DISPERSAL, SEGREGATION, AND TECHNOLOGICAL CHANGE: A COMPUTER SIMULATION MODEL OF THE DEVELOPMENT OF LARGE METROPOLITAN AREAS IN THE UNITED STATES DURING THE TWENTIETH CENTURY

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This thesis formulates a simulation model of the development of a large urban area in the United States between 1900 and 1960. The actual trends in the distribution of growth between the central city and suburbs are established using an indicator of dispersal based on the growth rate of the central city relative to that of the metropolitan area. The data sample used in quantifying these trends is all metropolitan areas in the United States with a population greater than 250,000, and corrections for population changes due to area annexations have been made. The changes in conditions outside the city which have influenced this development are discussed. These changes are divided into two types of driving force, one simply influencing the rate of growth of the city, the other, such as technological change in production and transportation, directly causing structural changes within the city. The simulation model formulates a set of assumptions on how these changes outside the city influence the development within the city in general and the trends of dispersal and racial segregation of urban population in particular.

The components of such a model are discussed and the literature on previous models of urban development reviewed in detail in light of the needs for simulation of urban growth on a time span of decades. The review establishes the absence of a 'systems' model which incorporates strong mutual interaction between processes such as growth of population, filtering of housing supply, and location of population. The assumptions inherent in the simulation language (DYNAMO) used to program

the finite difference equations of the model in this thesis are discussed, and the problems of model specification, parameter estimation, and model validation are reviewed.

The model simulates the changes in four classes of population (disaggregated by race and skill level), three classes of industry, three classes of housing, and five classes of land use in both the central city and suburb of a large city. The model is divided into three submodels--for the growth of total population and employment, changes in housing stocks, and location of population and employment. The behavior of each of the submodels and the complete systems model is discussed, and their response to changes in initial conditions, external driving forces, and alternative formulations of interactions presented. The behavior is compared to the data on trends in large cities in the United States and found to be in reasonable agreement.

The conclusions for models of urban development which are drawn from the results of this thesis include the need to incorporate:

1) strong interactions between the city and the world outside, which exist due to driving forces which change a) the rate of growth of the city, e.g., migration, and national economic development and b) the structure of the interactions within the city, e.g., technological change,

2) strong interactions between one part of the city and the remainder of the urban area, even if the model is primarily concerned with only that part, e.g., the central city, and

3) the interactions between processes within the city, which have usually been modeled independently, e.g., between housing markets, rate of total population growth of the city, and location of population.

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Part I

PART I

THE DEVELOPMENT OF LARGE US CENTRAL CITIES DURING THE TWENTIETH CENTURY

Chapter 1

INTRODUCTION

The most remarkable social phenomenon of the present century is the concentration of population in cities . . . What are the forces that have produced such a redistribution of population? Are they enduring? What is to be the ultimate result?

What are the economic, moral, political and social consequences of the redistribution of population? What is to be the attitude of the publicist, the statesman, the teacher toward the movement?

. . . (These questions) are not questions capable of off-hand answers, for they are parts of a great problem. It is the problem of dwindling district schools, of city labor disputes, of the tenement house, of municipal transit, of agrarian reforms, of the destitute country village, of the submerged tenth and the physical wastes of civilization, -- in short, it touches or underlies most of the practical questions of the day. The social problem that confronts practical people is in a very great degree the problem of the city. It is, therefore, of prime importance to ascertain the extent of the movement and its probable direction in the future: the forces that may be presumed to cause it; the more immediate as well as the ultimate consequences; and the possible remedies.[1]

Adna Weber, 1899

Adna Weber raised these questions in the introduction to his classic work on the growth of cities just before the transition from the nineteenth to the twentieth century. Almost three quarters of a century later the volume of literature expressing concern with the various aspects of the urban crisis indicates that the problems associated with urbanization (or at least our awareness of them) have intensified while our capability of ascertaining future probable directions, causes, consequences and remedies has improved very little. We continue to understand all too little about the natural forces driving the growth and evolution of large cities, e.g., about the causes of shifts in migration both between regions of the country and within urban areas themselves. The failure of the United States to develop or even seriously consider an urban growth policy at any level of government is just one indicator of our inability to deal with the questions Weber posed.

At the same time that we have been unable to come to terms with the issues of the redistribution of population to the city, a new set of problems dealing with the distribution of population within the city has arisen. Fundamental changes have occurred in the scale of individual urban concentrations, and in the processes which distribute population and employment over a metropolitan area. Concern over stagnating central cities and the pervasive sprawl at their fringes now dominates the initial worries over the increasing concentration of population in general.

The causes of these trends within the city are uncertain and the subject of much debate, but it is clear that the acceleration rate of technological innovation has played a crucial role. Technological innovation has accelerated the evolution of the structure of the city, eliminating some old problems, aggravating others, and introducing some new ones. The tendency of technological change to induce 'both positive and negative social change at the same time and in virtue of each other' is unavoidable because of the nature of the interaction between technology and social institutions. When dealing with complex social structures, such as the city with its multiple functions and interactions,

> The usual sequence is that 1) technological advance creates a new opportunity to achieve some desired goal; 2) this requires (except in trivial cases) alterations in social organization if advantage is to be taken of the new opportunity, 3) which means that the functions of existing social structures will be interfered

with, 4) with the result that other goals which were being served by the older structures are now only inadequately achieved.[2]

This sequence of one intervention or change interacting with the social structure to produce changes other than that desired is not confined to technological change. Any form of intervention with the 'natural' or existing structure can produce such results and the increasing size of both private institutions and government are providing mechanisms for an increasing variety and number of types of intervention. The dual problem of utilizing these opportunities, without creating more problems than are solved or inducing undesirable side effects which far outweigh the benefits achieved, is one which will continue to plague our society as long as it continues to stimulate change. Whether the intervention comes from the introduction of a new technology by the private sector, or by the application of new incentives and controls by the public sector, the character of the problem remains the same.

The resolution of this problem when dealing with change within the city is complicated by a number of factors including the diversity of the groups which comprise the city, the differences in judgments as to what is desirable and undesirable, and the scarcity of resources for coping with the problems. Yet even an ideal city with none of these difficulties would present two basic problems.

The first is how to anticipate the consequences of a specific intervention by either the public or private sector given the extreme complexity of the interactions between activities within the city. The second is how to deal with the aggravation of this basic complexity by the dynamic nature of the rest of the city. The structure of the city which determines the interactions is changing in time because of continuous shifts in other driving forces acting on the city, or because of other interventions by other actors -- the city refuses to stand still so that it can be properly analyzed and understood.

'Models' of urban development have been a basic part of the attempts to cope with and understand the changes in cities as they evolve. The models have ranged from the intuitive understandings which are expressed only in the minds of those with long experience in dealing with the city to the precise mathematical formulations of the equations of the massive land use projection models developed for the analysis of urban transportation systems. The central effort of this thesis has been the development of a computer simulation model which can serve as an aid in understanding and unraveling the two basic problems mentioned above -- the problem of complexity in number and types of interactions, and the problem of the shifting structure transmitting those interactions.

The model developed is a tool for advancing the theory of urban growth processes and our understanding of the influence of technological change on those processes. The model has alternative public policies as explicit inputs and provides insights into the gross effects of alternative urban programs. However, the separation of the city into only two spatial areas in this thesis is too coarse for the actual design and evaluation of operational policies for a specific city. The current work attempts to meet a primary need for dynamic systems models which provides more insight into urban growth processes by:

a) Putting into operational and testable form verbal statements of processes influencing urban development.

b) Incorporating interactions among urban growth processes which have usually been modeled as separate, non-interacting processes, for example, among industrial growth, unemployment and population migration.

c) Providing a tool for experimenting with alternative formulations and interactions.

d) Incorporating these interactions within an operational systems model which explicitly accounts for the dynamic and non-equilibrium nature of urban development.

It should be emphasized at the outset that the strong limitations of computer models for either practical applications or testing of theory are fully recognized. The analogy between the development of theory in the physical sciences and the social sciences is severely weakened by the difficulties in validating models of complex social systems. As for policy applications, within the foreseeable future, models will be able to provide only a limited part of the information actually considered in the political decision-making process. However, even under these limitations, which will be discussed more fully below, models have potentially important roles in both functions.

The model is designed to simulate the intermediate term (10 to 30) years) growth of the population and economy of large American central cities relative to their associated metropolitan areas during the first sixty years of the twentieth century. The model deals with growth over an intermediate time period because the main interest is in understanding the shifts in the interactions driving urban development, and the inertia of large cities prevents significant changes from occurring over periods less than a decade. Such changes can occur within shorter time periods in a part of the city, for example the residential and industrial relocation near a new highway or mass transit line (Route 128 in Boston, the new subway in Toronto), but not throughout the entire city. The reason for the upper limit on the time period is simply the uncertainty in forecasts of the major exogenous inputs to the model, especially the magnitudes and directions of technological change. When studying past behavior, this restriction can be relaxed because these inputs are known; this thesis will relax the restriction in analyzing the development of large US central cities in the period 1900 to 1960.

The model represents the city as a complex, dynamic system having strong reciprocal interactions between such activities as population, housing and employment. The model studies the response of that system to changes in its environment, where environment is taken to include the cultural and technological as well as the economic and physical. The model has been designed to aid in answering the following questions:

1. What have been the impacts of technological change in production and transportation on the location of population and employment in large metropolitan areas? The different impacts considered include the increasing demand for land for industrial sites, the increasing demand for higher skilled labor in the urban labor force, the declining need for physical proximity between production plants and major

transportation centers, complementary industries, and markets, the shift in consumption from manufactured goods to services, and the increasing mobility of the population with private automobiles and the virtually constant mobility of those without. The ability to anticipate future trends in urban development will depend upon the success in both unraveling the importance of these trends in the past and predicting their directions in the future.

2. What are the growth mechanisms within the city which interact with these externally driven changes in technology to produce the dispersal of population and jobs out of the central city, and to induce the failure of the natural processes of renewal of industrial sites and housing? In the past, the pressures induced by a finite, fixed land supply forced the continuous maintenance or re-utilization of urban space. If the new processes which have led to a growing number of abandoned sites within the city are to be effectively counterbalanced, they must be understood.

3. What are the roles of the time lags and delays inherent to the urban system in controlling the dynamics of its response to external and internal changes? In particular, the spatial redistribution of homes and industries in response to new location requirements, new opportunities, or new neighbors is strongly damped by economic and emotional investments in existing sites. What are the mechanisms controlling this redistribution? For a city growing at the typical rate of 2% to 5% per year the number of activities relocating during the year are of the same order or larger than the new growth which

has to be located for the first time. A second type of time delay, which will not be investigated in as much detail here, is that due to the finite aging rate of the population. Strong and relatively rapid fluctuations in the population birth rate produce 'lumps' of population which slowly age and pass from pre-school to school to labor force. These fluctuations place severe demands on the services provided in the city and create the prospect of excess capacity or over-expansion after a 'lump' passes.

4. What is the influence of the characteristics of the aggregate growth of the city in aggravating or alleviating the trends toward dispersal? Are the mechanisms dispersing population in a young city in the far West, growing rapidly due to population migration, substantially different from those in an old declining coal town in the Northeast? Is there a significant difference in the impacts of the alternative policies which could be used to control the dispersal trends in these two cities?

The same set of questions could be repeated with the trend of racial segregation of the black population into the central cities of large metropolitan areas substituted for population and employment dispersal. These parallel trends of dispersal and segregation are the two most important developments in the evolution of the modern metropolis in the US. This research hopes to add to the understanding of their underlying causes so that the trends can be controlled in the future.

In order to deal with the questions posed above, several basic assumptions which have dominated previous urban development models have been challenged here. These assumptions are:

1. The modeling of the growth of the population and economic activity within the city can be separated from the location of that growth. -- In other words, it has always been assumed that urban development could be divided into two separate processes - growth and location -- which could be modeled independently of each other. When dealing with aggregate totals, e.g., total population, this approximation is acceptable. However, when transfers between subdivisions of the aggregate, for example, upward mobility from one skill level or income level of population to another, need to be understood, the effects of spatial concentrations and differentials in physical mobility can no longer be neglected.

2. The aggregate growth of the population and employment in the city can be projected independently of the aggregate conditions within the city. -- Setting aside the issue of the coupling between the growth model and the location model, the future growth of the city has usually been projected with no consideration of such effects as the influence of population migration on the labor supply of the city and hence its attractiveness to industry, or the reciprocal effect of growth in industry on employment opportunities and thus population immigration.

3. Racial segregation can be ignored as a force affecting residential location decisions and the concentration of black population has been ignored as a problem to be simulated in urban development models.

-- Partial models and theories of racial discrimination exist; this research will begin the long overdue process of incorporating them into a more comprehensive urban development model.

The model developed in this work defines the state of the urban area in terms of the distributions of population, housing, and employment among the different parts of the city. The emotional and psychological state of the people in the city, which is the ultimate concern of urban public policies, is not dealt with explicitly in this work. The internal emotions of the individual are strongly influenced by such conditions as the tightness of housing, availability of employment, and intensity of urban development. Conversely, these emotions play a major role in activating the growth and distribution processes which this research has tried to model. However, the approach taken here has left the mechanisms at the individual level hidden and attempted to explain urban development processes in ahighly aggregated form.

These two choices of emphasis on the physical and economic rather than the psychological nature of the city, and on trends on a highly aggregate physical scale rather than the local neighborhood or community are two of the basic assumptions in this work. The first one was made because the economic and physical aspects of a city strongly influence the psychological state of its residents. Work on the development of 'social indicators' which reflect this influence is now being carried out. Models of the type developed in this thesis will be required if these indicators are to be useful in practice. The choice on the scale of aggregation was made on the basis of the combination of important trends which have been observed at this scale, and the faith that they could be explained in a useful causal manner at the same scale. There is little doubt that they can definitely be explained in terms of a much more complex set of forces acting on the individual level. The challenge is to determine whether or not this complexity is necessary or is reducible.

This thesis is divided into four major parts. Part I describes the trends in the development of large urban areas in the United States which are the focus of this work. The 'system' whose behavior is being studied and modeled is a large metropolitan area (population greater than 250,000) between 1900 and 1960. Chapter 2 presents the internal trends in the development of both the central city of such an urban area and the metropolitan area as a whole. The decentralization of total population and of industry, and the continued concentration of black population in central cities is discussed as a function of the residential density of the central city and of time. Chapter 3 presents the trends in the external driving forces which act on the city. Two general types of driving force are distinguished - those which affect rates and composition of growth without changing the structure of the interactions between activities, e.g., an economic depression or major immigration from Europe, and those which act directly on the structure of the city, e.g., technological change in transportation and production.

Part II builds the linkages between the model constructed in this research and the models which have preceded it. Chapter 4 is an overview of the components of an urban development model and presents five processes of urban development which need to be incorporated in such a model. Chapter 5 reviews the urban development models constructed to date in the light of the overview developed in Chapter 4. The concluding section of Chapter 5 discusses the failure of previous urban development models to formulate key aspects of urban development, such as expansion of the land supply, the dynamics of the housing supply, and the upgrading of population within the city. Even when some of these processes are included, the interactions between processes are neglected. Chapter 6 presents the details of the particular modeling approach used in this thesis. First, the assumptions and mathematical formulation implicit in a DYNAMO model are reviewed, and a simple example is presented to explain the notation and symbolism. Then the problems of specifying the structure of a 'causal' model, estimating its parameters, and developing confidence in its results, are reviewed. The similarities in the problems faced by those using formal econometric estimation techniques and those using less mathematically elegant or reproducible approaches are emphasized. A simple econometric model is converted into DYNAMO to facilitate the comparison between approaches.

Part III presents the computer simulation model itself. Chapter 7 discusses the variables of the model and the formulation of each of the three major submodels - employment and population growth, housing and employment, and population location. Chapter 8 analyzes the behavior of the model and compares the structure and results to those of the Urban Dynamics model developed by Forrester.

Part IV summarizes the results and primary conclusions of the thesis and discusses areas for future work.

FOOTNOTES

Chapter 1.

1. Weber, Adna, The Growth of Cities in the Nineteenth Century (reprinted by Cornell University Paperbacks, Ithaca, New York, 1967), p. 2.

2. Mesthene, Emmanuel G., "Symposium: The Role of Technology in Society," Technology and Culture, Vol. 10, 1969, p. 493.

Chapter 2

URBAN DISPERSAL AND SEGREGATION - THE PATTERNS OF EVOLUTION WITHIN THE CITY

As Weber described in his classic work on urban growth in the nineteenth century, cities have been a basic aspect of human existence for centuries and have created their own special types of problems for almost as long:

> The discussion of remedies (for overcrowding) began at least twenty centuries ago, and will perhaps continue twenty centuries hence. Plutarch's warning against the overgrowth of great cities (Pracepta Politica) and Cicero's constant effort to turn back the current of emigration from the country alike came to naught. Justinian tried to stop the current by legal measures, and medieval statesmen and monarchs followed a similar course. The extension of Paris beyond certain limits was prohibited by law in 1549, 1554, 1560, 1563, 1564, and 1672. In the time of the later Tudors and Stuarts, proclamation after proclamation was issued forbidding the erection of new houses in London and enjoining the country people to return to their homes.[1]

Yet as late as 1800 less than 3 percent of Europe's population lived in cities with a population of 100,000 or more[2] and just over 4 percent of the United States' population could be considered as urban. Until this time, the few large urban concentrations existed on the outstanding avenues of international trade and commerce and would grow and decline with the shifting of trade routes.[3] Until the arrival of the Industrial Revolution, the problems of the city affected only a small minority of the population, and the nature, scale, and functions of the city had remained stable for a period of almost 2000 years.[4]

The rapid urbanization of the world's population which began in the early nineteenth century soon changed this. By 1900 England, with 80 percent of its population classed as urban, had become the world's first urbanized nation, and the United States with 40 percent of its population[5] urban was well on its way to becoming the second. This urbanization involved much more than a simple expansion of the number of people living in cities, because the new metropolises which began to emerge were much more than simple enlargements of traditional cities. During the last half of the nineteenth century, the seeds were planted for major shifts in the character of urban concentrations and the processes which distribute their population and activities within them.

> Between 1860 and 1910 technology and migration, in a national context of rapid economic growth, had drastically altered the American urban environment. The process of change had called forth corresponding institutional and organizational modification. . . . Urbanization during these years contributed a variety of political and social problems which had become national concerns by the turn of the century. In addition, the foundations had been laid for a whole new series of economic relationships, both within the individual cities and among them in the urban network.[6]

The 'twentieth century metropolis' which was emerging during this period involved "complex changes in function and structure within the city and its suburban areas--decentralization of numerous activities, separation of places of residence and work, and a high mobility over greatly extended spatial areas."[7] The increasing specialization of economic activities within the city simultaneously with shifts in location requirements led to the separation of activities which had previously been closely coupled in space, e.g., the separation of central offices from manufacturing even within the same company. Similarly, improvements in communication and transportation technology have loosened the bonds coupling mutually dependent activities such as residence and employment or manufacturers and supplier together closely in space.

These changes did not begin in the United States nor have they been confined to its cities since. The exact nature of the shifts in urban development mechanisms has depended on the timing of the urbanization and the local cultural and economic context, so it is not surprising to find marked differences in them as one moves from Europe, to the United States, to Latin America, to the new developing nations. The events of the past few years and the mounting volumes of literature describing, analyzing, and prescribing the 'urban crisis' have made clear that these shifts have generated severe problems in American cities today. Whether or not the problems in the urban areas of the United States are more disturbing than those in other countries is a moot question -- the point is that they are severe and they are not adequately understood.

As was outlined in the introductory chapter, the primary concern of this thesis is the development of a computer simulation model which will be a useful analytical tool to those who attempt to understand and cope with the problems generated by the shifts in large urban areas. This chapter identifies the particular shifts which will be dealt with by the simulation model by reviewing several basic trends in the location of population and employment in urban areas in the United States between 1900 and 1960. After briefly examining the trends in urbanization in the U.S. and defining some needed indicators, the following three trends are discussed:

1. The increasing dispersal of population with deconcentration beginning earlier in the growth cycle and at lower densities.

2. A similar dispersal of industries and employment.

3. The increasing concentration of black population in central cities.

The trends presented are familiar and have been well established by many others, so this chapter should not be viewed as an attempt to advance the field of urban geography or demography. It merely provides basic background on certain aspects of the behavior of urban areas by quantifying three trends which are usually discussed qualitatively and demonstrating the longevity of behavior which is often viewed as relatively new. The matching of the behavior of the simulation model with the trends recorded in this chapter will provide a necessary, but by no means sufficient, first test of the formulation of the model.

A. Urbanization in the United States and the Role of Large Cities

Urbanization, as it will be used here, refers to the increase in the proportion of total population concentrated in urban settlements and in particular to a rapid rise in this proportion to fractions approaching one.

> A common mistake is to think of urbanization as simply the growth of cities. Since the total population is composed of both the urban population and the rural, however, the 'proportion urban' is a function of both of them. Accordingly, cities can grow without any urbanization, provided that the rural population grows at an equal or a greater rate.[8]

At the beginning of the nineteenth century, the population of the United States was overwhelmingly rural and it remained so for the next fifty years.

> Before 1820 the phenomenon of concentration of population was not to be found in the United States as a whole. In Maryland and Massachusetts, indeed, the urban population was gaining slightly upon the rural population, but in the other commonwealths, including New York, Pennsylvania, Rhode Island, where the largest proportions of urban residents were to be found, there was no such increase. In fact, the decade 1810-20 showed a relative decline of the cities in nearly all the States, and the urban population of the whole country held its own and no more.[9]

Figure 1 shows the rapid urbanization which had begun to reverse this situation by the end of the century and indicates that before 1900 the increase in urban population was fairly evenly distributed between large and small cities. By 1840 the United States had its first city

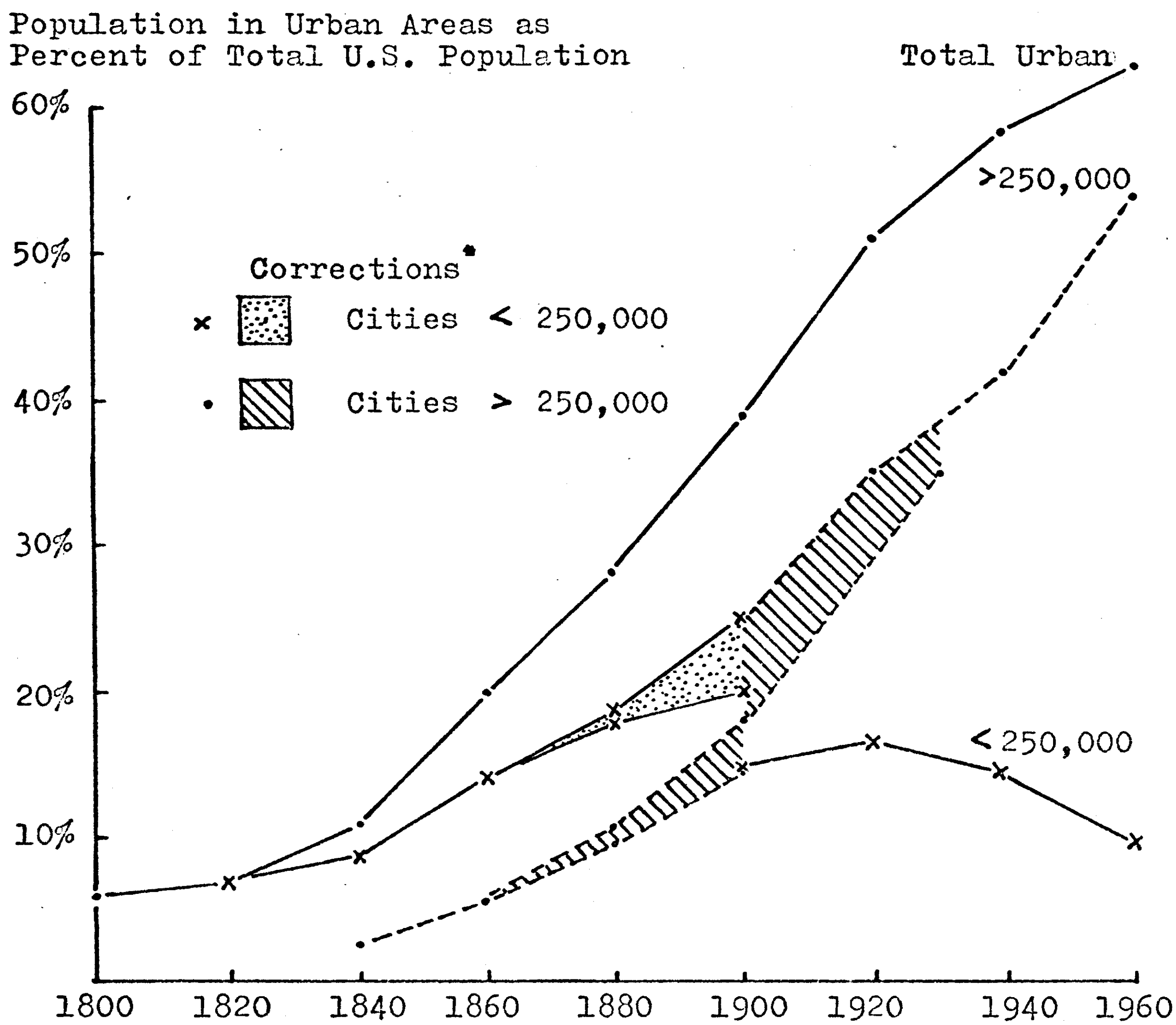

Fig. 1 Urbanization of U.S. Population and Distribution By Size of Central City 1800-1900

Source: 1. 13th U.S. Census 1910, Vol.1 Population General Report and Anaylsis Table 56
2. U.S. Census 1960 Vol. PC(1) 1A U.S. Summary Table 20
3. Bogue, D., Population Growth in SMA's 1900-1950

* Corrections due to difference between definition of 'city' as central city vs. metropolitan area.

with a population greater than 250,000 (New York) and by 1900 15 percent of the total United States population was living in cities of this size. Urbanization continued steadily throughout the next sixty years, with the exception of a short interruption during the Great Depression (1930-1940). However, about the middle of this period the importance of small cities began to decline and by 1960 less than 10 percent of the population of the United States lived in urban areas with less than 250,000 population.

Thus, as of 1960 the urbanization of the United States showed no signs of beginning to taper off and this urbanization is increasingly dominated by large metropolitan areas. This thesis has concentrated on understanding the development processes vital to these large cities (population above 250,000) and the remainder of this chapter will discuss the internal trends in the distribution of their population and employment between the old core and new fringes. The computer model developed in this research simulates the internal dynamics and external interactions producing these trends. The same trends and the problems they generate are found to some degree in smaller cities, but it is suspected that their degree and severity are much smaller. The growth and distribution model developed in this work should provide useful insights into the understanding of the development mechanisms of smaller urban areas, but that extension must be the subject of future research. From this point on, cities, urban areas, or metropolitan areas will refer solely to large Standard Metropolitan Statistical Areas (SMSA's) with populations greater than 250,000.

B. Development Trends Within Large Urban Areas

The development of suburbs on the fringes of large urban concentrations and the dispersal of population and employment into these outlying areas combine to form one of the most dominant trends in United States urban development. Although cities back through medieval times had had a form of fringe development, it was qualitatively different from those which have appeared during the last one hundred years or so.

> The preindustrial city for a long time had its 'faubourgs': a diffuse area of growth extra muros where people lived who were prevented--by guild restrictions or otherwise--from settling in the city or who could not feel at home there; a zone also where truck farmers had their gardens. . . . Apart from its functions as a truck farming district it was a marginal zone in some ways and a zone of just growth in other ways. It did not represent the search for and the conscious creation of a new (sub)urban environment.[10]

In other words, cities have inevitably grown at their fringes because of the finite capacity of the land in their center. What is new is the development of the fringe as a new type of urban area competing with the old central city and eventually causing its decline.

The preludes to this development in both Europe and the United States during the last half of the nineteenth century have been described by Wissink,[11] Weber,[12] and Hoyt[13] among others. Figure 2 provides an excellent case study of the extent to which this competition was carried during the twentieth century. The plot of the gross resi-

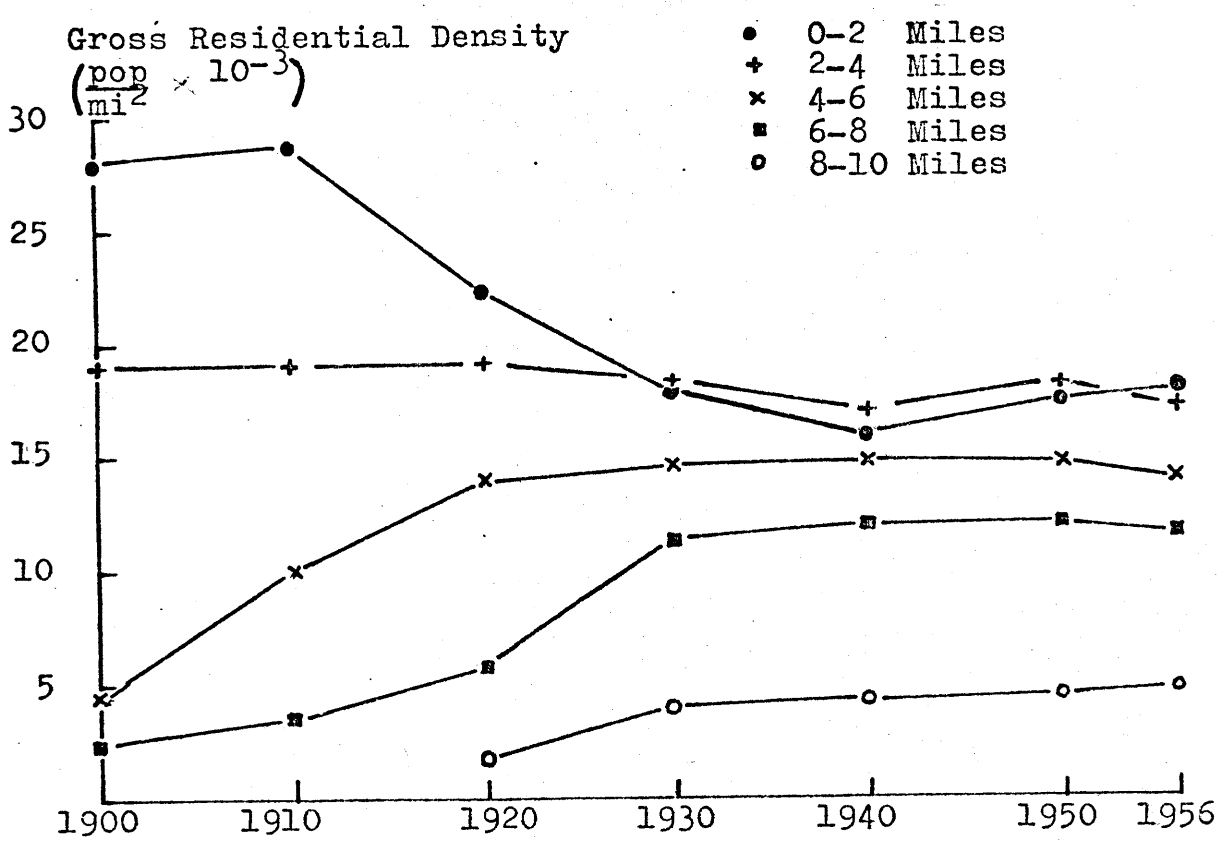

Fig. 2 Gross Residential Density vs. Time (For 5 Different Rings)

Source: Chicago Area Transportation Study, Land Use Forecast, p.52.

dential density profile of Chicago from 1900 to 1956 shows that the peak density within the core declined by almost a factor of two while the density at the fringes steadily increased. This figure provides an illustration of the types of trends which are of interest. Before presenting more comprehensive data, some issues concerning definitions and indicators must be addressed.

1. Definitions and indicators of Dispersal

The first question is, into how many areas or zones does the city have to be divided in order to adequately describe the trends in redistribution of old activities and location of new ones? Sharp variations in the density of both population and employment and local concentrations of these different activities exist on a relatively small scale. Any attempt to describe and explain the exact state of the city at any given point in time must reflect these small-scale variations by using an extremely fine set of small-scale zones with sizes on the order of neighborhoods or census tracts. The difficulties are that, first, no historical data with such a fine spatial breakdown exist over the time scales of interest in this study. Second, even if the data were available, trying to understand the major shifts in urban development mechanisms by analyzing the interactions between several thousand small areas in the city would further complicate an already extremely complex analytical problem. Since the interaction of each area with every other individual area must be considered, the number of interactions to be considered increases as the square of the number of areas.

Multiple small zone development models which divide the city into a large number of small areas rapidly tax the capacity of even the most advanced computers, but even sooner tax the capacity of the people who are attempting to understand development processes within the city. This problem of the indecipherable complexity of multiple area models confusing rather than illuminating the understanding of urban growth processes will be elaborated in the discussion of previous modeling efforts (Chapter 5).

In presenting the changes in the patterns of development within the city, the question is to what extent does the exact detailed state of the city need to be described and at what level of aggregation can significant trends be presented. A basic premise of this thesis has been that the gross aggregation of the city into only two zones--the older central core and its expanding fringe suburbs--is a useful way of examining the city. This breakdown has very severe limitations because it obscures differences within both the core city and fringe areas, yet the two-area description has been assumed to be adequate to describe the influence of the central city-suburb interactions on the development of the central city. If the emphasis of this study were on suburban development, the two-area breakdown would be completely inadequate. A specific suburban area or areas would have to be identified and the interactions of these areas with each other, with the remainder of the fringe area, and with the central city accounted for.

Given a conceptual breakdown into two areas, the problem remains of how to explicitly identify and distinguish between the two regions. A number of methods have been proposed including breaks in density profiles, workplace-residence relations, social and social-psychological, etc., but the practical problem of data availability essentially eliminates all boundary definitions other than political ones. In the data to be presented below the boundary of the central city is the one officially defined by local authorities and used by the United States Census. Corrections for boundary expansions during a given decade have been made from data on area changes during the decade and estimates of the population density of the areas annexed. Thus, although the region defined as the central city remains fixed during each ten-year interval, its boundaries can change between intervals. For example, the population 'growth' of the central city of Los Angeles due to the large area annexation between 1920 and 1930 has been subtracted from the total population increase to obtain the true growth within the 1920 boundaries. However, the boundaries used for the 1930-1940 interval are the official 1930 boundaries, i.e., those of 1920 plus the area annexed from 1920 to 1930.

The suburban area has been defined here as the difference between the central city boundary and the boundary of the entire metropolitan area. The metropolitan boundaries have been fixed for the entire 60-year time period as the 1960 Standard Metropolitan Statistical Area (SMSA)boundaries set by the United States Bureau of the

Census.[14] Since no determination of the degree of integration of the counties included as suburbs in 1960 was made for earlier decades, this boundary will tend to overestimate the role of suburbs during the period from 1900 to 1950. Correction for this error would accentuate rather than diminish the trends which will be presented.

The measure of the intensity of population concentration in each of the two areas is gross residential density, i.e., the total resident population divided by the total land area. (If a finer scale of spatial breakdown were used in the model, residential population would have to be supplemented by some measure of the daytime working population in order to accurately reflect the intensity of activities in areas such as the CBD [central business district].) An attempt was made to use net residential density, i.e., population divided by residential land, but sufficient data on the land use distribution in each city for the sixty-year period were not available. One of the difficulties in this measure is that a large annexation abruptly decreases the 'density' of a central city and falsely shifts it to a lower classification of density. However, the occurrence of such large annexations was sufficiently rare and the ranges of density within each class sufficiently broad that this was not a major problem. The gross density figure used was adequate for distinguishing between the three broad classifications of intensity of development (high--greater than 10,000 people per square mile; moderate--5,000 to 10,000; and low--less than 5,000).

Finally, a measure of the trends of decentralization of both population and employment is needed. Creating an adequate indirect measure of these trends is an extremely challenging task because of the need to distinguish between decentralization and the normal tendency of new growth to occur at the fringes of the city.

> Extensive attempts to measure the (suburban) trend and efforts to isolate its determinants are prominent in the literature. This is a field of research with more than ordinary difficulties of conceptualization and measurement. All too often researchers have somewhat naively accepted findings of differential growth rates between central and peripheral portions of urban communities as evidence of a specific process of 'suburbanization' or 'decentralization' without attempting an operational distinction between these alleged processes and the normal tendencies for expansion to occur on the periphery of the community area.[15]

One direct indicator that deconcentration has begun is the trend in the density of the central city, such as was presented in Figure 4 for Chicago. However, density does not begin to decline until total growth is negative, or until the out-migration of population exceeds in-migration plus births. Thus, this indicator is not particularly sensitive to the initial phases of suburbanization where only part of the growth of the central city is being diverted to the outer area. Bogue and Harris recommend a simple comparison of the proportion of population living in the suburban rings at the beginning and end of the period of observation.[16] However, this index has the same type of time lag and insensitivity to the early phases of suburbanization as the density trends, plus the inability to eliminate the normal growth at the fringes phenomenon.

In order to have an indicator which is sensitive to the early stages of suburbanization, rates of growth rather than levels of development must be used. Since levels of development, e.g., total population or total employment, are the integrals of rates of change over time, a shift in level must always have an inherent time lag when compared to the change in the rate which caused that shift. The index of suburbanization of population used in this study is the ratio of the average rate of growth of the core city population to the average rate of growth of the metropolitan population during a ten-year interval. This ratio measures the rate of growth of the central city relative to that of the city as a whole in order to cancel out fluctuations due to external forces such as economic depressions, fluctuations in migration patterns, etc. Plotting this ratio for a given city over time, one would expect it to have initially a value of one, or slightly higher, when the city is young and the intensity of development in the center city is low, then decline gradually to zero as the level of activities in the central city grew and approached the limits on tolerable densities, thus cutting off further growth. In the following section, this ratio will be plotted as a function of time for three different densities of central city as a function of density with time as the parameter.

The scarcity of consistent, time series data on the location of employment in urban areas since 1900 has prevented the presentation of an indicator for employment dispersal comparable to that for population. However, data on the trends at the beginning and end of the sixty year period are discussed and give some feeling for the shifts which have occurred. The trends toward increasing concentration of blacks in the central cities of metropolitan areas is documented using an indicator similar to that used to show the dispersal of total population, i.e., one calculated by comparing the growth of central city black population to that of the metropolitan area as a whole.

Many questions could be raised about these indicators, the data they are based on (particularly the early census data on location of black population) and the use of averages across all cities rather than individual case studies. However, except for correcting for area annexations to ensure a consistent definition of the central city boundaries, these difficulties in the data will be ignored. The purpose of the data presented below is to document three trends which will be understood through a computer simulation model. The questions which could be raised about the data could conceivably shift the details of trends somewhat, but in general the level of accuracy of the data is commensurate with that needed for the relatively aggregate model which has been developed.

2. The Dispersal of Urban Population 1900-1960

In order to calculate the trends in decentralization of population as measured by the indicator developed in the previous section, the rates of growth of central city population and metropolitan area population must be compared. This was done by calculating the change in the central city population and total metropolitan area population during each decade from 1900 to 1960. First, all metropolitan areas in the United States with a population greater than 250,000 at the beginning of a decade were divided into three classes on the basis of the gross residential density of their central city at the beginning of that decade. Then, the average of the percentage increases in central city and metropolitan area population were calculated for each decade,* with the change in central city population corrected for data annexation. This annexation correction was estimated from the changes in area of each central city, as described in Appendix 1. The error bars in the plots of rate of central city population change in this chapter indicate the sensitivity of the results to a factor of two variation in the correction for population annexations.

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* The primary references for the data used to calculate these rates of growth are the U.S. Bureau of Census documents identified in Appendix 1. Appendix 1 contains the data base used for all figures and tables in this thesis which do not have sources explicitly identified. It lists the cities in each density classification for each decade from 1900 to 1960, and gives the following information for each city for each of the six decades: total population, increase in total population, central city population, central city density, true increase in central city population, and the area and population annexed to the central city.

The average of the percentage increase in central city population, $\bar{\dot{P}}_c(\rho_c, t)$, and metropolitan population, $\bar{\dot{P}}_m(\rho_c, t)$, in each density class during each decade is plotted in Figure 3. The variable $\bar{\dot{P}}_c(\rho_c, t)$ was calculated by taking the sum of the percentage increase in the central city population of each city over all the cities in a given density class in a given decade, then dividing by the number of cities in that density class (Equation 1). The same formula is used in calculating $\bar{\dot{P}}_m(\rho_c, t)$

(1) $$\bar{\dot{P}}_c(\rho_c^k, t) = \frac{\sum_{i \epsilon S_k} \dot{P}_{ci}(t)}{N_k}$$

$\dot{P}_{ci}(t)$ = the percentage increase in central city population of city i during decade t

S_k = the set of all cities with central city densities within the range of density class k

N_k = the number of cities with central city densities within the range of density class k

With the exception of sharp decline for all metropolitan areas during the Great Depression, the average growth rates of the metropolitan areas as a whole remained relatively constant during this sixty-year period. The metropolitan areas with low density central cities

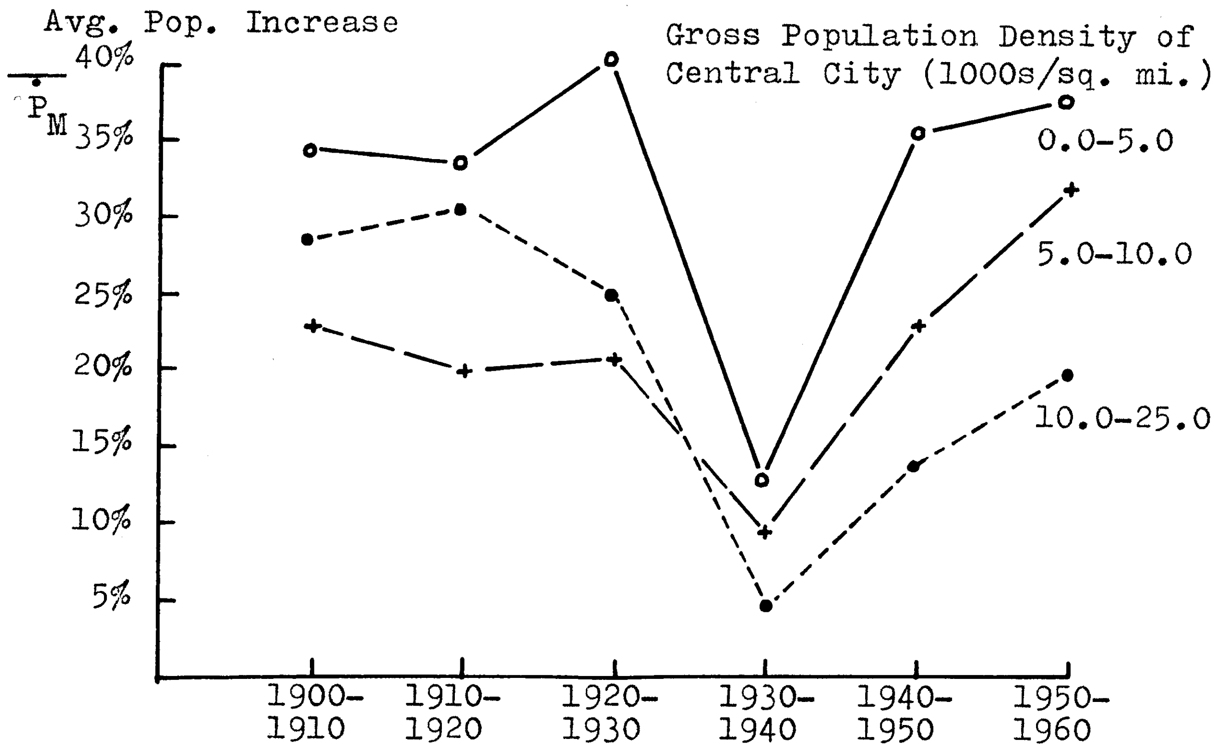

Fig. (a) Growth Per Decade of Total Population in Metropolitan Areas

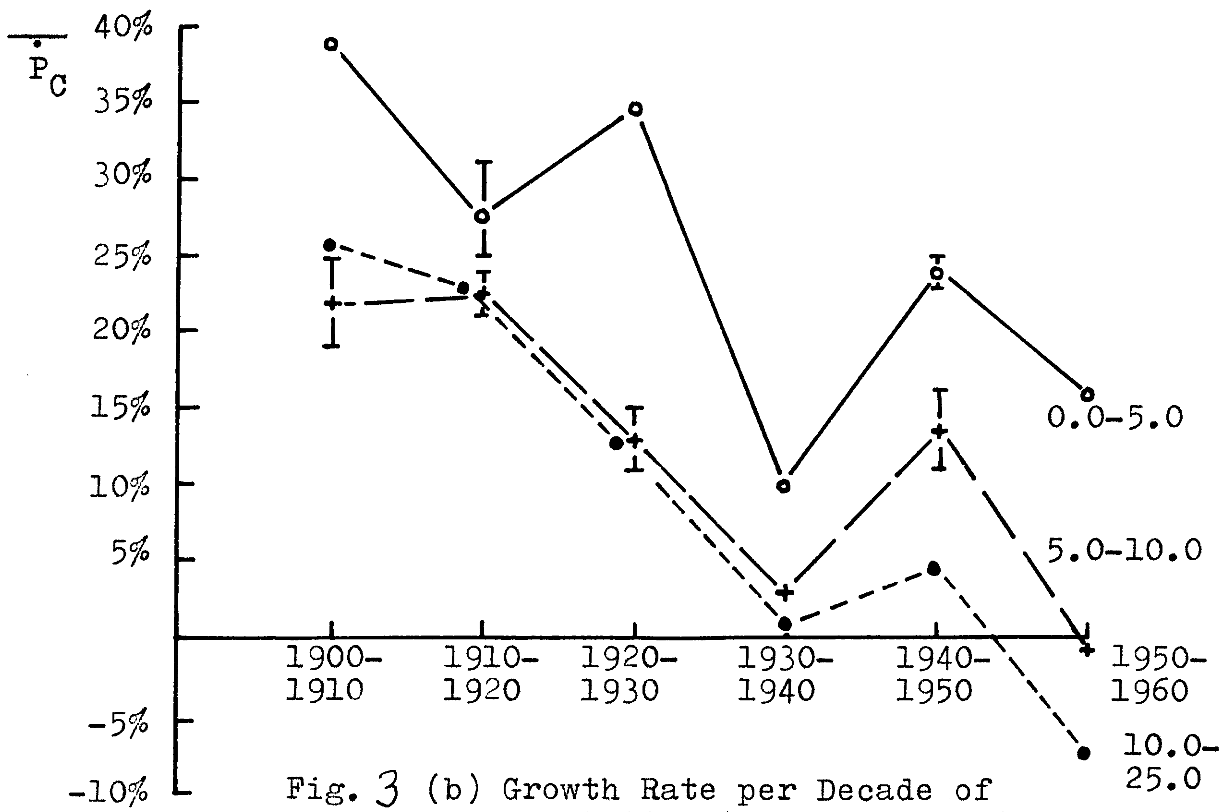

Fig. 3 (b) Growth Rate per Decade of Population in Central Cities consistently had a growth rate higher than those with moderate or high density cores. And, after the dip in growth rates for all areas during the depression, they were the quickest to increase their growth rates to pre-depression levels. The cities with high density cores never regained the growth rates achieved before the depression.

