportation planning, the study of activity systems serves a corresponding purpose in land use planning.

In sum, the importance of activities as a structuring force on land development patterns is by now widely accepted. Productive activities, retail and service activities, and household activities are the fundamental activity systems that have meaning for transportation planning. They generate most of the traffic in an urban area, and they determine, to a large degree, the competitive position of a region as a producer of goods and service, and therefore the well-being of its inhabitants.

In the above paragraphs, we have analyzed the urban activity system in terms of the decision making behavior of the principal actors in it. It was suggested that productive activities seek minimum cost locations, distributive activities maximum revenue locations, and household activities maximum satisfaction locations. Included also was a review of the fundamental influencing factors for each class of activities. In the following section, we turn to an examination of how this decision behavior may be expressed in model form and projected into the future.

4. Activity Allocation Models

The subject of urban activities and space is a broad one, combining, as it does, the concerns of geographers, demographers, urban and regional planners, transportation planners, economists, sociologists, and ecologists. Consequently, one finds a vast array of models which may be used for allocating urban activities over space; models that are analytic or statistical, deterministic or probabilistic, gravity or potential. Collectively they form a large and complex set of considerable dimensions. Therefore, it seems useful to draw on the notational and conceptual compactness of matrix algebra to identify a few of the more salient features of such models. A definitive discussion is beyond the scope of this paper. Indeed a mere listing of models that have been proposed would be tediously long. Hence we shall limit our discussion to only one of the more important models which have become operational during the past few years.

4.1. A Generalized Matrix Activity Allocation Model

Recent work in mathematical demography has demonstrated the utility of matrix representation of interregional population growth and distribution.[2] In particular, the most important contribution of the matrix formulation of such processes appears to be the separation of the growth process from the population that is undergoing this process. By using a projection "operator" to advance an interregional (or in this case, interzonal) population system forward through time, we readily may focus on the projection process itself, its application to another population, and its long-term implications.

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[2] Andrei Rogers, Matrix Analysis of Interregional Population Growth and Distribution (Berkeley, Cal.: University of California Press, 1968).

Moreover, the insights provided by the matrix model are frequently not obtainable by more conventional techniques of population analysis. In this section we shall demonstrate that the matrix approach, which has been so successful in analyzing interregional systems, may be adapted for purposes of intraregional analysis.

4.1.1. The Journey from Work to Home and Residential Location

Consider an urban region that has been divided into m zones, and assume that the population of this region locates with respect to its plac of employment. In short, assume that people, in striving to reduce the costs of their journey-to-work, tend to cluster in a regular manner around their places of employment. We may express this hypothesized relationship by the matrix equation

$$\underline{w}^{(t)} = M\underline{e}^{(t)} \tag{1}$$

where $w_i^{(t)}$ = total population in the i^{th} zone at time t;

$e_i^{(t)}$ = total employment in the i^{th} zone at time t;

M = a matrix growth operator that transforms the employment vector, at time t, into the corresponding population vector, at time t.

If one assumes that employees live and work in the same zone, the matrix M may be interpreted as a diagonal matrix whose nonzero elements denote the population-per-employee ratios (i.e., the reciprocals of the zonal labor force participation rates) of the respective zones. More realistically, however, we may wish to assume that the residences of the employees working in each zone are distributed among all zones according to some observed inverse relationship with distance or travel time. Thus we may define m_{ij}^* as the proportion of employees, working in zone i, who live in zone j.[3] Expanding this proportion by the population-per-employee ratio of the j^{th} zone, we may redefine the elements of the matrix M, as follows:

$$m_{ij} = m^{*}_{ij}\alpha_j \qquad (2)$$

where m^{*}_{ij} = proportion of employees who are employed in zone i and reside in zone j;

α_j = population-per-employee ratio of zone j.