During the same sixty years, the average growth rates of the central cities in all density classes steadily declined with the high density core areas having the sharpest drop and the low density cores the smallest (Fig. 3b). Between 1950 and 1960 the net growth of all central cities in the high density class was negative, a decline of almost 8 percent during the decade, and no individual central city in this class increased its population. Although no detailed breakdowns by density are available, the latest data indicate that this trend of declining growth rates for central cities of all densities has continued through 1968. From 1960 to 1966 the average annual increase in central city population was only 0.5 percent and from 1966 to 1968 it was -0.6 percent, i.e., an over-all net loss.[17]

Figure 4 plots the indicator of residential dispensal, i.e., the ratio of central city and metropolitan growth rates given in Figure 3. Normalizing the central city growth rate has deemphasized the fluctuations caused by economic forces influencing the growth of the entire metropolitan area, particularly the depression between 1930 and 1940.

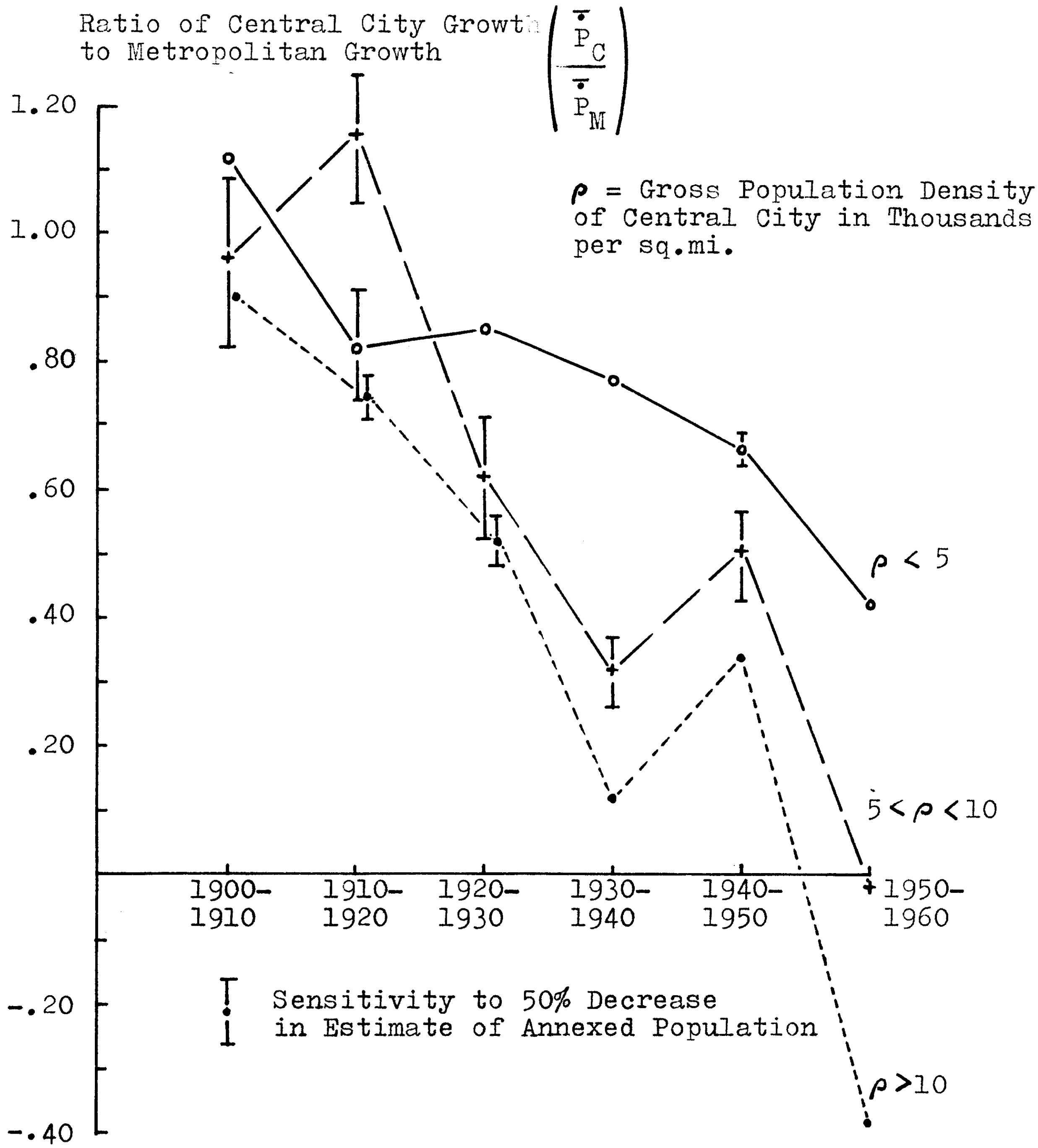

Fig. 4 Trends in Indicator of Population Dispersal as a Function of Time with Density as a Parameter

The figure shows a steady decline in the central city's participation in metropolitan residential growth for all three density classifications. Although negative growth rates for an aggregate density class occurred only in the last decade, the trend which produced these negative rates were clearly established in the first two decades of the century. The rise in the normalized ratio for the moderate density class in 1910-20 could be an artifact of the data; a constant or slight decline would be consistent with the errors indicated. One explanation of the rise in the ratio for the two higher density classes in 1940-50 are the strong constraints placed on manufacturing location and residential construction during World War II.[18] The two main points to be drawn from this figure are 1) the constant decline in the ratio implies that the process of decentralization of urban growth began quite early in the century and has been accelerating steadily ever since, and 2) although the highest density cities have consistently had the highest rate of decentralization at any given point in time, the trend toward decentralization of population growth in the lowest density cities had begun by the first decades of this century and had accelerated significantly by 1960. In other words, significant increases in the rate of decentralization had occurred at all density classes.

One explanation for the decline in absolute population of the central city which must at least be considered is the conversion of residential land to other uses pushing out the population. The sight of urban expressways being constructed on land which once held hundreds of families, or of new commercial centers and skyscrapers rising within the central city raises the question of whether the central city's smaller share of metropolitan population growth simply reflects a much smaller percentage of land being available for homes. The data in Tables 1 and 2 assembled by Niedercorn and Hearle in their study of land use trends in large American cities[19] shows that this has not been the case. Their data came primarily from land use surveys between 1940 and 1960, when the population dispersal trends were strongest, and indicate that central city residential land was still increasing at this time. The few cities which have land use studies available over a longer time period do not show a marked change in the fraction of land in residential uses, for example, between 1893 and 1958 the Milwaukee's residential land use increased only three percentage points.

3. Dispersal of Employment

With the long term trend in the dispersal of population clearly documented, what has been the trend in the location of employment? A consistent data series on the location of growth in employment similar to that presented above for population does not exist. However, the general nature of the trends in employment can be pieced together. At the beginning of the period of interest (1899) Weber had already

TABLE 1 MEAN PROPORTIONS OF LAND DEVOTED TO VARIOUS USES AT DIFFERENT TIMES

Type of Use	Proportion of Total Land		Proportion of Developed Land	
	Early Data	Late Data	Early Data	Late Data
Total Developed	.756	.784	1.000	1.000
Residential	.290	.310	.385	.398
Industrial	.085	.085	.110	.104
Commercial	.041	.040	.053	.050
Road and highway	.207	.198	.279	.254
Other public	.133	.152	.174	.193
Total Undeveloped	.245	.216		
Vacant	.233	.204		
Underwater	.012	.012		

TABLE 2 MEAN PROPORTIONS OF LAND DEVOTED TO VARIOUS USES AT DIFFERENT TIMES IN 12 CITIES WITH CONSTANT BOUNDARIES

Type of Use	Proportion of Total Land		Proportion of Developed Land	
	Early Data	Late Data	Early Data	Late Data
Total Developed	.802	.857	1.000	1.000
Residential	.300	.325	.374	.379
Industrial	.100	.106	.124	.124
Commercial	.045	.044	.055	.050
Road and highway	.203	.210	.254	.245
Other public	.154	.172	.194	.202
Total Undeveloped	.198	.143		
Vacant	.184	.129		
Underwater	.014	.014		

Note: The early data average approximately 10 years older than the late data (approximately 1960) for both Tables 1 and 2.

Source: Niedercorn, John H. and Hearle, Edward F., "Recent Land Use Trends in 48 Large American Cities," Rand RM 3664-1-FP, 1963, p. 6.

noted the strong tendency of manufacturing industries to shift to locations in the suburbs.[20] A Census Bureau survey of the growth of manufacturing industries in twelve of the thirteen largest industrial districts during the period 1899-1909 showed that, although the central city employment was growing strongly (41 percent during the decade), suburban manufacturing employment was growing more than twice as fast (98 percent).[21] Part of the differential in rates is due to the smaller basic level of suburban employment magnifying the percentage increase, but this does not account for most of the difference. In comparison, the growth rate of population in the suburbs of the ten largest SMSA's over the same period was only 25 percent higher than that of the central city population. Some of the forces stimulating this dispersal of employment have been described by Glaab:

> In the late nineteenth century the substitution of electric power for steam in industry and improvements in transportation made it possible for manufacturers to move away from central cities, and they were encouraged to do so by a number of factors: the need for vast amounts of cheap land to build factories incorporating all stages of large-scale complex production, lower taxes, and freedom from regulation of smoke and noise.[22]

Marked improvements in transportation technology and major shifts in production techniques and the distribution of final demand between goods and services continued steadily for the next fifty years. The net effect of these and other forces on the location of employment has been studied by Kain and his associates in their research on the growth rates of four types of employment in the central city and suburbs of forty large SMSA's from 1948 to 1963.[23] The results of their work are summarized in Tables 3 and 4. During each of the five-year intervals, the changes in employment in the central city paralleled the very slow growth, and in the last interval the decline, of central city population.

The interaction between these two basic trends in urban development--the dispersal of population and the shifting of employment to the suburbs--is one of the major areas of interest of this thesis. Can the trends in population and employment locations be considered independent of one another with people essentially moving out in search of a 'better way of life' and industry shifting in response primarily to its new need for large plots of land, changing composition of inputs, etc.? Has the availability of employment in the suburbs acted as a strong magnet drawing residents out of the core city? Or has the interaction been reversed--the outward migration of population providing both a labor force and market drawing out core city industry and services? The 'true' answer is clearly some mixture of all three possibilities and the urban growth model has been developed as an aid in understanding the composition and interactions within this mixture.

4. Segregation of Blacks within the Central City

> About nine-tenths of the increase in the nonwhite population of the United States between April 1960 and 1966 was in the central cities of the SMSA's. . . . Of the 2.9

TABLE 3 ESTIMATED MEAN ANNUAL PERCENTAGE CHANGES[a] IN POPULATION AND EMPLOYMENT FOR THE CENTRAL CITIES AND SUBURBAN RINGS OF 40 LARGE SMSA's (1950 CENTRAL CITY BOUNDARIES)

	--- Central City---			-------Ring---------		
Item	1948-1954	1954-1958	1958-1963	1948-1954	1954-1958	1958-1963
Employment						
Manufacturing[b]	1.9	-1.7	-0.4	13.2	6.9	6.0
Wholesaling[c]	0.8	0.2	-0.2	24.9	16.6	15.1
Retailing	-0.6	0.1	-2.0	11.3	13.5	13.4
Services	1.6	3.9	0.9	18.0	16.6	13.5
Population[d]	0.2	0.1	-0.5	8.7	6.4	5.5

[a] Simple, unweighted averages of individual city percentage changes.

[b] Data pertain to 1947-1954.

[c] Wholesaling data available for 39 SMSA's only.

[d] Obtained by interpolation and extrapolation of 1940, 1950, 1960 and 1965 data.

Reference: John Kain, "The Distribution and Movement of Jobs and Industry," in The Metropolitan Enigma, edited by James Wilson, 1968.

TABLE 4 ESTIMATED NUMBER OF CENTRAL CITY AND SUBURBAN RINGS (OUT OF 40) HAVING EMPLOYMENT AND POPULATION DECLINES (1950 CENTRAL CITY BOUNDARIES)

	----Central City----			-------Ring-------		
Item	1948-1954	1954-1958	1958-1963	1948-1954	1954-1958	1958-1963
Employment						
Manufacturing[a]	15	30	28	6	9	11
Wholesaling[b]	16	18	21	4	0	1
Retailing	27	17	37	4	0	0
Services	7	4	15	2	1	0
Population[c] (legal boundaries)	17	16	18	1	2	0
Population (1950 central city boundaries)	21	22	24	1	1	0

[a] Data pertain to 1947-1954.

[b] Wholesaling data available for 39 SMSA's only.

[c] Obtained by interpolation and extrapolation of 1940, 1950, 1960 and 1965 data.

Reference: John Kain, "The Distribution and Movement of Jobs and Industry," in The Metropolitan Enigma, edited by James Wilson, 1968.

> million gain in the nonwhite population over the 6 year period, 2.5 was in the central cities of the 212 SMSA's of 1960. This represents a continuation of the concentration of nonwhite growth in the central cities that has characterized recent decades. . . . As a result of this gain, well over half (55%) of the nonwhite population is now living in the central cities.[24]

Table 5 presents the data on long-term trends in the racial composition of core cities and suburbs. Between 1900 and 1965 the proportion of the central city population that is non-white tripled, while the proportion in the suburbs was cut in half.

TABLE 5 PROPORTION OF NONWHITE POPULATION IN SMSA's 1900-1965

Year	Percent Nonwhite in the Central City	Percent Nonwhite Outside the Central City
1900	6.8%	9.4%
1910	6.9	8.1
1920	7.3	7.0
1930	9.0	6.4
1940	10.1	6.0
1950	13.1	5.7
1960	17.8	5.2
1965	20.8	5.0

Source: Alan K. Campbell and Seymour Sacks. Metropolitan America (New York: The Free Press, 1967).

The racial segregation of blacks and whites in United States urban areas has been clearly documented and is a major cause of several of our most significant urban problems. Racial segregation can be defined and studied at several levels--regional, metropolitan, or neighborhood. In this study the level of interest is metropolitan--what are the factors causing the continued concentration of the black population within the central city, even in the presence of forces stimulating a significant outflow of white population? The segregation existing at the two other levels--regional and neighborhood--will enter directly as contributing causes of segregation at the metropolitan level, but they will not be principal areas of concern here.

Figure 5 presents the population growth trends which have created the situation described above. The ratio of the increase in population in the central city to the increase in the metropolitan area as a whole is plotted by race for three different densities of central city from 1900 to 1960. (See summary table in Appendix I.) Thus, if the increase in white population were equally distributed between the central city and suburb the ratio would be 0.5; if all of the increase occurred in the central city, the ratio would be one. The growth in white population has been corrected for area annexations as described previously and the error bars in Figure 5 again indicate the sensitivity of the results to a factor of two change in this estimate of annexed population. The black population in the suburbs was small enough at all times that it was not necessary to make such a correction. The

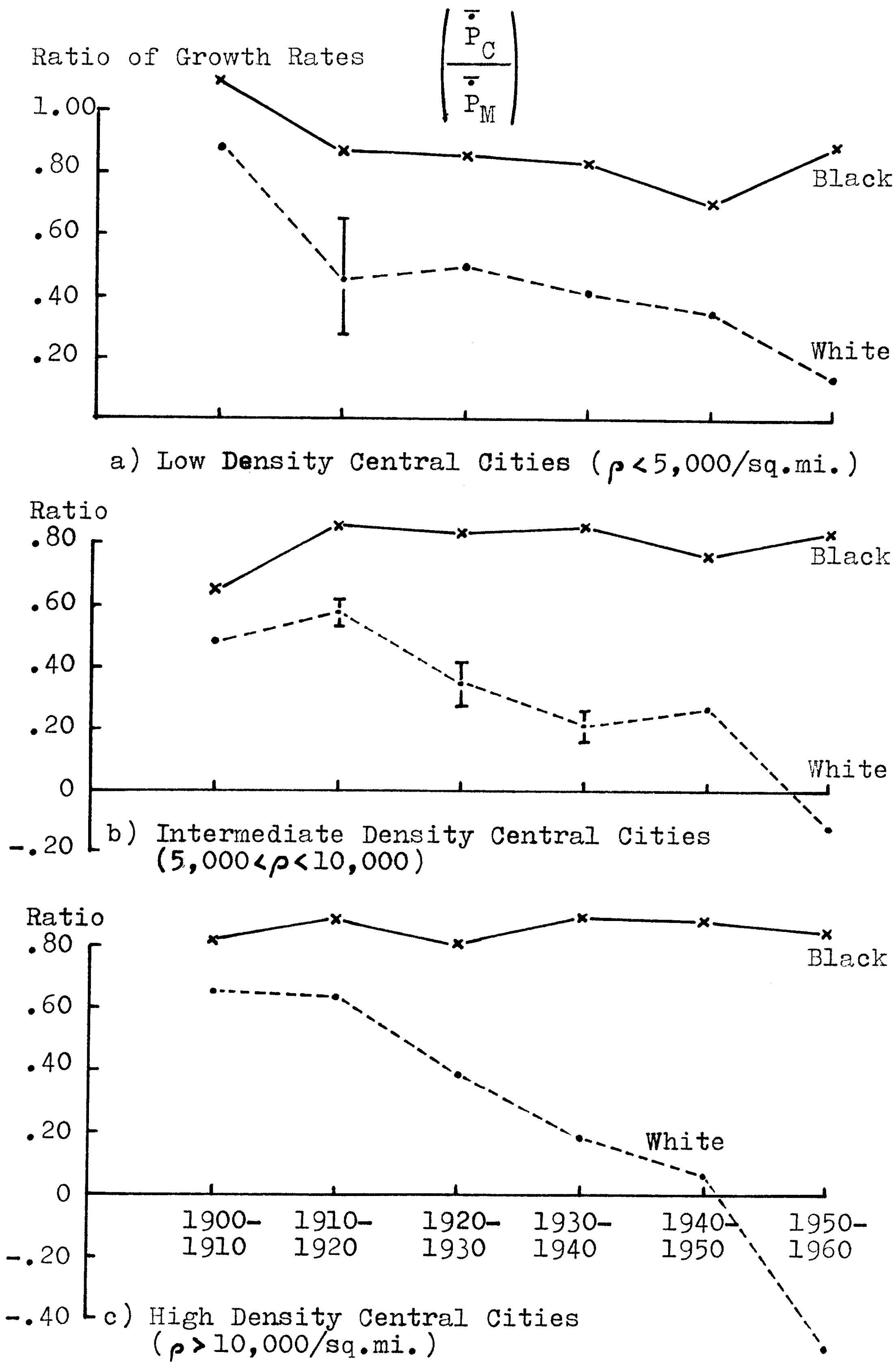

Fig. 5 Central City Increase in Population as a Fraction of Metropolitan Increase, by Race, 1900-1960

figure shows that, as was described in Section 2 of this chapter, the central city's share of the growth of white population steadily declined over the sixty-year period, with the strength of the decline increasing with the density of the central city. Simultaneously, 80 percent to 90 percent of the increase in urban black population was being concentrated in the central city. This concentration of new growth has not varied significantly with either density or time. In 1900 no significant difference existed between the distribution of the increases in black population and white population. Since that time, the white population has become increasingly mobile and begun to migrate inexorably toward the suburbs while increases in the black population have remained fixed in the same location patterns as existed at the turn of the century. The result has been a steady increase in the segregation of the two races--a trend which led the Kerner Commission to its basic conclusion that "Our nation is moving toward two societies, one black, one white--separate and unequal."[25]

Before this trend can be reversed, either by stemming the flow of whites out of the central city, or increasing the flow of blacks into the suburbs, a much better understanding of causes which created it must be developed. The grossly oversimplified and blatantly inaccurate causality implied in statements such as every time the Negro population in the Nation's cities goes up by one, three whites flee to the suburbs simply muddles the problem. The passage and enforcement of open housing legislation would remove one obstacle from the path of blacks to the suburbs, but what other obstacles remain? The model developed in this thesis begins to analyze this problem using a full simulation model of urban development. The racial mechanisms included in this model are incomplete. They gloss over or exclude several aspects which would have been treated much more completely if understanding urban segregation had been the primary focus of this research. However, given the importance of the trends toward racial polarization within urban areas, it was crucial to begin the process of incorporating racial interactions into an urban development model. An extensive review of previous work on urban development models found no model which either recognized this trend or attempted to deal with it. The inclusion of racial forces in this model, even in their present crude formulation, is an attempt to "expand the present style of land use modeling so as to be able to model social and environmental processes related to education, health, poverty, social tensions, and environmental degradation."[26]

5. Summary

The trends of population dispersal, employment dispersal, and racial segregation which have developed since the turn of the century provide clear evidence of radical changes in mechanisms of growth and development of American central cities. The recognition of these trends and the critical problems they have generated is not new--during the past fifteen years they have been overviewed, reviewed and analyzed repeatedly in the torrent of literature which threatens to add to rather than aid the 'urban crisis.' The data above have been presented at the risk of increasing this threat for the following reasons:

1. To document the growing concentration of the population of the United States into larger metropolitan areas. This trend provides the main rationale for focusing this study exclusively on large SMSA's (greater than 250,000 population).

2. To demonstrate that major trends of dispersal and segregation cut across the differences between individual cities. The aggregate data presented provide convincing proof that variations between cities in industrial and population composition, growth rate, etc., may affect the exact timing and strength of the trends, but can not eliminate them.

3. To reemphasize that the problems of dispersal and segregation did not arise overnight during the decades after World War II, but have resulted from a continuous evolution of the American city during the twentieth century. The shifts in urban development which created these problems were clearly established by the second decade of the century and just as clearly have been accelerating ever since. The massive inertia of large

metropolitan areas combined with the high thresholds for identifying new problems have seriously delayed the recognition of both the shifts and their significance. The exact nature and seriousness of the threat which this delay has created for our society has already been eloquently treated by others--there is no need to dwell upon it here.

4. To explicitly identify a set of trends which will provide the 'behavior' to be simulated by an urban development model. The identification of the trends is a first step in excluding inputs and interactions from the model. Quantifying the trends over a 'significant' time period provides the data for the first tests in validating the model.

If the trends in urban development are to be controlled, as they must, the forces both inside the city and out which generate them must be understood. The focus of this thesis is creating a moderate sized computer simulation model of urban development which will enhance that understanding. Technological change has multiplied the number, severity, and complexity of the problems in American cities. Our increased technical capabilities must be used to create tools, such as this model, which can deal with the new types and levels of complexity of those problems. Just as technological change has not been the sole or even dominant factor in creating these problems in the past, technology alone can not be sufficient to deal with them in the future. However, it does provide vital and indispensable tools which must be developed and used much more effectively if the challenge of the problems now before us is to be met.

The urban development model which has been constructed deals with two types of dynamic process--the internal interactions within the metropolitan system and the coupling of this system with the external forces continuously acting on it. The details of the internal dynamics will be treated in the discussion of the model itself (Part III). The next chapter will elaborate on the trends in the more important external driving forces acting on the city.

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22. *Ibid.*, p. 275.

23. Kain, *op. cit.*

24. U. S. Bureau of the Census, "Population of the U.S. by Metropolitan and Non-metropolitan Residence, April 1966 and 1960," Current Population Reports, Series P-20, #167, p. 1.

25. *Report of the National Advisory Commission on Civil Disorders* (The Kerner Commission), 1968, p. 1.

26. *Urban Development Models*, Special Report #97, Highway Research Board, 1968, p. 16.

Chapter 3

THE EXTERNAL DRIVING FORCES FOR EVOLUTION AND GROWTH

The strong interactions between the many components of a city make its internal structure complex and its behavior over time difficult to anticipate and unravel. These internal qualities are without a doubt a prime determinant of its growth and development. However, the city is also a system in close contact with a vital, continuously evolving environment--an environment which not only exchanges people and materials with the city, but also contains driving forces which strongly influence the evolution of the city. The dynamics of the city's behavior are determined by the interaction of these external driving forces with the internal structure of the city in much the same way as the motion of a set of weights coupled by springs is governed by the resonances of external physical driving forces with the internal natural frequencies of the mechanical system. If placed in an environment with constant external forces the city could conceivably achieve a 'steady state' behavior within the time periods of interest in this work (ten to thirty years.) Indications are that this in fact was the case for pre-industrial revolution cities during some stages of their growth.

Today, however, the city's environment is anything but static. An awareness of the interactions of changes in the setting of the city with the urban system is vital to the understanding of the development of the city. The city does not control these external changes; there is no significant feedback in the sense that the interactions induced in the city in turn modify the external shifts. But just as the analysis of the behavior of a complex mechanical system requires a knowledge of the magnitude and frequency spectrum of the forces acting on it, an analysis and projection of the development of a city requires a similar understanding of the shifts of the world surrounding it.

If it were possible to construct a 'complete' model of urban and social development, such changes as technological innovation, economic depressions, migration waves, etc., could be generated internally within the model. In this sense, the model constructed in this work is a partial model and requires exogenous estimates of trends in certain key factors. This chapter discusses the time dependent exogenous factors which have been included in this model and the reasons for their inclusion. The factors have been divided into the following two main types:

1) Changes in the external environment of the city which are direct driving forces for the growth of the city.--The model developed in this research deals with the expansion and contraction of four basic quantities within the city: population, employment, housing, and land. The changes in these quantities are influenced by the conditions within the city, but as will be shown in this chapter, they are also governed by forces outside the city. For example, while wage and employment opportunities within an urban area are important determinants of its in-migration of population, the effects of such external driving forces as economic or political oppression stimmulating the flow of migrants from Europe, or shifts in locational preferences and mobility stimulating migration to the western U.S. must be accounted for by the model.

2) Exogenous shifts which directly change the

parameters in the internal mechanisms of the city--The interactions within the city cannot be considered as fixed. Gradual shifts over time, for example, in preferences as new levels of affluence are achieved, or in the bonds between complementary activities as the speed of intracity travel increases by an order of magnitude, do change the response of the city to the same aggregate growth forces.

Figure 1 provides a simple illustration of the difference between these two types of driving force. The symbols in the diagram were developed by Forrester[1] and will be used extensively in explaining the model developed in this work. The rectangular boxes represent the 'levels' of the system being modeled. The set of level variables completely and uniquely specifies the state of the system at any point in time. They are calculated by integrating the rates of change of the level variables over time (the boxes with 'valves'). The rates of change control both the flows into a given level from the external environment (the 'clouds'), e.g. the immigration of low-skilled population into the city, and the flows <u>between</u> levels within the city,

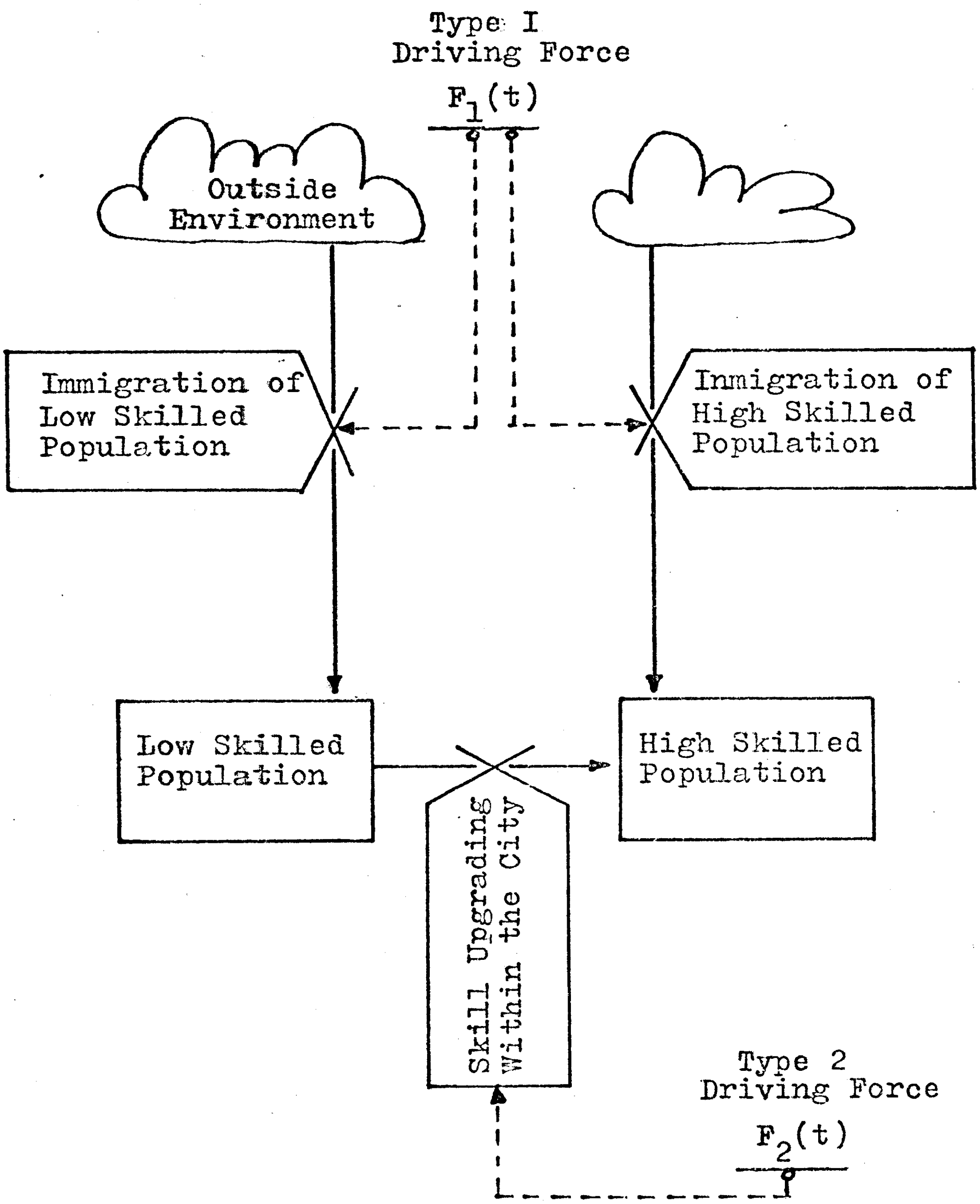


Fig. 1 Schematic of Difference Between the Influence of the Two Types of External Driving Forces

e.g. increases in skill level due to formal education or on-the-job training. The Type 1 external forces influence only the former type of rate, and thus influence the city by directly changing the flows into it.

Type 2 driving forces influence the flows between levels by shifting the internal parameters, and thus the structure, of the model. One example of a Type 2 change in Figure 1 is technological change in production techniques increasing demand for upper skilled labor and thus increasing the importance of educational background for both informal and formal skill upgrading. A second is changes in location requirements for industry pushing manufacturing to the outskirts of the city and thus decreasing the access of low skilled central city residents to the opportunity for skill upgrading.

The use of external driving forces which have strong influences on the rate and nature of growth of the city explicitly assumes that many of the determinants of urban development lie outside the boundaries of the city. In other words, that many of the differences between the development of rapidly expanding retirement havens in Florida and the declining coal towns of Pennsylvania have been caused by such forces as shifting social and income structure or the decline in the expansion of the national market for coal. These external forces must be explicitly incorporated in the model because they influence the timing and severity of such internal trends as dispersal and segregation; thus, they affect the effectiveness of alternative prescriptive policies. Also, an important class of urban development problems arise from the transient response of the city as it adjusts to a new type or magnitude of driving force for growth. The model should be useful for studying the types of transients produced and methods for controlling them.

Both classes of exogenous driving forces can be generated in three primary ways: through shifts in norms, or what is desirable and acceptable to people, through shifts in efficiency, or what is economically competitive, and through shifts in technology, or what is actually possible. All three are interdependent and the actual realization of significant change requires elements of each of them. In particular, the diffusion of technological innovation through a social structure requires both economic feasibility and social acceptance.[2]

One of the chief objectives of the simulation model constructed in this thesis is to provide a tool for understanding how technological change has interacted with and modified the structure of one of our most important social institutions--our cities. The dispersal and segregation trends within the city have occured simultaneously with several major technological developments. The simultaneity is no accident--technological change has both generated and accentuated the evolution of the city. The task of the next two sections of this chapter is to identify the exogenous changes, both technological and non-technological, which have driven this growth and evolution. The third section will summarize these forces and discuss how they have interacted with the internal dynamics of the city, and the concluding section will discuss the role of the simulation model developed in Part II of this thesis.

A. Exogenous Driving Forces for Growth of the City (Type 1 Driving Forces)

This section presents the trends in population birth and mortality rates, interregional migration, national economic development, and construction of new housing for the U.S. between 1900 and 1960. Each of these driving forces directly affects the growth of one of the major classes of urban activities--population, employment, and housing--

and conversely, the changes of each of the major classes of activities are influenced by an external driving force. The causal explanations for the fluctuations in the external forces lie outside the city itself. Alternative theories and explanations for explaining and projecting these trends exist and are the subject of controversy and modelling efforts in their own right, but the discussion of these theories is beyond the scope of this work. The discussion of exactly how these trends combine with the conditions within the city to determine the aggregate growth of the city must wait until the formulation of the growth model in Part II.

1) Population birth and mortality rates

Figure 2 presents the trends in birth and mortality rates by race for the U.S. as a whole. Mortality rates have declined continuously, asymptotically approaching 10 per 1000, and the differential between races has been virtually eliminated during this period. Birth rates show a sharp decline during the depression, followed by a sharp rise from 1940 to 1950. The combined effect of these trends on the natural growth rate of population is given in Figure 3. These data have not been corrected for shifts in the age structure of the population, and they do not reflect

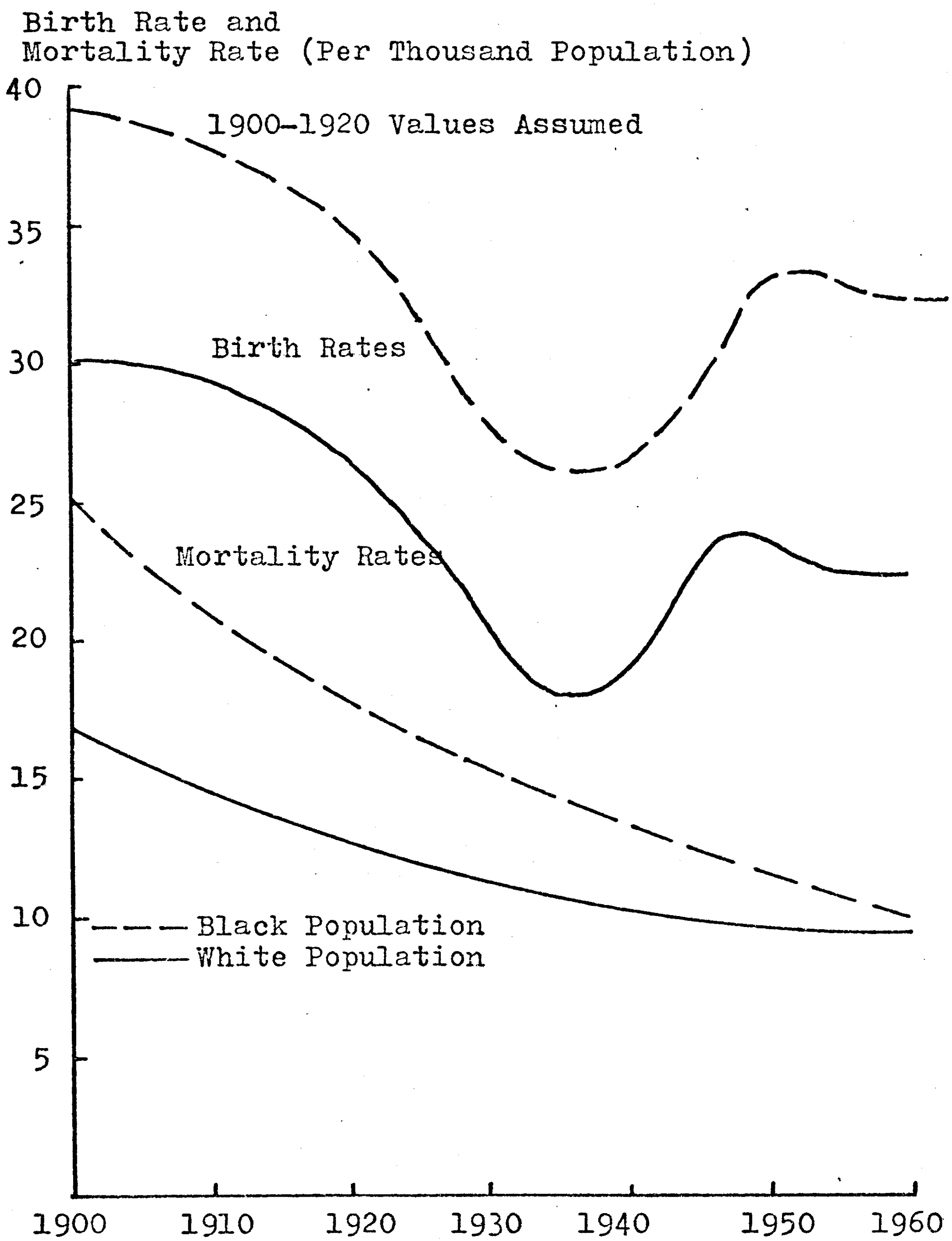


Fig. 2 National Birth and Mortality Rates by Race, 1900-1960.

Source: Vital Statistics of the U.S., 1967, Vol. I, pp. 1-4, Vol. II A, pp. 1-2.

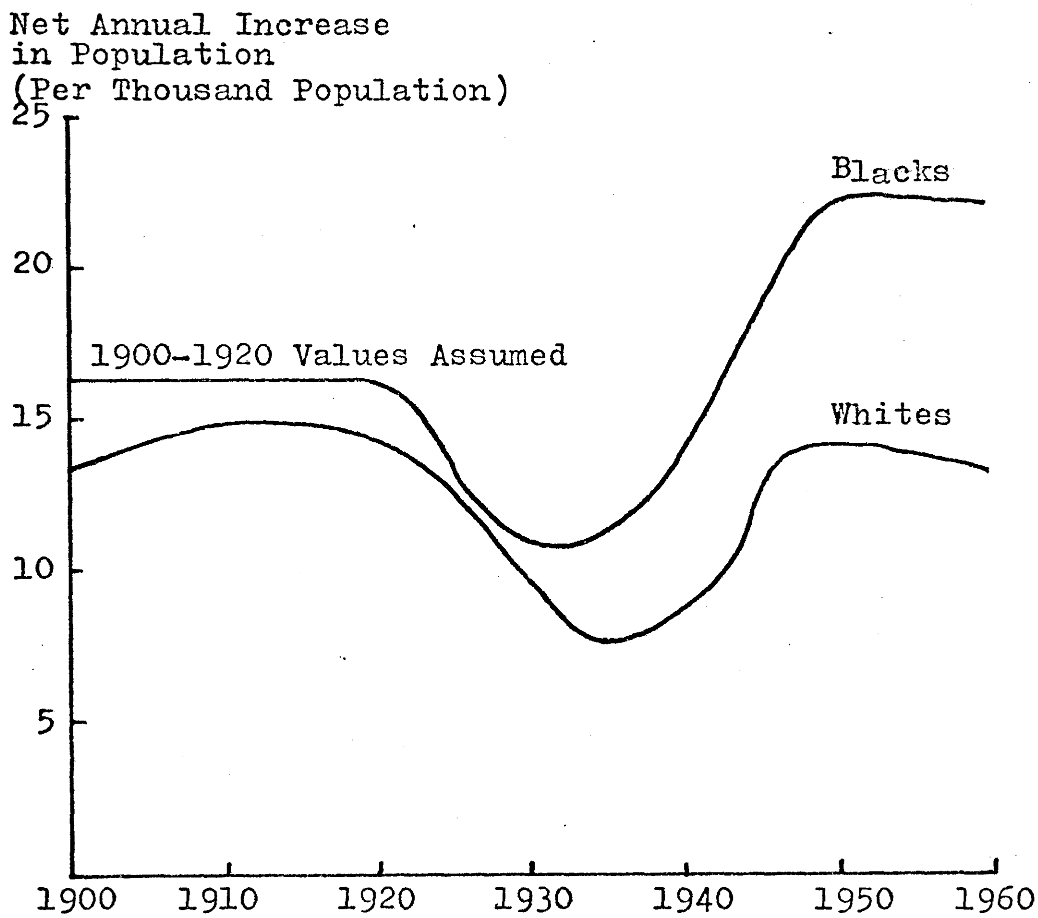


Fig. 3 Net Natural Population Growth Rate by Race, 1900 to 1960

Source: <u>Vital Statistics of the U.S., 1967</u>, Vol. I pp. 1-4, Vol. II pp. 1-2.

the differences between birth and mortality rates in urban areas versus rural areas. During the nineteenth century, the latter approximation would have been unacceptable,[3] but improvements in city health standards and the increasing fraction of population in urban areas have made gross national statistics an acceptable indicator of the trends in urban areas. The data in Figure 2 have been used as inputs for the model and determine the birth and death rates of the urban population at any point in time.

2) Interregional Migration of Population

The potential role of interregional migration in driving urban growth has been clearly demonstrated by the phenomena of such cities as Los Angeles, San Diego, Phoenix, Detroit, Tampa-St. Petersburg, and Miami. Some of the quantum jumps in inmigration to these cities could be explained in terms of rising employment opportunities (e.g., Detroit), but in many cases the driving force has been an accelerating shift in 'irrational preferences' for favorable climate and a certain style and atmosphere of living. For example, Los Angeles increased from a population of 50,000 in 1890 to 1.2 million in 1930, an average increase of 8% per year sustained over a period of 40 years.[4] Fogelson has described the components of this increase as "the immigration of the midwesterners, the conversion of the countryside (from farming to sub-divisions), and the industrialization of the economy. Each of course stimulated the other, but by and large, the newcomers antedated the subdivisions and both preceded the factories."[5] He goes on to discuss the non-economic influences encouraging the migration:

> After all, if the dissatisfied farmers and storekeepers and their children were just seeking economic opportunity in an urban setting, they could simply have moved to eastern and midwestern metropolises. Many, as the tremendous growth of New York and Chicago in the late nineteenth and early twentieth centuries indicated, did precisely that. At the same time, however, more and more of these people were less and less willing to devote their entire lives to improving their material positions...For newcomers planning to relax as well as to work, Southern California's dry warmth was particularly appealing. For them the region's mountains, deserts and oceans were fascinating, not frightening. In revolt against a way of life and a means of livlihood these people saw Southern California as a terrestrial paradise. And while their more ambitious friends departed for Chicago and other midwestern cities, they decided to resettle in Los Angeles.[6]

The significant differences in the migration rates of the major regions of the U.S. are illustrated in Table 1. Some of the differences can clearly be explained in terms of the variations in the vitality of the

TABLE 1. NET MIGRATION RATE FOR REGIONS, BY METROPOLITAN STATUS, OF STANDARD ECONOMIC AREAS (SEA)

Region	Total	Metropolitan SEA's	Nonmetropolitan SEA's
United States...	+1.8	+9.2	-8.7
Northeast..........	+0.9	+1.0	+0.4
North Central......	-0.3	+5.3	-7.0
South..............	-3.0	+14.6	-14.4
West...............	+19.1	+28.8	+0.2

Source: U.S. Bureau of the Census, Current Population Reports, Series P-23, #7, "Components of Population Change, 1950 to 1960"

industries within each area, but the option of non-economic driving forces for migration such as those described by Fogelson must also be included in the model. In the present model this has been done by including an exogenously set multiplier which can be varied in time, as will be discussed in more detail later.

The need to separate migration flows by race in the model is clearly indicated by Figure 4. For example, white migration remained virtually constant between 1920 and 1950, while in the same period non-white migration first

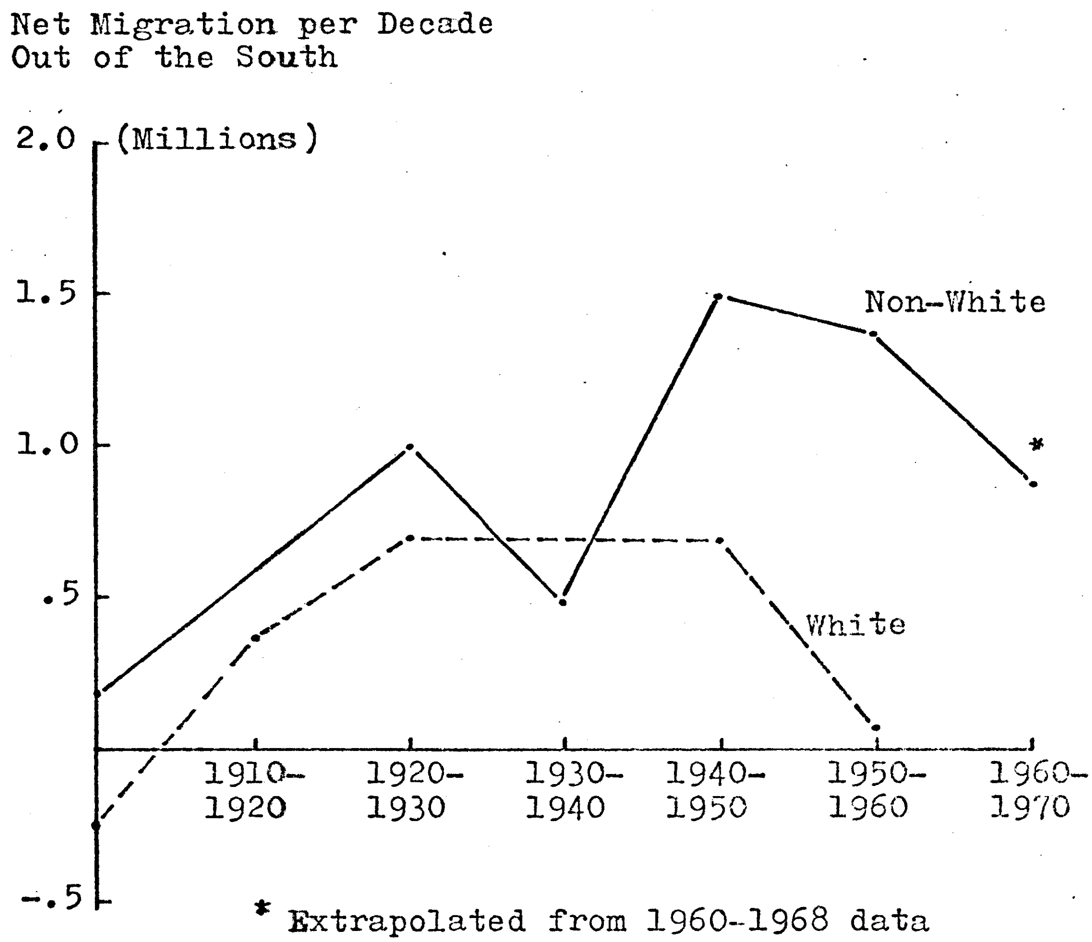


Fig. 4 Net Migration Per Decade out of the South by Race, 1900 to 1970

Sources: 1. John Kain, Race and Poverty: The Economics of Discrimination, p.9.
2. Current Population Reports, Series P-23, no. 26, "Social and Economic Conditions of Negroes in the U.S.", p.2.

3-15

decreased by a factor of two, then increased by a factor of three. The sharp decline in non-white migration since 1940 has paralleled the decline in white migration. The differences in such characteristics as skill or age structure of the migrants is completely inadequate for explaining such variations in both differentials and absolute magnitudes in the flows. In order to simulate the effects of the large magnitudes and fluctuations in non-white migration which some cities have experienced, the white and non-white migration flows into the city have been separated and some of their parameters varied independent of one another.

3) Aggregate National Economic Growth and Its Regional Redistribution

Before presenting the trends in U.S. economic development which have been influencing urban growth, the economic structure which has been assumed in the simulation model must be explained. The breakdown presented is by no means the only one conceivable, and the next paragraph is presented for illumination rather than for justification. The three classes of industry used in the model and the method of assigning employment broken down by the normal

S.I.C. classifications to the simple three class model are essentially those used in the study by Hamilton, et al.[7] Some alternative formulations of urban economic structure, and the rationale for the selection of the one given here will be presented in the modeling literature review in Chapter 6.

In the model, the total employment in the city has been divided into three parts. The first is the export base sector which produces primarily for markets outside the city. The growth of this sector can be simulated in a number of ways, most of which are determined by conditions outside the city. For example, holding the exact composition of the export sector fixed, growth can be caused by national increases in the demand for the products produced, with the city sharing in proportion to its share of total production (proportional growth). In addition, the city or region can have some unique advantages which tend to concentrate existing production and new national growth disproportionately (differential growth). Note that the differential growth can just as easily be differential decline. Removing the restriction on the exact composition of the export sector, growth can also be driven by the ability of the city to attract new types of industries, i.e., to diversify its industrial base. Relating the export base sector in the model to the more conventional one digit S.I.C. classification, the export base sector used here consists of all mining industries and 90% of the manufacturing industries.

The second part is the residential service sector. It provides all of the services and manufacturing required to support the population of the city and includes the remaining 10% of manufacturing, all retail and wholesale trade, personal services, and finance, insurance, etc., and parts of construction, government, and transportation. The growth of the employment in this sector depends upon the increases in local demand from a rise in either population or per capita consumption, upon shifts in the productivity of labor in this sector, and upon the size of the city. The last effect comes from some industries having minimum sizes which require a minimum market in order to justify local 'production' of either products or services.

The third sector is business services which provide support for both the export base and residential sectors. It consists primarily of the remainder of transportation, government, and construction and grows primarily as a result of the growth of employment in the two other sectors. Figure 5 shows the distribution of employment in urban areas among the three sectors from 1900 to 1960, calculated using Hamilton's allocation of S.I.C. categories to the simpler three sector model, and historical data on the U.S. employment.

In this formulation economic growth can be induced by simple increases in population through the residential service sector, but the dominant driving force is the export base. As has been described, the national trends in aggregate growth and redistribution of the industries in this sector are important determinants of the growth in the local export base. The first sixty years of this century have been marked by both large fluctuations in aggregate growth and major trends toward regional redistribution. Figure 6 presents the magnitude and growth rate of trends in total U.S. employment in the export base industries. The causes for the severe fluctuation in growth rate include such various factors as the effects of World War I and II, the depression of the 30's, the shift of final demand from

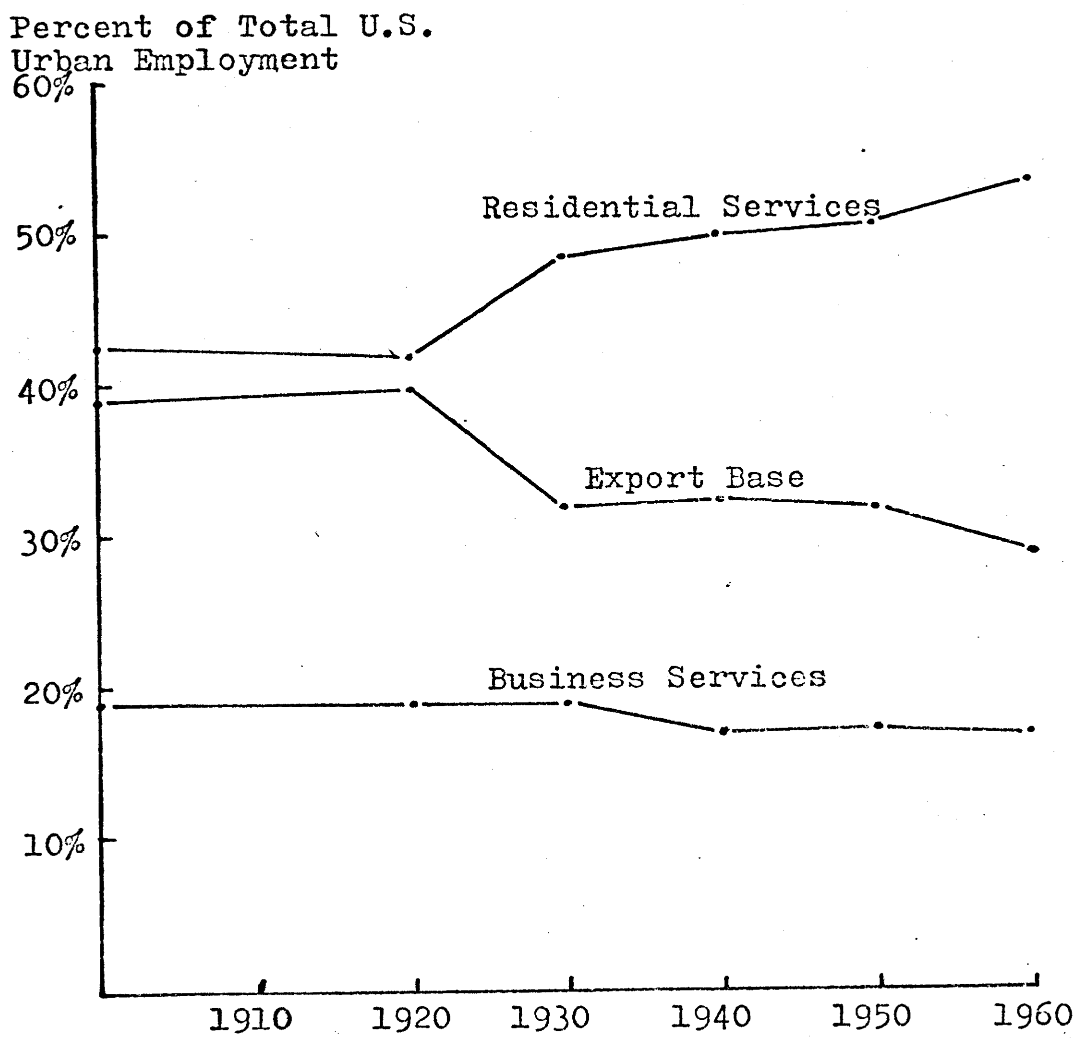
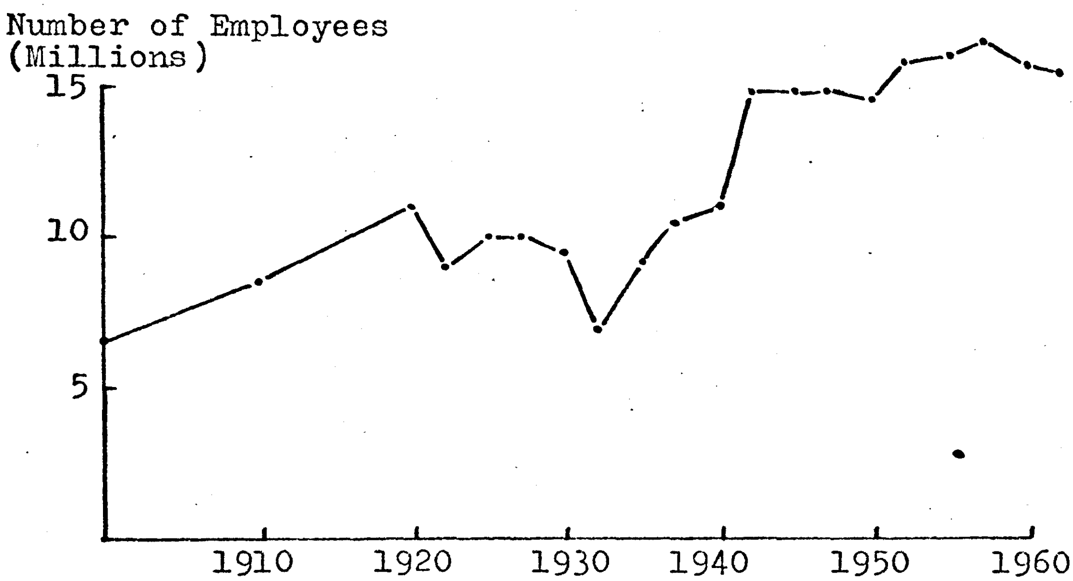


Fig. 5 Distribution of Urban Employment Among Three Sectors, 1900-1960

The sources below provided historical data on the distribution of employment by industry. The method of allocating employment in each type of industry to the three categories in the figure is discussed in the text.

Sources: 1. Statistical History of the U.S. From Colonial Times to the Present, 1967, Series D- 63.

2. "Employment and Earning Statistics for the U.S., 1909-68", Bureau of Labor Statistics, Bulletin 1312-6, p.xvi.



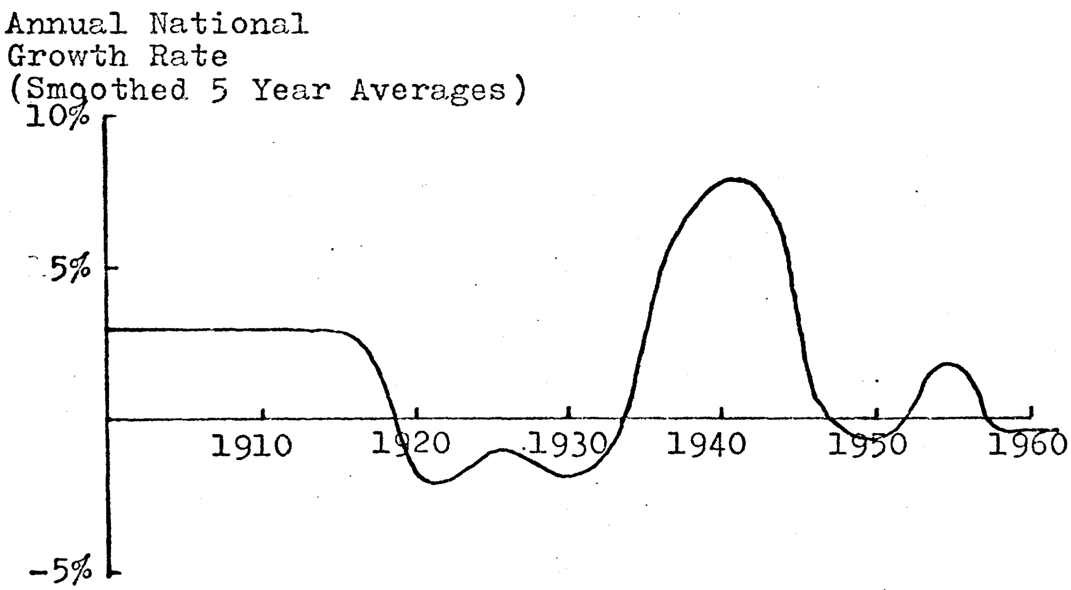


Fig. 6 National Trends in Export Base Industries, 1900-1960.

Source: 1. Statistical History of the U.S. From Colonial Times to the Present, 1967, Series D 60-61.
2. "Employment and Earning Statistics for the U.S.:1909-1968", Bureau of Labor Statistics, Bulletin 1312-6, p. xvi.

manufactured goods to an increasing amount of services, and continuous increases in labor productivity.[8]

The steady redistribution of manufacturing employment, which comprises the overwhelming bulk of the export base, among the regions of the U.S. has been well documented by several major economic studies. Easterlin, in his discussion of manufacturing in Kuznet's landmark study on the redistribution of population and employment in the U.S. between 1870 and 1950, concluded that during this period

> ...the single most noteworthy development is not the change in the relative positions of the states, nor even the very rapid and widespread growth of the labor force in the non-agricultural industries, but rather the increasing similarity among states of the industrial distribution of the labor force.[9]

Concentrating on the trends over a smaller time period, Fuchs found that

> Since 1929 there has been a substantial change in the location of manufacturing in the United States. The direction of redistribution has fairly consistently been from north to south and from east to west. In 1929 the South and West together accounted for less than one out of every four United States manufacturing employees and for only one-fifth of the value added by manufacture. By 1958 their share of United States manufacturing had increased to one-third as measured by either variable.[10]

The net result of these trends is that the formulation of the growth of the export base for a city must take into account both types of national trends--aggregate growth and regional redistribution. In the model the former has been dealt with by making the growth rate of the local export base proportional to that of the national. Differential shifts are treated by using an exogenously determined multiplier to account for regional effects and an internally calculated multiplier to account for the local labor supply.

4. Construction of new housing

The expansion of the housing supply in the city is affected by the balance between the demand for housing and the supply available to meet that demand. Given the same increase in population, or potential demand for new housing, the actual demand is determined by a number of factors both originating from inside the city, e.g., wave levels, and local unemployment, and outside the city, e.g., market interest rates.[11] Similarly, the response of the housing industry in supplying excess demand depends on such factors as government controls, interest rates and financing requirements, etc. Figure 7 shows the sharp fluctuation in annual

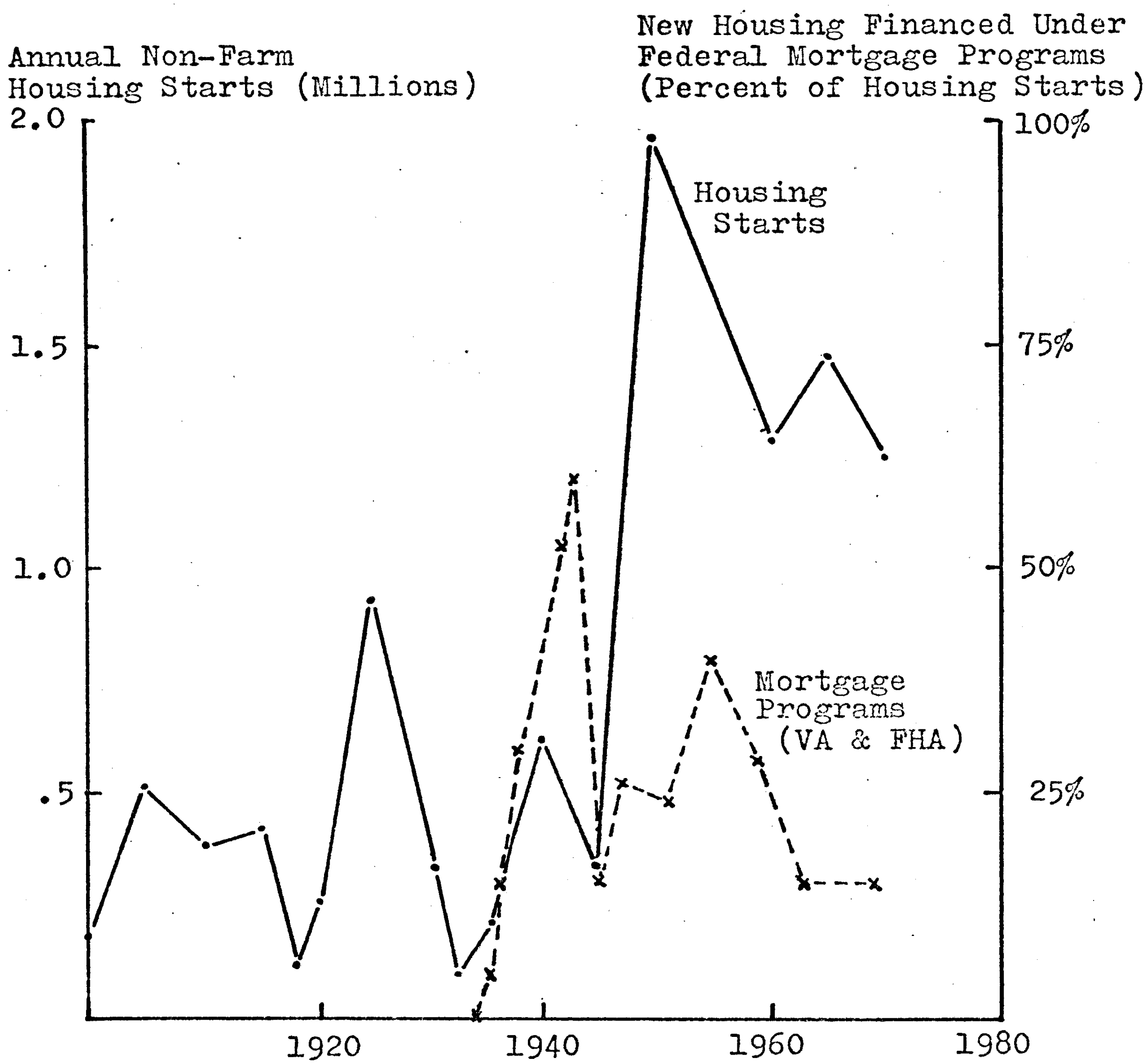


Fig. 7 Total U.S. Annual Non-Farm Housing Starts and Federal Mortgage Programs, 1900-1970.

Sources: U.S. Housing and Home Finance Agency, Eleventh Annual Report, 1957, Tables A-1, A-3 and A-5.
The Economic Report of the President, 1970, U.S. Government Printing Office, pp. 224-5.

level of new non-farm housing starts in the United States between 1900 and 1970. These rapid shifts have been strongly influenced by forces beyond the control of the city, some of the more obvious examples being the controls on materials during WW I and WW II and the effect of record highs in the prime interest rate during the late 60's. In the model, external forces are formulated by having an externally determined and time dependent multiplier of the demand for housing.

B. External Shifts Changing Internal Parameters--Technological Change and the City

Technological change is not the only force driving shifts in internal parameters, but for large American cities during the twentieth century, it has been a major one. This section will detail the ways in which technological change in production and in transportation has interacted with the internal growth and development processes of the city. The quantum jumps in mass media communications, particularly as they affect expectations, distortions in perceptions, and delays in information transfer, are a clear omission from this discussion. This omission is a part of the general exclusion from this work of any explicit formulation of political processes and interactions as was described in Chapter 1. The question of public policy as an exogenous input for the control of both the diffusion of technical innovation in particular and urban development trends in general will be discussed in the conclusion to this Chapter.

1. Production Technology--Effects on Industry

The continuous increases of the partial productivities of both capital and labor in the U.S. economy (Figure 8) reflect in an aggregate way major changes in both industry and the urban labor force, but the trends in other indicators must be used to unravel the exact interactions with the city.[12] First, changes in productivities in the various sectors of the economy, and the shifting of the composition of final demand from manufactured goods to services has caused a restructuring of the urban economy.[13] This restructuring, indicated previously in Figure 5, involves a decline in the role of export base activities producing goods for consumption outside the city, and an increase in the service sectors producing for markets inside the city. In the past the location of export base activities has been sensitive to such core city attractions as long distance transportation centers

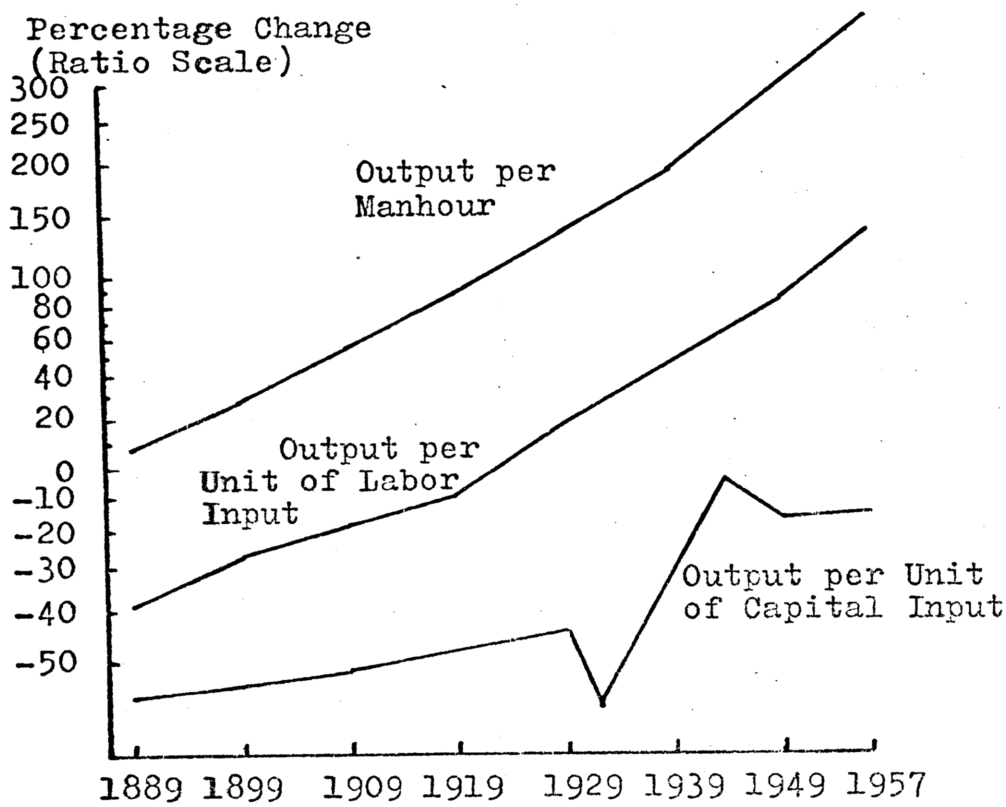


Fig. 8 Partial Productivity Ratios for the U.S. Economy, 1889-1957.

Source: John Kendricks, _Productivity Trends in the U.S._, Princeton University Press, 1961, p.69.

(both rail and water), large easily accessible labor force, proximity of complementary activities, etc., while the importance of local markets to the service sectors distributed them somewhat more uniformly to match the distribution of population within the city. Thus, the combination of increasing importance of the service sectors and the increasing dispersal of population in themselves would have been sufficient to cause some increase in the dispersal of employment.

However, the location requirements for the export base sector have also been changing.[14] A major fraction of the manufacturing industries, which dominate this sector, have developed assembly line production techniques which require single story horizontal layouts instead of the previous multiple story buildings. This change alone makes the old sites obsolete and leads to the need for large plots of land which cannot be pieced together economically in the central city and often cannot be assembled at any price. The demand for employee parking caused by the increasing dependence of the labor force on private cars for commuting to work, and the accompanying need for off street unloading sites to accommodate the increasing volume of truck freight has accentuated this need for more land per employee. The data collected by

Hoover and Vernon illustrate the magnitude of combined effects of production and transportation changes on industrial land needs.

> The effects of new processes on land requirements in recent years have been phenomenal. The extent of the change is suggested by a survey of space used in 1956 in 239 plants in the New York Metropolitan Region located outside of the old cities of the Region. The pre-1922 plants stand on 1040 square feet of plot space per worker, while the plants built from 1922 to 1945 occupy 2000 square feet and those built after 1945 occupy 4,550 square feet of plot space per worker. (The lowest figure corresponds to a density of approximately 45 workers per acre, the highest approximately 10 workers per acre.)[15]

Although her information is now somewhat dated, Muncy showed that this trend was not affecting all classes of manufacturing uniformly and that the distribution of density of new plants was still relatively broad, with 25% of them having employee densities above 50 employees per acre (sample of WW II plants).[16] Differential effects not withstanding, the projections are that the average land absorbtion coefficient for manufacturing will continue to decline at a rate of approximately 8% per decade for the next three decades.[17] (The land absorbtion coefficient is the acres of space required per employee.)

The rising importance of large plots of land for industrial sites has pushed manufacturing out to the urban fringe, but technological change has also had a more subtle effect in increasing the rate at which old sites become obsolete.

> That it is not uniform growth but a constant change in production patterns that has been the outstanding feature of progress has been forcefully brought forth by Burns in his analysis of production trends in the U.S. since 1870.
>
> ...Burns also demonstrates how technological progress involves, together with a rise and rapid growth of some new industries, retardation, stagnation, or decay of some old ones. Introduction of new commodities obviously curtails the production of the old ones for which they are substituted. Similar effects result from the substitution of new materials, fuels, or equipment.[18]

Each of these three changes in urban industries--the shift toward more employment in local services rather than export manufacturing, the rising demand for larger amounts of industrial land, and an increasing rate of obsolescence of old industries are included within the simulation model of Part II. Section C of this chapter provides a flow diagram showing exactly how these changes interact with each other and with those stimulated by transportation technology, and begins to provide some clues to the policy options for controlling the development trends which result.

2. Production Technology--Effects on the Urban Labor Force

Thus far, only the effects of production changes on industry have been mentioned, but equally important changes have occurred in the urban labor force. In order to deal with the increasing specialization of production and service activities, myriads of new classes of jobs demanding higher levels of training and proficiency have arisen. Even within traditional industries, the composition of the occupational categories of the labor force has shifted toward the white collar clerical and administrative and away from the blue collar laborer. Finally, the skills required within a given occupational category, such as operatives and craftsmen, have continuously increased as the tasks performed become increasingly specialized and the machinery used becomes increasingly complex. Gottman has summarized these trends as follows:

> In this latter group (trade, finance, government, and other services) which will soon account for more than half of the total employment in the nation, the variety of jobs and professions has constantly proliferated, owing to the affluence of society and to new problems arising from higher average incomes or legal and technological developments. ...In the

> manufacturing and construction industries many more people are employed in secretarial and managerial activities, creating new specialized professions and decreasing the numbers of workers in the trades and services. Thus, the gamut of urban occupations has been quickly widening and it promises to continue to create new specialties and new trades.[19]

In order to include the effects of these developments, the labor force of the city has been divided into two skill categories--upper and lower; the concept of skill level as used here involves the effects of both experience and more formal education. The categories of professional and technical, managerial and official, and craftsmen and foremen have enough of one or the other types of training to be classified entirely as upper skill level. The categories of private household workers and nonfarm laborers fall completely in the lower skill level. The important categories of clerical, sales, service workers, and operatives have been split into the two skill levels on the basis of the educational requirements in each category. Using 1960 census data, the fraction of the labor force in each category with a high school education or better was taken as the fraction in the upper skill level. Educational attainment is admittedly an imperfect indicator of the level of skill involved in a given job, but was felt to be a better representation of the increased specialization than the only other alternative, i.e., income distribution.

The changes in the skill distribution of thelabor force over time due to shifts between occupational categories was initially calculated using the occupational distribution at each point in time and the 1960 divisions into high and low skill levels. However, this did not reflect the increase in formal educational requirements within occupations and could not be reconciled with such trends as that presented in Figure 9. The increase in the fraction of total population having four years of high school education or more went from fourteen percent in 1910 to fifty percent in 1970 and is both a cause and an effect of the increased educational requirements in semi-skilled occupations. Detailed historical data on educational levels by occupation were not available so they were estimated by assuming that the fraction with a high school education or more doubled during the sixty year period from 1900 to 1960. This assumption was made only for the occupations with mixed skill distributions in 1960 (Figure 10); those entirely allocated to either upper skill or lower skill

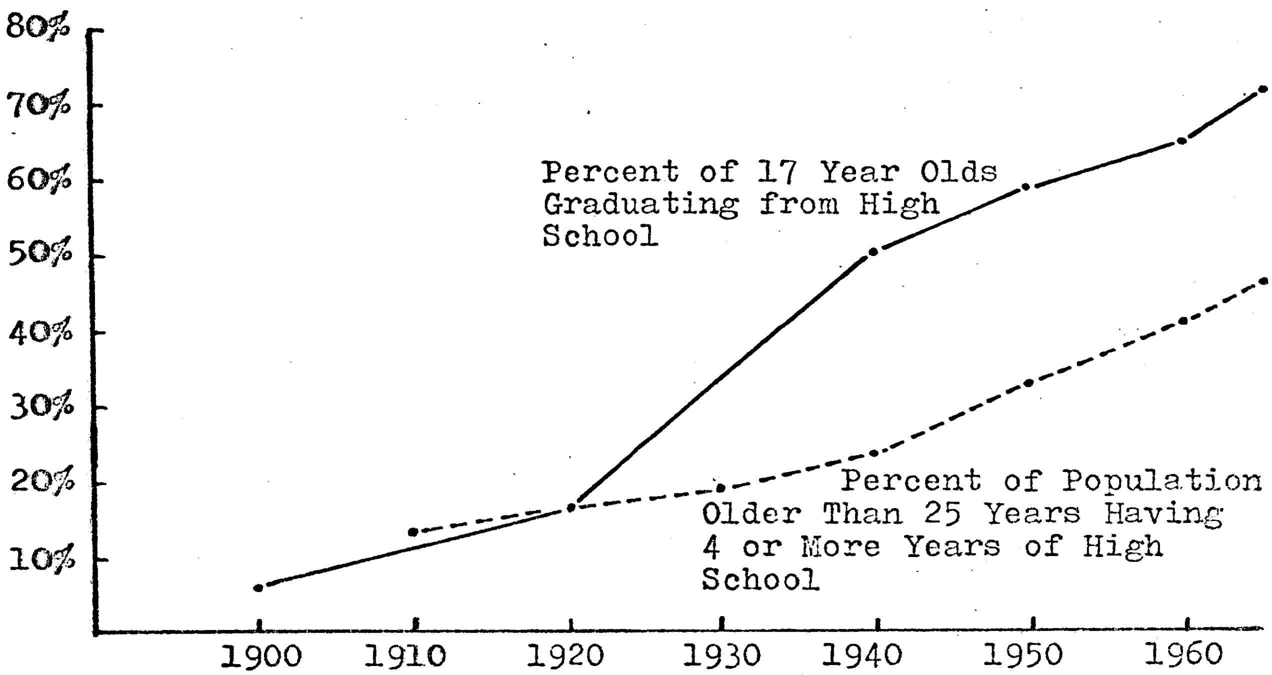


Fig. 9 Trends in Educational Attainment of U.S. Population

Source: Statistical Abstract of the U.S., 1968, U.S. Bureau of the Census, 1968, p. 127.

2. Digest of Educational Statistics, 1968 Edition, U.S. Dept. of Health Education and Welfare, p.9.

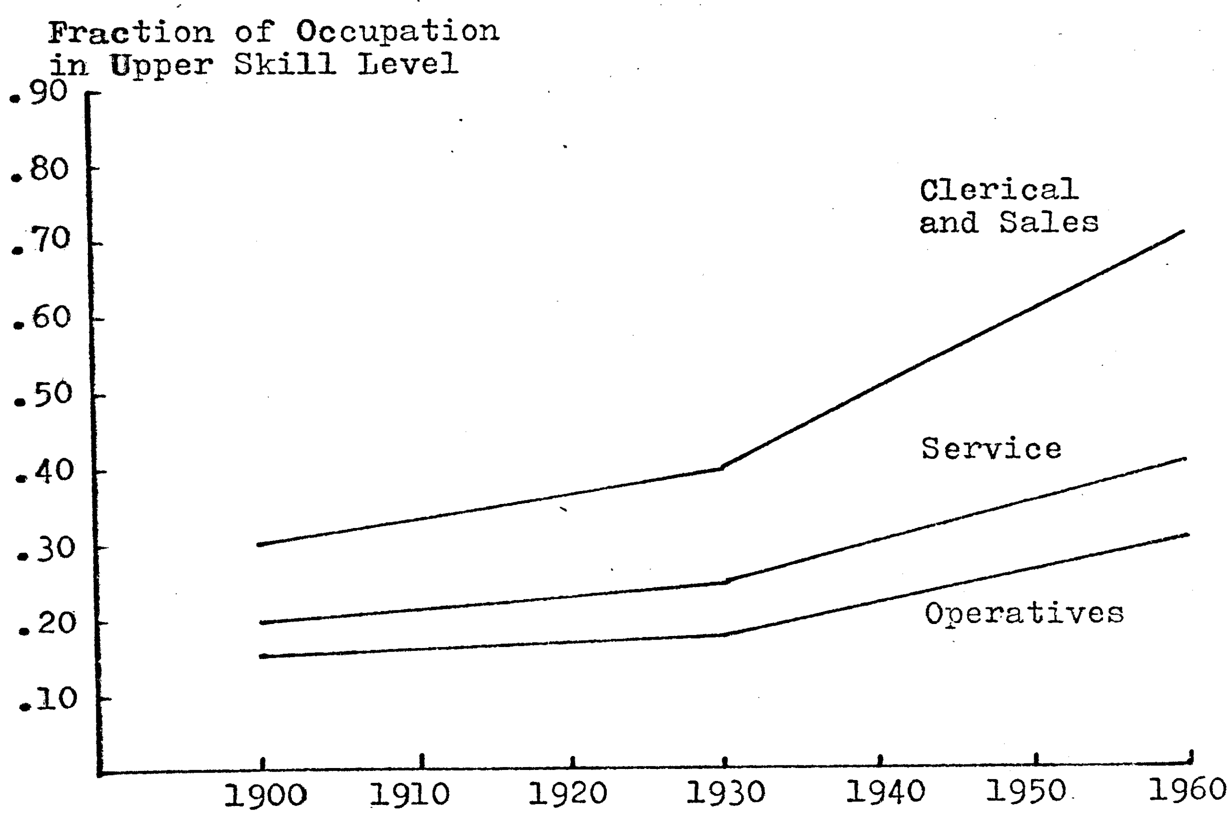


Fig. 10 Assumed Variation of Skill Coefficients for Three Occupations, 1900-1960

remained constant. The combination of the redistribution among occupations and the increasing educational demands within occupations produced the trend shown in Figure 11. The fraction of the non-agricultural labor force classified in the upper skill level increased from forty percent to just over sixty-four percent between 1900 and 1960, with approximately one-half of the rise being caused by the redistribution among occupations, and the remainder due to the increased skill level within each occupation. This assumed change between 1900 and 1960 in the distribution of skill levels within each occupation leads to an increase in the percentage of labor force classed as skilled, which is roughly comparable to the increase in the fraction of population having four years or more of high school education (twenty-four percent versus thirty-six percent). If the extreme assumption is made that in 1900 only managers and proprietors were skilled and all other occupations had no skilled employees, the proportion of the labor force classed as upper skilled in 1900 drops from forty-one percent to thirty-three percent.

Having established the trend, the question now is:

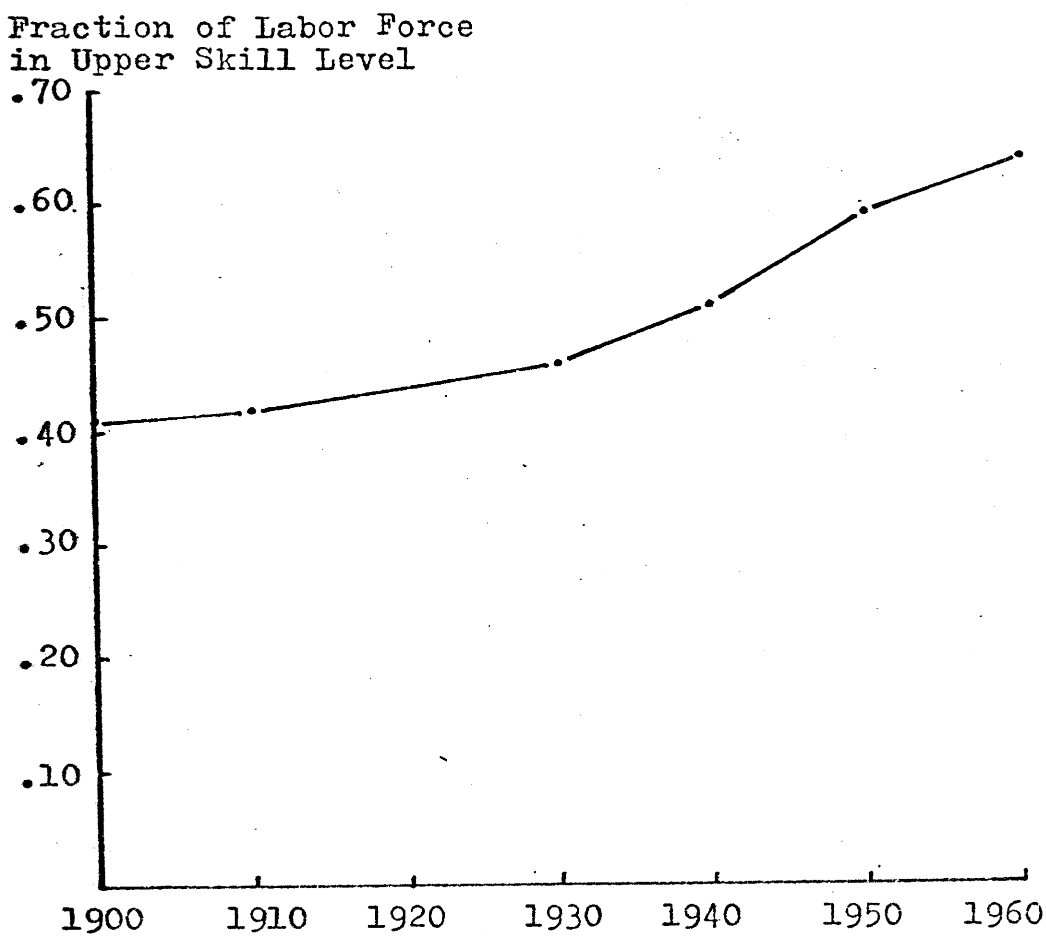


Fig. 11 Fraction of Total Non-Agricultural Labor Force in Upper Skill Level, 1900-1960.

The sources below were used for historical data on distribution of the U.S. labor force by occupation. The labor force was divided into low and high skilled using the multipliers in Fig. , by assuming that professionals, officials and managers, and craftsmen and foremen were 100% high skilled, that laborers were 0% high skilled, and the distribution of the other three occupations was as shown in Fig. .

Sources: 1. The Statistical History of the United States from Colonial Times to Present, 1967, p. 74.

2. The Outlook for Technological Change and Employment, Vol.I of Appendices to Technology and the American Economy, p.I-134.

3. The skill coefficients assumed in Fig. .

how did the increasing demand for higher skilled labor effect such processes as the location of industry, the upward mobility of labor from low to high skills, etc.? The interactions outlined in Section C of this chapter will begin to answer this question.

3. Transportation Technology--Effects on Industry

The literature on this subject and on the effects of transportation technology on residential population location is voluminous and no attempt will be made here to encompass it. (The review of location models in Chapter 6 covers major parts of this literature.) Instead, this section merely presents the major influences which have been identified and cites a few basic references for further elaboration of points which will be simplified and discussed quite briefly. The primary transportation phenomena being studied are the effect of the introduction of the truck for freight distribution, and the introduction of the private automobile for commuting to work. Moses has provided an excellent description of the two stages of the influence of the truck on the location of manufacturing activities. After describing some of the factors leading to the domination of the core city for industrial location during the nineteenth century, he describes the trends since the turn of the century.

> Only after technological changes occurred in transportation was the attraction of a non-core location strongly felt. The major change was the introduction of the truck, which reduced the cost of moving goods within cities. Its effect on the spatial structure of cities can be divided into two phases. During the first, the motor truck was introduced and became the dominant form of intra-urban carriage, but interurban carriage was still done by railroads. In this period--the first two decades of this century--firms could leave the core but were still tied to it for shipments to and from other regions. This tie was weakened during the second phase when improvements in the truck and the inter-regional highway system meant this mode could be used for long distance transport. The full impact of this change was probably not felt until the revival of a strong peacetime economy after World War II. The attractiveness of the satellite area in this period was increased by the automobile which allowed firms to draw labor from a broad area.[20]

For manufacturing activities facing the increase in land requirements discussed in the last section, these trends meant that they could take advantage of the land supply available on the urban fringes. Activities serving the local urban market could now move to more efficient distribution points located just outside the high density core and in the rapidly growing fringes.[21] The opposite trend of an increasing concentration of some economic activities, such as central offices, at the same time that production and distribution functions were dispersing, reflected the widely divergent location requirements caused by differences in their land needs, material inputs, and labor force.[22] Excellent case studies on these trends are available in New York City,[23] and the northeastern seaboard,[24] while Kain,[25] Vernon,[26] and Meyer, Kain and Wohl,[27] have produced more general summaries.

Only the first phase in Moses' description of the effects of trucks on freight distribution will be dealt with explicitly in the model. The model is a representation of only one city, so the changes in inter-regional freight transportation will be de-emphasized. Also, since the truck and the private automobile use the same road systems and are dependent upon very similar technologies, their introduction and diffusion will be assumed to occur simultaneously and at the same rate.

4. Transportation Technology--Effects on Individual Mobility

In 1900 the personal car was still a curiousity and the electric trolley and steam locomotive dominated personal transportation within the city. However, steady improvements in the automobile and the economies of assembly line production between 1910 and 1930 caused a virtual explosion in the number of cars in the U.S. and the country approached one car for every household by 1930. Intra-city mass transit suffered accordingly (Figure 12), although the pressures of first the depression and then World War II slowed and then temporarily reversed the decline of public transportation in favor of the private car. The end of the war produced a clear and inexorable reversion to the trends interrupted in 1930. Between 1945 and 1960 the number of cars in the United States more than doubled while the total number of mass transit passengers declined from 23 billion per year to just over 10 billion.