Thus we have the matrix equation:

$$\begin{bmatrix} w_1^{(t)} \\ w_2^{(t)} \\ \cdot \\ \cdot \\ \cdot \\ w_m^{(t)} \end{bmatrix} = \begin{bmatrix} m_{11} & m_{21} & \cdots & m_{m1} \\ m_{12} & m_{22} & \cdots & m_{m2} \\ & & & \\ & & & \\ m_{m1} & m_{m2} & \cdots & m_{mm} \end{bmatrix} \begin{bmatrix} e_1^{(t)} \\ e_2^{(t)} \\ \cdot \\ \cdot \\ \cdot \\ e_m^{(t)} \end{bmatrix} \quad . \qquad (3)$$

4. 4.1.2. Employment Growth and Population Growth

Equation (1) relates a region's interzonal employment distribution, at time t, to its interzonal population distribution at the same point in time. The model is therefore static and may be calibrated on the basis of cross-sectional data. In order to introduce a dynamic dimension to the model, we may adopt a model of employment growth and then trace through the implications this growth has on the region's population. Alternatively, we may posit a model of population growth and then focus on the implications

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[3] The author is grateful to a former student of his, Robert Garin, for this observation. See: Robert Garin, "A Matrix Formulation of the Lowry Model for Intrametropolitan Activity Allocation," Journal of the American Institute of Planners, XXXII:6 (November 1966), pp. 361-364.

of this growth for employment. Both aspects will be treated in this section.

Assume that employment growth and distribution, in the study area, may be represented by

$$\underline{e}^{(t+1)} = S\underline{e}^{(t)} \tag{4}$$

where s_{ij} = the proportion of employees, working in zone i at time t, who are working in zone j at time t + 1;

s_{ii} = the sum of two proportions: (1) the proportion of employees, working in zone i at time t, who are working in zone i at time t + 1, and (2) the region's net "new" employees (i.e., "employee births" and employee-migrants into the urban areas less "employee-deaths" and employee-migrants out of the urban area) that are attributable to zone i, during the time interval (t, t + 1), as a proportion of total employees working in zone i at time t.

Then, by Equations (1) and (4), we have

$$\underline{w}^{(t+1)} = M\underline{e}^{(t+1)} = MS\underline{e}^{(t)} \quad , \tag{5}$$

and the model now has a recursive dynamic component.

Let us turn to a consideration of the implications of population growth on employment growth. We begin by defining a matrix model of population growth that is similar to the one defined for employment growth. That is, we adopt the following matrix model:

$$\underline{w}^{(t+1)} = G\underline{w}^{(t)} \tag{6}$$

where $w_i^{(t)}$ = total population in the i^{th} zone at time t;

g_{ij} = the proportion of the population, residing in zone i at time t, who are residing in zone j at time t + 1;

g_{ii} = the sum of two proportions: (1) the proportion of the population, residing in zone i at time t, who are residing in zone i at time t + 1, and (2) the region's net "new" population (i.e., births and migrants into the region less deaths and migrants out of the region) that are attributable to zone i, during the time interval (t, t + 1), as a proportion of total population residing in zone i at time t.

We now may establish the following useful relationship between the two alternative formulations. Combining Equation (6) with Equation (1), we have

$$\underline{w}^{(t+1)} = G\underline{w}^{(t)} = GM\underline{e}^{(t)} \tag{7}$$

whence, by Equation (5),

$$GM\underline{e}^{(t)} = MS\underline{e}^{(t)} \tag{8}$$

$$G = MSM^{-1} \tag{9}$$

or

$$S = M^{-1}GM \quad . \tag{10}$$

Since it is generally more difficult to obtain empirical data for calibrating S than G, the relationship defined by Equation (10) has considerable utility.

4.1.3. Stable Growth Rates and Distributions

It is of course clear to everyone that the matrices M, S, and G in the above matrix equations will not remain constant through time and that therefore in a forecasting effort they would need to be predicted at each recursion of the model that is used. Nevertheless, it is of some theoretical interest to derive what may be referred to as a "speedometer" reading of where we are headed if things do not change. In this way we could compare today's "speedometer" reading with yesterday's, to see if the "horizon" projection to which we are headed has shifted, and, if so, in what direction. This may be done by recursing the model until it reaches a stationary state, that is, an unchanging growth rate and spatial distribution.