There is no question that these opposing trends in private transportation and mass transportation have had major effects on the patterns of growth and development of American cities--the problem is to understand how the influence of shifts in transportation have been enhanced

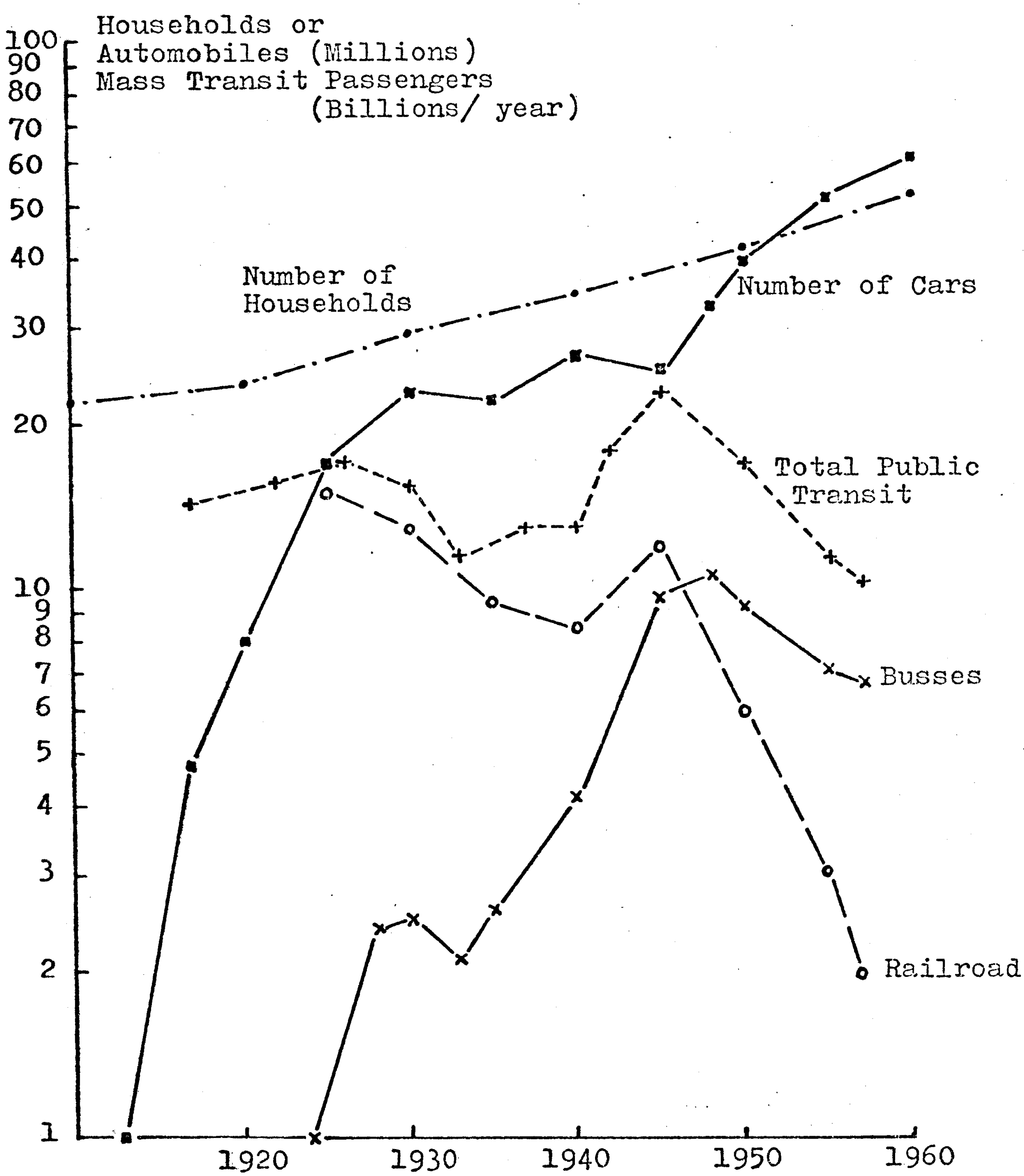


Fig. 12 Public and Private Intracity Transportation 1900-1960

Source: Statistical History of the U.S. From Colonial Times to the Present, 1967 by other technological changes during the same period, by implicit and explicit policies in such areas as housing, and by the mechanisms of growth inherent within the city itself. The widespread introduction of the private automobile has expanded the land supply of the city and permitted the dispersal of population detailed in Chapter 2, but what were the centrifugal forces pushing that dispersal? For example, what have been the relative roles of such developments as the outward flow of employment, the increased concentration of blacks, and the easier availability of single family housing due to federal mortgage guarantee programs? The car has allowed the spatial separation of jobs and home, but what were the forces acting on both industry and the individual which led to the utilization of that potential?

The steady rise in the mobility of the urban population has been widely heralded and the problems of urban sprawl and commuter congestion belatedly recognized, but what have been the effects of the other portion of the urban transportation trends--the fixed level or even decline in non-automobile transportation services in an environment where mobility has evolved from a luxury to a basic human need for survival? Many groups are hurt by this disparity in private and public transportation services, including the very young and the very old in the low density suburbs, and the poor wherever they live. This study will examine this question by taking careful note of the differentials in access to employment for the car owner versus the non-car owner. The problem of servicing the needs of non-car owners for purposes other than the trip to work is important, but has been assumed not to be central to the understanding of trends in urban development and location.

The effect of income level on availability of a car and the type of transportation which is used to travel to work is given in Table 2. People with a family income less than $3000 per year use automobiles to commute to work less than one-third as frequently as people with incomes greater than $5,000 per year. One of the implications of the dominance of the different means of transportation for travel to work of different income groups is illustrated in Table 3. For the same commuting time, a person living in central Boston and traveling by car has access to 50%

TABLE 2. DISTRIBUTION OF PERSONS CLASSIFIED BY FAMILY INCOME AND BY METHOD OF HOME-TO-WORK-TRANSPORTATION[a]

Family Income	Automobile			Public Transportation or Combination[b] (%)	Walk or Bicycle (%)	All Means (%)
	Driver (%)	Passenger (%)	Total (%)			
Under $1,000	15.9	4.7	20.6	25.1	54.3	100.0
$1,000 - $1,999	14.1	-	14.1	71.7	14.2	100.0
$2,000 - $2.999	18.9	3.0	21.9	57.5	20.6	100.0
$3,000 - $3,999	26.7	8.5	35.2	51.5	13.3	100.0
$4,000 - $4,999	36.6	12.0	48.6	41.4	9.0	100.0
$5,000-- $9,999	50.0	9.1	59.1	31.2	9.7	100.0
$10,000-$14,999	54.3	1.9	56.2	36.6	7.2	100.0
$15,000 and over	63,3	-	63.3	36.7	-	100.0
Unknown[c]	41.7	4.2	45.9	39.8	14.3	100.0
Totals	43.2	6.7	49.9	38.6	11.5	100.0

[a] Nationwide automobile-use study of locations having a population of 100,000 and over, spring 1961.

[b] Public transportation alone or public transportation with automobile.

[c] Income not reported (amounted to 13 percent of sample).

Source: Bostick, T.A., and Todd, T.R., "Travel Characteristics of Persons Living in Large Metropolitan Areas," Highway Research Board Record #106.

TABLE 3. AUTO AND TRANSIT ACCESSIBILITIES IN BOSTON

Moderate Income Jobs ($4,000 to $7,000) Reachable Within	South End (central city) Transit	South End (central city) Auto	West Newton (suburban) Transit	West Newton (suburban) Auto
10 min.	5,500	53,000	1,400	7,600
20 min.	82,500	136,900	3,800	47,400
30 min.	118,600	213,300	9,800	143,000
40 min.	159,500	272,700	38,400	267,600
50 min.	187,900	344,800	112,800	343,700
60 min.	234,000	361,200	152,500	371,700
70 min.	254,800	379,300	182,100	385,700

Source: Herr, Philip B. and Fleisher, Aaron, "The Mobility of The Poor," report produced by the Joint Center for Urban Studies, Cambridge, Mass., for the Department of Housing and Urban Development, 1969 (Part II, p. 27).

more jobs than his counterpart traveling by mass transit. An individual living in the suburbs and traveling by car has ten times as many jobs available to him within a one-half an hour commute than a worker traveling the same time period by mass transportation. The model in Part II will attempt to provide some insight into the effects of such differentials in mobility on the distribution of urban population.

Before passing on to the next section, a note on how the external inputs described above are actually obtained is in order. When dealing with the past, the trends in regional migration, national economic development, the introduction of new production and transportation technology, etc., are reasonably well documented only at grossly aggregate levels. Even at the relatively coarse disaggregations used in this research, long term historical data are extremely difficult to find, especially in consistent series. At the other end of the time horizon, the forecasting of economic and technological trends over time periods on the order of one to three decades is still almost in the realm of magic. The uncertainty of the estimates of these vital external inputs will continue to make sensitivity analysis requisite of any analysis of urban development trends.

C. The Interactions Between Technological Change and Urban Growth Processes

Section B has discussed several changes in production and transportation technology and their effects on different activities in the city one at a time. This section will summarize these individual interactions and show how their effects are related to one another through shifts in the location and composition of population and industry. The diagrams presented in this section will identify the major interactions between technological change and urban development mechanisms which are encompassed within this study, but this graphical and verbal presentation can tell nothing about the relative strengths and roles of these interactions. The forces influencing aggregate growth, described in Section A of this chapter, are not discussed again here, but are recognized as affecting the levels and rates of change of the supplies of labor and jobs, and thus of the impacts induced by technological change. The use of the computer simulation model for determining the nature and extent of aggregate growth rates on the evolution of the city, the relative importance of the different technological shifts, and the effectiveness of alternative policies for controlling the trends which they have produced will be discussed in Section D. It should be recognized that the formulation of the interactions presented here is highly schematic and intended primarily to provide a guide to the more formal mathematical representation represented by the computer model.

1. The Dispersal of Industry

Figure 13 is a diagram of the major interactions driving the dispersal of industry out of the central city. The rectangular blocks in the diagram represent external driving forces, while the circles define the development processes which are affected by the driving forces and which interact with one another to produce the changes in urban development patterns. For example, in Figure 13 the demand of export base activities for more land in order to accommodate horizontal production and employee parking needs increases the rate of obsolescence of central city

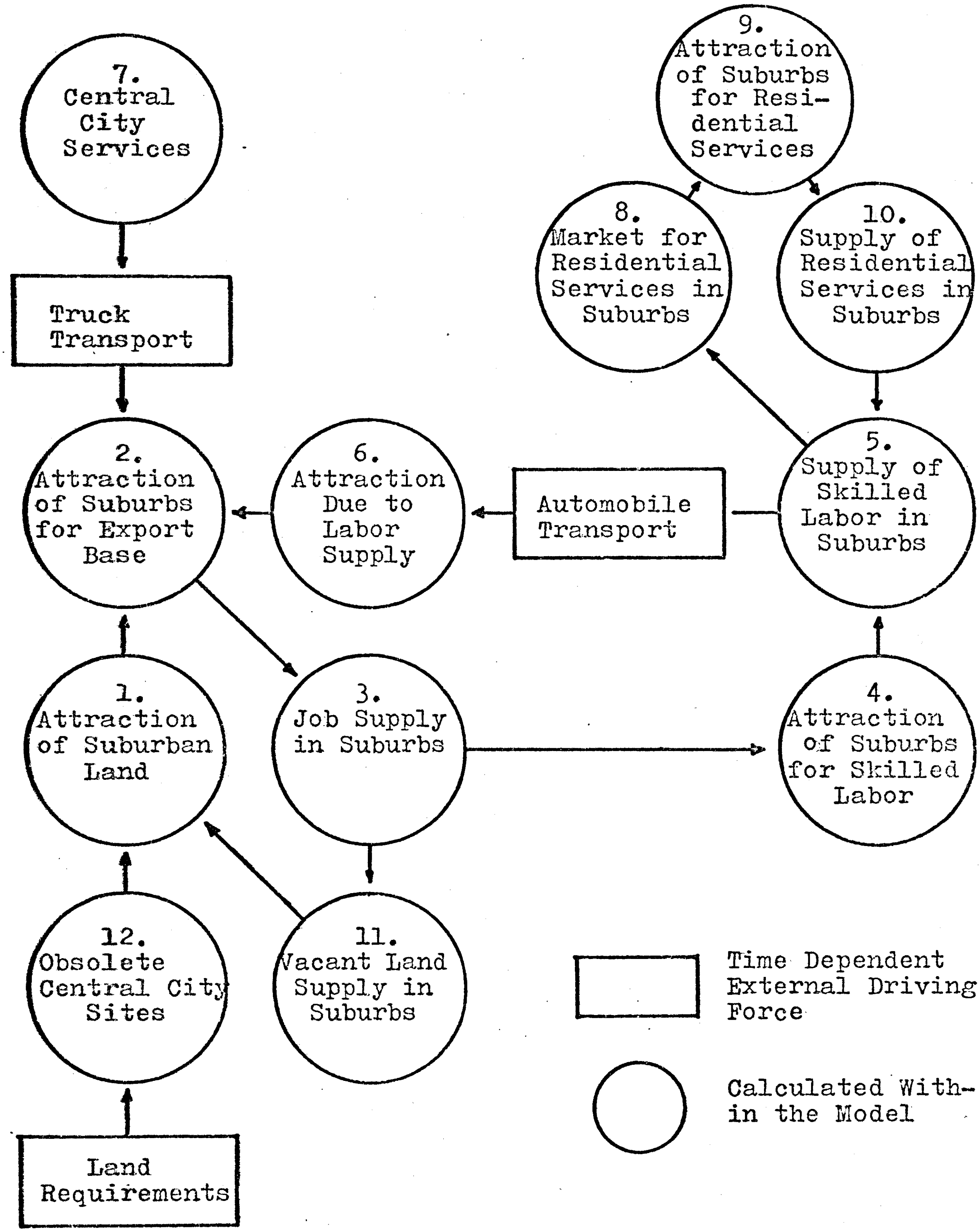


Fig. 13. Schematic of Interactions Driving Dispersal of Industry

sites (1) and enhances the attractiveness of vacant suburban land (2). At the same time, improvements in freight transportation are making suburban locations more attractive for industrial sites by relaxing the need for close physical proximity to central city transportation centers and complementary industry (7). Improvements in private auto transportation are increasing the mobility of the upper skilled workers and thus the effective labor supply available in the suburbs (6). All of these forces increase the attractiveness of the suburbs (2) and stimulate the flow of export base jobs to the outer area (3).

The outflow of job opportunities enhances the attractiveness of the outer areas for the labor force (4) and stimulates the outflow of population to the suburbs (5). This flow increases the labor force available in the suburbs, thus closing one feedback loop (2-3-4-5-6-2), and increases the market for residential services in the suburbs (8). The latter effect stimulates an outflow of residential service employment to the suburbs which again increases the job opportunities in the fringe areas and closes another loop (8-9-10-3-4-5-8). A similar loop for the business services sector is included in the model but was excluded from the diagram to avoid excessive complexity. The movement of both industry and population into the suburbs uses up the vacant land supply and provides negative feedback to control the growth from continuing indefinitely.

In summary, the dispersal of industry involves the interactions between a number of feedback loops (including two involving the business service industries which are excluded from the diagram) and the trends in land requirements for export base industries, truck transportation, automobile transportation, and skill distributions in occupations.

2. Dispersal and Segregation of Population

Figure 14 presents the interactions causing the dispersal of population and the segregation of the residential location of the two skill levels of labor force, with low skill levels tending to concentrate in the central city and upper skill levels in the suburbs. Although racial prejudices and segregation forces are an important component of the simulation model, for simplicity they

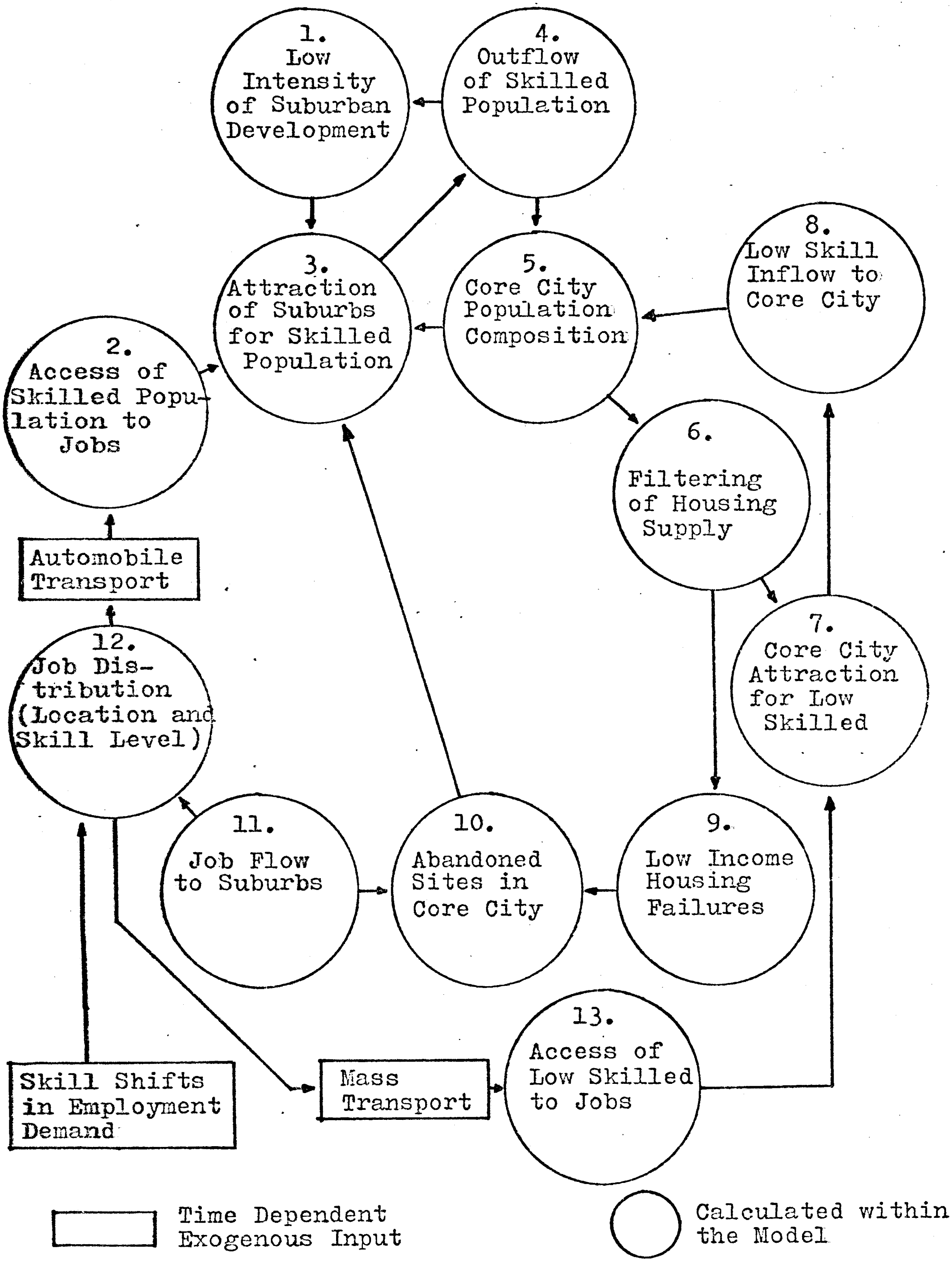


Fig. 14 Schematic of Interactions Causing Dispersal and Segregation of Population

have been omitted from Figure 14. The addition of race as a population characteristic would alter Figure 14 by 1) intensifying the response to shifts in population composition, 2) restricting the availability of housing, and 3) restricting the access to skilled jobs. These changes accentuate the degree of population segregation when considering racial distribution rather than skill level, but do not change the basic mechanisms involving population composition and prejudices, availability of housing, and accessibility of jobs. For simplicity in both the model and in the diagram, it has been assumed that the lower skilled labor force is entirely dependent upon mass transportation and does not have access to a personal car. The upper skill class of population uses mass transportation for the first decade or so of the century, but then utilizes the automobile after it is introduced.

The supply of undeveloped land in the fringe areas holds an inherent attraction for residential development (1) but this characteristic is insufficient by itself to attract significant numbers of people. The combination of outmigration of industry (11) described above, and improvements in transportation increases the access to jobs from the suburbs (2) and stimulates the outflow of skilled population (4). This force is not felt nearly as strongly by the low skilled population because of their dependence upon mass transportation. The change in the composition of the population of the inner city induced by this differential effect causes a filtering in the housing supply towards lower quality structures (6). Failures in the housing market (9) which will be discussed later create abandoned sites in the city (10), which are increased further by the outflow of industry (11). This deterioration of the central city increases the relative attractiveness of suburban areas and closes the feedback loop (3-4-5-6-9-10-3).

The dependence of the low skilled population upon mass transportation for access to jobs (13) and the low cost housing supply available in the central city (6) reinforce the attractiveness of the central area for that population class (7). The resulting growth in the low skilled population of the central city (8) reinforces the shift in the population composition and closes the loop

(5-6-7-8).

In summary , ignoring the issue of race, even this simple interaction diagram has three coupled feedback loops (3-4-5-3, 3-4-5-6-9-10-3, and 5-6-7-8) being influenced by the trends in automobile and mass transportation, and in the skill levels required in industry. Note that the loops described in this section, and those in the previous section are coupled to each other other through the influence of labor supply on the movements of export base industries, of market location on residential service location, and of job availability on residential location.

Escaping from the world of feedback loops and interaction diagrams for a few moments, the basic process being elaborated above can be simplified somewhat to clarify just what is trying to be understood. Consider two cities of two radically different eras--the first a 'traditional city' before the changes in production and transportation technology and the second a modern metropolis in the last half of the twentieth century. In the former, the high density central city, which contains the overwhelming majority of population and economic activity has long since reached a saturation density of activities appropriate for the building technology and standards of the time. Both residences and employment sites age and deteriorate over time, but the exhaustion of the limited supply of space within the city forces a continuous renewal of structures in the city. Some shifts in the composition of population and industry occur, but at a rate slow enough to be accommodated within the natural renewal processes. For the most part the boundaries between different activities and classes of population are relatively well defined and stable.

In the modern city this has changed. Transportation has opened up vast supplies of new land that relieve the pressures which had previously forced renewal. Industries which had competed fiercely for central locations now find that those locations are unacceptable and no longer meet their needs. Home owners are haunted by the spectre of sudden shifts in population composition, vacant buildings and storefronts, and the knowledge that the condition of their neighborhood depends upon what *everyone else* does, not just what the individual does. The *requirement* for continuous upgrading and renewal has been replaced by the option of maintaining the central city. It is quite clear that this option is not being exercised. The purpose of this study is to provide some insights as to why, to understand exactly how technological changes have interacted with the development and renewal processes of the city to create the situation where it is more advantageous to move out than to renew. In the process, something should also be learned about how far and how fast the deterioration of the central city is likely to continue and about what some effective approaches for halting and reversing it may be.

D. The Role of the Model in Understanding the Effects of External Forces

The rationale for using a computer simulation model for unraveling the processes described above is quite simple--the human mind is not capable of keeping track of the highly coupled set of interactions presented in Section C. It is expected that for separate stages in urban evolution, simplified models of the dominant interactions can be constructed which explain most of the behavior, which do not require a computer simulation to understand, and which are useful for making projections for limited time periods. However, when trying to decipher the process of transition from one mode of behavior to another, from the dominance of one set of interactions to another in a system composed of many strongly coupled interactions, the problem quickly transcends human capacities. The task of identifying the essential feedback loops in order to understand the dynamics of the transition process itself will be the first application of the model after discussing it in Part II. However, the first step must be the construction of a model which includes the major, strongly plausible forces which could be influencing that process of transition.

This unraveling of the evolution of the city involves the interactions of the two types of external driving forces discussed in detail in this chapter - those directly driving flows from outside the city, such as population migration or employment growth, and those influencing the internal structure of the city, such as the changes in production and transportation technology. One of the questions which will be addressed in the analysis of the model is the sensitivity of the effects of the internal changes caused by technological change to different levels and types of driving forces for growth. For example, is a city growing rapidly due to population migration much more sensitive to some types of technological change than one growing slowly due to a gradual expansion of its economic base? The externally determined multipliers for population migration, export base growth, and housing construction are the knobs which allow the analyst to control and vary the type of city he is studying while maintaining the same set of internal interactions.

Reversing the time horizon of the model and looking to the future rather than the past, important questions need to be examined about the likely trends in urban development over the next few decades in the absence of external intervention. This requires estimates of likely trends in technology, and a study of the sensitivity of the results to varying rates of national economic growth and migration rates. Finally, the relative leverage and effectiveness of alternative interventions need to be evaluated. In the present model, this can only be done on a coarse scale but some feeling can be obtained for the differential impacts of transportation improvements (e.g. all families guaranteed access to a car, or to a public system with the performance characteristics of a car), vs. housing programs, vs. skill upgrading programs.

These are some of the potential applications of a dynamic growth model of the city, but it must be emphasized that the model developed in this thesis produces results which are suggestive rather than definitive. This research has focused on creating an operational version of a model of the transition of cities from one stage to another. The work has addressed itself to the issues of extending the range and types of interactions included in such models, and not to producing outputs which can be used for policy evaluation. The concluding chapters of Part III will present some tentative insights into the vital questions about the effects of different types of policies. However, the hope is that the knowledge gained about the theory of growth and development processes in modern metropolises in this work will be applied in a new set of models more suitable for aiding in deciding upon urban policies.

Footnotes, Chapter 3

1. See Forrester, Jay, Industrial Dynamics, (MIT Press, Cambridge, 1961), or Urban Dynamics, (MIT Press, Cambridge, 1969).

2. For more discussion of the close interactions between technological and social change, see the work of the Harvard Program on Technology and Society, e.g. Mesthene, "The Role of Technology in Society," Technology and Culture, Vol. 10, Oct. 1969, p. 493; or the Annual Reports beginning in 1963.

3. For a discussion of these differentials and the trends in urban mortality and birth rates see Kingsley Davis, "The Urbanization of the Human Population," in Cities, produced by Scientific American, pp. 10-12, or Adna Weber, The Growth of Cities in the Nineteenth Century, republished by Cornell University Press in 1963, particularly Sections II and III in Chapter VI.

4. Fogelson, Robert M., The Fragmented Metropolis: Los Angeles, 1850 to 1930 (Harvard University Press, Cambridge, 1967), p. 77.

5. Ibid., pp. 132-3.

6. Ibid., pp. 70-73.

7. Hamilton, H.R., et al, Systems Simulation for Regional Analysis: An Application to River Basin Planning, (MIT Press, Cambridge, 1969). See Chapter 9 and Appendix B for a detailed discussion of the employment model and the methods used to classify different types of industry.

8. See for example Jean Gottman's discussion in Megalopolis: The Urbanized Northeastern Seaboard of the United States(M.I.T. Press, Cambridge, 1961) p. 204, or John Kendrick, Productivity Trends in the United States, National Bureau of Economic Research Publication #71 (Princeton University Press, Princeton, 1961).

9. Easterlin, Richard A., "Redistribution of Manufacturing," in Population Redistribution and Economic Growth of the United States 1870-1950, Vol. II, Analysis of Economic Change (American Philosophical Society, Independence Square, Philadelphia, 1960), p. 78.
For a more detailed discussion of the exact nature of these shifts, a comparison with shifts in population distribution, and an analysis of some of the causes, see pp. 110-116.

10. Fuchs, Victor R., "The Determinants of the Redistribution of Manufacturing in the United States Since 1929," Review of Economics and Statistics, Vol. 44, 1962, p. 167.

11. Grebler, Leo and Maisel, Sherman J., "Determinants of Residential Construction: A Review of Present Knowledge," in Page and Seyfried, Urban Analysis: Readings in Housing and Urban Development (Scott, Foresman and Company, Glenview, Illinois, 1970), pp. 60-72.

12. The Manpower Revolution: Its Policy Consequences, edited by Garth Mangum (Doubleday and Co., Garden City, New York), p.35.

13. See for example Chapters 4 and 5 in Hoover, Edgar M. and Vernon, Raymond, Anatomy of a Metropolis (Harvard University Press, Cambridge, 1959) or Chapter 11 in Gottman, Jean, Megalopolis (M.I.T. Press, Cambridge, 1961).

14. One of the numerous discussions of this is Vernon, Raymond, "The Changing Economic Function of the Central City," reprinted in Urban Renewal, The Record and the Controversy, edited by James Q. Wilson (M.I.T. Press, Cambridge, 1966), pp. 12-18.

15. Hoover and Vernon, op. cit., p. 27.

16. Munch, Dorothy A., Space for Industry, An Analysis of Location Requirements for Modern Manufacturers, Technical Bulletin #23, Urban Land Institute, 1954, p. 12.

17. Center for Real Estate and Urban Economics, University of California, Jobs, People and Land, The Bay Area Simulation Study (BASS), University of California Printing Dept., 1968, p. 160.

18. Gourvitch, Alexander, Survey of Economic Theory on Technological Change and Employment (Augustus Kelley Publishers, New York, 1966, originally printed 1940), p. 206.

19. Gottman, op. cit., (Footnote 7), p. 206.

20. Moses, Leon and Williamson, Harold F., "The Location of Economic Activity in Cities," American Economic Review, Vol. LVII, 1967, p. 213.

21. Chinitz, Benjamin, Freight and the Metropolis (Harvard University Press, Cambridge, 1960).

22. Chinitz, Benjamin, discussion of session on Transportation and Patterns of Urban Development, American Economic Review, Vol. LVII, May 1967, p. 238.

23. Chinitz, op. cit., Freight and the Metropolis; also see Hoover and Vernon, op. cit., particularly Part II.

24. Gottman, op. cit., particularly Part Three.

25. Kain, John F., "The Distribution and Movement of Jobs and Industry," in The Metropolitan Enigma, edited by James Q. Wilson (Harvard University Press, Cambridge, 1968).

26. Vernon, *op. cit.* (Footnote 12).

27. Meyer, J.R., Kain, J.F., and Wohl, M., *The Urban Transportation Problem* (Harvard University Press, Cambridge, 1965), Chapters 1 and 2.

PART II

DYNAMIC MODELS OF URBAN DEVELOPMENT: REVIEW AND OVERVIEW

Chapter 4

URBAN GROWTH AND DISTRIBUTION MODELS: AN OVERVIEW

This chapter sketches the issues, contained in the following four questions, which must be resolved prior to the discussion or creation of the models themselves. What is the purpose of the model? What information is desired from it, i.e., what are its input variables? What are the significant interactions and processes affecting these variables individually and relating them one to another? What information is needed about these processes and from the system being modeled, i.e., what are the data requirements of the model? These questions are discussed in the light of the model described in Part III, but for the most part the discussion of the specific resolution of these questions is deferred until Chapters 7 and 8.

A. Purposes and Variables of the Models

1. Theory Development vs. Policy Analysis

Two complementary, but sometimes conflicting, purposes for these models can be distinguished. The first is their use in making theories of urban development operational so that theories can be tested and refined. This function of models in the evolution of our understanding of complex social systems such as the city has been treated extensively by Blalock.[1] For example, the numerous alternative formulations of gravity models for the interactions between sources of employment and residential location, or between purchasing potential and retail store location, has allowed the testing and development of alternative theories for the exact measures and mathematical form of the effects of distance and size on the location of urban activities. The second purpose of models is their function as tools for projecting the future state of the system they describe, and especially for evaluating the impact of alternative policies on that future state.

The metropolitan area transportation studies carried out in the US in the late 1950's and early 1960's provide several excellent examples of attempts to use urban development models to design and evaluate alternative public policies, in this case metropolitan transportation systems.[2]

The complementarity and potential sources of conflict of these two functions has been described by Harris:

> This identity of interest (between decision makers and social scientists) is expressed by the fact that each, from his own point of view, is interested in conditional predictions

> regarding function and development. The scientist makes use of conditional prediction as a method of testing theories. The decision maker or planner uses conditional predictions . . . in evaluating the putative consequences of innovations and changes in policy designed to affect urban processes. The difference between the approaches in these two different contexts arises not out of the formal content of the methods, but out of the selection of variables and of measurements of consequences, that is, the selection of inputs to and outputs from the predictions.[3]

The two functions do not have to be conflicting, but the metropolitan area transportation studies mentioned earlier provide an excellent example of the dangers of incorporating them both into a single study. Because of their close ties to transportation agencies and transportation planning, the urban growth and development models created in these studies over-emphasized the influence of transportation and accessibility on urban development at the expense of other forces, particularly social ones. It was extremely difficult to justify basic sociological studies of the influence of differentials in income on mobility, or of segregation and other social preferences on location, when the sponsors for the work on the models were federal or state transportation agencies. Second, even when the desire to include a more complex set of forces within the model existed, the need for highly disaggregated results for inputs to the transportation network analysis models forced the use of very simple interactions. It was not uncommon to have to project population and employment for each of 500 to 1000 separate zones within the region. Even with a modern digital computer, the need for results on such a fine spatial grid severely restricts the complexity of interactions between areas and activities which can be included.

For urban growth models in general, this potential conflict between practical policy applications and the development and testing of alternative theories is particularly strong. The policies being analyzed in the practical applications have their strongest effects concentrated within a relatively small part of the metropolitan area, e.g., a freeway primarily influences the growth of the few miles surrounding it, a low income housing program is felt primarily by the immediate neighborhood of the new housing, improvements in city services such as education, trash disposal, police protection, etc., must be local rather than city wide because of budget and manpower constraints, etc. Even when a program covers the entire city or the metropolitan region, e.g., revision of zoning codes or new interpretations of the types of allowable land use constraints, the effects of the program are highly localized because: 1) no single policy change can affect the full range of activities located in an urban area. The range of urban activities is so broad and so diverse that any policy must have differential effects on them, and the relative location and concentration of these differential effects is critical for the evaluation of the policy. 2) Even if a policy could be designed with no differential effects after completion of the program, the impossibility of completing any program instantaneously implies that differential effects will exist over time as the program is implemented. In programs involving major construction this consideration of finite reaction time raises the question of the staging of the new additions over time. For policies which are primarily legal and theoretically affect the region as a whole instantaneously, it must be recognized that these policies do not actually affect urban development until they are enforced. Resource constraints inherently make it impossible to enforce them uniformly, so once again the issue of the strategy determining the sequence of application of new policies is raised.

The highly localized nature of the effects of urban policies implies that the information needed to evaluate alternative policies, must be disaggregated on a very fine spatial scale. At the same time, as will be discussed in Chapter 9, the influences of a policy which directly affects only a small area are in fact determined by the interactions of that small area with the rest of the city. Thus, in order to project the results of even a highly localized policy, the high mutual accessibility and strong interactions between the parts of a city imply that the entire city must be incorporated within the model. These two requirements of comprehensive coverage at a relatively fine scale have led to the very large number of spatial zones contained within most urban growth models for policy analysis (The Detroit Transportation and Land Use Study - TALUS - has 1500 zones, the Bay Area Simulation Study of San Francisco - BASS - has 700, the Delaware Valley Regional Planning Council models have 200, Baltimore's REGRO model has 700). Similarly, the limited range of most policies in terms of the groups or classes of activities directly affected requires that the variables being projected be finely disaggregated along other dimensions such as income level, skill level, age, and race for population, or, density, cost ownership, for housing.

The question of how fine a level of detail such as shifts in housing supply, location of population, and location of industry is necessary to simulate the major interactions in urban processes is one of the unresolved issues in the theory of urban development. The demand of policy applications for an extremely high level of disaggregation becomes a prime source of conflict between the development of models for such applications and those for use in the development of theory, because it inhibits experimentation with different types of interactions and different levels of disaggregation. In particular, the need to include each of the interactions between a large number of individual zones seriously limits the range of interactions which can be included within the model, and hinders the ability to experiment with different forms and combinations of those interactions. The freedom to carry out such experiments in alternative formulations is mandatory if the present poor state of the theory of urban development is to be improved.

However, a more fundamental source of conflict between the two purposes arises from the different sets of operational priorities which they imply. The high degree of disaggregation of variables makes urban development models very large and complex. Research in the design and formulation of such models is difficult under ideal circumstances, and inherently involves a high degree of uncertainty. In contrast, policy applications inherently imply a sense of pressure to supply specific information on specific projects by specific dates. Also, the temptation to draw upon the staff and preliminary forms of the model for aid in fighting the inevitable firefights or emergencies can seriously dilute and hinder the research work on the model, whether the staff is located in the agency or outside of it.

2. General Purposes of this Modeling Effort

The models being developed in the research presented in this report have the explicit function of attempting to develop and advance the theory of urban development in general, and the influence of technological change on that development in particular. When completed, they will provide useful insights into the effects of alternative policies on a gross scale; however, they are not being designed for the evaluation of specific policies and will not in themselves be useful for such. They will instead attempt to meet a primary need in the field of urban development for dynamic systems models which provide more insight into urban growth processes by:

a) putting into an operational and testable form the existing alternative verbal statements of processes influencing urban development,

b) determining which interactions are important in urban development by experimenting with alternative formulations and combinations of forces drawn from a much wider range of interactions than those incorporated in existing urban development models, and

c) incorporating these interactions with an operational systems model which explicitly accounts for the dynamic and non-equilibrium nature of processes of urban development.

These three functions of the models being developed excluded several possible research orientations in urban modeling which are important, but simply cannot be encompassed within the present work. One of these orientations was the research in models designed to generate alternative plans and policies within the model (see for example Schlager).[4] The possible combinations of policy alternatives available in a number of fields is becoming so complex that assistance is needed to ensure that a sufficient range and variety of plans is generated for testing and to determine what levels of detail the plans need to be formulated. (See Manheim's work on hierarchial structure and decomposition.)[5] A second possible orientation was the development of models for evaluation of alternative plans. The combination of increasing concern with differential effects at the local level, increasing level of disaggregation of output variables, and the incredible speed of modern computers is presenting decision makers with an overwhelming volume of information which it is impossible for them to assimilate without mechanical aids (See Reference 6). The explicit exclusion of these possible research orientations from the present work and the concentration on the urban development process itself focuses the research somewhat, but is still too general to serve as a sufficient statement of purpose. In order to limit the variables contained in the model and exclude possible interactions from it, a more operational statement of the exact problems in urban development under study is required.

3. Specific Problem and Variables

The general class of problems attacked by urban development models is that of understanding what governs the physical development of the different parts of a metropolitan area. What forces shape the location of activities such as population and employment? How does the present pattern of activities influence future shifts in these forces? What trends and forces outside the city need to be known to understand the future possibilities for development within the city?

The three trends of dispersal of population, dispersal of employment, and segregation of population identified in Chapter 2 are the specific behavior which the model developed in this research has been developed to analyze and interpret. The information needed to study these trends over time, define the primary output variables of the model, i.e., the population (black and white), and employment located within each area of the city as a function of time. The theory of the interactions between variables and the types of forces causing the three trends determines both 1) the additional levels of disaggregation of the primary output variables, e.g., population by income or industry by function, and 2) the additional variables which must be calculated within the model or supplied from outside it, e.g., the state of the housing supply in each area, the availability of vacant land, or the accessibility between areas. A complete list of all the major variables contained by the model developed in this research and the manner in which they were disaggregated is given in the first section of Chapter 7.

The list of variables, either aggregated or disaggregated, which could be included in an urban development model could be extended ad infinitum. However, no single model can, or even should, attempt to include all possible variables and interactions between them. The non-selective addition of variables and the inclusion of all conceivable interactions usually results in confusion rather than understanding, because the important interactions become buried within a mass of output data which can neither be analyzed nor interpreted. The deliberate, careful choice of the specific output variables which the model is supposed to "predict" and of the interactions and internal variables needed within the model in order to understand the causal forces driving these output variables, is the heart of the modelling process. The role of an explicit, clear statement of the exact nature of the problem being attacked by the model in the process cannot be overemphasized. A "general purpose" model does not exist. Each model has its own distinct objectives and a specific problem which it is attempting to understand and simulate. The evaluation of the appropriateness of the variables and mechanisms within a given model, and the comparison of alternative models can only be done on the basis of a clear understanding of these objectives and of this problem.

B. Basic Processes in Urban Development

This section briefly outlines four basic processes (and one special case of two of them) which are fundamental components of a model of urban development. These processes are discussed below in terms of shifts in "activities," which is just a term used to represent population, housing, employment, or any of the other variables in the model which accumulate or change in time. This section only sketches what is meant by each of these processes and gives some examples as illustrations. A review of the methods and techniques used to model them in the past will be deferred until Chapter 5.

1. Aggregate growth of activities which is driven by forces outside the city

This is the process through which the city interacts directly with its external environment. Regional, national, and sometimes international economic conditions strongly influence the flows of new migrants into the city and the addition of new industries. These flows are modified by the conditions existing within the city, e.g., employment level, labor force characteristics, market, etc., but the role of the potential for growth established beyond the boundaries of the city itself cannot be underestimated. Projections of the magnitude and details of this exogenously driven potential growth are a fundamental input to urban development models.

2. Aggregate growth driven by forces within the city

This process reflects the self-sustaining nature of growth generated directly by the existing activities within the city. For population, it consists of the net births. Housing and service classes of employment grow in response to the growth in urban population (i.e., total market). Manufacturing employment can be driven by import substitution, i.e., the population can reach a size large enough where total demand is sufficient to justify local production instead of importing.

3. Internal shifts within different classes of the same activity

The disaggregation of the major variables of urban development models into a number of subclasses makes the shifts between these subclasses within a given activity a process which must be explicitly accounted for. Each activity is in effect a subsystem of the model with flows among its separate states as well as to and from the world outside the main system. The "filtering process" of upper-income housing through several intermediate stages to slum housing is one example of these internal shifts. The upgrading (and conversely, deterioration) of the labor force from unskilled to skilled is another. Shifts in the composition of the demand for labor can be driven by changes in the industrial composition of the area, changes in production technology, and long term consumption shifts, e.g., the increased consumption of services in place of durable goods over the last 50 years.

4. Location of activities within the city

This process allocates to the different areas within the city the aggregate growth from both internal and external sources. It also must deal with the relocation of activities which had been located previously, but are being either "pushed out by competing activities," or "pulled out" by changes in production or transportation technology, shifts in preferences or tastes, or shifts in the location of other activities. It is similar in conflict to the processes included in #3, but deals solely with shifts of activities between spatial zones.

The competition between different areas for the location of these activities occurs on the basis of three classes of characteristics:

a) the availability of physical space - the location of an activity in an area requires land. If no free land is available, the possibility of displacing an existing activity, e.g., displacement of small businesses by high rise apartments and office buildings, must be considered. The difficulty in assembling the site, and potential for future expansion are two non-physical characteristics which should be accounted for.

b) Local availability of the "inputs", "markets", and "services" required by the activity--this characteristic just reflects the degree to which the local area meets the basic requirements of the activity. For industries, these requirements include labor force, raw materials, intermediate goods, supporting services, and market. For population, they include employment, housing, physical amenities, retail and municipal services, etc.

c) Local accessibility to the above factors--the requirements needed by an activity do not necessarily have to be physically located within the area being considered for location. Their effective availability must be estimated in terms of their accessibility by the appropriate means of transportation. This need to include the effects of accessibility to activities in all other areas of the city even when dealing directly with just one or a few of them is the most complicating of urban development.

5) Growth in the supply of space in the city

The physical growth of the city, either through expansion at the fringes or by increases in building height, is just a special case of the aggregate growth processes described in sections (1) and (2) above. However, the growth of this particular 'activity' is such a fundamental aspect of urban development that it merits separate attention. The finite capacity of land to contain activities implies that the total land supply available to the city places an uncertain, but definitely limited upper bound on the city's size. The manner in which the city expands this basic commodity is a process which must be unraveled if the dynamics of urban development are to be understood.

The above five processes have been presented separaterly as if they were independent of one another. In fact they are closely interrelated to one another, and operate simultaneously to determine the pattern of urban development over time. The nature of some of these interrelations will be discussed in the final sections of this chapter after a brief review of the types of information inputs needed for urban models.

C. <u>Data Requirements</u>

The following three classes of information are required for the operation of any model of urban development.

1. Initial conditions--the magnitudes of all the variables of the model at the beginning of the study must

be specified. For some of the more highly disaggregated models of specific cities, the assembly of this inventory of existing activities can be one of the more expensive and time consuming actions in the entire model building process.

2. Internal parameters--these are the constants of the mathematical formulations in the interactions contained within the model. They are required to convert verbal statements of an interaction, e.g., "the influence of an external source of employment on the attractiveness of an area for residences is proportional to the size of the employment source and decays with increasing distance between the source and the area," into a precise mathematical statement. For the statement above, what is the constant of proportionality, and what is the exact rate of decay with distance? The constants can be estimated by independent studies not directly concerned with the model building effort itself. More commonly, the models are "calibrated" directly during construction by using time series data (usually two or at most three points in time) on the city being modeled. Inadequacies in the detail and time span of the data available for such calibration, implicit assumptions about stability of interactions and casual forces, doubts about the ability to quantify some of the more important interactions, and fundamental theoretical questions about the

degree to which the structure of the model can be specified using empirical observations (the identification problem) raise serious questions about the validity of all urban development models. Questions of estimation of internal parameters and validation of models of complex social processes in general and urban development in particular will be discussed in more detail in Chapter 6.

3. Exogenous driving forces--each of the five basic processes in urban development discussed in Section B above is sensitive to exogenous forces which must be specified in order to determine the pattern of urban development. Some of these forces can be controlled and appear as alternative policies, e.g., future location of transportation networks, zoning policies, stimulation of parts of the labor and housing market, location incentives for industry, etc. Other forces are uncontrolled and must be projected or estimated. The most important of these are the potentials for expansion of export base industry and population migration. The influences on housing construction and technological change in transportation and production were each discussed in detail in Chapter 3.

D. Interrelations between components

Figure 1 presents a schematic presentation of the

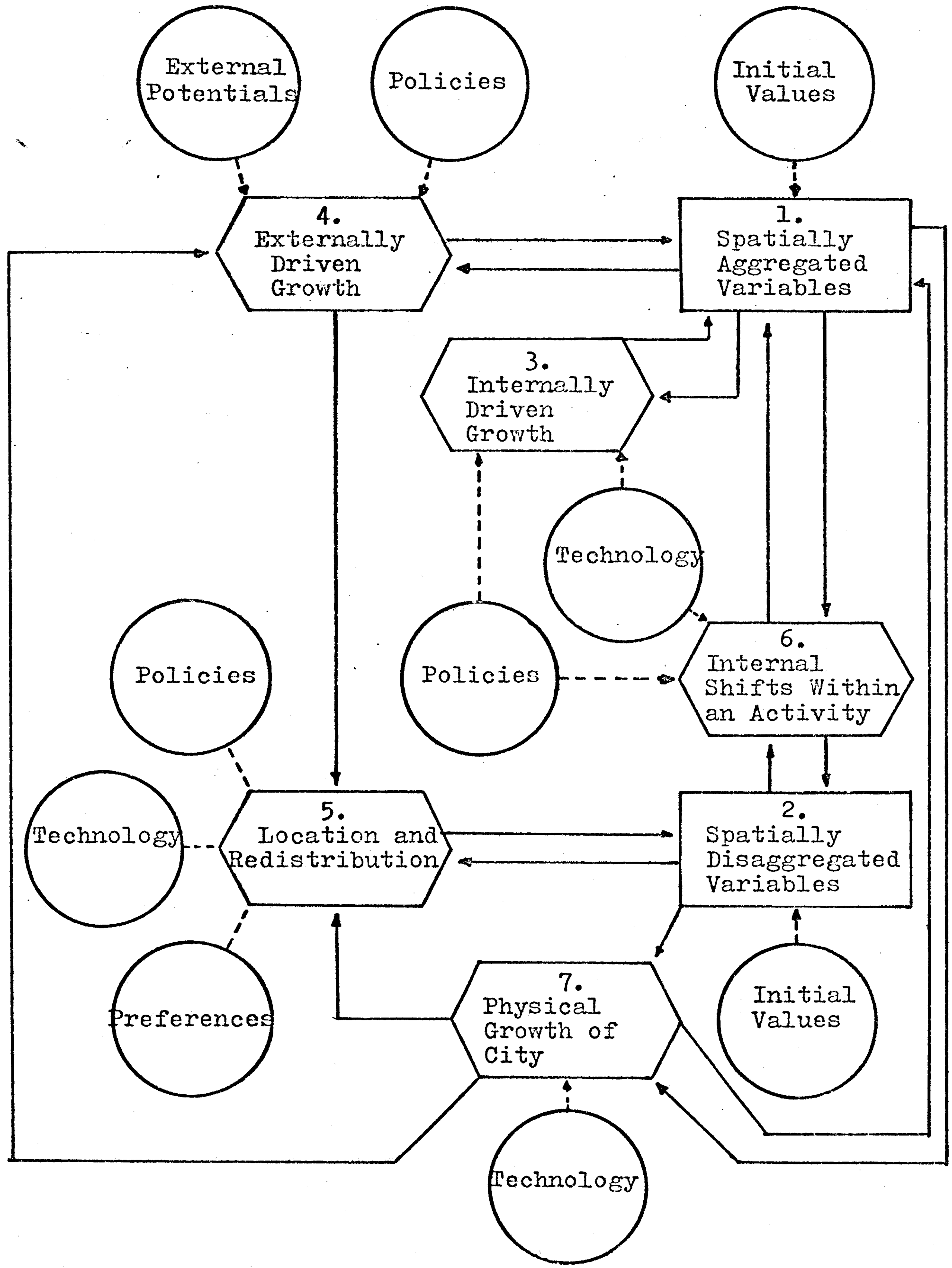


Fig. 1 Schematic of Interactions and Inputs

interrelations between the various components of an urban development model which have been discussed separately above. The functions and purpose of the model do not appear explicitly in the diagram, but they implicitly shape the variables and the relative strengths of the interactions contained within each of the individual processes. In the diagram the elements in a circle are the inputs which are completely specified outside the model, the elements in rectangles are the state variables which specify the state of the system at a fixed point in time and require initial values, and the elements in diamonds are the basic processes described in section B above.

At the beginning of the operation of the model, the aggregate variables (1) and spatially disaggregated variables (2) take on their exogenously specified initial values. (The aggregate variables are just the sum of each of the spatially disaggregated variables over all regions.) Internally driven aggregate growth (3) increases the aggregate variables and is primarily a function of the aggregate variables. Externally driven aggregate growth (4) is also governed by the aggregate state variables, but is more sensitive to policies, technology, and especially the exogenously determined potentials for economic growth and population migration. Both new aggregate growth and redistribution of existing activities are inputs to the location process (5) for distribution to the different zones in the city. Policies, the state of technology, the existing distribution of activities, and local preferences shape this location process and also determine the activities which need to be redistributed within the city. Internal shifts between the subclasses of a given activity (6) similarly depend upon existing distribution of activities, state of technology, and policies. These shifts are the only process which simultaneously changes both the aggregate and spatially disaggregated variables. The process of physical growth of the city (7) is coupled to the aggregate variables in both directions - pressures for more activities coupled with technological change can drive physical growth, while absence of land for growth can inhibit growth of activities. Physical growth also influences location by providing alternative zones for location, and the rate and direction of physical expansion in turn is influenced by the existing distribution of activities, particularly in the urban fringe.

Although the particular time scale and focus of the problem under study by a given urban development model may shift the relative importance of the interactions and processes described above, all urban development models must account for each of the above interactions in some way. This includes, of course, the possibility of <u>explicitly</u>

assuming that the process is not important and thus need not be included. The following chapters will demonstrate the variety of ways in which the processes can be formulated.

E. Dimensions for Comparing Urban Development Models

Table 1 presents five dimensions (purpose, scope, theory, methodology, and relevance) which can be used to compare alternative models of urban development. These major dimensions are not independent of one another, e.g., the specific problem selected under the Purpose strongly influences the range of variables and disaggregation under Scope, or the causal mechanisms selected under Theory sometimes uniquely determines the mathematics included under Methodology. However, the subclasses, e.g., 1) processes, 2) output variables, 3) level of disaggregation, and 4) type forces, within one of these major dimensions, constitute an independent set of sub dimensions. The alternatives listed under each of the sub dimensions are meant only to indicate the types of alternatives available and is not a comparative listing. The annotation and examples given with the table make it self-explanatory, so it is not discussed in detail here. Its functions are to provide a concise summary of the major aspects of urban development models and to make explicit the choices involved in the construction of those models. The table supplements the diagram of interactions presented in Figure 1, and that figure should be used to determine some of the interactions between the dimensions of Table 1.

Table 1 Dimensions for Comparing Urban Development Models (This table synthesizes and supplements the work of Harris,[7] Lakshmanan,[8] Lowry,[9,10] and Kilbridge.[11])

A. Purpose

1. General Purpose
   a) Policy evaluation (see Lakshmanan's distinction between planning models which introduce criteria for choice, and simpler impact models)
   b) Development and testing theory

2. Specific problem being attacked and analyzed, e.g. ,
   a) Decentralization of population and employment'
   b) Local concentrations of low income and/or black people
   c) Failures of housing market

B. Scope

1. Basic processes (see section B of Chapter II in this report)
   a) Externally driven aggregate growth
   b) Internally driven aggregate growth
   c) Internal shifts within a given activity
   d) Location of activities
   e) Growth of the physical supply of space in the city

2. Output variables , i.e., what impacts or results are needed?
   a) Population
   b) Employment
   c) Housing

3. Level of detail and characteristics used for disaggregation of variables, etc.
   a) Spatial zones: by cost, density, access, topography
   b) Population: by income, race, family size, etc.

c) Employment: by product, size, location characteristics

4. Type of forces included (Lakshmanan's 'coverage' or Harris's holistic vs. partial), e.g.,
   a) Spatial extent, e.g., central city vs. metropolitan vs. regional
   b) Accessibility-- measures used by mode and type of activity, e.g., aggregate gravity model access by transit to employment
   c) Land use and site characteristics-- existing land use, density, holding capacity, vacancy rate, etc.
   d) Housing preferences
   e) Social preferences, e.g., racial and economic segregation
   f) Municipal policies, e.g., zoning, sewage and other services, tax rates, etc.

C. Theory

1. Degree of interdependence between spatial distribution of activities and rate of aggregate metropolitan growth

2. Time dependence of interactions, e.g., Harris's dynamic vs. static

3. Sources of changes in magnitude and distribution of activities
   a) Analytical (Harris) or 'transparent logical' (Lakshmanan) -- uses models whose parameters explicitly reflect a given set of preferences, level of technology, and city structure
   b) Descriptive (Harris) or 'Black box statistical' (Lakshamanan) -- models whose parameters are based on empirical correlations which adequately describe past trends in spatial form, but give little insight into how changes in technology, preferences, or structure will

affect those trends in the future.

4. Causal mechanisms and perspectives (See Lowry)
   a) Growth and shifts in supply
   b) Growth and shifts in demand
   c) Market balancing (perfect or imperfect) of supply and demand
   d) Pareto optimality of all actors
   e) Optimization, e.g., minimum site costs, by individual actors

D. Methodology

1. Mathematics, e.g.,
   a) Econometric-- statistical estimation of sequential or simultaneous equations
   b) Input-output analysis
   c) Multiplier techniques, e.g., projection of time series, economic base theory, share of national or regional growth, etc.
   d) Trend analysis, e.g., projection of time series data, fitting to density gradients decaying exponentially with distance from CBD, gravity models of interaction over distance
   e) Linear programming
   f) Dynamic programming
   g) Stochastic or Monte Carlo simulation
   h) Machine simulation interrupted by human judgement
   i) Linear and non-linear feedback simulation

2. Measures of independent variables, both what is included and its functional form, e.g.,
   a) Accessibility -- travel time, straight line distance, out of pocket costs, total costs
   b) Desirability of housing types
   c) Level of municipal services
   d) Site characteristics-- net or gross residential

density in population or DU's per acre; amenities such as slope, view, etc.

3. Calibration and verification
   a) Approach -- e.g., prediction of past data, prediction of future, logic, i.e., do the parameters and results 'make sense.'
   b) Type of data-- cross sectional between several areas at one point in time, or time series or one area over an extended period.

E. Relevance

1. Is the model applicable to the processes of interest as defined in the purpose and scope of the study? Does it yield any insight into the policies and processes being studied?

2. How difficult is the model to work with?
   a) Has it been used or formulated beyond the conceptual stage?
   b) How easily can the relationships within it be manipulated?
   c) What are the data requirements for calibration and input?

3. What is the model's 'validity' and the criteria used to assess its validity? Lakshmanan suggests the criteria of accuracy, simplicity, stability, and parametric plausibility

Chapter 4 Footnotes

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2. Zettle, Richard M., and Carli, Richard R., "Summary Review of Major Metropolitan Area Transportation Studies in the U.S." Special Report, Institute of Transportation and Traffic Engineering, University of California, Berkeley, 1962.

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9. Lowry, Ira, "Seven Models of Urban Development: A Structural Comparison," Highway Research Board Special Report #97, 1968.

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11. Kilbridge, Maurice, et. al., " A Conceptual Framework for Urban Planning Models," Management Science, February, 1969.

CHAPTER 5 - REVIEW OF EXISTING MODELS

The following chapter briefly reviews the existing techniques for modelling each of the five major processes in urban development which were presented in Chapter 4. The techniques for each process are discussed in order of increasing complexity. The references for the footnotes in this chapter have been expanded, cross-referenced, and annotated in an extensive bibliography on urban development models in Appendix II. The first section of that bibliography is a list of review articles on urban models. The article by Harris,[4] and the summary[6] of the 1967 Conference on Urban Development Models listed there are particularly good summaries of the state of the art of modelling techniques and the major issues in urban modelling, respectively. The second section outlines the major modelling efforts in the United States and lists their major references. The third section has separate portions for the location models of population, industry, and retail employment. The final section gives some basic references on the specific simulation language (DYNAMO) used in this thesis. (See Chapter 6.) The major reference in this last section, Urban Dynamics by Professor Jay Forrester, is reviewed separately in Chapter 8 of this report. (Note: the two footnotes above refer to the article number in Section I of the bibliography in Appendix II. All further footnotes in this chapter will refer to the article number in Section III of that bibliography.)

A model can only be evaluated in terms of the purpose for which it is being considered. The models discussed in this chapter are reviewed from the perspective of the purpose of the model created in this work, i.e., from the standpoint of their suitability in providing insight into the structural changes which have occurred in the city during the first 60 years of the twentieth century. Many of the models and approaches to be discussed will be found to have serious shortcomings when viewed from this perspective. This should not be interpreted as a criticism of their creators because most of them were never intended to deal with urban development over the time periods of interest in this study and many were deliberately formulated as excluding some of the dynamic processes which are a primary focus of this thesis, for example the equilibrium models such as Lowry's model of metropolis.

The review is primarily intended to give some basic background and insight into the approaches which have been used to model the major aspects of urban development discussed in the previous chapter. A 'complete' review of the modeling work which relates to all aspects of urban growth and development is clearly beyond the scope and intent of this chapter. Since the bulk of the work in modeling of urban development itself has concentrated on the location of population and employment within an urban area, this review focuses on this one aspect at some sacrifice to the other four. However, some discussion of and the citations for some of the basic references in each of the five aspects of urban development have been included.

A. Models of Aggregate Growth of Activities

A basic assumption underlying all models of urban development to date (except for Forrester, Ref. # 7 in Section IV of Appendix I) is the separating of the total population and employment in the city growth from location and distribution processes. They make the crucial assumption that the projection of aggregate growth is independent of, and can be separated from, the distribution of activities within the city and the policies and other forces affecting the distribution. Under this assumption, urban development models can be split into two separate parts - 1) the models of the attraction and stimulation of aggregate growth, of population and employment and 2) models of location and redistribution of these activities. The aggregate models include growth driven both externally and internally; the dangers of failing to distinguish between the two types of growth mechanisms will be discussed later.

In most studies, the city as a whole is considered as a small region, attention is focused upon the increases in population and employment, and projections are made drawing upon the techniques of regional growth analysis. A surprisingly large number of forecasts in smaller studies are made on the basis of straightforward extrapolation of historical growth, or the combination of extrapolation of some fraction of the growth plus the use of multiplier analysis relying on fixed simple ratios. Projections of employment using 'economic base studies' [9,12] or labor force participation rates are two of the more popular forms of the latter technique. Proportional and differential shift techniques[8] are slightly more elaborate and take into account both national growth and estimates of the fraction of that growth which the city is likely to attract based on estimates of shifts in its competitive advantage.

Structural models for projecting growth in population based on highly disaggregated (by age, sex, and race) cohort analysis using disaggregated birth, death, and migration rates have been used in larger studies. These models are a significant improvement over simple multiplier techniques, but major uncertainties remain in the estimation of migration rates, and the effects on them of changing policies and conditions for relatively small areas like the city.[10] The more sophisticated projections of employment can be based on these detailed population projections using variable and time dependent labor force participation rates, on structural input-output models accounting for the existing composition of industry and the (assumed) fixed interaction coefficients between them, or on projections of regional income and expenditures which are converted into employment. For a more detailed review of all of these techniques, see Chapter II of the BASS report, Jobs, People, and Land,[16] Isard's work,[6] or Chapter 4 of Systems Simulation for Regional Analysis: An Application to River Basin Planning, (H.R. Hamilton, et al., MIT Press, Cambridge, 1969). Also, Meyer (Reference 10 in Section 1 of Appendix II) presents an excellent critical and comparative review of four theoretical foundations of regional economics; 1) location theory, 2) multiplier analysis, 3) input-output theory, and 4) mathematical optimization techniques.

The BASS report also contains a good description (p. 32) of the difficulties in making aggregate projections for small regions with a large export component of final demand. In essence, the demand attracted to the region is a function of the competitiveness of the production supplied there, while simultaneously, the production is dependent upon the success in attracting outside demand. All of the techniques described above are based on fixed projections of the demand attracted by the region. Ranges of projections are sometimes used which reflect uncertainty both in the national future and in the degree of coupling of the region to the nation. The approaches vary in their level of sophistication in unraveling the response of the urban system to a given final demand. However, they all fail to attempt to understand explicitly the consequences of future policies and conditions within the urban area on the coupling to the outside economy which stimulates that demand. For example, Swanson points out the need to include the dynamic interaction between migration and unemployment. The model in the Hamilton book above, the model by Swanson (Ref. # 10 in Section IV of the bibliography), and the model by Forrester

(Ref. # 7 in Section IV) are three important exceptions to this statement.

The general tendency of urban growth models to deal with demand at the exclusion of supply has been pointed out by Winger (Winger, Allan, "Supply Oriented Urban Economic Models" AIP Journal, January, 1969, pp. 30-35.) This characteristic of neglecting the constraints imposed by supply considerations is particularly important in modeling the expansion of housing. As will be discussed below, housing is an important determinant of residential location, but the constraints on changes in housing supply are usually completely neglected in urban growth models. In particular, the time lag in responding to demand, the influence of outside forces such as government policy and interest rates, and the difference in the response of different sectors of the housing market (particularly low income) to increases in demand are ignored almost without exception in the urban growth models to date. Of all the modeling efforts described in Section II of the bibliography, only the BASS study explicitly incorporates mechanisms for decrease and expansion of the housing supply. The San Francisco CRP model[53] does intensively study housing supply, but to the exclusion of all other aspects of urban development.

B. Models of Internal Shifts between Classes of a Given Activity

Considering the three major types of activity of interest in this thesis, i.e., population, housing, and industry, the modeling of internal shifts between classes of each of these activities is one of the most neglected areas of modeling of urban development. The transitions between different types of industry are nil and will be neglected in this work. However, the upgrading of population from low skill levels or incomes to higher ones, and the filtering of housing stock over time are fundamental processes in the city which have received far too little emphasis in models of urban growth.

The filtering processes between different types of housing are omitted because as was noted above, most of the models do not explicitly describe the housing supply in any form whatsoever. The San Francisco CRP model is an extremely detailed attempt to understand filtering in housing, and particularly the effects of different policies on the housing market. Forrester (Ref. # 7 in Section IV of Appendix I) incorporates an interesting formulation of filtering at a much coarser level of aggregation than the San Francisco effort. The BASS Residential Model has filtering between and demolition of 6 classes of housing supply, but the filtering is independent of demand.

Only one of the existing models explicitly accounts for the mechanisms which would shift a person from one income or skill class to another, but these mechanisms are implicit in the net 'birth', 'death', and 'migration' rates used in the cohort analysis for their aggregate projections. Although some of his mechanisms are questionable, Forrester's Urban Dynamics model alone has attempted to identify and incorporate the forces driving these shifts into an urban development model.

C. Location Models

The urban development models constructed to date have concentrated almost exclusively upon this aspect of urban growth. Using separate aggregate growth models for the forecasts of the magnitude of activities needed to be located in a given time period, they focus on the mechanisms which determine the physical distribution of that growth within the city.

The activities located usually include three classifications of employment -- manufacturing, retail, and other --

and one class of population. Often, there is further disaggregation within these categories. With the exception of the large simultaneous regression models, which allocate all new activities in a given time period simultaneously, the models usually have sub models for each of the main types of activity and locate them in the following sequence: manufacturing employment, population, and retail employment. Interactions between the distributions of activities may require the model to iterate at each step until a consistent set of distributions is obtained. The following is a brief review of the major approaches used in locating each of the following basic classes of activity - population, manufacturing employment, and retail employment. (This review draws heavily upon Harris' article - Ref. #4, Section I. See it for further discussion of these models and others not discussed here).

1. Allocation of Manufacturing Employment

The simplest allocation technique is to have a human being determine the location of new employment sources on the basis of site characteristics and industry requirements. All models have some "unique locators" types of industries which must be located in just this way. In some of the studies, the limitations of the models being used make this component a significant fraction of the total employment.

The requirements of an industry include labor force, intermediate goods, raw materials, markets, and land. Harris describes (Ref. #4 in Section I of Appendix I) how initially it was felt that transportation and site costs dominated these requirements so they could be simulated using a linear programming solution to minimize costs. For example, the Southeast Wisconsin Regional Planning Commission[21] uses a two stage model which first screens alternative sites to determine which should be input to the linear programming model in the second stage. However, the need to account for labor assembly costs, questions about the validity of the assumption of optimizing behavior on the part of management, and rapid shifts in production technology have limited the value of this approach. The Interim Industrial Allocation Model for the Baltimore Regional Planning Council[20] formulated the linear programming problem in a much more general manner which included the options of maximizing the "value" of the industries in the city, minimizing the development costs, or maximizing the industrial development impact. However, little information was given on how the values associated with these objective functions were to be estimated.

An alternative approach is to use regression analysis to calibrate the relative weights of the different site characteristics, and then use the resulting regression equations to calculate the relative attractiveness of the different zones. The results can be used in a number of ways. The attractiveness indices can then be used directly together with capacity constraints to distribute new growth (eg., the Puget Sound Model - Ref. #43 of Section II). Instead, the regression equations can be formulated to directly yield the shift in employment, eg., the EMPIRIC models (Ref. #28 of Section II) and Detroit TALUS model.[20] Or again, the attractiveness indices can be used to calculate the potential for migration between areas (LINTA submodel of the Delaware Valley Regional Planning Council).[22] The INdustrial IMPact (INIMP) model of the Pittsburg CRP[19] made an initial allocation of growth on the basis of existing employment, checked the resulting distribution against capacity and minimum size constraints, then made a final réallocation to areas in order of decreasing attractiveness, using a random draw among equals. (This model was formulated to deal with only a small fraction of the total employment, located primarily in the central city. It never became operational). The fixed coefficients of all of these regression models imply that they cannot deal with technological change which shifts location requirements. Some of their other problems will be discussed in the concluding paragraph below.

The manufacturing employment submodel[16] of the BASS study attempts to deal with some aspects of technological change by using time varying parameters for the land area required, the average size of the firm, and the accessibilities between different areas. The model first eliminates from consideration zones which are lacking key factors, then calculates the relative attractiveness of the remaining zones on the basis of a regression equation. Separate regression equations are used for each of 8 subgroups with the independent variables being 20 types of density, and 4 types of services. A "unit" of industry is then awarded to the zone with the highest attractiveness and its attractiveness revised. The process of allocation unit by unit followed by revision of the score is continued until all employment is allocated. Relocation was formulated by postulating that the relocation out of a given zone was proportional to its density.

Some of the more important problems facing the above models are: 1) the driving forces and time scales for relocation of industry, 2) technological changes, shifts in consumption, and other factors which make the location requirements variable over the time scale of the projection (usually 20 to 50 years), 3) the size limitations on the model which force the aggregation of industries over types and over sizes which mask differentials in location requirements, and 4) some form of prescreening of sites in a stage separate from the actual allocation seems to be mandatory. For elaboration on these points and models, see Rose,[20] Harris (Ref. #4 in Section I of Appendix I), and the BASS study.[16]

2. Retail Employment Location

The location model for retail employment must include two types of interaction. First, there is the interaction between the "store" and its potential market scattered over space. Gravity potential demand models[27, 29] with demand proportional to some measure of purchasing power in the zone and decaying as some power of the distance or travel time from the store to the zone are one way of describing interaction. However, models based on this form of aggregated ambient demand alone do not produce the degree of clustering and hierarchical structure of retail activities which is observed in practice. (They do produce some; see Harris,[27] p. 7.) These patterns, accentuated by the nonlinearity of attractiveness of size and the economies of scale of complementary activities, have been analyzed statistically by Rogers,[32] but in a formulation that is not directly useful for prediction because of the failure to reference either market demand or consumer behavior. An _ex post_ analysis including the effects of markets, minimum sizes, agglomeration tendencies, and stratification of markets has been carried out by Berry[23,24] but his formulation requires prespecification of non-overlapping market areas and thus is also not directly useful for _ex ante_ allocation. The combination of gravity potential demand models with minimum size constraints has been a common way of attempting to deal with both types of interaction.[25, 26, 29, 30]

All of these models are essentially equilibrium models, although some of them include constraints on the maximum amount of employment which can be shifted out of a zone within one period. The implicit assumption is that the lower investment in fixed plan and the extreme dependence upon demand makes retail activities much more responsive to shifts.

Some of the problems being faced in these models include the determination of behavioral parameters for travel behavior of customers, the economies of scale and minimum sizes as a function of specific type of trade, and the joint demand generated by complementary activities. It should be noted that retail employment accounts for a very small percentage of the total land use. Although it is a major destination for intra-urban trips, its exact importance in urban development is open to question, and it is possible that it has attracted an inordinate amount of attention and effort for many applications of urban development models.

3. Models of Residential Location

The simplest technique for distribution of households is to use estimates of the land available for residential use and average densities to calculate a "holding capacity". This capacity can be modified by estimates of the fraction which is likely to be used, and judgments on special factors such as local amenities, neighborhood prestige, work opportunities, etc. (See the Chicago Area Transportation Study

Final Report, Land Use Forecasts Vol. II, or Hamburg, J.R., and Creighton, R.L., "Predicting Chicago's Land Use Pattern" AIP Journal, May 1959, pp. 67-72.) However, such a discriptive technique cannot take into account in any systematic manner the influences of the location requirements of people for example jobs, housing, schools, access to services, etc., on the pattern of location.

Lowry's model (Ref. #38 Section II) for Pittsburg attempted to introduce the mutual interactions between population and employment by making residential location explicitly dependent upon an aggregate measure of the access to employment opportunities. One component of employment (retail trade and other population centered services) was then allocated on the basis of access to distributed population, and the allocations iterated until a consistent equilibrium distribution was obtained. Three of the basic shortcomings of this model were: 1) it distributed the total amount of each activity in the city at one point in time, thus was a static equilibrium model, 2) it did not account for the effects of available land (except through a capacity constraint), housing, and other site characteristics, and 3) it used a gross measure of access (airline distance between points) which could not reflect changes in the transportation system. The first two weaknesses have supposedly been removed in the later work by Putnam and Teplitz (Ref. #40 and 42 in Section II).

The Penn-Jersey Transportation Study (now the Delaware Valley Regional Planning Commission) was an attempt to significantly advance the state of the art of residential location models. Modifying the linear programming formulation of Herbert and Stevens,[44] this model attempted to incorporate explicitly 1) the trade offs between site characteristics and access to employment opportunities, and 2) the feedback between alternative transportation network designs and residential location.[41, 43] Although they were designed to predict the location of population and employment as inputs for travel demand models to be used to evaluate different transportation systems, none of the residential location models before P-J had the transportation system influencing location patterns. Because of technical difficulties and some of the conflicts generated by having a research program tied closely to a specific, operational program (See Chapter 4, Section A), this model was never completed within the Penn-Jersey Study itself. Work on it has continued at the University of Pennsylvannia and it is now being included in the Los Angeles models (Ref. #30 Section II). Some of the critiques of this formulation are: 1) the linear programming formulation optimizes the residential location pattern in the aggregate Pareto Optimal sense, rather than the individual decision units. There are major doubts whether the behavior is optimizing as opposed to satisfying (i.e., searching for something that meets a minimum criterion rather than for the best out of all possible choices), and whether an aggregate optimization adequately describes an optimizing process that occurs on the level of the individual locating unit. 2) There are major difficulties in measuring the values associated with different site characteristics and determining their stability over time and space.

The work at the University of North Carolina[35, 37] uses a stochastic model of the location decision in contrast to the optimizing, deterministic behavior above. An increment of residential development, disaggregated by cost and density of development, is allocated to the zones of an urban area on the basis of a probability calculated from access to work, streets, and schools, availability of sewers, etc. (The effect of these factors is modified by a time lag).

As Harris notes (Ref. #4 in Section II, p. 398):

> Despite their many interesting features and their insights into consumer and entrepreneural behavior, these efforts have not attempted to provide a model or group of models which could be used for long term projections and for complete market stimulation.

The problem of determing the relative weights of the different locational requirements of population has been attacked in a number of models by using econometric estimation. Using historical time series data (usually two or at most three points in time) the coefficients (a_i) of such factors (X_{ij}) as accessibility, density, services, etc., in the equation for the "attractiveness" of an area are estimated. The way that these attractiveness indices are used, i.e., the nature of the location mechanisms or processes implied, varies.

The TALUS model (#28 of Section II) allocates population directly from the weighted attraction functions, i.e.,

$$\Delta P_j = \sum_i a_i \quad X_{ij}$$

where

P_j = the population increment allocated to the j^{th} area in a given time interval

a_i = the weighting function of the i^{th} characteristic

X_{ij} = the value of the i^{th} characteristic in the j^{th} district, e.g., the population in the area with incomes over \$5000/yr.

(# 18 of Section II)

The Activities Allocation Model which was the final output of the Penn - Jersey study (by then the name had changed to the Delaware Valley Regional Planning Commission - DVRPC first allocates new growth in proportion to the existing distribution of population. Then it uses weights a_i to determine the attraction A_k of each area. The differences in attraction were used to calculate the outmigration between areas under the restriction that no migrations were negative, i.e., out migrations only occured to areas with a higher attraction.

$$\Delta P_k = \left[\sum_i (M_{ik} - M_{ki}) + b\ P_k \right] \Delta t \quad , \quad i \neq k$$

$$M_{ik} = P_k L_k (A_k - A_i) \qquad M_{ik} = 0$$

$$A_k = \sum_i a_i X_{ik}$$

where

M_{ik} = the outmigration from area i to area k

$b \& L_k$ = constants

A_k = the composite attraction of the area k

The REGRO model of Baltimore (#5 of Section II) allocated the increase in population proportionally to a composite attraction like the A_k above and the holding capacity of the area as determined by its density and land area.

$$\Delta P_k = \Delta P_t \frac{(A_k)^{1.35} HC_k}{\sum_i (A_i)^{1.35} HC_i}$$

where

ΔP_t = the total increase in population to be allocated

HC_k = the holding capacity of the area k

A_k = the composite attraction of the area k

The EMPIRIC model (Section II, #28) used a form similar to that of the ix REGRO model but without the holding capacity. The Puget Sound model (Section II, #43) also used a form similar to the REGRO model, but involving a logarithmic transform on the attraction function

$$\Delta P_k = \Delta P_t \left(\frac{l_k}{\sum_i l_j} \right)$$

$$l_k = \left(HC_k\right) \quad \left(GR_k\right)$$

$$\log GR_k = \sum_i a_i X_{ik}$$

where

HC_k = the holding capacity of the area k

GR_k = the ratio of the predicted growth of the area k_i to the potential growth of the area k^i.

The BASS residential location model[34] deals with the question of attractiveness of site characteristics and location by explicitly including the effects of factors such as land slope, access to employment, and housing supply. The model housing supply and demand determines the distribution of population by balancing the two. The housing supply sector includes construction, demolition and filtering of six classes of housing. The formulation of these processes is extremely simple because the model assumes 1) demolition rates independent of demand or external conditions, and 2) that the ratios of housing supplies in each of the three income classes remains constant. The combination of new aggregate growth of population and demolition of existing housing determines the total demand for new housing. The potential supply, or effective holding capacity of each zone is calculated on the basis of land supply, site characteristics (such as slope), and land absorption coefficients. The percentage of this potential supply actually developed in a zone is calculated as being proportional to the accessibility of that zone to existing and newly located employment.

Thus, the final allocation itself is independent of access to factors other than employment, and of site attractiveness based on amenities and services. As is pointed out in the BASS report (p. 265), the model fails to distinguish the difference in the pressure exerted by a household with a wide range of alternative locations, and one with a very restricted selection. Like many of the other models, BASS includes only one accessibility parameter for all activities and classes of population. As will be discussed in Chapter 7, (and has been mentioned in Chapter 3), the mobility of different income classes can be radically different. The following are some of the major problems and issues in modelling residential location: 1) the mechanisms determining location, e.g., optimizing vs. satisfying, and the scale at which they need to be modelled, e.g., individual vs. aggregate, are still unresolved issues. Bypassing this question by using econometric models which calculate shifts directly on the basis of regression equations calibrated with historical data is an inherently unsatisfactory solution to this problem. The fixed coefficients in such models cannot and will not reflect basic structural changes in the city, the influence of technology, and the influence of the changing pattern and composition of activities themselves on the causal forces underlying the constant coefficients. 2) The determination of the relative weights of different residential location requirements based on household preferences is in difficulty because of a lack of both data and theory. 3) The measures of accessibility and the degree of disaggregation, by both user characteristics and trip purposes, required in the location models, are still uncertain. 4) The role of time delays, e.g., in the perception of conditions influencing location, or in the mechanisms changing the housing supply, in dynamic location models is just beginning to be recognized.

4. Relocation and redistribution

The discussion above has concentrated on the location mechanisms in residential location models. However, the processes for redistribution and relocation of existing activities are equally, if not more, important in urban development and merit separate examination. The Activities Allocation Model (Ref. #18, Section II) included migration from zone to zone driven by differences in attractiveness as one of its primary mechanisms. The BASS model[34] had internal migration forced by demolition of housing, but contained no mechanisms for 'normal' moves. The TALUS residential location model[36] incorporated a matrix of probabilities of shifts from one zone to another. These probabilities were a function of the life cycle designation of the household, e.g., unmarried and less than 45 years old, married with no children, etc., but were not sensitive to the relative conditions in the two zones.

The theoretical understanding of the mechanisms driving relocation which is expressed by these formulations is very poor. Once the decision to relocate has been made, it should be possible to treat the relocating unit merely as another unit of 'new growth' and determine its destination using the location techniques discussed above. However, there is a strong need for the development of theory for the first stage of this process--under what conditions does a family decide to move? Some of the unanswered questions are: what factors is the family 'observing' over time, what are the critical values of these factors which stimulate migration, and what are the delays in the perception of these parameters, and between the decision to move and the actual move?

E. Summary: The Need for Dynamic Systems Models

The above review of existing models shows how previous work has tended to concentrate on individual pieces of the urban development and to be distributed rather unevenly among them. The processes of physical expansion of the city and of internal shifts between subclasses of housing, population and other activities have been particularly neglected. However, in addition to the need to strengthen the theory and models in these areas, there is a critical need to begin assembling these separate pieces together into a 'systems model' of urban development. Sections D and E of Chapter 4 have indicated in schematic form some of the major couplings or feedback loops that exist between the basic processes reviewed above. The following section will first discuss some of the specific interactions which create this feedback and need to be taken into account in such a systems model. Feedback mechanisms have often been included within a model of a given urban development process, especially within location models. However, several types of important feedback between the basic processes themselves have been sorely neglected. After the identification of some of these omitted loops, this section concludes with a brief discussion of the factors in urban development which require that urban growth be dynamic, and have non-equilibrium formulations.

1. Interactions Between Processes

In Figure 1 of Chapter 4, any closed continuous path from one process to another and then back represents a feedback loop. Such a loop implies that the causality is circular rather than linear (see Chapter 6), and that mutual interactions exist between the two processes. Although most of the examples discussed below have direct paths to and from the interacting processes, this by no means has to be true in general. Many of the more important loops in complex systems have paths which pass through several intermediate variables or processes, and the identification of all such loops can become quite involved.

a) Interaction between aggregate growth of population and conditions in the city - this loop is eliminated in any study which makes an exogenous forecast of growth in population and employment without adjusting that forecast on the basis of the conditions which would result if the growth actually occured. One of the basic types of interaction creating this loop was identified by Lowry. (Migration and Metropolitan Growth: Two Analytical Models, Chandler Publishing Co., San Francisco, 1966, pp. 78-9):

> The agenda of urban and regional research should give a high priority to the development of a better specified model of the dynamic interactions between migration and changes in employment--that is, to a model which specifically indicates the migration response to a change in employment opportunities, and also the change in employment opportunities resulting from a given quantity of in and out migration.

The Bay Area Simulation Study (BASS) also discusses this problem briefly (pp. 32-3):

> Serious question is raised as to the legitimacy of forecasting either the supply side or the demand side independently at the regional level. Consequently, the forecaster is forced toward the position that the ultimate solution to the regional forecasting problem lies in a structural model which will provide the necessary dynamic interaction between supply and demand.

Swanson's model (#10 in Section IV) is the only known attempt to construct such a model at the scale of an urban region.

b) Loop between spatially disaggregated housing supply and demand, and internal shifts in housing supply (between 1 and 6 in Figure 1)--this loop represents the effects of the distribution of housing demand upon the construction, demolition and filtering of the housing supply (filtering just means the shift in the same housing unit from one class to another, e.g. subdividing a three story single family home into apartments.). This loop is fundamental in any model concerned with the cycle of growth, stagnation, and deterioration of areas within the city. It should be noted that although the BASS model did have a housing supply model which included filtering and demolition, the filtering and demolition rates were independent of housing demand and thus the feedback loop was broken.

C) Loop between redistribution process and spatially disaggregated variables (between 5 and 2 in Figure 1)--this interaction was discussed in detail in the discussion of residential location models and will not be repeated here. The questions and issues in industrial relocation are very similar to the ones raised there, and the importance of this process in urban development will be elaborated in #2 below.

The following two loops deal with the role of expansion of land supply and can be neglected for short term models (5 to 10 year projections.) Even for longer term models, these interactions can be approximated to some extent by using increases in accessibility to a fixed land supply to effectively expand the land available.

d) Loop between physical growth and externally driven growth (between 4 and 7 in Figure 1)--this loop represents the basic constraint which land supply places on growth. If the land supply is fixed, then a finite upper bound is set on the magnitude of the activities the city can contain. The past one hundred years have seen a rapid expansion of the land supply available to any given city. The limit on population and employment size has been raised by at least an order of magnitude. What is the process by which this land has been (and will be) added and how sensitive is it to a "potential demand" for new growth?

e) Loop between physical growth of the city and redistribution (between 5 and 2 in Figure 1)--this interaction represents the pull of new land on activities which are already located in the city, particularly under the influence of technological change in production requirements or of shifts in tastes and preferences. In the opposite direction, this interaction also reflects the pressure which congestion exerts for expansion of the total land supply. This latter interaction is probably weak, but it needs to be investigated.

2. Need for Dynamic Non-Equilibrium Models

A basic assumption implicit in many aspects of the urban growth model constructed in this research is that a dynamic model which allows for non-equilibrium is required to model urban development. The combination of time lags in the response of the urban 'system' and time dependent external forces which strongly influence the city make a static equilibrium formulation unsatisfactory for most of the aspects of urban development.

The rapid rate of change of technology during the past two centuries has led to significant shifts in the forces governing urban growth and distribution on a time scale smaller than the readjustment time of the urban area. The readjustment of activities to achieve equilibrium with a new set of external forces can only occur as fast as the redistribution of housing and industry. The high financial and emotional investments in a given location, and the imperfect transmission of information on existing conditions and opportunities implies that this readjustment process has minimum thresholds of discrepancies needed to initiate it and further time lags in responding once activated. These same characteristics of information distortion and finite response time, e.g. the time needed for construction or training, lead to lags in the adjustment of housing supply to demand, and of the labor force to demand, which are also important in determining dynamic behavior. However, the fundamental role of the redistribution process in adjusting the distribution of activities in the city in response to strong external driving forces makes the time lags in redistribution a basic parameter of the dynamic behavior of the city, and the prime source of the non-equilibrium nature of its growth.

The relatively long time scale of the changes in urban structure and the difficulties in defining and isolating the interactions involved has often led to a simple analysis of the city using fixed interrelations and constant trends. For short term projections involving limited policy changes, such an approximation is acceptable, but in general the projection of the future state of the city and the design of programs and policies to influence that future demand a better understanding of its internal processes. Projections covering either long (greater than ten years) time spans or involving analysis of policy changes which shift the internal structure of the city require an understanding of how that structure is expected to evolve and how policies may interact with other parts of the structure.

The net conclusion of this review is that in effect no model of urban development exists today. Significant work has been done on the development of the theory and models of individual aspects of urban development. Aggregate growth models are beginning to give us some insight into the processes and forces driving regional growth on an urban scale. Location models are attempting to predict the fine scale distribution of this growth for inputs to transportation models. Some isolated models are attempting to deal with internal shifts within housing supply and the labor market. We have the beginnings of some stochastic models for exploring the process of urban expansion at the fringes of the city. Yet all of these are models of separate aspects of and processes within urban development, not urban development itself. Because of the interactions between these separate processes, their cumulative results acting together are much more than a simple linear combination of their results one at a time or sequentially.

A system model is needed which assembles the existing pieces within a single framework, and then experiments with the dynamic interactions among them. Previously, such an effort would have been impossible because of our lack of understanding of the individual processes themselves. Even today, gaping holes exist in this understanding of some of the processes, but enough has been accomplished in working with the processes one at a time that a beginning can be made in trying to combine them. The model presented in Chapter 7 is an attempt to begin the assembly of such a system model.

Footnotes, Chapter 5

(The footnotes to Chapter 5 refer to the works listed in Appendix II. The references are to Section III unless specified otherwise.)

Chapter 6

FORMULATION OF COMPLEX DYNAMIC MODELS: FORRESTER'S APPROACH COMPARED TO MORE FORMAL MODELING TECHNIQUES

The question of how to specify the structure of a model and estimate its parameters is one of the fundamental issues in modeling. The model constructed in this research has been formulated in the DYNAMO language developed by Forrester[1] and Pugh[2]. Many of the models previously formulated in this language have stimulated controversy in both management science[3] and urban studies[4] because of 1) the failure to 'formalize the processes' used to specify the structure and parameters of the model, 2) the unusual and tenuous nature of some of the variables, and 3) the failure to validate the models with any well defined technique. Forrester's 'intuitive' techniques drawing upon interviews with individuals having a working knowledge of the system have been contrasted with 'rigorous' estimation and validation procedures, e.g., of econometrics.

This chapter will develop a point which should be obvious, but which seems to have escaped in the furor over specific models and, sometimes, personalities. The difficulties in specifying the interactions of a model and of estimating the parameters of its structure come from basic problems in establishing causal relations and from the mathematical representation of the system, not from the particular language used to formulate that representation. Different languages can be appropriate for formulating different types of mathematical representations of a system. The DYNAMO language was designed to readily formulate sets of lagged variable equations in which time delays and feedback between variables are important determinants of the behavior of the system. However, these lagged variable representations of systems can also be expressed in languages amenable to econometric analysis (e.g., the SCROLL language of Kuh)[5]. Such dynamic econometric formulations have been arousing increasing interest in the econometric literature. This chapter will attempt to begin the process of linking these two approaches to formulating and testing models of dynamic systems.

Sharp differences have existed in the actual utilization of these two approaches in the past, particularly in the types of validation criteria emphasized. Yet neither of them have established an indisputable advantage in representing dynamic social systems for which the stringent tests of controlled experiments are not available. Both approaches should and must draw upon the strengths and experiences of the other--from econometrics, the ability to extract limited information on structure and parameters from statistical information; from DYNAMO, an emphasis on the dynamics of the behavior of the system and the implications of uncertainties in parameters and structure on that behavior rather than a slavish devotion to reproduction of data to .1%.

As was noted before, both the lagged variable econometric models and the DYNAMO models are alternative formulations of the same class of mathematical representation of real world processes. Each approach has its own characteristic strengths and weaknesses, but those strengths and weaknesses are complementary rather than clashing. Improving the current poverty of dynamic representations of social and economic systems vital to our society will require a synthesis of those strengths.

Section A and B of this chapter discuss the general form of dynamic models of urban development like that constructed here, the notation and symbols standard with DYNAMO, and the assumptions implicit in any model constructed in DYNAMO. Section C presents a simple econometric model of urban growth which has been converted into DYNAMO in order to facilitate the comparison of the two modeling approaches. Section D and E treat the problems of model specification and validation respectively. The model developed in this research is characterized as 'causal' and the first part of Section E attempts to shed some light on the interpretation of that elusive term in this work.

A. The General Characteristics of the Model

1. Dynamic as Opposed to Static

The formulation of the urban development model constructed in this research is equivalent to a set of first order finite difference equations.

1) $\Delta y_i = f_i \ (y_i, .., y_m, z_j, .., z_n) . \Delta t \quad i=1....m$

$j=1....n$

where y_i = i^{th} endogenous variable, i.e., a variable determined by the model

z_i = i^{th} exogenous variable, i.e., one specified outside the model

$\Delta y_i = y_i \ (t + \Delta t) - y_i(t)$

In the model the difference equations have been written as lagged variables.

2) $y_i \ (t + \Delta t) = y_i \ (t) + f_i \ (t) . \Delta t \quad i=1....M$

The only general restrictions assumed about the form of the equations are that 1) they must be first order in time and 2) a difference must not be explicitly a function of any other difference, i.e., the f_i's above must not contain Δy_i as an argument. The consequences of these two restrictions will be discusses below in Section B. One of them is that the variables y_i completely specify the state of the system being modeled hence they will be called state variables.

This difference formulation implies that the variables are expected to be time dependent so the model will be dynamic rather than static. The model may have a static or 'rest' state in which all variables are constant in time[6], but one of the chief interests of the analysis is the behavior of the system in approaching this rest state. Even if the rest state (corresponding to a perfect balance between the "forces" in the model) exists in principle, the system can be strongly damped so that it only approaches the rest state asymtopically during the time period of interest. Alternatively, the system can be unstable and have an oscillatory behavior which passes through the rest state, but never achieves equilibrium there.

A second main interest of the analysis will be the equilibrium or steady state behavior of the system and the conditions necessary to reach that equilibrium. A particular concern is the 'market mechanisms' which govern the balance between supply and demand of activities such as labor force (controlled by migration) or housing (controlled by new construction and filtering). Imperfections in these mechanisms can lead to either an oscillatory behavior as the system hunts for a rest state or to an undesirable rest state. Understanding both the nature of these market imperfections, and the nature of the interaction of the market mechanisms in general with the time dependent external driving forces acting on the city are important keys to understanding the behavior of the city.