Recall Equation (5), and consider the population projection that is generated by an unchanging regime of employment growth and home-to-work structure. Since

$$\underline{w}^{(t+1)} = MS\underline{e}^{(t)} \quad ,$$

and

$$\underline{w}^{(t+2)} = MS\underline{e}^{(t+1)} \quad ,$$

by substitution, using Equation (4),

$$\underline{w}^{(t+2)} = MS^2\underline{e}^{(t)} \quad ,$$

and, in general,

$$\underline{w}^{(t+n)} = MS^n\underline{e}^{(t)} \quad . \qquad (11)$$

Consider, next, what happens as n, the number of time periods, gets very large, that is, as n approaches infinity. It can be shown that in such instances the vector of basic employment, and hence the population vector as well, stabilizes around a distribution that grows at a constant rate of growth and remains proportionately constant. That is, at stability, each zone's share of the total population and employment remains the same over time, even though the total itself increases at a constant rate. Moreover, it can be shown that this constant rate of growth is the dominant characteristic root of the nonnegative matrix growth operator, and that the stationary distribution is the associated characteristic vector. These results all stem from the stability properties of nonnegative matrices and are summarized in several currently available texts.[4]

4.1.4. A Numerical Example

At this point, let us turn to a numerical example to clarify the arguments that have been presented thus far. We draw on the data for the hypothetical town of Lartsville that is presented in a prospectus published by a recent metropolitan area transportation study.[5] The town has been divided into ten zones which have the following employment totals for time t, say the year 1960.

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[4] The relevant essentials of the theory of positive and nonnegative matrices that we need for the above analysis may be summarized by the following theorem:

Theorem: If S is a square nonnegative matrix, then there exists a nonnegative characteristic vector x, associated with a nonnegative characteristic root, v, which is greater or equal to the absolute value of any other characteristic root of the matrix S.
For further details the reader should consult: F. R. Gantmacher, The Theory of Matrices (New York: Chelsea Publishing Co., 1959), vol. 2, pp. 50-112; Samuel Karlin, Mathematical Methods and Theory in Games, Programming, and Economics (Reading, Mass.; Addison-Wesley, 1959), pp. 246-256; and Rogers, op. cit.

[5] Gibson W. Fairman, Prospectus, Los Angeles Regional Transportation Study, September 1960. Also see, Garin, op. cit., and Andrei Rogers, "A Note on the Garin-Lowry Model," Journal of the American Institute of Planners, XXXII:6 (November 1966), pp. 365-366.

1960

Zone	Employment
1	4500
2	0
3	0
4	0
5	0
6	9000
7	0
8	1000
9	0
10	0
Total	14500

Garin, in his paper,[6] suggests the following journey-to-home function

$$m^*_{ij} = \frac{e^{-0.1t_{ij}}}{\sum_j e^{-0.1t_{ij}}} \quad . \tag{12}$$

where t_{ij} = travel time from zone i to zone j in minutes. Applying this function to the interzonal travel times that exist in Lartsville in 1960 (Figure 1), Garin finds the matrix $\underline{M}^*$ that appears in Figure 2. If we assume, as did Garin, that the population-per-employee ratios, α_j, in all zones are equal to 2.5, we may use Equation (1) to derive the following 1960 population distribution for Lartsville:

$$\underline{w}^{(1960)} = \begin{bmatrix} 3812 \\ 3172 \\ 4290 \\ 2560 \\ 4520 \\ 4658 \\ 1612 \\ 3598 \\ 4048 \\ 3875 \end{bmatrix} \tag{13}$$

6 Garin, ibid.

FIGURE 1.--INTERZONAL TRAVEL TIMES IN LARTSVILLE

From \ To	1	2	3	4	5	6	7	8	9	10
1	2.00	5.25	3.22	10.50	4.94	9.44	15.86	7.94	10.94	12.66
2		1.50	3.75	5.25	5.47	9.97	10.61	8.47	11.47	13.19
3			1.50	7.72	1.72	6.22	13.08	4.72	7.72	9.44
4				2.00	6.00	10.50	5.36	6.00	9.00	10.72
5					1.50	4.50	11.36	3.00	6.00	7.72
6						2.00	15.22	6.86	3.86	3.86
7							2.00	8.36	11.36	13.08
8								2.00	3.00	4.72
9									1.50	1.72
10										2.00

Source: Garin [74], p. 362.