2. Simulation as opposed to closed form solution

Closed form solutions exist for many simple sets of finite difference equations[7], but not for systems of the complexity of the model developed here. The complexity arises from the number of variables involved in the system, the 'feedback' between these variables, the non-linearities in some of the coefficients, and the irregular behavior of the outside driving forces acting on the city. In particular, the model developed here emphasizes the role of feedback between variables in growth and development of the city. (Exactly what is meant by feedback and some ways of determining whether it exists are presented in the following two sections.) The lack of any analytic solution implies that the behavior of the system over time must be calculated using step by step integration of the difference equations. Under the restrictions imposed in DYNAMO on the rate equations this integration procedure is quite straightforward. The condition that no difference or rate of change be dependent upon another rate implies that the set of different equations is recursive, i.e., no simultaneities must be solved. Thus, given the values at the beginning of the run, the rates of change (the f's in equation 1) of the m state variables can be calculated. Assuming that these rates are constant over the time interval Δt the change in the state variables can be calculated and added to original values to give the new values of the variables at $t + \Delta t$. The new values of the variables are used to calculate the new rates of change, the new rates of change are used to calculate the next change in the variables, and the process is repeated until the time specified as the end of the simulation is reached. (For the details of the operation of the simulation, e.g., the determination of the proper time interval, Δt, between calculations, see Appendix 3.)

It should be emphasized that the model has been formulated in DYNAMO solely because that language offered a set of packaged functions (especially the excellent model debugging routines) which were useful and with which the author was familiar. Any of a number of standard programming languages (e.g., Fortran)[8] or simulation packages (e.g. SCROLL)[9] is just as capable of representing the same set of finite difference equations and integrating them over a specified time period.

B. <u>The Implications of Formulating the Model in DYNAMO</u>

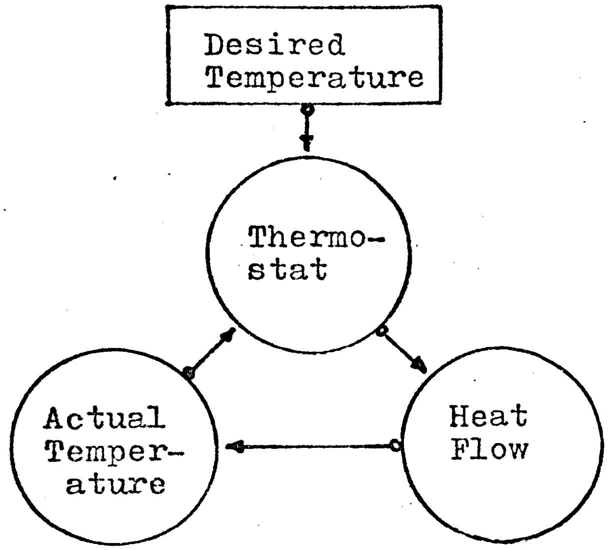
1. Notation - the representation of a simple feedback loop

The DYNAMO language was developed for the formulation of models of systems in which feedback between variables played an important role. Figure 1 presents a simple system with one feedback loop, two schematic illustrations of the system, and four alternative formulations of the quantities involved. The second schematic contains much more information and defines the state variables y_i (levels in Forrester's terminology) represented by rectangular boxes. The elements of the functions, f_i, controlling the rate of change of the state variables are represented by the boxes with 'valves' on the end. The exogenous variables are represented by quantities written above a solid line with no box around them. The underlined name in each box is the symbol used to represent that quantity in the model, and the number in parentheses is the number of the equation which defines the variable in the model. For example, the state variable of the system is the temperature in the room, T, and is defined by equation 4.1 in the list at the bottom of the figure. (The letters after the decimal point in the names of variables in DYNAMO equations is the equivalent of a time subscript. (See footnotes 1 or 2)

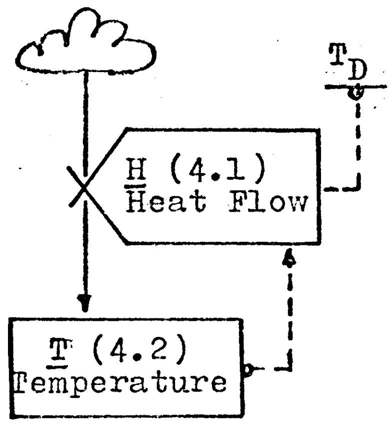
A dotted line implies an information transfer, and the arrow indicates the direction of transfer, e.g., the information about existing temperature is transferred to the rate variable controlling the heat flow in order to determine the heat input to the room. A solid line indicates an actual flow, e.g., the flow of heat from outside the system (represented by the 'cloud') into the room to changes in temperature. Any time that a closed path can be drawn following the directions of information transfers and flows from one state variable out to rates and other state variables and back to the initial state variable, a feedback loop exists. The feedback loop implies that the forces present in the system are circular and represent a 'chicken and egg' situation rather than simple one way influence. In other words, the temperature in the room produces a heat flow which produces a change in temperature which produces a change in the heat flow.

The behavior of the system in Figure 1 for the case of the heat flow being a linear function of the temperature with negative slope is shown in Figure 2. If the temperature is displaced from the desired temperature T_d, the temperature will exponentially approach T_d. For other types of 'policies' or control functions (the variation of heat flow with temperature) the behavior of the simple system would be different. If the structure of the system were modified by introducing a second state variable, e.g., the temperature in an adjacent room, and a time dependent external input were included for example, a schedule of the temperature shifts due to opening and closing of doors, the possible behavior of the system is greatly complicated. The temperature can now oscillate and the system has natural frequencies which, if matched by the frequency of the external driving forces, can lead to explosive instabilities. Once some criteria for 'optimum' behavior were established, the model could be used to design a system structure or heater control policy which optimized the performance of the system.

a) Schematics



1. Interactions



2. Rates and Levels

b) Alternative Formulations

1. Differential Equation

$$\frac{dT}{dt} = \alpha H$$

$$H = b(T_D - T)$$

2. Integral Equation

$$T = \int_0^t \alpha H(t)\, dT$$

$$H = b(T_D - T)$$

3. Difference Equation

$$T_{t+1} = T_t \; \Delta t \cdot \alpha H_t$$

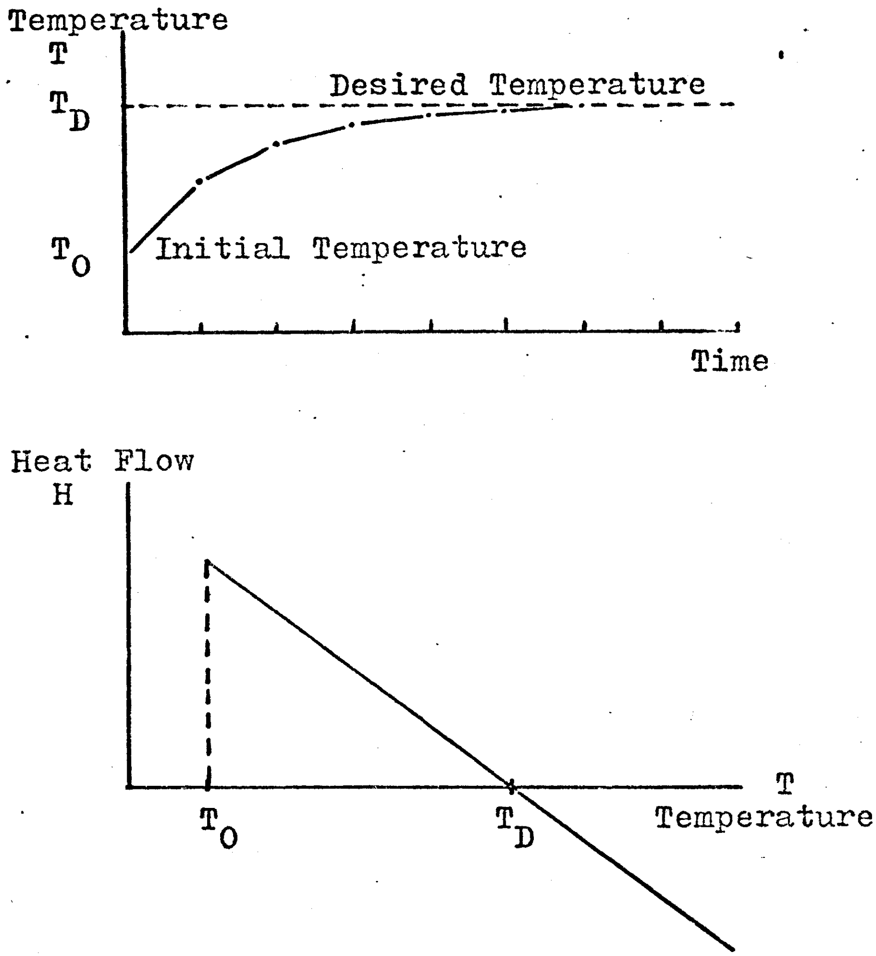
$$H_t = b(T_b - T_t)$$

4. Dynamo

4.1 T.K = T.J + (DT)(αH.JK)

4.2 H.KL= b * (TD-T.K)

Fig. 1 Equivalent Formulations of a Simple Feedback Loop



T_O= Initial Temperature
T_D= Desired Temperature

Fig. 2 Behavior of the Simple Negative Feedback Loop Shown in Fig. 1.

The discussion of the dynamics of urban development models incorporating feedback will be foregone until the analysis of the model developed in this research. For an introduction to the behavior of simple feedback systems see Blalock[10] or Forrester[11]. For a discussion of some of the feedback loops which occur in social systems see Buckley[12], Deutsch[13], Simon[14], or Bruner and Brewer[15].

2. Restrictions on model structure imposed by DYNAMO

As mentioned in Section A, the formulation of the model in DYNAMO imposes the restrictions of first, the equations being first order in time and second, the difference functions (rate equations) not being a function of other differences (rates) in the same time period. The effects of these two restrictions are discussed in the following paragraphs.

a. Restriction to first differences --

The restriction to first differences is equivalent to saying that the equations for the changes in the state variables between time t and $t + \Delta t$ depend only upon the values of the state variables at time t. Systems with higher order differences require explicit information on the state variables at $t - \Delta t$, $t - 2 \Delta t$, . . . $t - n \Delta t$ where n is the order of the highest difference. Since the values of the state variables at time t are an accumulation of the changes over the total history of the simulation, the state of the system at previous time periods does influence the behavior of even the first difference equations, but the influence is implicit rather than explicit. (Note that the order of the system of N first order equations is N.)

The time 'delays' referred to frequently in DYNAMO models should not be confused with the time lags associated with lagged variable formulations. The time delays are system parameters whose values can be extremely important in determining the dynamic response, e.g., the natural frequencies, of the model, but they are a particular type of coefficient in the model structure. As should be clear from comparing equations 3 and 4 in Figure 1, the time period between variables in the lagged variable formulation is the interval spacing 'DT' in DYNAMO.

The final class of time lag in DYNAMO models is introduced by exponential time averaging or smoothing functions. These functions are equivalent to a distributed lag with weights which decline geometrically back through time, with the general form of the weight being $\frac{(1-1/T)^{n-1}}{T}$, where T is the time constant of the smoothing function.[1b]

$$\tilde{X} = \frac{1}{T} \quad X_1+(1 - 1/T)X_2 +(1-1/T)^2X_3 +\ldots+(1-1/T)^nX_{n+1}$$

where

$\tilde{X}$ = the time averaged value of the variable X

For this distribution of weights, all the information about the lagged variables needed to update the average to time $t + \Delta t$ is contained in the value of the average at time t. Thus, this form of distributed lag can be represented as a first difference equation and the general restriction of DYNAMO equations to first differences still holds.

b. Restriction that the value of no rate at time t be an explicit function of another rate[17].

This restriction and the definition of a static variable imply that only level variables are state variables of the system. Combined with the restriction to first difference equations, this implies that the state of the system is completely specified at any point in time by the values of the level variables at that point in time. No information on prior history is required and the future behavior is independent of the behavior by which the system reached the present state. In other words, if a system initially had two radically different patterns of behavior, but eventually both patterns reached the same state, the behavior after reaching that state would be identical. (The only exceptions are 1) when the external driving forces are different and 2) if the system has stochastic inputs. See note 32.

The second consequence of the restriction on the form of the rate variables is that when combined with the differencing scheme it implies that the system of equations has no simultaneities, i.e., the equations are recursive and the simulation will never have to solve a system of equations to find a consistent solution. When dealing with static models, this recursive formulation implies one way causation and no feedback relationships or reciprocal causation between two or more variables is present[18]. However, when dealing with dynamic formulations this is no longer true. In general, systems of differential equations are recursive with respect to differential time intervals independent of whether or not feedback is present[19]. The existence of feedback can only be determined by tracing the links between the state variables through the rates of change. The schematic diagram of rates and levels illustrated in Figure 1 provides an excellent tool for doing just that.

The exclusion of simultaneity from the equations is convenient because it simplifies computation of the rates, but it also has a more fundamental significance. A simultaneity implies a set of variables which mutually determines one another in a 'causal circle.'

> To accept a causal circle is, in the laboratory meaning of the word 'cause,' to suppose that the value of one variable is determined by the value of another variable whose value cannot be determined until that of the first has been determined.

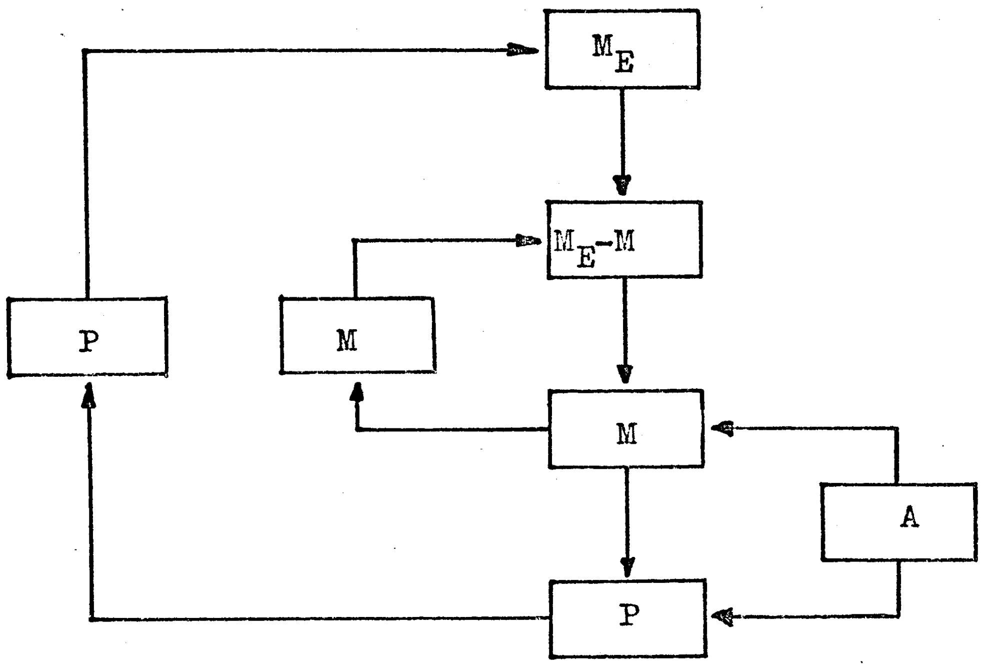
> To assume that the values of the two variables determine each other makes sense only in an equilibrium system, and such a system provides no explanation of how the equilibrium comes about (of change or of causal connection among the endogenous variables of the system).[20]

The equilibrium process implied by a simultaneity in the equations should be explicitly represented in a dynamic model rather than treating it implicitly through a solution scheme. However, it should be noted that the condition that no rate be a function of another rate is much more restrictive than the requirement of no simultaneities in the equations.

C. The Formulation of a Simple Econometric Model in DYNAMO

In order to provide an example of some of the points to be made in Sections D and E, this section presents a simple model in two alternative forms - the original econometric model of SMSA growth developed by Niedercorn and Kain[21], and the diagrams and equations of the equivalent DYNAMO formulation. Figure 3 gives the flow diagram and equations as developed by Niedercorn and Kain. The first parameter (α_{11}) of the model was estimated from the mean proportion of manufacturing employment to total population in 39 SMSA's in 1954. The other parameters (alpha's) were estimated by least square regression analysis of each equation using data on population and employment changes in 39 SMSA's between 1954 and 1958.

a) Schematic



b) Equations

1. $M_E = \alpha_{11}P$

2. $M = \alpha_{21}(M_E - M) + \alpha_{22}A + \alpha_{23}$

3. $P = \alpha_{31}P\left(\frac{M}{M} + \alpha_{32}A + \alpha_{33}\right)$

Where α_{ij} = Parameters of Model
M = SMSA Manufacturing Employment
M_E = Equilibrium SMSA Manufacturing Employment

ΔM = Change in M
P = SMSA Population
ΔP = Change in P
A = An Exogenous Input Reflecting the Persistence of Growth, Taken as Number of Decades Since City Reached 50% of its 1950 Population

Fig. 3 Niedercorn and Kain's Econometric Formulation of a Model of Urban Growth

The model as originally formulated calculated only one change in population and employment. Given the initial values of population, P, and employment, M, the increments in P amd M over the specified time period were calculated from the three equations and the simulation terminated. In principle, there is no reason why these increments could not have been added to the original values of P and M which would be used to calculate the increments during the next time period, these added to the modified P and M, etc., and the run continued for as long as desired.

Figure 4 is the schematic diagram of the equivalent DYNAMO formulation of the Niedercorn and Kain model and Figure 5 gives the equations and variables definitions for the DYNAMO model. Figure 6 gives the equations for the variables and constants of the DYNAMO model in terms of the variables and parameters of the econometric mode.

What changes have resulted from the conversion? All that has occured is a translation of the same set of equations from one language to another, so in reality there is no significant difference. The number of equations has increased from 3 to 9, but this is due to more explicit definitions rather than from any additional complexity of the structure. All of the parameters of the model are now identified in terms representing 'real world' processes,

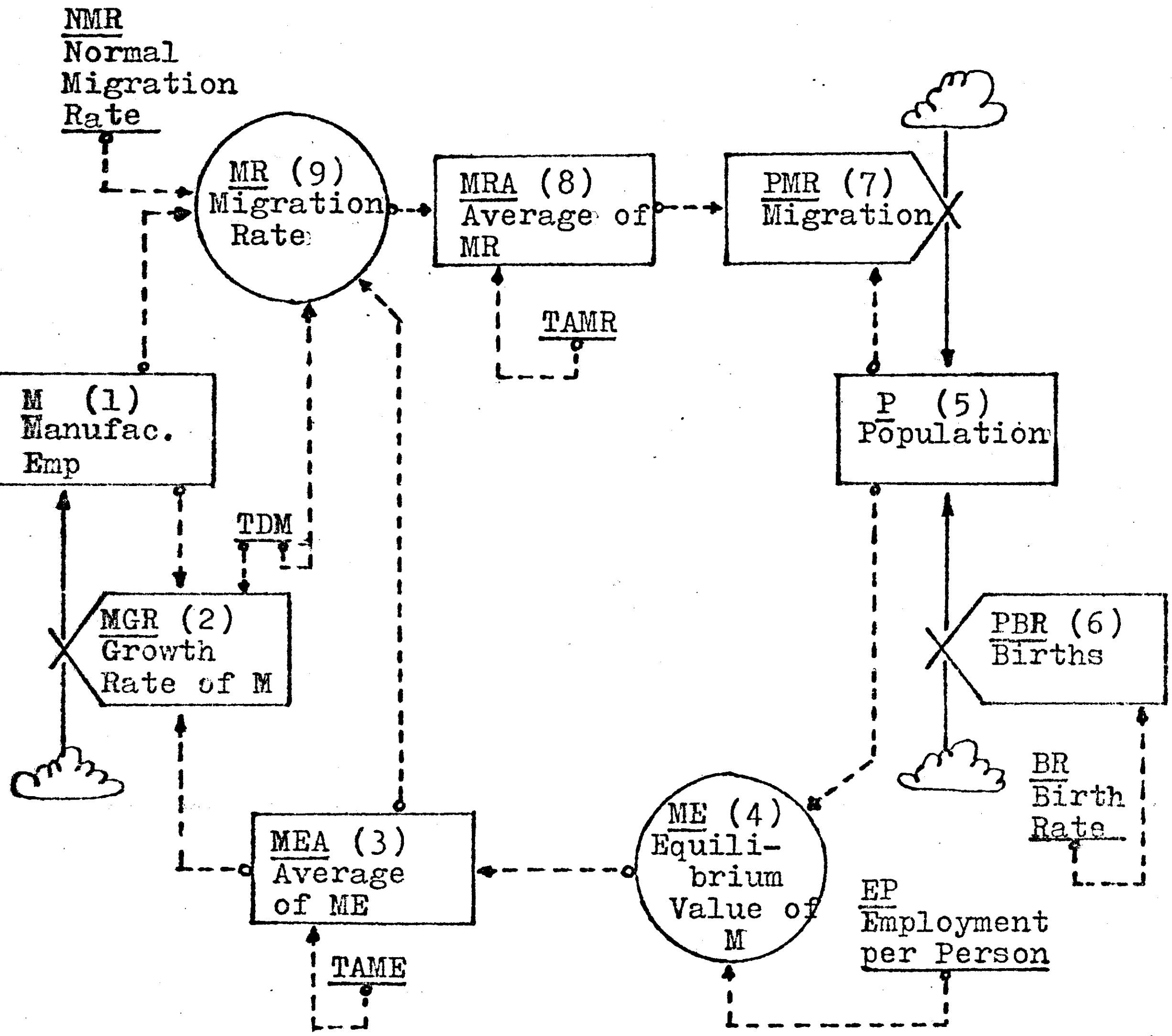


Fig. 4 Schematic of DYNAMO Formulation of Neidercorn and Kain's Urban Growth Model

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(Note: a* implies multiplication)

```
1L    M.k=M.j + DT * MGR.jk
2R    MGR.kl=(MEA.k-M.k)/TDM
3L    MEA.k=MEA.j + (ME.j-MEA.j)/TAME
4A    ME.k = EP *  P.k
5L    P.k = P.j + DT * (PMR.jk + PBR.jk)
6R    PBR.kl = P.k * BR
7R    PMR.kl = P.k * MRA.k
8L    MRA.k = MRA.j + DT * (MR.j-MRA.j)/TAMR
9A    MR.k = ((MEA.k/M.k) - 1.0) * NMR/TDM
```

where

M = SMSA manufacturing employment
MGR = growth rate of M
TDM = time delay in expansion of M to its equilibrium value
ME = equilibrium value of SMSA manufacturing employment
MEA = time averaged value of ME
TAME = time constant used in averaging ME to obtain MEA
EP = the manufacturing employment per person in the SMSA at equilibrium
P = SMSA population
PBR = population growth rate due to natural births
BR = birth rate of the population
PMR = population growth due to migration from outside the SMSA
MR = net migration rate of population as determined by employment growth
MRA = time average value of MR
TAMR = time constant used in averaging MR to obtain MRA

Figure 5 DYNAMO Formulation of the Neidercorn and Kain Growth Model

$M = M$
$MGR = \Delta M$
$ME = M_e$
$MEA = M_e \frac{\alpha_{22}}{\alpha_{21}} A + \frac{\alpha_{22}}{\alpha_{21}}$
$TDM = 1/\alpha_{21}$
$EP = \alpha_{11}$
$P = P$
$PBR + PMR = \Delta P$
$BR = (\alpha_{31})(\alpha_{33})$
$MRA = \alpha_{31}\frac{\Delta M}{M} + \alpha_{31} \times \alpha_{32} \times A$
$MR = \alpha_{31} \frac{\Delta M}{M}$

The two time constants, TAME and TAMR, used for averaging the equilibrium employment (ME) and the migration rate (MR) replace the 'aging variable' A and its two regression coefficients in the original econometric model, but do not have a formal algebraic equivalent.

Fig. 6 Equations for Converting the DYNAMO Formulation of the Niedercorn and Kain Growth Model Back into the Original Econometric Formulation.

e.g., the constant α_{11} is the manufacturing employment per person in the SMSA, the product $\alpha_{31} \cdot \alpha_{33}$ is the birth rate of population or α_{21} is the inverse of the time delay in adjustment of employment to its desired value. For the most part, this change simply eases the interpretation of the results and reflects the parameter estimation 'techniques' often used in DYNAMO formulations. It cannot be considered a significant difference between the two formulations.

The DYNAMO formulation has modeled the 'persistence' of urban growth rates as a time averaging of the equilibrium manufacturing employment ME and of the migration rate MR. In contrast, Niedercorn and Kain modeled it by including the independent variable A, "the number of decades since the city reached one-half its 1950 population"[22]. However, as was noted above, the time averaging function in DYNAMO is equivalent to a distributed lag with a set of coefficients determined by the averaging constant. The mechanics of actually including such a distributed lag were facilitated by the DYNAMO language, but there is nothing to prevent the formulation of persistence in growth in terms of lagged variables in the econometric version of the model.

D. The Specification and Estimation of the Model

1. The first step in constructing a model is the selection of the exogenous and endogenous variables to be included on the basis of the particular problem being studied

and some theory to the probable causes of the behavior which underlies the problem. Given this set of variables, the next step is to construct a model structure, i.e., to specify which variables enter each of the equations for the endogenous variables of the model. Once the structure is established, various techniques can be used to estimate the coefficients in each equation from data on the system under study. The initial structure can be modified by eliminating variables from equations in which their coefficients are insignificant, so the estimation of parameters can interact with the specification of structure. However for purposes of discussion the two processes will be separated.

1. Specification

The specification of the structure of the model requires statements about the theory of the interactions between the variables being studied. The alternative of making no a priori assumptions, e.g., simply stating that each variable is a function of every other variable, and letting the data and estimation procedures determine which variables are 'unimportant' (e.g., if they have statistically insignificant coefficients) is excluded because of the identification problem. When dealing with a system of simultaneous equations being estimated at the same time,

> ...the nature of the model to be estimated itself implies that the parameters of a given equation cannot be logically inferred on the basis of empirical data alone. Structural estimation is impossible without the use of a priori information...either from economic theory or from the results of other studies of different types of data... One literally cannot hope to know the parameters of the equation in question on the basis of empirical observations alone, no matter how extensive and complete these observations may be. Observational information cannot identify the equation to be estimated - cannot distinguish it from a host of other possibilities each as capable of generating the observed data as the true one.[23]

As has been discussed previously, lagged variables can be used to convert the simultaneous equations into a set of recursive equations which eliminates the identification problem. However, this introduces equally touchy problems, e.g., of autocorrelation in the estimation procedures.[24]

One technique useful for helping to specify the structure of systems of linear equations is path analysis.[25] This technique establishes tests on combinations of partial correlation coefficients which must be satisfied if certain types of structure exist between the variables. However, like all other techniques, it still cannot specify the structure uniquely. There are always at least two structures which will satisfy the same set of conditions on the coefficients.

In summary, it should be clear that the specification of the structure of the model requires a priori assumptions based on a theory, and this theory is the foundation of the model. This is truly independent of the procedures used for estimating the coefficients of the structure or for testing the validity of the model.[26]

2. Estimation

Once the model structure has been specified, the problem remains of estimating the parameters of that structure. One approach, that used by Niedercorn and Kain in the example in Section C, is to use historical data on the variables of the model to estimate the parameters by econometric methods.[27] These estimates have the happy qualities of being aesthetically pleasing because of their mathematical foundations and reproducibility. Unfortunately, for the dynamic models of urban growth of interest here, this method requires data that is often not available or encounters difficulties in satisfying the assumptions on the nature of the 'errors' or disturbances in the data.

A second approach is to rely on well established statistical information to estimate parameters which have an obvious 'real world' interpretation, e.g., the ratio of manufacturing employment to population which was estimated by Niedercorn and Kain independent of the econometric techniques. Birth rates, migration rates, land use densities, etc., are just a few examples of parameters which can be calculated in this way. Note that each determination of a parameter in this way is equivalent to an a priori restriction on the model and is one approach to satisfying the identification problem.

A final approach is to utilize information which is intuitive, in the sense that it has not been quantified, measured, and recorded, rather than statistical in form. The importance of judgement in evaluating and interpreting such information makes it highly controversial, but the state of both data and theory in social sciences today requires its use. Forrester has been a major source of controversy both in management science and more recently in urban studies because of his frequent use of this type of information.

> In the design and justification of a model, we need to call upon the full variety of knowledge that is available about the system. Most of our knowledge is in the experiences and the minds of people who have observed and worked with the system. Much information is in the descriptive literature. Only occasionally will there be numerical and statistical evidence sufficient to settle important model building questions.[23]

Although informal information sources are often used in DYNAMO models, the method of estimating the parameters which appear in the model is completely independent of the use of that language. Any of the approaches to estimating coefficients, including formal econometric estimation, can and have been used to specify the parameters of DYNAMO models.[29] Conversely, econometric model builders have also recognized the need to include concepts on which direct statistical information is lacking. The following statement is by Blalock, one of the most respected voices among the builders of causal models:

> We would suggest that if a larger number of explicit attempts were made to use multivariate causal models, even where not all the variables are as yet measurable, we might be in a position to take advantage of those mathematical and logical techniques that are being used so effectively in a field such as economics. In doing so we might be able to advance beyond common sense, while at the same time clarifying our basic concepts and developing a body of specific propositions relating to those variables in the complex manner in which they appear to be related in real life situations.[30]

3. The Procedures Used in This Work

The structure of the urban development model to be discussed in Part III was specified primarily on the basis of existing theories of urban population and industrial growth, industrial and residential location, and expansion and filtering of the housing supply. The variables influencing each of these processes are standard in the sense that most of them have appeared frequently in descriptive discussions, even if many of them have not been explicitly formulated in an operational model. The model to be presented here, like any other model, has its foundations on an a priori set of assumptions about the structure of the model which can only be made with these theories. The nature of the theory underlying the formulation, and how it relates to previous formulations is discussed in Chapters 7 and 8.

The parameters of the interactions in the model were estimated in a number of ways. No new econometric analyses were carried out, but the results of Lowry's econometric analysis of influences on population migration to urban areas and Niedercorn's and Hearle's study of land use and marginal land absorption coefficients were incorporated. For the most part, the constant coefficients and the time dependent exogenous variables of the model have been determined from outside studies and reliable data. The major exception is the time constants of the various delays and averaging processes (distribution lags) of the model. These time constants and most of the nonlinear coefficients expressed as table functions in the model have been estimated by doing just that - estimating them by "reasonable" assumptions based on a feeling for the process rather than on hard factual information. For example, all of the 'attraction functions' defining the influence of such factors as housing availability, job supply, racial composition, etc., on residential location were estimated this way. In all cases the general shape of the non-linear curves being estimated was clear. The main question was about scale factors, e.g., the attractiveness of an area will decline as the housing shortage in it increases, but how fast does it decrease and at what point does the decline 'saturate.' In other words, at what point are conditions so bad that getting worse does not really make a difference? The resolution of these questions for each of the parameters where they arose will be discussed in the description of the model in Chapter 7. The issue of trying to prove that both the formal estimates and these informal sources of information for the parameters of the model have resulted in an adequate formulation of the 'true' processes is treated in the next section.

E. The Issues of Causality and Validation

The issues of causality and validation are closely coupled with the criteria appropriate for validation. If the model is intended to be descriptive rather than causal (the distinction is discussed below), then its validity can be established relatively simply through statistical criteria such as the percent of the variance of the data accounted for by the model. If the model is causal, these same statistical tests are no longer sufficient and, as will be described below, can even be misleading. Before pursuing the differences between the validation of causal and descriptive models, a digression on the differences between those two types of models is required.

1. Causal vs. descriptive models

Modeling in the social sciences has long been plagued by the debate over causality. Blalock's discussion of Bunge[31] gives some insight into what is implied by a causal relation

> According to Bunge, one of the essential ingredients in the scientist's conception of cause is the idea of 'producing,' a notion that seems basically similar to that of forcing. If X is a cause of Y, we have in mind that a change in X produces a change in Y and not merely that a change in X is followed by or associated with a change in Y. Thus although the idea of constant conjunction may be made a part of one's definition of causality, conjunction is not sufficient to distinguish a causal relationship from other types of associations. For example, day is always followed by night, and childhood by adolescence, but we do not think of the first phenomena in each pair as a cause of the second. The idea of production or forcing is absent; days do not produce nights.[32]

Blalock accepts the objections raised to the concept of causality. One being that simple cause and effect relations are too simple to describe reality and are "much more a property of the observer than of the real world itself."[23] Another being that causal relations can never be tested empirically in the strictest sense of the word because "Clearly, a causal relationship between two variables cannot be evaluated empirically unless we make certain simplifying assumptions about other variables (e.g., no environmental forcings or postulated properties operating in unknown ways)."[34]

Yet even with these philosophical caveats he maintains that it is still useful to think in causal terms when trying to understand and model processes in the real world.

In contrast, 'descriptive' models establish statistical correlations between variables which have been found to fluctuate together,[35] for example the correlation between the number of firemen at a fire and the damage caused by the fire or between the height of hemlines of women's skirts and the Dow-Jones industrial average. In some cases high correlations between variables can reflect causality in the sense defined above, but often the correlation only indicates the presence of an intervening variable which is actually causing the behavior of interest. The essential difference between causal and descriptive models is the concern of the former in identifying the intervening variables which may be behind the correlations established in the latter. The level to which the intervening variables have to be pursued depends upon the applications and purpose of the model. A causal formulation of the forces acting on a mass connected to a spring in terms of the empirically measured spring constant can be completely satisfactory for understanding many characteristics of the dynamic behavior of that system, e.g., resonance with external driving forces. There is no need for a causal formulation at the next level of what causes the spring constant to have the observed value, unless the model is being used to examine the system under conditions which may radically change the spring constant, e.g., extreme oscillations, major changes in temperature, etc.

Since it is impossible to establish with certainty that all the intervening variables have in fact been included in the model (see the discussion of validation below), there are no formal a priori ways of distinguishing between the two types of models, particularly none in terms of the mathematical form of the equations used.[36] The test of whether or not a change in one variable does in fact lead to a change in the second can establish that a model may be causal. However, such tests are never sufficient to prove causality. At any time a model which was previously 'verified' as causal can be found to have omitted a key intervening variable which is in fact 'causing' the behavior. In other words, any causal model can be converted to a descriptive model simply by postulating the existence of an intervening variable which was not considered previously.

If this is the case, then why all the fuss over the 'difference' between causal and descriptive models? The rationale for the focus on causal modeling in this thesis arises from the belief that the development of large urban areas in the US is not completely predetermined and that opportunities for influencing that development do in fact exist. Models can serve at least two roles in enhancing the number and potential effects of these opportunities. First, they can aid in anticipating where the problem areas are likely to lie. Second, they can help to evaluate the effectiveness of alternative approaches to reducing those problems. If the structure of the city were static and the interactions between activities fixed, then descriptive and causal models would be equally effective in both these roles. However, as was discussed in Chapter 3, strong social and technological forces are acting on the structure of the city and at this point in history it appears that the structure is in fact evolving. Similarly, many of the policies evaluated by urban development models represent a deliberate attempt to change the structure of interactions between activities in order to remedy a problem that was created by the present structure.

Having a focus on some conception (even if that conception may turn out to be wrong) of the causes of the interactions between activities in the city results in a better chance of formulating changes in the structure of the city due to natural evolution, e.g., from culture or technology, or to direct intervention, e.g., from the construction of multi-lane expressways. A descriptive model implicitly assumes that interactions between variables are fixed because it is based on correlations in past behavior which are assumed to continue into the future. There is always some time span, determined by the rate of change of the structure of the city and the level of accuracy required in the results of the model in the evolution of the structure of the city over which such a static approximation to the structure of the city is valid. When this time span is exceeded, it should be possible to formulate another descriptive model which would describe the interactions in the city for the next time period. One of the yet unexercised potential roles of causal models is to provide insight into the limitations of the descriptive models based strictly on extrapolation of past correlations and into the transitions between them.

A focus on causality also aids in improving the model. A model is an 'experimental design' which must be tested in order to establish the adequacy of the design relative to the purposes for which it was formulated. If the original design is found lacking, the causal theory used to justify the exclusion of some interactions and the inclusion of others provides a basis for the logical and systematic investigation of other possible sets of assumptions. Even if the model is not lacking, the causal theory implicit in it often provides insight into the limits of the model and into the changes in structure which may extend those limits.

2. Validation of the Model

In order to serve its two roles of theory development and projection of change, the models must be validated, i.e., some process must be used to test the theory contained in the models and to build confidence in their projections.

In validating a model, all aspects of its formulation are tested, including 1) the original definition of the system, i.e., the choice of variables included, 2) the specification of the interactions between these two variables, i.e., the model's structure, and 3) the estimation of the parameters of the interactions. Each of these aspects of the formulation rely on theoretical inputs and in validating the model, one is essentially testing the validity of the a priori assumption or theory on which the model is based.

The problem is how to test the models in general and the urban development model developed in Part III in particular. One of the strongest tests is the prediction of new phenomena which have not been previously observed, e.g., the development of lasers from theories of the rate of energy transfer between different energy levels. However, this approach is extremely difficult to use with models of urban development. First, the time scale of the changes being predicted is of the order of years or even tens of years. Second,the combination of strong influences by forces outside the urban system (See Chapter 3) and the lack of a laboratory where those forces can be removed or controlled makes an experiment virtually impossible to conduct. Third, the concept of conducting experiments with social systems involving large numbers of people is one which raises basic ethical and moral questions. Finally, the presence of 'noise' or random fluctuations in the inputs to the real system implies that prediction may not be an adequate test of the model.[38]

If data on future behavior is not available, then the only other source is the past. Here the distinction must be made between checking the model against the same data that was used to estimate the parameters of the model and tests using additional sources of data. In the former category, Christ[39] discusses three types of 'non-predictive' tests for econometric models, i.e., tests not based on preparing a prediction of previously unobserved data and then checking to see whether the prediction of previously unobserved data and then checking to see whether the prediction is borne out. The three types are 1) analysis of the regression and correlation coefficients, 2) analysis of the residual or 'unexplained' differences between the values estimated by the model and the data used to estimate its coefficients, and 3) checks on the a priori restrictions used in formulating the model. The last test is particularly useful when restrictions are certain enough to be formulated quantitatively and incorporated in the model, but can be checked qualitatively against the results of the model.

However, at best these non-predictive tests verify little more than the curve fitting capabilities of the estimation techniques used. The dangers in interpreting even perfect correlation as an indicator of causality have already been discussed. (Alker[40] provides an excellent review of the specific types of fallacies often encountered in making such causal interpretations.) If data sources independent of those used to estimate the coefficients of the model are available, then the model can be used to 'predict' these data. Christ describes four different types of such predictive tests for econometric models which provide a much stronger validation of the model.

A second class of criteria emphasize the comparison dynamic behavior of the model to that of the real world. Kuenne[41] provides several examples of the analysis of the dynamic behavior of models near their equilibrium points. Forrester[42] discusses the verification of dynamic models in terms of ability to reproduce such characteristics as natural frequencies, magnitudes of oscillations, abruptness of changes over time, phase shifts between variables, and amplification or suppression of external disturbances. Adelman[43] and Naylor[44] carry this one step further by carrying out statistical analysis on the output of the model and comparing the results to the statistical analysis of the behavior of the real world. In particular in her analysis of the results of a model of the US economy Adelman computes the average duration of a cycle, the mean length of expansion and contraction phases, and the degree of clustering of peaks and troughs about the turning points of the general business cycle. Naylor provides extensive references to the work on spectral analysis of the output of the model and discusses the much higher information content of such analysis compared to a simple study of sample means and variances.

A third approach to validation develops confidence in the model by determining its sensitivity to changes in structure and parameters. By observing the consequences of changes which reflect the degree of uncertainty in various aspects of the model, one can determine whether or not that uncertainty has serious consequences on the stability of the model and the conclusions drawn from its behavior. Whenever minor changes produce drastic shifts in behavior, the formulation of the model must be carefully reviewed to ensure that the interactions producing the shift are plausible. If they are, the information on the sensitive parameters of the model provide guides to leverage points which may be useful in designing alternative policies and to characteristics of the system which should be the subject of more detailed research and study.

The question of how to carry out such a sensitivity analysis of models involving a number of parameters and having a structure which allows for non-linear interactions is a serious one. The changes of individual parameters one at a time provides no information on the potential consequences of multiple changes at the same time, yet the number of possible combinations of simultaneous changes which need to be investigated rapidly outstrips the time and money constraints of realistic research programs. Bonini[45] provides an example of the use of statistical sampling techniques, (specifically fractional factor design) to reduce the number of combinations which need to be investigated to determine the higher order interactions between parameter changes.

The techniques described above can increase confidence in the model, but the basic problem of the impossibility of proving causality remains. Once the behavior of the model matches in a general manner the behavior observed in the real world and the results are not obviously implausible, it becomes impossible to distinguish between the alternative structures which produce similar results.

> The basic difficulty is a fundamental one: there seems to be no systematic way of knowing for sure whether or not one has located all of the relevant variables. Nor do we have any fool proof procedures for deciding which variables to use.[46]

Although causal models may never be undisputedly verified as representing the 'true' causal forces in the city, such complete verification is not necessary for the models to be useful. The simple causal model of a mass connected to a spring with a constant spring constant provides useful information on the future behavior of the system. The consequences of changing the value of the spring constant in the presence of a certain frequency spectrum of external driving forces can be determined without an understanding of the causes of this spring constant. (Ford Motor Company's 'computer designed' suspension system for its automobiles is the result of an extension of such an analysis.) Similarly, partially validated models (there are no other kind) can be extremely useful in anticipating changes in urban growth.

The validation of the model so that it can be used in this way becomes a 'multistage process' of gradually building confidence in the model by investigating its behavior under extreme conditions, determining its sensitivity to changes in parameter values, and becoming familiar with the dominant interactions within it. The process is inherently a negative one of demonstrating that the model is not invalid rather than ever proving that it is valid. As Forrester notes, "A model which shows no significant inconsistency with the full range of information available from the real system has passed a powerful composite test, even if each individual test is weak."[47]

The urban development model of this research has been validated by such a multi-stage process relying on data on the development of large US metropolitan areas from 1900 to 1960. The emphasis of the research was the development of a model of an 'idealized' large US metropolitan area which exhibits the three trends discussed in Chapter 2, so a comparison of the behavior of the model with these trends was the first check on the formulation. In addition the behavior of each of the major components of the model, e.g., population growth or housing filtering was tested independently under several combinations of conditions including isolation from external driving forces and exposure to step changes in driving forces.

The only criterion in the evaluation of the response was that it be 'reasonable' and not be inconsistent with what has been observed in reality. No statistical tests on the fit of the predicted behavior of the model to either cross sectional data for a set of cities or longitudinal data for a given city was attempted because the focus of this model was the dynamics of the behavior. Rather than attempting to replicate the behavior of the city to some arbitrary specification, the model seeks to understand the interactions of the city with the outside driving forces acting on it. Chapter 3 has discussed the nature of these external forces. Chapter 7 will present the model used to answer the questions of the relative roles of the internal interactions which govern that response.

Footnotes, Chapter 6

1. For an introduction to Forrester's approach to modeling complex systems see Forrester, Jay W., Industrial Dynamics (MIT Press, Cambridge, 1961); Forrester, "Industrial Dynamics--After the First Decade," Management Science, Volume 14, March, 1968, pp. 398-414; Forrester, Principle of Systems, (privately printed, available from the author at MIT, Cambridge, Massachusetts.)

2. For a concise yet relatively complete summary of the DYNAMO language and its use see Pugh, Alexander L., DYNAMO User's Manual (MIT Press, Cambridge, 1961), and the various supplements and updates which are available from the author at MIT.

3. For a 'non-partisan' evaluation of the applications to simulation of industrial systems see Ansoff, H. Igor, and Slevin, Dennis P, "An Appreciation of Industrial Dynamics," "Management Science, Volume 14, March 1968, pp. 383-397. Forrester's response followed in, "Industrial Dynamics--A Response to Ansoff and Slevin, " in Management Science, Volume 14, pp. 601-618.

4. Forrester, Jay W., Urban Dynamics, (MIT Press, Cambridge, 1969). A few of the reactions to Urban Dynamics, Forrester's extension of his approach to the modeling of urban growth, are Gregory Ingram's review in the Journal of the American Institute of Planners, (May, 1970), John Kain's review in Fortune (November, 1969), and Arron Fleisher's review in Technology Review, (February, 1970)

5. Kuh, Edward, and Eisner, Mark, Manual for the TROLL system, Econometrics Project, MIT, revised version January, 1969. (SCROLL is the language of the TROLL system.).

6. Kuenne, Robert E., The Theory of General Economic Equilibrium, (Princeton University Press, Princeton, 1963), Introduction.

7. See Hildebrand, F. B., Method's of Applied Mathematics, (Prentiss-Hall, Englewood Cliffs, New Jersey, 1952), Chapter 3.

8. Bonini, Charles P., Simulation of Information and Decision Systems in the Firm, (Prentiss-Hall, Englewood Cliffs, 1963). Bonini presents a finite difference model of the firm formulated in FORTRAN.

9. Kuh and Eisner, op. cit.

10. Blalock, Hubert M., Theory Construction: From Verbal to Mathematical Formulation (Prentiss-Hall, Englewood Cliffs, New Jersey, 1969) Chapters 4 and 5.

11. Forrester, Jay W., Principles of Systems (privately printed and available from the author at MIT, Cambridge, Massachusetts).

12. Buckley, Walter, Sociology and Modern Systems Theory (Prentiss-Hall, Englewood Cliffs, New Jersey, 1967). Chapters 3, 6.

13. Deutsch, Karl W., The Nerves of Government (The Free Press, Toronto, 1966), Part II.

14. Simon, Herbert A., Models of Man, (John Wiley & Sons, New York, 1957), Chapter 13.

15. Bruner, Ron and Brewer, Gary, Organized Complexity, (in press)

16. Forrester, Industrial Dynamics, op. cit., Appendix E. For a review of the literature on distributed lags in econometric modeling, see Nerlove, Marc, "Distributed Lags and Demand Analysis for Agricultural and other Commodities," US Dept. of Agriculture, Agriculture Handbook #41, US Government Printing Office, 1958.

17. DYNAMO does allow this restriction to be violated in that a rate at time t can be made a function of a rate in the previous time period, t-t, however, Forrester strongly recommends against this (see comments on loops without levels in Appendix O to Industrial Dynamics, or p. 14 in Urban Dynamics, notes 1 and 4 above respectively.) If this option is used, the state variables must be expanded to include either the rates used in calculating other rates, or alternatively, the levels which enter into the rates used in equations for other rates. The latter option implies that the equations now include second difference equations rather than only first differences.

18. Blalock, Theory Construction, op. cit., p. 48.

19. Wold, H. O., "Ends and Means in Econometric Model Building: Basic Concepts Reviewed," in U. Grenander, ed., Probability and Statistics, (The Harold Cramer volume), (Almquist and Wiksell, Stockholm, 1959). See also Chapter 5 in Blalock, Theory Construction. . .cited above, and pp. 52-60 in Blalock, Causal Inferences in Nonexperimental Research, (University of North Carolina Press, Chapel Hill, 1964), p. 9.

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22. Ibid., p. 127.

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24. See Blalock, Theory Construction, op. cit., pp. 78-84, and Fisher, ibid., Chapter 6.

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27. Christ, Carl, Econometric Models and Methods, (John Wiley and Sons, NY, 1966), Kane, Edward J., Economic Statistics and Econometrics, (Harper and Row, New York, 1968), and Koopmans, Tjalling C., Statistical Inference and Dynamic Economic Model, (Wiley and Sons, New York, 1950).

28. Forrester, op. cit., Industrial Dynamics, p. 117.

29. See for example, Hamilton, H. R., et al., Systems Simulation for Regional Analysis: An Application to River Basin Planning, (MIT Press, Cambridge, 1969).

30. Blalock, Hubert M., "Making Causal Inferences for Unmeasured Variables From Correlations Among Indicators," American Journal of Sociology, volume 69, 1964, p. 62.

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32. Blalock, Hubert M., Causal Inferences in Nonexperimental Research (University of North Carolina Press, Chapel Hill, 1964), p. 9. The introductory chapter of this book is an excellent summary of the basic literature and issues in causality.

33. Blalock, Hubert M., "Theory Building and Causal Inferences," in Blalock, Hubert, and Blalock, Ann, ed., Methodology in Social Research, (McGraw Hill, New York, 1968), p. 161.

34. Blalock, op. cit., Causal Inferences in Nonexperimental Research, p. 13.

35. Strotz, R. H. and Wold, H. O., op. cit., p. 417.

36. de Neufville, Richard and Stafford, Joseph H., Systems Analysis for Engineers and Managers, (McGraw-Hill, in press), now available as Report R70-19, Department of Civil Engineering, MIT, Cambridge, Mass.) See Chapter 12.

37. Harris, Britton, "Quantitative Models of Urban Development: Their Role in Metropolitan Policy Making," in Perloff, Harvey S. and Wingo, Lowdon, ed., Issues in Urban Economics, (Johns Hopkins Press, Baltimore, 1968), p. 364.

38. Forrester, op. cit., Industrial Dynamics, Appendix K.

39. Christ, op. cit., (note 27), Chapter 10.

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41. Kuenne, op. cit., (note 6), Chapter 8.

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45. Bonini, op. cit., (note 8).

46. Blalock, op. cit., Causal Inferences in NonExperimental Research, p. 14.

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PART III

A COMPUTER SIMULATION MODEL OF THE GROWTH OF A LARGE AMERICAN CITY

Chapter 7

A DYNAMIC MODEL OF URBAN DEVELOPMENT

The central effort of this thesis has been the development of a computer simulation model of urban growth as an aid in understanding the causes of intermediate term trends in the development of large U. S. central cities. The specific objectives of the model and the trends which are of interest have been presented in Part 1. The components of the model were outlined in Chapter 4 and the previous attempts at modeling these components reviewed and critiqued in Chapter 5. This chapter will present the essentials of the structure of the model itself.

First, the selection and disaggregation of the primary outputs or state variables are outlined. Then, the structure of the model itself is discussed. The urban development model (PHASE 2) has been divided into three main submodels, one each for the growth of population and employment in the metropolitan area as a whole, one for the growth and filtering of the housing supply in the central city and suburb, and one for the location and redistribution of population and employment in the two areas. Sections B, C, and D of this chapter describe the main equations and interactions within each of these submodels and the data sources used to derive the parameters of the interactions. Only the more important equations are given here, but a complete listing of each of the submodels and of the complete urban development model are given in Appendix 3. As is described in detail in Appendix 3, each of these submodels can be run independently of the other two in order to simplify the analysis of the total model. This separability of the submodels was crucial to the understanding and unraveling of the major interactions within the model as a whole. In order to separate the submodels, the information transfers or links between them had to be explicitly identified and accounted for in the independent versions of the submodels. These links between the submodels are an important aspect of the structure of the urban development model and are discussed in the concluding section of this chapter. The results of the model, including an analysis of the relative importance of the interactions within and between each of the main submodels, will be presented in the next two chapters.

A. Primary Variables and Their Disaggregation

The primary variables of the model are four classes of population (black upper skilled, black lower skilled, white upper skilled and white lower skilled), three types of industry (export, residential services, and business services), three types of housing (upper skilled, lower skilled, and abandoned), and five classes of land use (residential, industrial, transportation and public, vacant, and abandoned). The growth model calculates the aggregate totals for both suburb and central city of the four classes of population and three types of industry, but the output of the model gives the values of these and the other variables separately for each of the two areas of the city. In deciding the types and detail of the dimensions to use in breaking down major classes of variables such as population or housing into subclasses, the desire to keep the model as simple and parsimonious as possible plays against the desire both to check its behavior at greater levels of detail and to reflect the causal mechanisms which are felt to be important. Two major questions must be dealt with in deciding upon the disaggregation to be used:

1. Within a given dimension of disaggregation (for example, income vs. age...vs. skill level, etc, for population) is the level of detail of

disaggregation which is adequate for describing trends, also adequate for formulating the causes of those trends? The classical example of this problem in urban development modeling is the issue of the level of spatial aggregation needed, i.e., how many separate zones does the city have to be divided into when modeling its behavior over time. Part 1 has shown that the vital trends of dispersal and desegregation can be described at the very coarse level of only two zones, but can the forces causing these trends be formulated at such a gross level?

2. Given the diverse nature of the types of causal processes and interactions which must be included within the model, can a small set of dimensions for disaggregation be found which are adequate for formulating all of those processes? For example, size of firm is an important dimension for determining the location of an industry, but has virtually no bearing on aggregate growth.

In this model the first question, level of detail, was always resolved in the direction of the simplest possible breakdown; for example, for population only two classes (high and low, black and white) were used for each dimension. Industry was broken down into three classes because: a) it was believed to be absolutely necessary to the formulation of urban economic growth, and b) since the industrial breakdown was quickly reduced to a two-level skill level breakdown, the model was not noticibly complicated by the use of three rather than two types of industry. The abandoned classification was added to housing because of the need to distinguish between housing which was vacant and useable and that which was physically present in the city but at such an advanced state of deterioration that it contributed nothing to the supply of housing actually available. The breakdown of land uses in the city was relatively standard and needs no elaboration.

The resolution of the second question will be presented by reviewing the alternative dimensions which were considered for population and industry variables. In the model population is disaggregated by location (central city and suburb), race (black and white), and skill level (high and low). The breakdown by location and race came directly from the formulation of the problems being studied. The decision to provide a further breakdown was based on the need to incorporate the effects of changes in production technology on distribution of skill levels demanded, of differentials in transportation mobility, and of differences in the housing demanded. Income was seriously considered as an alternative to skill, and at several points in the model skill is used as a surrogate for income level. (See Table 1 for an indication of the overlap.) However, in formulating the upward mobility processes and the impact of changes in production technology, it was found that shifts in skill provided a better representation than changes in income.

The disaggregation of population by age was also considered because birth, death, and outmigration rates are a strong function of age. Also, several of the problems of the city arise from the growing concentrations of elderly people and the strains on facilities induced by baby "booms." It was decided that the problems relating to age were not central to the study, and that the approximations of average rates of birth, death, and migration were acceptable. For example, although the cities of San Jose, California and Albany, New York have radically different population age

TABLE 1. Fraction of Different Occupations Considered Low Skilled Under Alternative Criteria Based on Education and Income, and the Fraction Used in the Model.
(Data for Male Experienced Non-Farm Labor Force, 1960)

	In Model	Education Criterion	Income Criterion
1. Total Labor Force	36%	51%	45%
2. Professional	0%	12%	23%
3. Managers	0%	34%	27%
4. Craftsmen and Foremen	0%	61%	41%
5. Operatives, etc.	70%	74%	57%
6. Services (including private household)	60%	70%	78%
7. Laborers	100%	83%	80%

Table 1 compares the fraction of the labor force in each occupational classification which would be considered "low skilled" under an education criterion (less than 12 years of high school) and an income criterion (less than $5,000/yr). The first column is the fraction of the occupational group which was assumed to be low skilled in the calculations of the coefficients for the model. (For 1960.)

Source: 1960 Census of Population, Vol. PC (2) 7 B, *Occupation by Earnings and Education*, Table 1.

structures, outmigration rates calculated from age specific rates are 35 per thousand vs. 31 per thousand, a difference of only 11%.[1] There is 'feedback' between age structures and migration flows, but it was not felt to be significant at the levels of accuracy of this study. The growth model does separate out children by race from the rest of the population, but that is in order to deal with the time lag between birth and entering the potential labor force. (See Section B in this chapter. For a discussion of the dependency of population growth on age structure, see Rogers.[2])

The breakdown of employment into the classes of residential service, business service, and export base was set by the growth model. In considering the disaggregation of population, the two dimensions of income and skill level were sufficiently similar to one another that no major conflict resulted in using one as a surrogate for the other, and either of them was sufficient to formulate the main interactions in growth, skill shifts, location and redistribution. In industry this is not quite as true. In particular, the characteristics influencing the location of industry do not neatly overlap the dimensions appropriate for modeling growth. The industrial categories lumped together into the three growth sectors have quite different location requirements, and the choice of a unique set for each set will involve oversimplification. For example, the location of all export base industries will have the same relative dependence upon material inputs and labor, and all residential service industries will be primarily dependent upon access to their market. In addition to lumping together dissimilar industries, the model also completely neglects size of firm as a determinant of location. The effects of trends in the size of firm as a second reason for the increasing demand for larger industrial sites have not been investigated at all in this work and are clearly an area for future study.

This section has outlined some of the main issues and assumptions involved in the particular choice of variables which has been made. The nature of the assumptions and the rationales for the specific dimensions for disaggregation which were selected will become clearer as the structure of the components of the model are discussed in the following sections.

B. Population and Employment Growth Submodel

The submodel for the growth of population and employment simulates the increase of population disaggregated by race and skill level and employment disaggregated by function for the metropolitan area as a whole. The forces driving growth of the adult population include births, deaths, aging of children, outmigration and inmigration. The forces driving increases in employment include national trends in manufacturing growth, local regional advantages, increases in population, and changes in the composition of the total labor force. The linkages between the population and employment sector occur through the increase in employment providing services to the population, and through the effect of excess labor (or unemployment level) on the inmigration of population and industry.

1. Population Growth

Figure 1 shows the basic structure of the population growth model. The population increases due to births and to inmigration, and declines due to deaths and outmigration. Adults produce children at a rate given by the exogenously determined birth rate (Figure 1 in Chapter 3); the children age over time and become adults to produce more children,

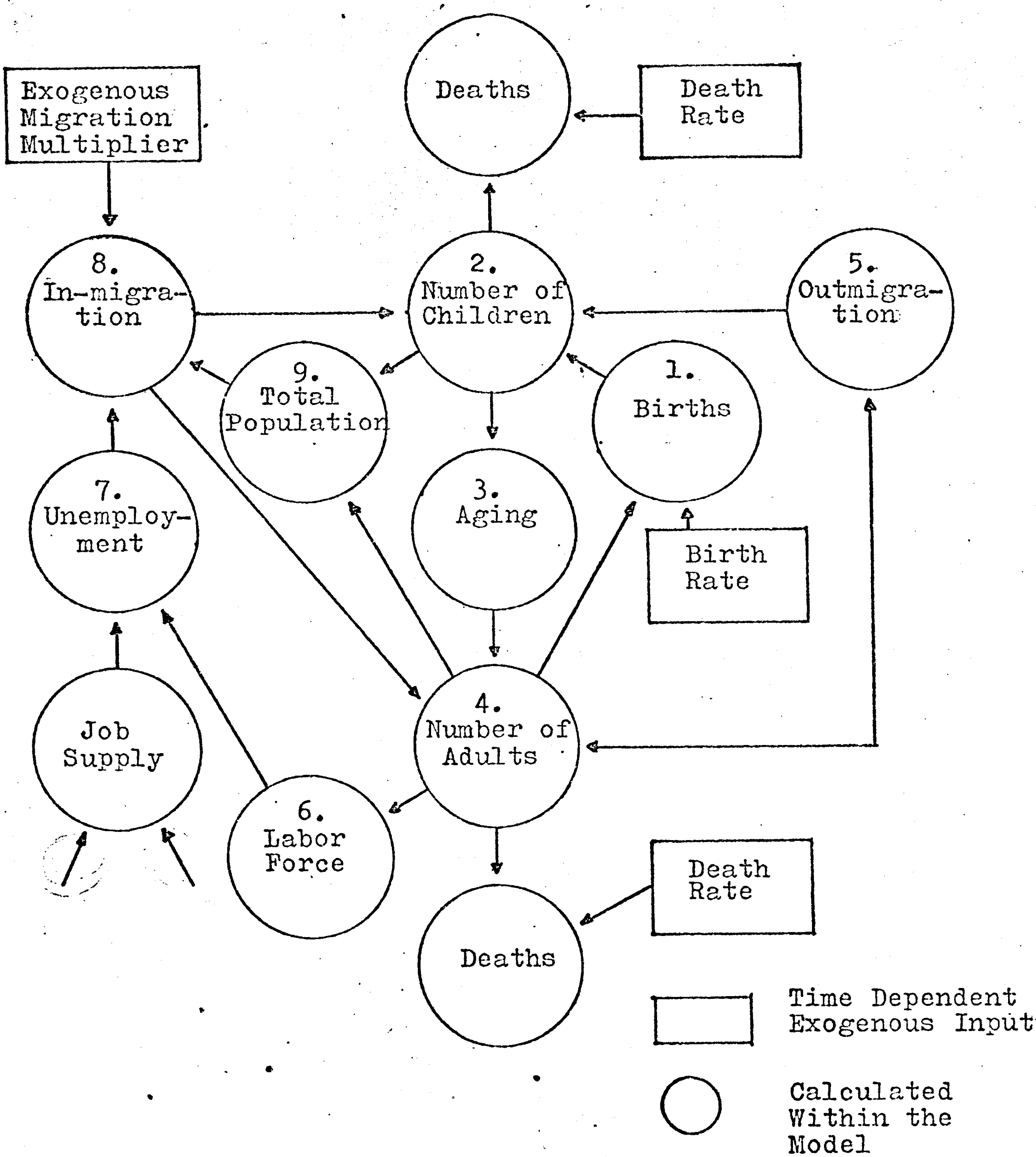
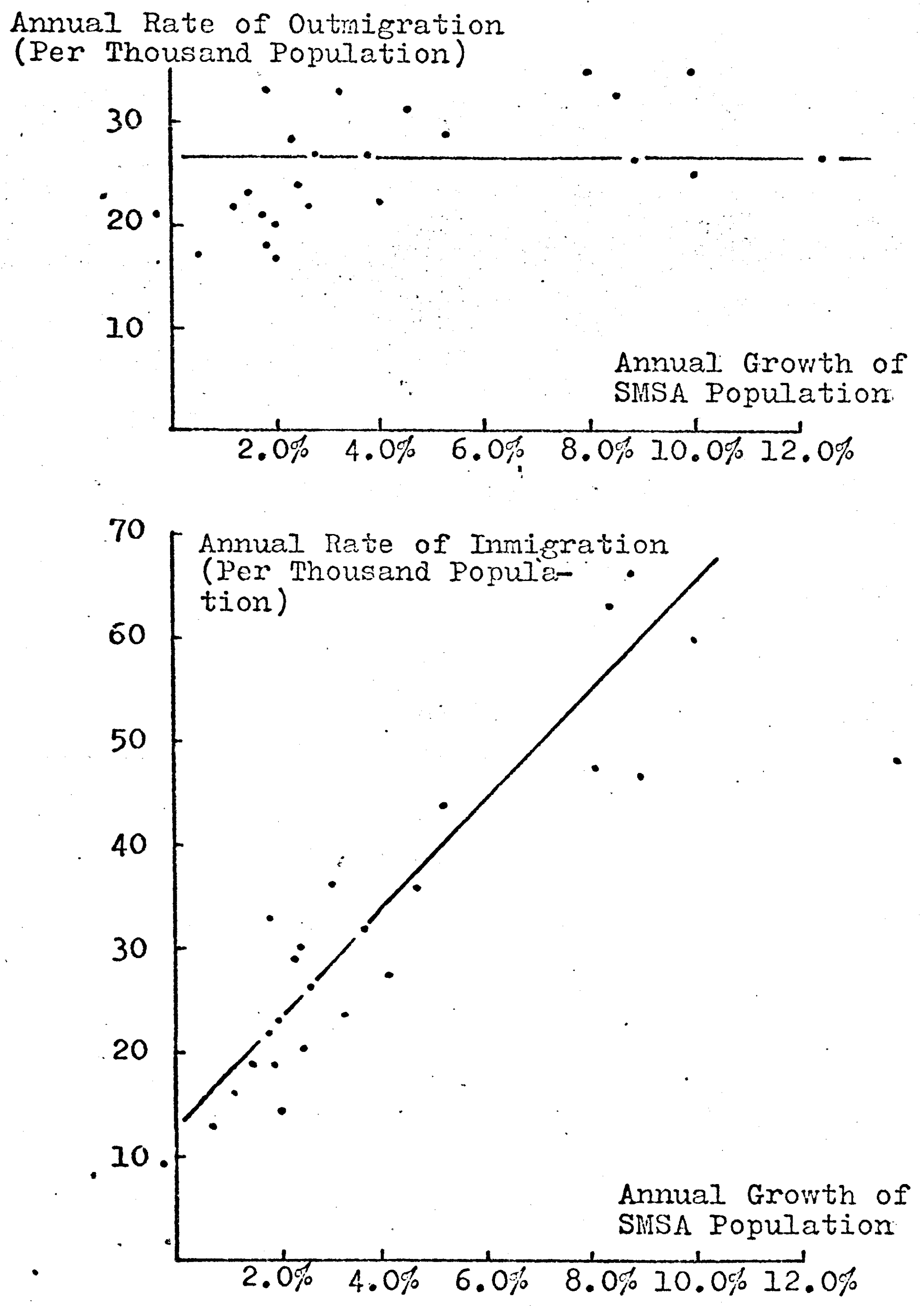


Fig. 1 Schematic of Model of Growth of White Population (Model of Black Population Growth is Identical)

thus closing the loop (1-2-3-4-1). The number of both children and adults are depleted by deaths at a rate specified exogenously (Figure 1 in Chapter 3). The birth and death rates have been assumed to be independent of the conditions within the city (although at extremes of deterioration this assumption would break down), thus the differentials in population growth rates between cities at a given point in time must be explained in terms of differences in their migration flows.

Figure 2 (a) shows the data which was the basis for the assumption that the rate of outmigration from a metropolitan area is insensitive to the rate of growth of that area. In other words, the process which acts as a valve controlling the rate of growth of the city is a changing inmigration (Figure 2 (b)) in the presence of a relatively fixed level of outmigration. If the city is not "attractive" enough to stimulate inmigration, the fixed level of outmigration can cause a net decline in population. If the city becomes extremely attractive, inmigration increases accordingly, but outmigration does not decline. Perloff has described some of the causes for the differences between the two types of migration:



Each point represents a different city. The growth and migration rates are average annual rates over the period 1955-1960.

Fig. 2 Population Inmigration and Outmigration as a Function of Metropolitan Growth

Source: 1960 Census of Population, Vol. PC (2) 2C, Mobility for Metropolitan Areas.

> One feature of the movement of persons within the continental U.S. that seems to play a major role in the population income relationship has to do with certain basic differences between inmigration and outmigration situations. When a region offers unusually attractive job and living opportunities, and when it can absorb new labor force from outside its borders at relatively high wages, it can and does draw persons from many parts of the nation. Even if only small numbers should come from each of the various outside states, the cumulative inmigration can be large. Quite a different situation obtains in a region which, in terms of relative job and income opportunities, is 'overpopulated.' All the personal migration decisions must be made within the one area. Thus the proportion of persons who are willing to leave the area to improve their economic situation becomes a critical factor.... This suggests that migrants are likely to keep arriving into a region offering unusually attractive wages until the interregional wage differential is dampened, but that outmigration from any given area will not always be at the volume and rate called for by the objective situation (i.e. the wage and income differentials).[3]

In the model the outmigration of adults is equal to the adult population in each skill level times a constant of proportionality estimated separately for each skill level from 1960 census data.[4] The differences in outmigration rates for adults by skill level and in skill composition of the black and white adult population (Table 2) are assumed to totally explain the differentials in aggregate migration rates by race, as is shown in Table 3.

TABLE 2. Occupation and Skill Level of the Urban Population
Population by Race, 1960
(Millions of Employees)

		Total		Black	
Occupation	Fraction High Skilled	Number	Number High Skilled	Number	Number High Skilled
1. Professional & Technical	100%	5.89	5.89	.248	.248
2. Managers, Officials, etc.	100%	4.27	4.27	.077	.077
3. Craftsmen, Foremen & Kindred	100%	6.43	6.43	.318	.318
4. Clerical & Kindred	70%*	7.88	5.12	.348	.245
5. Sales	70%*	3.77	2.65	.076	.053
6. Operatives	30%*	8.48	2.55	.995	.298
7. Service Workers & Private Household	30%*	5.59	1.68	1.622	.486
8. Laborers, Except Farm & Mine	0	2.11	-	.587	-
Total		44.9	29.1	4.32	1.72
Fraction High Skill			65%		40%

* Estimated from fraction of this occupation with 12 years or more education

Legend: For each occupation the table lists the fraction of that occupation which is assumed to be classes as upper skilled and the number of total and black employees in that occupation in 1960.

(continued)

TABLE 2.

Sources:

1. U.S. Census of Population, 1960, Vol. PC(1) 1D, U.S Summary, Detailed Characteristics, Table 203.
2. Current Population Reports, Series P-20, #155, "Negro Population," Sept. 1966.
3. U.S. Census of Population 1960, Vol. PC(2) 1C, Nonwhite Population by Race, Table 32.

TABLE 3. Outmigration Rates of Adults (Age 18 Years) by Race and Skill Level 1955-1960

		Blacks	Whites
1. Outmigration of Adults (rate per thousand adults)		18	27
2. Skill Composition of Adult Population			
	High Skill	40%	65%
	Low Skill	60%	35%
3. Outmigration Rate by Skill Level (rate per thousand in skill level)			
	High Skill	31	31
	Low Skill	9.0	9.0

Legend: Rows 2 and 3 give the differences in skill population by race, and the differences in migration rates by skill level which produce the aggregate outmigration rates of row 1.

The outmigration rates for children are calculated by multiplying the adult population by the number of children per migrant (CPM). CPM is assumed to be a constant over time and is estimated from the age structure of urban migrants in 1960. The formulation of outmigration for adults creates the loop (4-5-4) in Figure 1, and for children, the loop (4-5-2-3-4).

One of the major consequences of the assumptions that urban outmigration is independent of the conditions within the city is that it makes possible a formal estimation of inmigration to a metropolitan area without specifically comparing the destination city with each of its possible sources of inmigration. In other words,

> if the total volume of outmigration from place i is a function of the size and structure of place i's population, and if place i's incoming share of migrants from other places is a function of the size and condition of place i's labor market, then the explanation of net migration to place i can be found without direct comparison of the characteristics of place i to those of each other place j, k, etc. At most we need to consider the overall mobility of the population of the U.S. (a function of its size and structure) and the condition of the national labor market.[5]

The formulation of inmigration to the city used in the model follows the simplest form used by Lowry for aggregated inmigration flows, but extends it to migration disaggregated by race and skill level.

(41)* IMWU = IRWU * P * MWPOT * MUAT

where

IMWU = inmigration of white upper skilled adults
IRWU = proportionality constant for white upper skilled adults
P = total population in the metropolitan area
MWPOT = externally determined potential for migration of whites
MUAT = attraction of the metropolitan area for upper skilled migrants of either race

The first term is the usual constant of proportionality, which has been estimated from 1960 census data for each of the four inmigration flows (Table 4).

TABLE 4. Inmigration Rates
Of Adult Population by Skill and Race
1955-1960
(Per Thousand Total Metropolitan Population)

Population Group	White Low Skill (IRWL)	White High Skill (IRWU)	Black Low Skill (IRBL)	Black High Skill (IRBU)
Rate	3.9	7.8	.78	.52

The second term accounts for the effect of the size of the metropolitan area on inmigration by making the rate proportional to the total population. The third term takes into consideration the potential for migration to the city which is established by conditions outside the city as described by Lowry. The final term measures the attraction of the city

* The number beside an equation refers to the number of the equation in the complete listing of the model in Appendix 3.

for migrants because of its labor conditions.

Although Lowry achieved better results for an attraction based on both employment opportunities and wage rate, employment opportunities alone, as measured by unemployment rate, was adequate to explain much ($R^2 = .6$) of the variance in inmigration. Lowry found that the migration to a city varied approximately as the inverse of its rate of unemployment, and, as is shown in Figure 3, that functional relationship is used in the model. Figure 3 shows that the inverse power relation is truncated for unemployment rates less than 1% or greater than 10%, and is adjusted to a value of one at 4% unemployment. The dotted line indicates the function used to test the effects of the higher skilled labor force being more sensitive to unemployment than low skilled labor. This formulation of adult inmigration creates the feedback loops (4-6-7-8-4), (4-9-8-4), and (4-1-2-9-8-4) in Figure 1.

Figure 1 shows the basic types of interactions, but has oversimplified the actual structure of the model because the diagram does not show the adult population divided into its two skill levels. The main feature obscured by this simplified presentation is the dependence of inmigration of

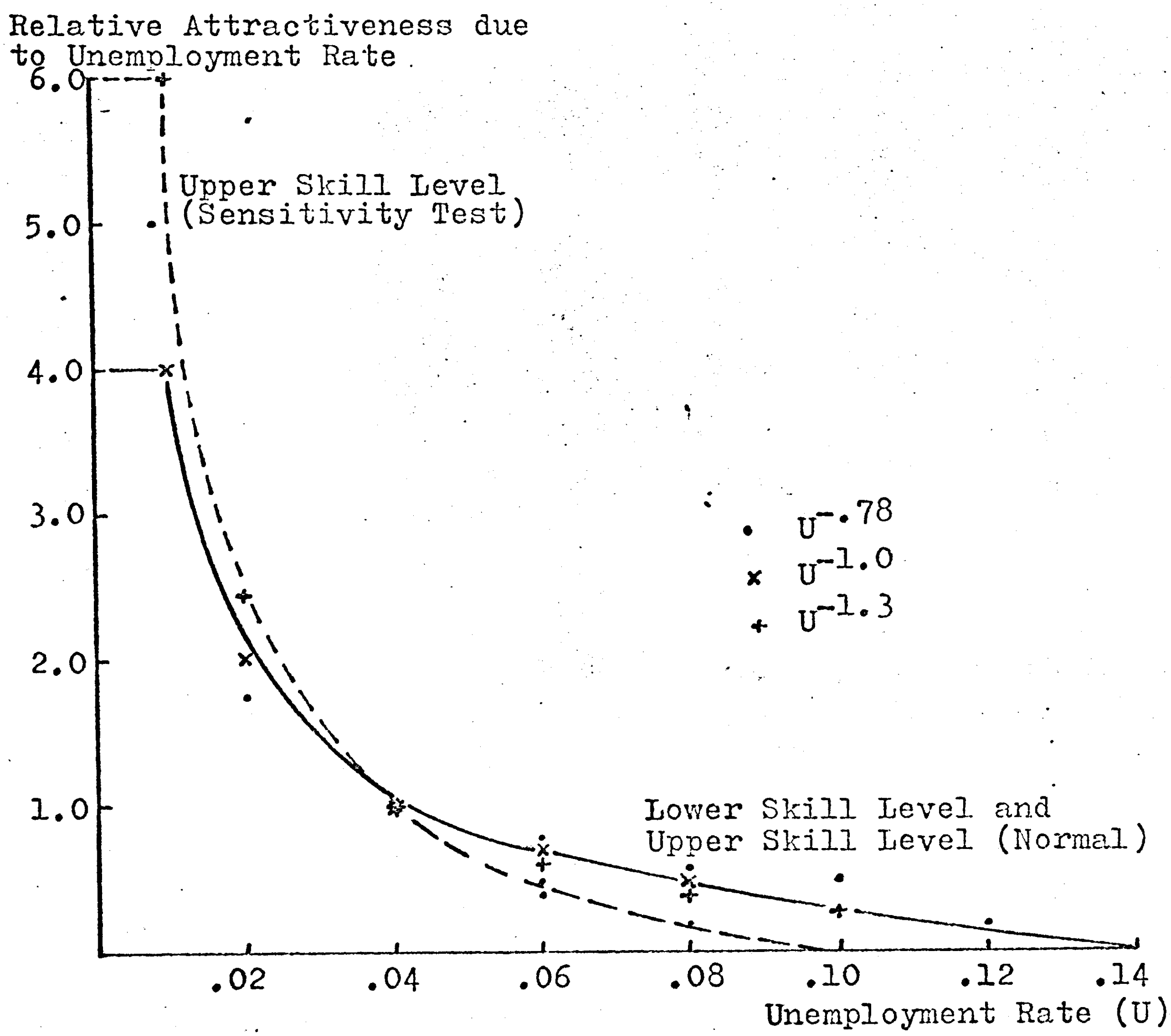


Fig. 3 Attraction of City for In-migration of Population due to Employment Opportunities

high skilled and low skilled population on two different rates of unemployment. As will be explained in part 3 of this section, the model computes an unemployment rate for upper skilled labor in addition to the overall unemployment rate for the total labor force. The inmigration of upper skilled labor is assumed to be dependent upon the unemployment rate in the upper skilled labor sector; in other words, this portion of the labor force is more discriminating in the types of opportunity which attract it. The low skilled labor force responds to rate of unemployment of the total labor market for both skill levels because opportunities in the lower skill level do not imply a downgrading of economic position and openings in the upper skill level represent opportunities for upgrading.

The inmigration of children is taken to be proportional to the inmigration of adults, using the same constant (CPM = children per migrant) that was used in calculating outmigration.

The final rate of population change within a skill level is the aging of children into adults. The model has assumed a uniform age distribution for children at all times, i.e., that a fraction (5%) of the total number of children become adults each year. This assumption ignores the variation in the detailed age structure due to shifts in birth rate over time and the non-uniform age distribution of migrant children, but does incorporate the basic time delay before a shift in birth rate is reflected in increased labor force.

Figure 4 shows how the birth, death, inmigration, and outmigration rates for adults and children are combined to produce the growth model for white population in the two skill levels. (The structure for the growth of the black population is identical.) The rectangular boxes indicate the 'level' variables whose change over time is determined by the rates of flow (non-rectangular boxes) into and out of them. In Figure 6 the three level variables are the numbers of white children (CW), white low skilled adults (PWL), and white upper skilled adults (PWU). The rates affecting CW are the birth rate (CWBR), the net migration rate (CWNMR), the death rate (CWDR), the rate of aging into low skill adults (CWAL), and the rate of aging into upper skilled adults (CWAU). The levels representing the two skill levels of adult population (PWU and PWL) have rates

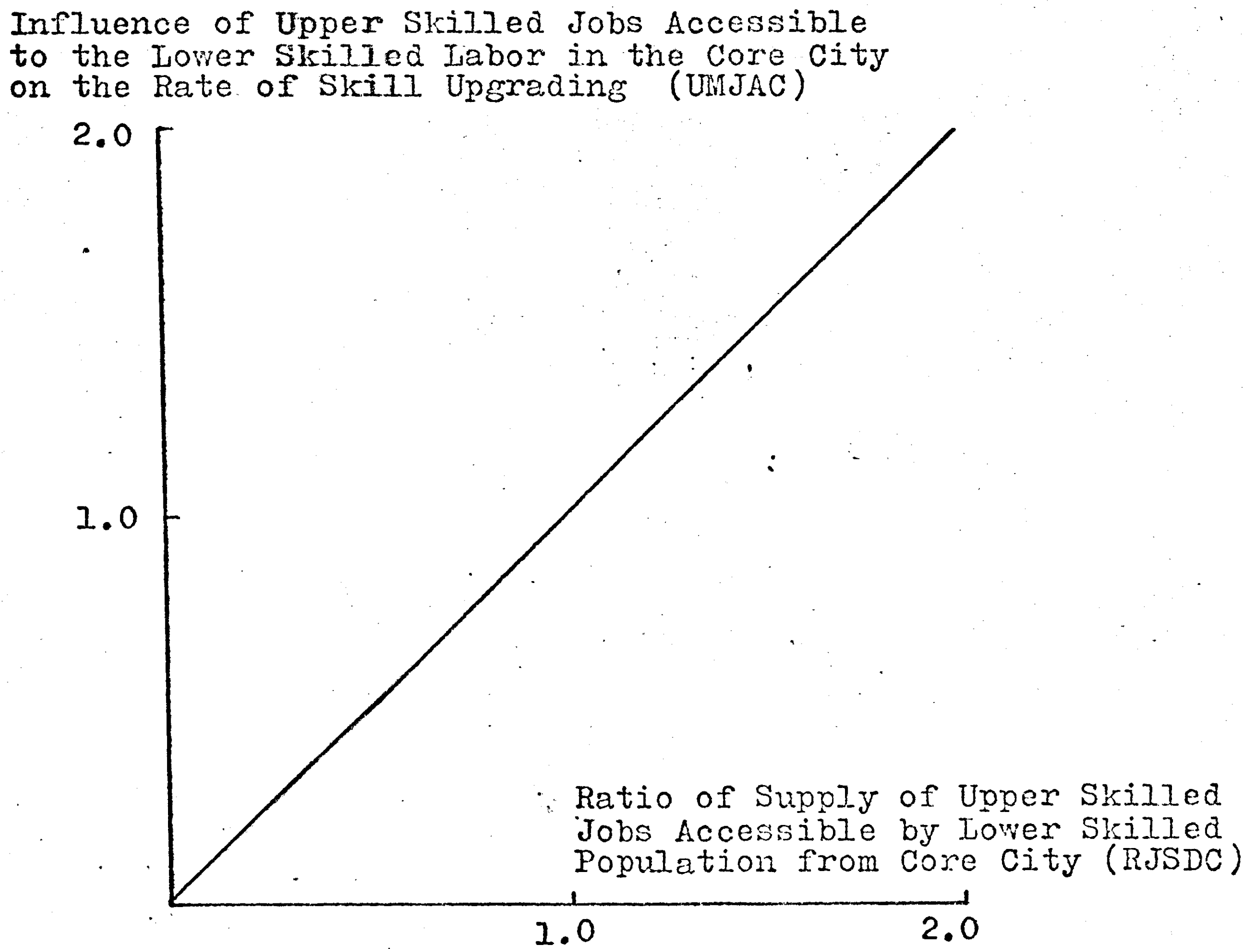


Fig. 4 The Influence on the Rate of Skill Upgrading of Lower Skilled Population in the Core City of the Upper Skilled Job Supply Accessible from the Core City Using Lower Skilled Accessibilities.
(The rate of transfer of lower skilled population to upper skilled in the core city is proportional to UMJAC, a second multiplier, and the normal rate.)

reflecting children aging into adults (CWAU, and CWAL), adult deaths (PWUDR, and PWLDR), and net migration of adults (PWUMR and PWLMR). The detailed equations for these rates for the black population are given in equations 1 - 24 of Appendix 1 and equations 25 - 39 for the white population.

In addition to changes in population within each skill level due to migration, aging, etc., the model allows for the flows of population between skill levels due to the upgrading of skills. This process is indicated in the flow diagram of Figure 4 by the rate variable PWUR connecting the upper and lower skill levels. As will be discussed below, the upgrading rate is formulated separately for each of the two areas of the city so in the model PWUR is replaced by the sum of the upgrading rate PWCUR for the core city and the upgrading rate PWSUR for the suburbs.

The upgrading process involves formal education received within schools, on the job training, and accessibility to jobs. This process will be formulated here in an extremely simplified manner which ignores the differences in the educational system of the two areas and concentrates on the differences in the access to employment. Also, racial discrimination in the upgrading process will be ignored.

The rate of upgrading of a lower skill level to the upper skill level within an area is assumed to be the product of the lower skilled population in that area and a variable rate. For example, for the lower skilled whites in the core city

PWCUR = PWLC * ULRC

where

PWCUR = the number of lower skilled whites in the core city converted to upper skilled in a year
PWLC = the number of lower skilled whites in the core city
ULRC = the fraction of lower skilled population in the core city converted to upper skilled in a year (the same for whites and blacks)

The fraction upgraded, ULRC, is determined by the product of a normal upgrading rate, and two multipliers reflecting the effects of the shortage of upper skilled labor in the city as a whole and the access of lower skilled population to upper skilled jobs from each area. For example,

ULRC = URL * UMU * UMJAC

where

URL = the 'normal' fraction of the lower skilled labor in an area which is converted to upper skilled in a year
UMU = the upgrading multiplier due to shortage of upper skilled labor
UMJAC = the upgrading multiplier due to the accessibility of upper skilled jobs to lower skilled population living in the suburbs

The format of the upgrading rate in the suburbs ULRS is the same, but a different accessibility multiplier is calculated.

The influence of changes in the shortages of upper skilled labor in the metropolitan area on the multiplier UMU is given in Figure 5. When there is exactly zero excess, the multiplier is equal to one; as the excess increases to 20%, the multiplier declines to zero; and as the excess becomes negative (i.e., a deficiency of upper skilled labor), the multiplier increases.

The influence of the accessibility of the lower skilled to the upper skilled jobs is shown in Figure 6. RJSDC is the ratio of the supply of upper skilled jobs accessible from the core city using low skilled transportation to the number of low skilled laborers in the core city. (The ratio RJSDS is the analagous variable used to calculate the influence of access on job upgrading in the suburbs.)

2. Growth of Employment

Figure 7 shows the schematic of the subsector of the model for growth of employment, with total employment being divided into three classes--export base, residential services and business services--as was explained in Section A.3 of Chapter 3. The rate of growth (IEXR) of the export base employment (IEX) is given by

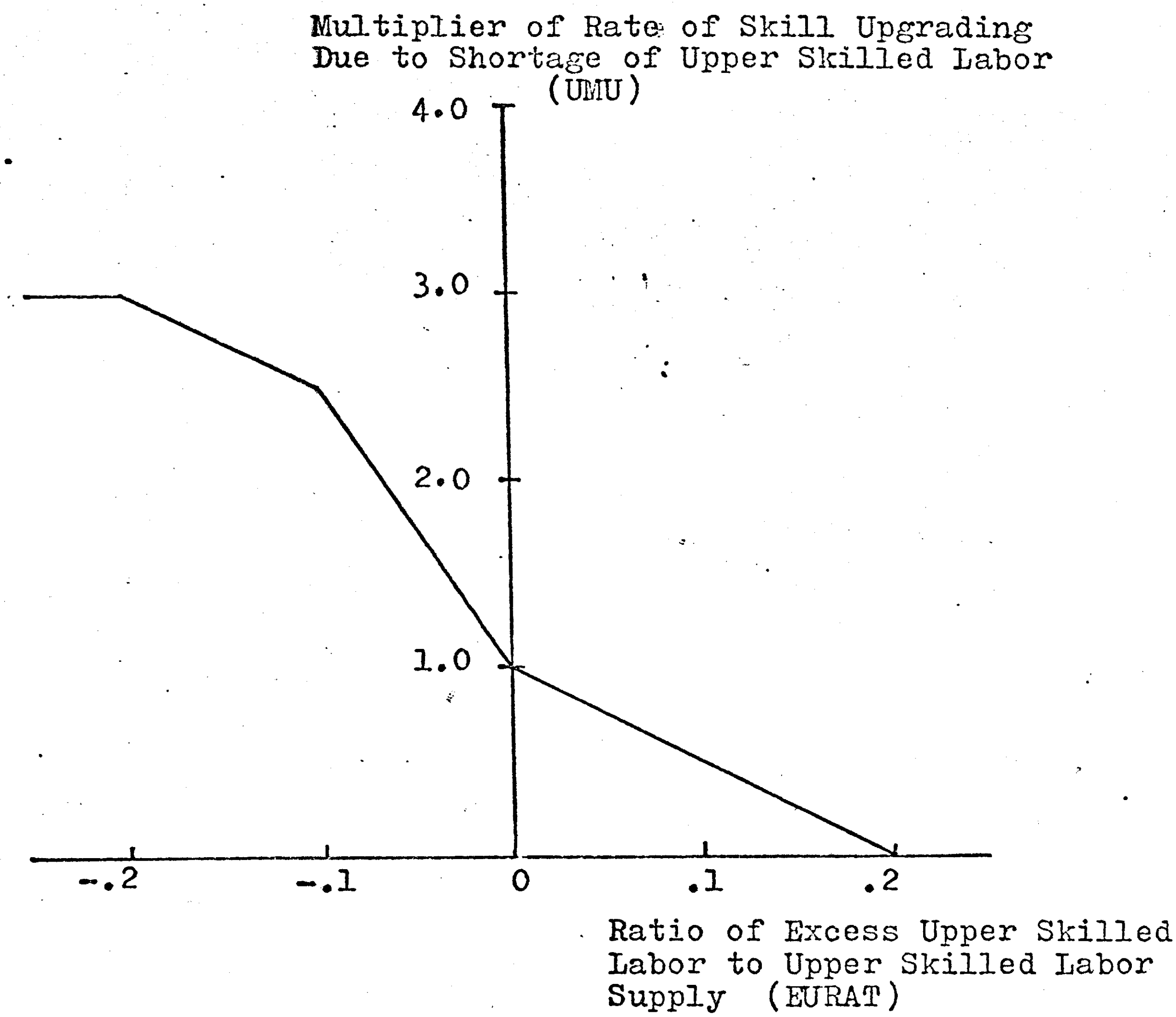
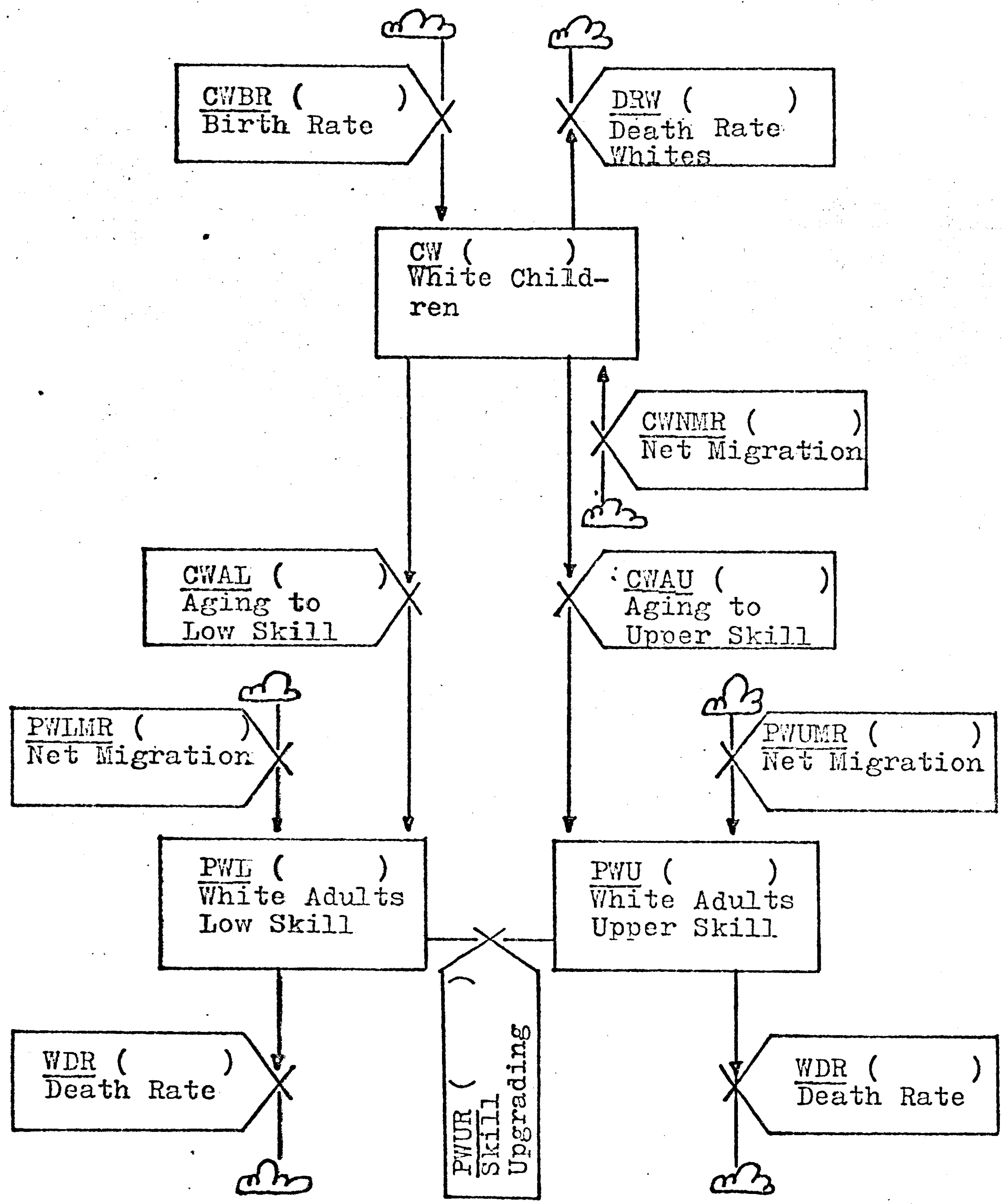


Fig. 5 Influence of Conditions in the Upper Skilled Labor Market for the Metropolitan Area on the Rate of Skill Upgrading of Lower Skilled Labor. (The rate of transfer of lower skilled population to upper skilled is proportional to UMU, a second multiplier, and the normal rate.)