FIGURE 2.--THE JOURNEY FROM WORK-TO-HOME MATRIX

$$M^* = \begin{bmatrix} .172 & .117 & .123 & .069 & .099 & .075 & .054 & .076 & .060 & .056 \\ .124 & .170 & .136 & .117 & .114 & .073 & .068 & .085 & .063 & .053 \\ .152 & .136 & .146 & .092 & .136 & .103 & .071 & .105 & .083 & [illegible] \\ .073 & .117 & .078 & .163 & .089 & .067 & .154 & .092 & .073 & .068 \\ .128 & .114 & .143 & .109 & .139 & .123 & .084 & .125 & .099 & .092 \\ .081 & .073 & .091 & .069 & .103 & .157 & .057 & .085 & .123 & .136 \\ .043 & .068 & .046 & .116 & .052 & .042 & .216 & .073 & .058 & .054 \\ .095 & .085 & .106 & .109 & .120 & .097 & .114 & .138 & .134 & .125 \\ .070 & .063 & .078 & .081 & .089 & .131 & .084 & .125 & .156 & .169 \\ .059 & .053 & .066 & .068 & .075 & .131 & .071 & .105 & .152 & .164 \end{bmatrix}$$

Source: Garin [74], p. 362.

Now let us add the dynamic component to this numerical example. Recall Equation (4) and assume that Lartsville's 1970 employment size and distribution may be predicted by means of the following growth process:

$$\begin{array}{ccccc} \underline{e}^{1970} & & S & & \underline{e}^{1960} \\ \begin{bmatrix} 10900 \\ 0 \\ 0 \\ 0 \\ 0 \\ 10300 \\ 0 \\ 1500 \\ 0 \\ 0 \end{bmatrix} & = & \begin{bmatrix} 2.00 & 0 & 0 & 0 & 0 & .20 & 0 & .10 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .08 & 0 & 0 & 0 & 0 & 1.10 & 0 & .04 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .02 & 0 & 0 & 0 & 0 & 0 & 0 & 1.41 & 0 & 0 \\ 0 & 0 & 0 & 00 & 0 & 0 & 0 & 00 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} & & \begin{bmatrix} 4500 \\ 0 \\ 0 \\ 0 \\ 0 \\ 9000 \\ 0 \\ 1000 \\ 0 \\ 0 \end{bmatrix} \end{array} \qquad (14)$$

Then we may readily draw on Equation (3), once again, to find Lartsville's 1970 population size and distribution:

$$\underline{w}^{(1970)} = \begin{bmatrix} 6902 \\ 5478 \\ 7188 \\ 4060 \\ 7125 \\ 6570 \\ 2528 \\ 5605 \\ 5750 \\ 5375 \end{bmatrix} . \qquad (15)$$

Turning, next, to a consideration of the long-term implications of the growth process defined in Equation (14), we find that the dominant characteristic root, v, of the growth matrix, S, is equal to 2.0, and that the associated characteristic vector, $\underline{x}$, when normalized to sum to unity, is:

$$x = \begin{bmatrix} .892 \\ .0 \\ .0 \\ .0 \\ .0 \\ .079 \\ .0 \\ .029 \\ .0 \\ .0 \end{bmatrix} \tag{16}$$

We may interpret these results as follows: if all the parameters of the system and its behavior were to remain forever as they are now, Lartsville's employment ultimately would double every ten years and its proportional distribution would remain in the form described by the vector $\underline{x}$ in Equation (16). The corresponding "horizon-year" population would also double every ten years and would assume the equilibrium proportional distribution described by the vector $\underline{y}$, where

$$\underline{y} = M\underline{x} \tag{17}$$

$$= \begin{bmatrix} .162 \\ .119 \\ .147 \\ .073 \\ .128 \\ .087 \\ .044 \\ .097 \\ .077 \\ .066 \end{bmatrix}$$

Summarizing the changes of the spatial distributions over time, we have:

Zone	Employment			Population		
	1960	1970	Horizon	1960	1970	Horizon
1	.310	.480	.892	.105	.122	.162
2	.0	.0	.0	.088	.097	.119
3	.0	.0	.0	.119	.127	.147
4	.0	.0	.0	.071	.072	.073
5	.0	.0	.0	.125	.126	.128
6	.621	.454	.079	.129	.116	.087
7	.0	.0	.0	.045	.045	.044
8	.069	.066	.029	.099	.099	.097
9	.0	.0	.0	.112	.101	.077
10	.0	.0	.0	.107	.095	.066
Total	1.000	1.000	1.000	1.000	1.000	1.000

4.2. Existing Operational Models: The Garin-Lowry Model

The above matrix formulation of intraregional employment and population growth and distribution leads to a very simple and compact expression of a empirically verifiable relationship between the spatial patterns of population and employment in an urban area. It can be used to assess the spatial implications of changes in the size of the labor force and labor participation rates, and changes in accessibilities to employment centers. The model also relates employment growth to population growth and, more importantly, it readily accepts refinements in the hypothesized population-employment linkages. It readily may be extended and altered to assume the structure of existing activity allocation models. For example, employment may be disaggregated into basic and non-basic components and the model generalized to assume the form of Lowry's model (79, 74).

The Garin-Lowry model distinguishes between three broad classes of activities: a basic sector of industrial, business and administrative establishments with predominantly non-local clients; a retail sector of business, administrative and other establishments serving a fundamentally local demand; and a household sector consisting of the residential population. Given the geographical distribution of a projected volume of basic employment, the model first distributes the forecasted residential population by relating places of residence to places of work, and then allocates projected retail activity by relating retail employment to the spatial distribution of residential population.

Define the spatial distribution of basic employment in a region by the vector $\underline{e}_b^{(t)}$ and assume that the residential population generated by these basic employees may be found by Equation (1). That is, let

$$\underline{w}_b^{(t)} = M\underline{e}_b^{(t)} \quad . \tag{18}$$

Now consider the distribution of the non-basic employees who serve this residential population. Assume that the number of such employees for each zone i may be found by applying a non-basic employee-per-person ratio, β_i say, to the population of each zone. Further, assume that the spatial disposition of these employees may be found by means of a journey-to-shop function which distributes the non-basic employees, serving each zone's population, over all other zones according to some observed inverse relationship with distance or travel time. Thus, we may define n_{ij}^* as the proportion of non-basic employees, serving the population in zone i, who are located in zone j. We have, then,

$$\underline{e}_{nb}^{(1)} = N\underline{w}_b^{(t)} = NM\underline{e}_b^{(t)} \tag{19}$$

where $\underline{w}_b^{(t)}$ = "basic population" at time t;

$\underline{e}_{nb}^{(1)}$ = distribution of non-basic employees that are needed to serve the "basic population;"

$n_{ij} = n_{ij}^*\beta_i$.

The superscript of unity in $\underline{e}_{nb}^{(1)}$ may be defined as the iteration number, since the newly located non-basic employees will generate a "non-basic population" and, therefore, a demand for more non-basic employees to serve this population. That is,

$$\underline{w}_{nb}^{(1)} = M\underline{e}_{nb}^{(1)} = MNM\underline{e}_b^{(t)} , \tag{20}$$

and, hence

$$\underline{e}_{nb}^{(2)} = N\underline{w}_{nb}^{(1)} = NMNM\underline{e}_b^{(t)} , \tag{21}$$

or

$$\underline{e}_{nb}^{(2)} = (NM)^2\underline{e}_b^{(t)} , \tag{22}$$

and, in general,

$$\underline{e}_{nb}^{(n)} = (NM)^n\underline{e}_b^{(t)} . \tag{23}$$

It is apparent that with each new increment of non-basic employment we have an associated increment of residential population:

$$\begin{array}{ll} \underline{e}_{nb}^{(1)} = (NM)\underline{e}_b^{(t)} & \underline{w}_{nb}^{(1)} = M(NM)\underline{e}_b^{(t)} \\ \underline{e}_{nb}^{(2)} = (NM)^2\underline{e}_b^{(t)} & \underline{w}_{nb}^{(2)} = M(NM)^2\underline{e}_b^{(t)} \\ \vdots & \vdots \\ \underline{e}_{nb}^{(n)} = (NM)^n\underline{e}_b^{(t)} & \underline{w}_{nb}^{(n)} = M(NM)^n\underline{e}_b^{(t)} \end{array}$$

Thus, total employment, $\underline{e}^{(t)}$, and total population, $\underline{w}^{(t)}$, will be equal to the following sums, where I denotes the identity matrix:

$$\begin{aligned} \underline{e}^{(t)} &= \underline{e}_b^{(t)} + \underline{e}_{nb}^{(1)} + \underline{e}_{nb}^{(2)} + \cdots + \underline{e}_{nb}^{(n)} + \cdots \\ &= [I + (NM) + (NM)^2 + \cdots + (NM)^n + \cdots]\underline{e}_b^{(t)} , \end{aligned} \tag{24}$$

and

$$\begin{aligned} \underline{w}^{(t)} &= \underline{w}_b^{(t)} + \underline{w}_{nb}^{(1)} + \underline{w}_{nb}^{(2)} + \cdots + \underline{w}_{nb}^{(n)} + \cdots \\ &= M[I + (NM) + (NM)^2 + \cdots + (NM)^n + \cdots]\underline{e}_b^{(t)} . \end{aligned} \tag{25}$$

Garin shows that under very general conditions on the product matrix NM, which are met in empirical applications of the model, the series:

$$I + (NM) + (NM)^2 + \cdots + (NM)^n + \cdots$$

converges to the inverse of the matrix (I - NM). Hence we may rewrite Equations (24) and (25), as follows:

$$\underline{e}^{(t)} = (I - NM)^{-1}\underline{e}_b^{(t)} \tag{26}$$

and

$$\underline{w}^{(t)} = M(I - NM)^{-1}\underline{e}_b^{(t)} \quad . \tag{27}$$

Notice that by substituting Equation (26) into Equation (27), we obtain the expression for the generalized matrix model presented in Equation (1):

$$\underline{w}^{(t)} = M\underline{e}^{(t)} \quad .$$

To illustrate the operation of the Garin-Lowry model, consider once again our numerical example of Lartsville. For simplicity, assume that $\beta_i = \alpha_i = 2.5$ and that $N^* = M^*$. Then we may compute the inverse of (I - NM) which appears in Figure 3 and derive the following spatial distributions:

FIGURE 3.--THE INVERSE OF (I - NM)

$$(I - NM)^{-1} = \begin{bmatrix} 1.097 & .095 & .095 & .089 & .092 & .089 & .086 & .089 & .087 & .086 \\ .100 & 1.102 & .099 & .099 & .097 & .093 & .097 & .094 & .091 & .090 \\ .117 & .115 & 1.115 & .111 & .114 & .111 & .107 & .111 & .109 & .108 \\ .094 & .098 & .094 & 1.101 & .095 & .092 & .104 & .095 & .093 & .092 \\ .120 & .118 & .119 & .116 & 1.119 & .117 & .114 & .117 & .116 & .116 \\ .097 & .095 & .098 & .095 & .099 & 1.103 & .093 & .099 & .103 & .104 \\ .068 & .073 & .069 & .078 & .070 & .068 & 1.086 & .072 & .070 & .070 \\ .111 & .111 & .112 & .112 & .113 & .113 & .113 & 1.114 & .115 & .115 \\ .101 & .099 & .102 & .102 & .104 & .109 & .103 & .107 & 1.111 & .112 \\ .090 & .089 & .092 & .091 & .093 & .100 & .092 & .097 & .101 & 1.103 \end{bmatrix}$$

Source: Garin [74], p. 362.

Zone	Basic Employment	Total Employment	Population
1	4500	5835	7126
2	0	1387	6673
3	0	1640	8383
4	0	1351	6033
5	0	1718	8801
6	9000	10472	8303
7	0	1000	4217
8	1000	2639	7709
9	0	1549	7898
10	0	1405	7352

As before, we may derive the "horizon-year" implications of this model. If, once again, we assume the employment growth process defined by Equation (14), we find the following development through time to stability:

	Basic Employment			Total Population		
Zone	1960	1970	Horizon	1960	1970	Horizon
1	.310	.480	.892	.098	.107	.127
2	.0	.0	.0	.092	.096	.108
3	.0	.0	.0	.116	.119	.130
4	.0	.0	.0	.083	.083	.085
5	.0	.0	.0	.121	.122	.123
6	.621	.454	.079	.115	.107	.093
7	.0	.0	.0	.058	.062	.058
8	.069	.066	.029	.106	.106	.105
9	.0	.0	.0	.109	.103	.091
10	.0	.0	.0	.102	.095	.080
Total	1.000	1.000	1.000	1.000	1.000	1.000

The Garin-Lowry model is a simple, yet powerful, tool for expressing and analyzing the relationships between employment and population. Refinements in several of the more important relationships may be introduced. For example, Garin shows how one can extend the model to include shopping trips that do not originate from the home by introducing a _journey from work-to-shop function_. Other refinements may be introduced by stratifying employment and population and their associated ratios and journey functions.

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