The names in capital letters in each box are the names of the variables in the model. The number in parenthesis is the number of the equation which defines the variable in the program listing in Appendix III.

Fig. 6 Flow Diagram of Growth Model for White Population

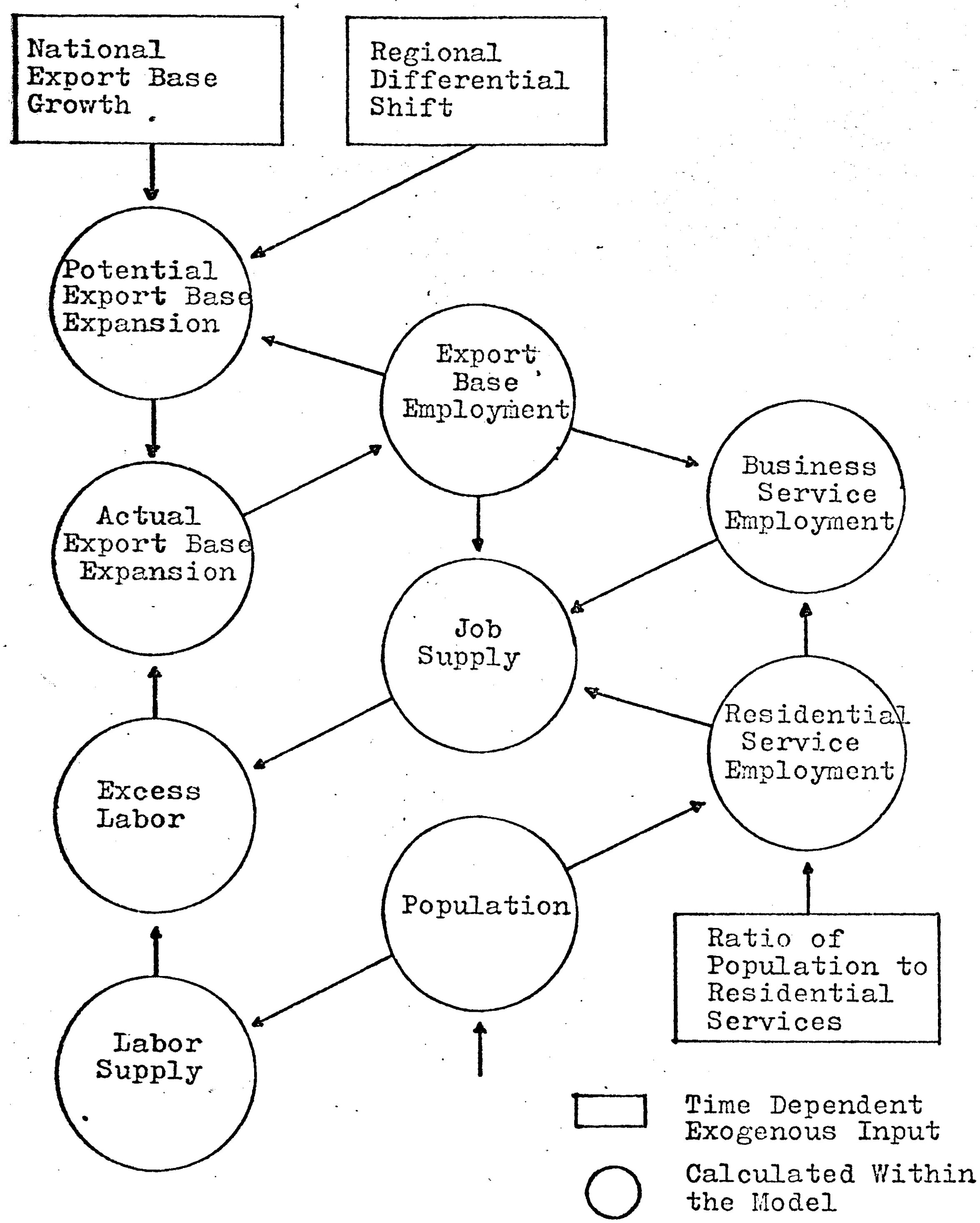


Fig. 7 Schematic of Employment Growth Model

(42) IEXR(t) = NIEXGR(t) * IEXPOT(t) * IEX(t) * EAT(t)

where

IEXR(t) = rate of growth of export base employment at time t

NIEXGR(t) = national rate of growth of export base employment

IEXPOT(t) = regional differential shift modifying potential for export base expansion

IEX(t) = current amount of export base employment

EAT(t) = attractiveness of employment force modifying potential export base expansion

The first two terms account for the proportional growth due to national expansion of export base employment and differential shifts due to particular regional conditions, such as the regional redistribution trends described in Chapter 3. The national rate of expansion of employment (Figure 3 of Chapter 3) takes into account shifts in market or consumption, and shifts in labor productivity. The differential shift term is an exogenously determined multiplier which is estimated on the basis of the region in which the city is located. The modified rate of expansion is multiplied by the existing level of export base employment to calculate the potential increase in employment. This potential increase is modified by a multiplier (EAT) which reflects the availability of excess labor within the city. The variation of EAT with the excess of labor over jobs, shown in Figure 8,

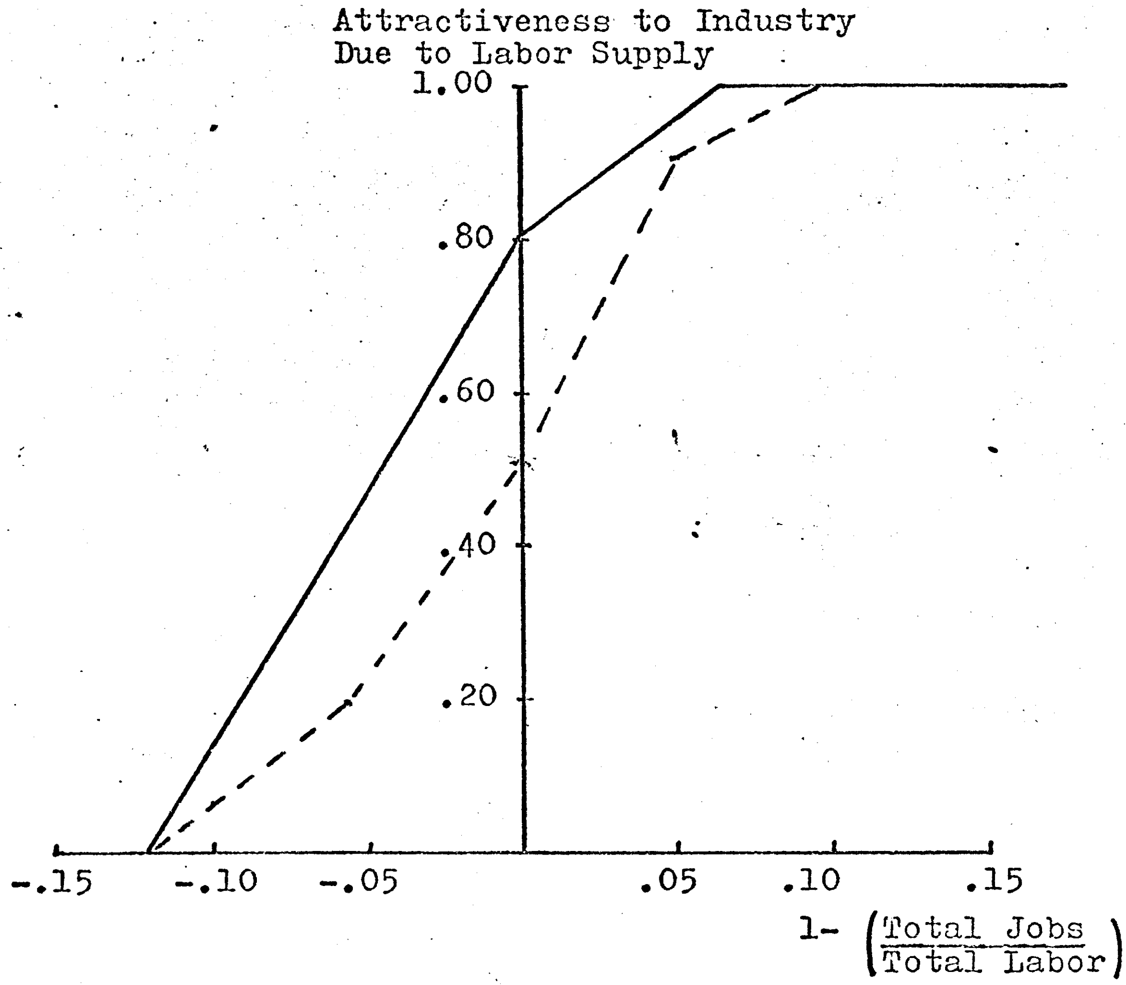


Fig. 8 Attractiveness of Metropolitan Area for Export Base Expansion Due to Availability of Labor Supply

Source: Swanson, Carl, "A Model of Kent County Michigan", unpublished report by A.D. Little Co., 1969, (to be published in Journal of American Institute of Planners).

is based on data collected by Swanson. (See citation for Figure 8.) When the number of available jobs exceeds the labor supply by 12%, expansion of the export base is cut off. As the deficiency of labor declines, the attractiveness of the area increases and the growth of the export sector approaches the exogenously determined maximum potential. Thus, the growth of the export base sector is strongly dependent upon conditions both inside and outside the metropolitan area.

The formulation of growth of employment in the residential services follows that used in the model of the Susquehanna River Basin by Hamilton,[6] et al. The residential service employment should be a function of population income composition at a given point in time, and per capita consumption and labor productivity over time. However, Hamilton found that it was not necessary to include income composition at each point in time because: 1) income reflects the general wage level of the region and increased spending in services may not produce proportionately higher employment because of wage differentials, and 2) the increased spending on services by persons with higher incomes may be used to buy more expensive goods and services which do not require more employees.[7] Thus, in the model the employment in the residential service sector is proportional to total population and not to the income distribution of the population (Figure 9).

An examination of the trends in the ratio of the total number of employees in the residential services in the U.S. to the total U.S. urban population shows that the ratio has increased steadily over the sixty years between 1900 and 1960 (Table 5), i.e., that the rise in productivity in the service sector is not offsetting the long term increases in per capita income and consumption of services.

TABLE 5. Ratio of Residential Service Employment to Total Population (RSPR)

	1900	1920	1940	1960
RSPR	.100	.106	.123	.165

Sources:
1. Bureau of Labor Statistics, Dept. of Labor, "Unemployment and Earnings Statistics for the U.S., 1909-1968," Bulletin #1312-6.
2. Historical Statistics of the U.S. from Colonial Times to the Present.

Thus, in the model the constant of proportionality between residential service employment and total population has been made a function of time.

Specifically, the equation used is

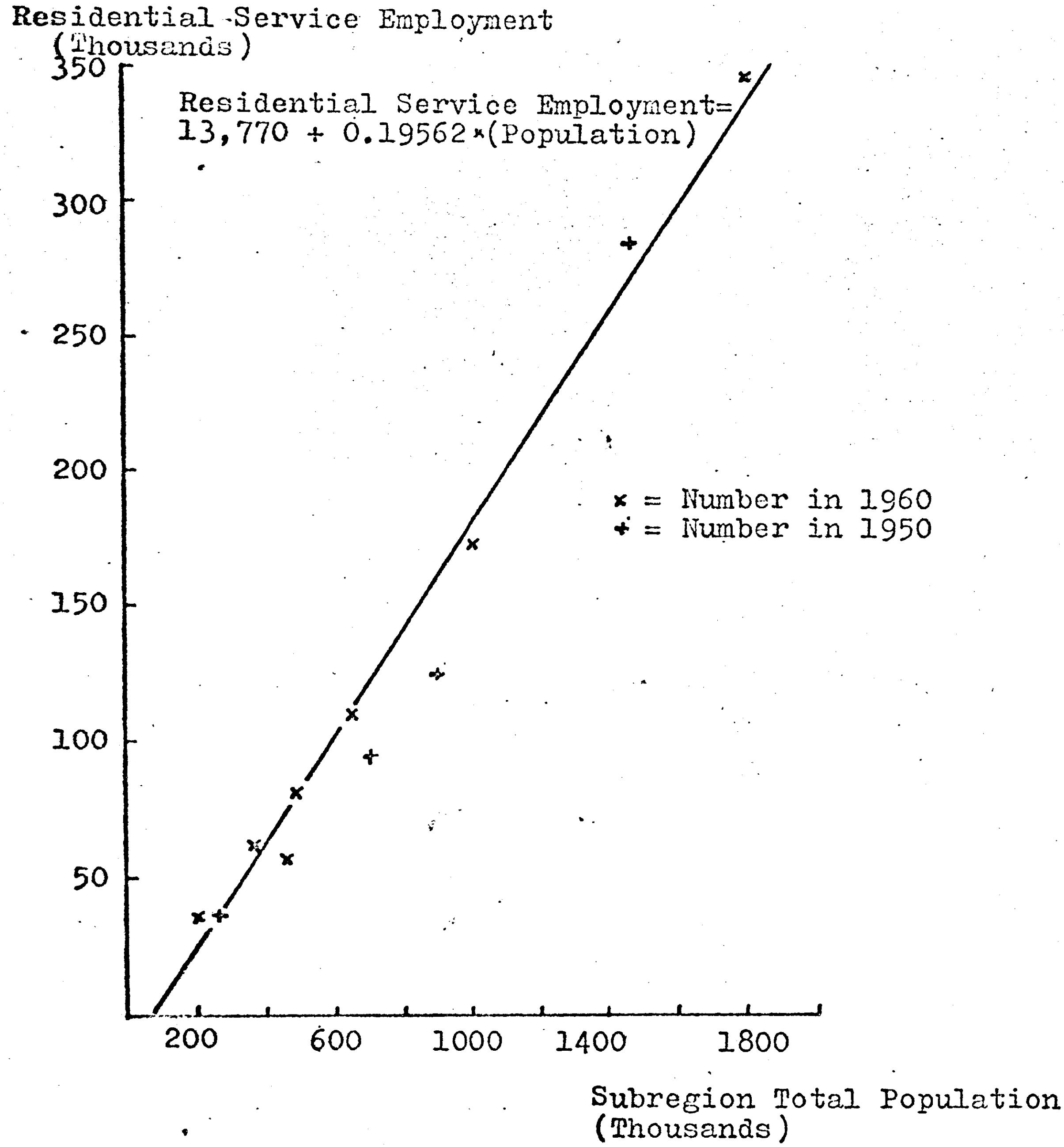


Fig. 9 Subregion Residential Service Employment Against Subregion Total Population, 1950.

Source: Hamilton, et al, Systems Simulation for Regional Analysis, M.I.T. Press, Cambridge, 1969, p. 170.

(47) $IRS(t) = P(t) * RSPR(t)$

where

IRS = employment in residential services
P = total population
RSPR = ratio of residential service employment to population (Table 5)

The final sector is the business service employment. The employment in this sector has been modeled as proportional to the total employment in the other two sectors, i.e.,

(46) $IBS(t) = BSR * [IEX(t) + IRS(t)]$

where

IBS = employment in business services
BSR = ratio of business service employment to employment in export base and residential services
IEX = employment in export base
IRS = employment in residential services

The value of the constant of proportionality BSR was checked over the period 1900 to 1960 and found to be essentially constant at a value of $0.22 \pm .02$.

In summary, the three equations given above (equations 42, 46, and 47) form the heart of the employment growth model.

3. Coupling between Population Growth and Employment Growth

Figure 10 shows the coupling between population

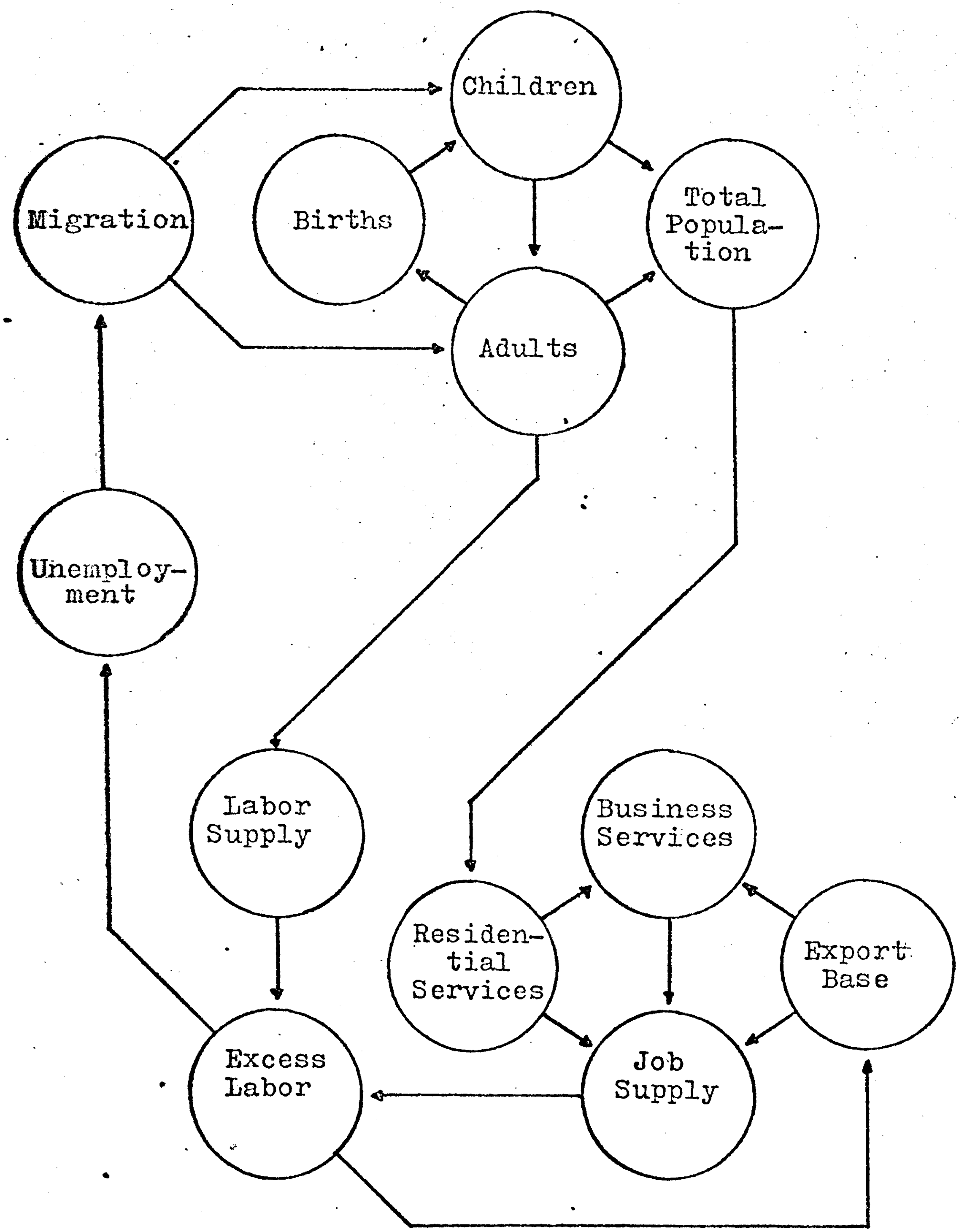


Fig. 10 Schematic of Linkages Between Population Growth and Employment Growth

growth and employment growth. The most direct coupling comes from increases in population driving an increased demand for residential service employment. A second type of coupling occurs through the dependence of population migration on rate of unemployment, of export base expansion upon excess labor supply, and of unemployment on excess labor supply. In the first stage of this process, the adult population is converted to a supply of labor through multiplication by a labor participation rate. The labor force participation rate (LFPR) has been assumed to be constant through time because

> The proportion in the labor force in this country does appear to be what Klein and Kosobud have happily termed one of the 'great ratios' of economics. Indeed, estimates of my own suggest that the proportion of the population of 14 years and over in the labor force was 55.5 percent under McKinley, was much the same under Harding, and even by Mr. Eisenhower's time had risen only 3 percentage points.[8]

The labor supply compared with the job supply available from all three employment sectors determines the excess labor supply which controls the expansion of export base employment, as was explained in the previous section.

The excess labor supply is then converted into a rate of unemployment as shown in Figure 11. If the labor market were perfect, the fraction of excess labor would exactly equal the unemployment rate and there would be no unemployment when the excess was zero or negative (solid curve). The inefficiency of the labor market is indicated by how far the actual curves are separated from the ideal curve. The market for upper skilled labor has been assumed to be more efficient than that for the labor force as a whole so the curve for the upper skilled labor force is closer to the ideal. These two rates of unemployment then influence the rate of migration of the two skill levels of adults and the children they bring with them, thus increasing the total population and the total labor force.

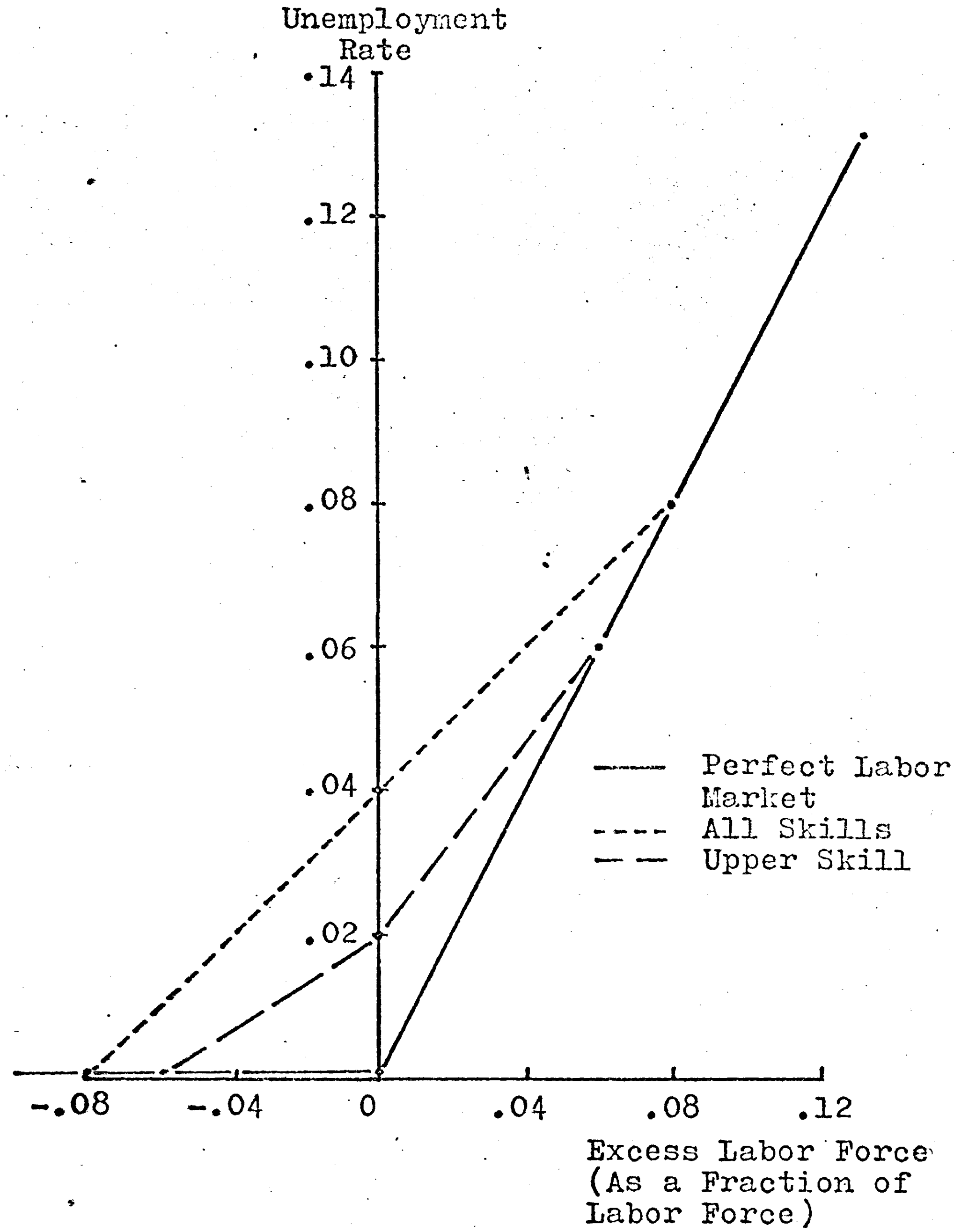


Fig. 11 Rate of Unemployment as a Function of Excess Employees

C. Housing Submodel

The housing submodel simulates the changes in the supplies of three types of housing (for low skilled population, upper skilled population, and abandoned) in both the suburbs and core city. The interactions controlling the changes in each area are identical so the housing market in only one area, the core city, will be discussed. The housing markets in the two areas are coupled through changes in the demand for housing as people move between the central city and suburbs, but the response of the two markets is decoupled in the sense that changes in housing supply in one area are not directly dependent upon the housing supply in the other. The division of the housing supply in each area into the categories of low skilled housing, upper skilled housing, and abandoned housing accounts for the housing submarkets existing because of differences in cost and location. The model also uses race as a third dimension for distinguishing submarkets, but the details of this partitioning will be described in the following section on the location submodel.

Figure 12 is a schematic of the primary state variables (levels) and their rates of change for the housing market

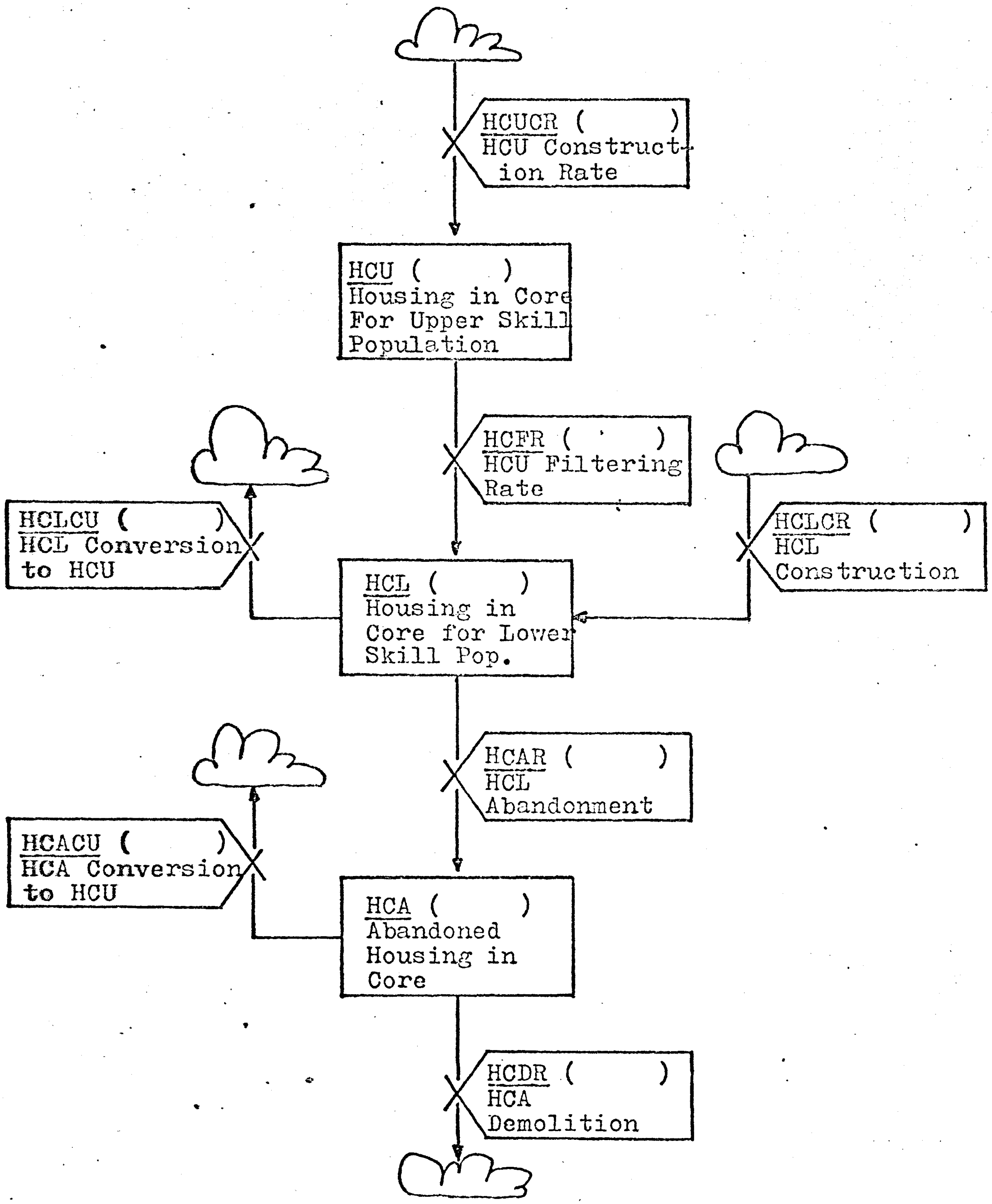


Fig. 12 Schematic of Rates and Levels in the Housing Sub-model for theCore City.
(An identical, parallel structure of rates and levels for the housing market of the suburbs is also contained in the model.)

of the central city. (For an explanation of the notation of the diagram and the distinction between state variables and their rates of change, see Section A of Chapter 6.) The primary state variables are the three housing stocks--housing for upper skilled population (HCU), lower skilled population (HCL), and abondoned (HCA). The corresponding variables for the suburban market are HSU, HSL, and HSA. The rates of change of these stocks include flows between the three types of housing (i.e., the 'filtering' of the housing supply), new construction, and demolition. The upper skilled housing stock is increased by the construction rate HCUCR and decreased by filtering (HCFR) down to the housing for lower skilled population. The lower skilled housing stock increases due to the filtering (HCFR) from above and government construction programs (HCLCR), and decreases as a result of abandonment (HCAR) and conversion (HCLCU). Abandoned housing increases due to the rate of abandonment of low skilled housing (HCAR), and decreases due to demolition (HCDR) and conversion to the upper housing stock (HCUCU).

The main driving force for changes in the housing stocks in each area is the balance between the supply of housing in the area and the demand for housing from the population living in that area. The balance is expressed as a ratio of supply to demand, but exact form of the ratio controlling each of the flows varies. The demand for housing can be modified due to economic conditions or government restrictions; the value of the ratio used to control the change can be an average over time rather than the instantaneous value, etc.

The formulation of the housing market used here takes particular note of the role of government intervention. The shifts in all three categories of housing are affected by these controls, but the strongest influence is on the housing for lower skilled population. As is discussed in detail below, the combination of low incomes, or ability to pay for housing, and high standards in building codes and construction controls have led to a formulation where the flow of housing units <u>into</u> the low income category is independent of the demand.

The first three parts of this section discuss each of three types of housing and the formulation of their associated rates of change separately. The fourth part is a description of the calculation of housing densities and residential land use, and the section concludes with an outline of the housing policy options. The treatment of the consequences of the interactions between the three types of housing is left until the analysis of the model in Chapter 8. It must be emphasized that developing a model which reflected the full intricacies and complexities of the housing market was not one of the main objectives of this research. The model discussed in this section has made a number of simplifying assumptions about both the structure of the market, e.g. failing to distinguish between rental and owner occupied units, and about the interactions between components, e.g. the formulation of the filtering and abandonment processes. A dynamic housing model was included within the urban growth model because of 1) the importance of housing as a determinant of residential location and a user of land in the city, and 2) the non-equilibrium inherent in changes in the housing stocks. The formulation here has concentrated on the characteristics of changes in the housing stocks as:

1. being strongly interconnected by the filtering from one level to another,
2. being driven by changes in population (taking

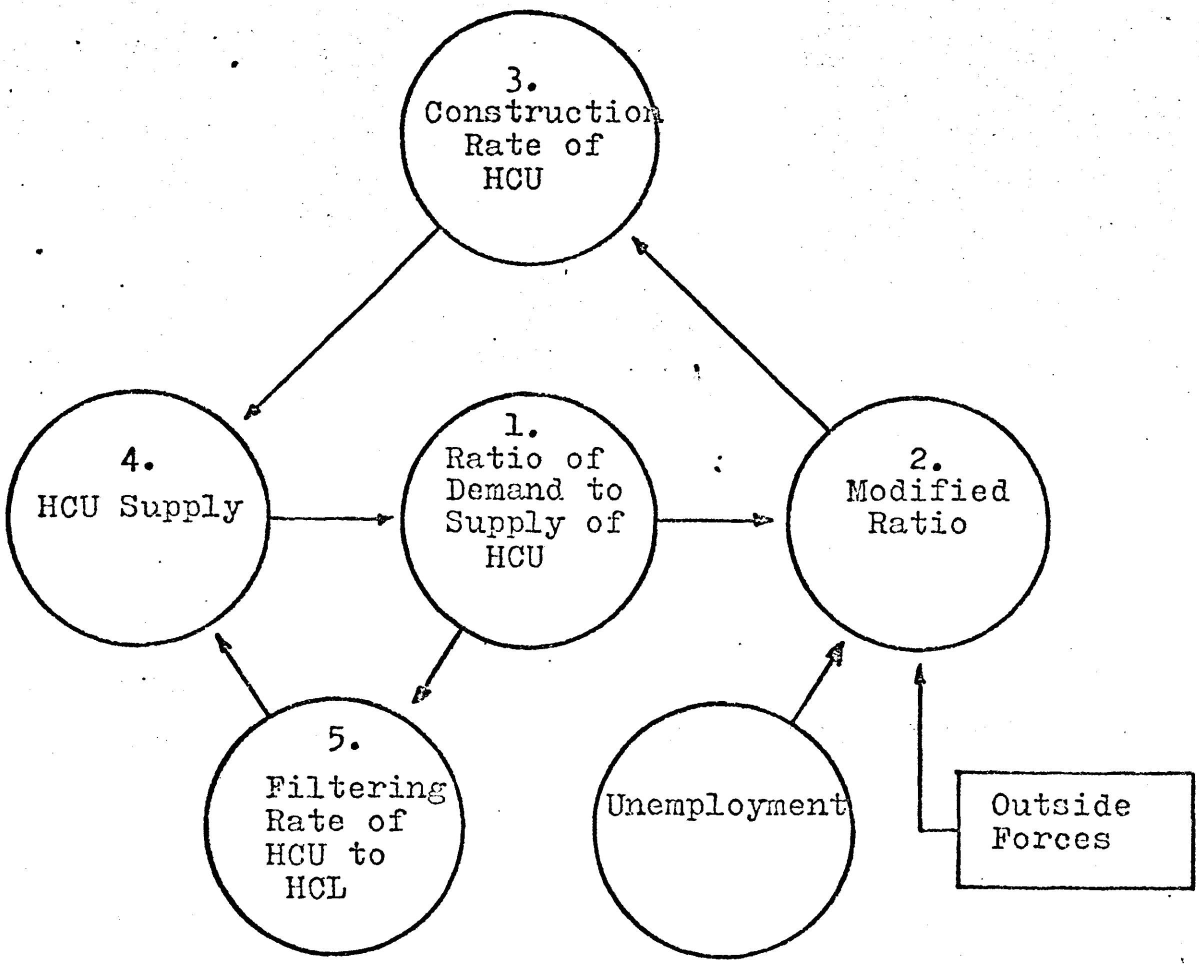
note of the importance of distinguishing between the ability of different income groups to register their demand for housing in the private market),

3. involving long time lags to change significantly the stock of housing,
4. absorbing smaller amounts of land as the degree of development increases.

The simplification of the housing model has occurred only at the expense of the ability to investigate many interesting and challenging problems concerning the dynamics of the housing market, and its interaction with external forces such as interest rate, materials costs, alternative government policies, etc. In particular, the model cannot determine the direct effects of governmental supports and financing, e.g. FHA and VA programs, on either the volume of new construction or the demand for housing. Once the direct impacts of such programs have been estimated by other models, they can be incorporated into the model created in this work and the effects on development and location patterns determined. This model is limited to showing the effects of shifts in housing demand, e.g. through rent or income supplements, or change in housing supply, e.g. through construction and demolition.

1. Housing for Upper Skilled Population

Figure 12 shows two rates governing the changes in the supply of upper skilled housing (HCU)--the construction rate (HCUCR), which increases the housing stock, and the filtering rate (HCFR), which shifts upper skilled housing down to lower skilled housing. Figure 13 shows the interactions which govern these two rates and illustrates the key role of the ratio of housing demand to supply. The construction of new housing is governed by the modified ratio of demand to supply (LOOP 1-2-3-4-1). In the modified ratio the 'true' demand based on the upper skilled population in the area is decreased by unemployment within the city, and by outside controls, e.g. those imposed officially during WW II or unofficially by high interest rates in the late sixties. The filtering is governed by the actual ratio of demand to supply (LOOP 1-5-4-1). As will be explained in the analysis of the housing model in Chapter 8, under normal conditions, i.e. when the modified ratio equals the 'true' ratio, the two rates can be combined into a single function



HCU = Housing for Upper Skilled Population in the Core
HCL = Housing for Lower Skilled Population in the Core

Fig. 13 Interactions Controlling the Changes in the Housing for Upper Skilled Population in the Core City.
(The structure of the interactions in the suburban market is identical.)

of the ratio of supply to demand. Then the formulation of the changes in HCU becomes equivalent to a simple negative feedback loop.

a) Construction of upper skilled housing

This discussion concentrates on the determinants of the total expansion of the supply of housing for the upper skilled population. The question of how this expansion is split between new construction on vacant land and conversion of existing housing is treated in Part 2 of this section. The equation governing the expansion of the upper skilled housing supply is

HCUCR = HCER * HCU

where

HCUCR = construction rate of upper skilled housing
HCU = the existing stock of upper skilled housing
HCER = the fractional increase per year in HCU

The variable HCER, which determines the rate of change of the housing stock, is a function of RHCUM, the modified ratio of demand to supply of HCU, as is shown in Figure 14. When the demand for housing exceeds supply, the ratio of the increase in the housing supply to the increase needed to achieve a ratio of demand to supply of one is a measure of the responsiveness of the housing market. This ratio can be expressed

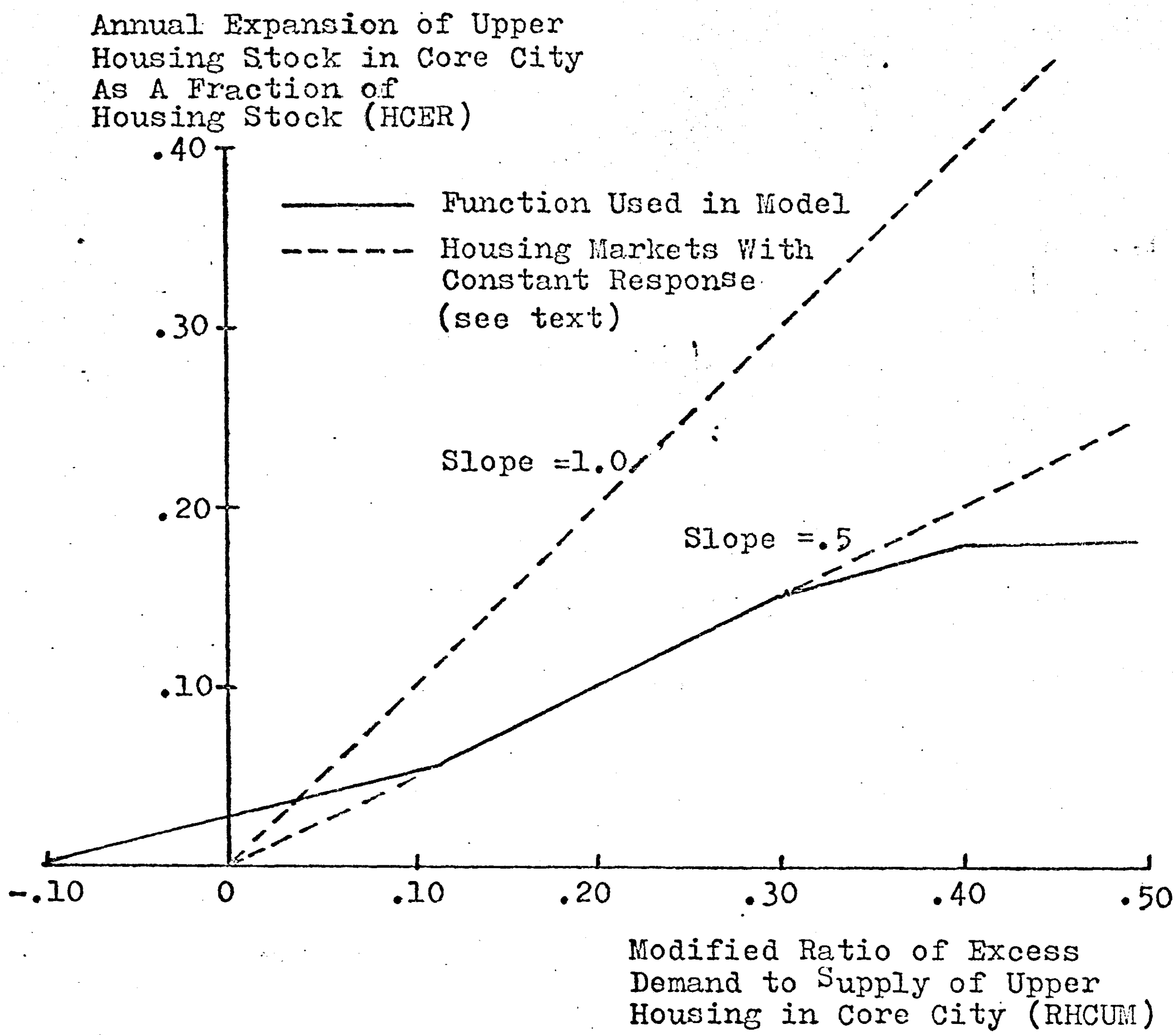


Fig. 14 Rate of Growth of the Upper Skilled Housing Stock as a Function of the Modified Ratio of Demand to Supply

algebraicly as

$$\frac{\text{Housing increase}}{\text{Incremental housing need}} = \frac{\text{HCER} \cdot \Delta t}{\text{RHCUM} \quad .0}$$

where

HCER $\cdot\Delta t$ = the expansion of the housing supply in time Δt and Δt has been taken as one year

RHCUM = the difference between housing supply and effective housing demand in the upper skilled housing market, with the difference expressed as a fraction of the upper skilled housing supply (See the next page.)

It can be expressed graphically as a slope in Figure 14. Specifically, the ratio at a given value of RHCUM is the slope of the line intersecting the curve for HCER at that value of RHCUM and passing through the origin. (See Figure 14.) A market in which supply deficiencies were eliminated in one year independent of the amount of excess demand would be represented by a straight line of slope 1.0 intersecting the RHCUM axis at RHCUM = 1.0; if only one third of the deficiencies were eliminated each year, the slope would be .33, etc. (Note that the slope defining the 'responsiveness' of the housing market is not the local slope of the plot of HCER in Figure 14.)

Functional dependence of HCER upon RHCUM shown in

Figure 14 was derived in terms of this concept of responsiveness. The curve bends over at higher values of excess demand, reflecting the decline in the markets' responsiveness, i.e. saturation of production. For values of RHCUM near 1.0, i.e. near the point where excess demand equals zero, the market has a residual production of 3% of the existing stock because of normal turnover. In the normal operating range, corresponding to excess demands of between 5% and 30%, the market produces about one-half of the excess demand in a year. The value of one-half was chosen on the basis of Muth's analysis[9] of housing production and demand in the U.S. between 1915 and 1941 in which he found that the housing market as a whole produced one-third of the excess demand annually. The responsiveness was increased to one-half because this formulation is only considering the construction of upper income housing. This submarket should be more responsive than the total market considered by Muth because the later includes the low income sectors which have essentially zero response.

The demand to supply ratio used in computing HCER is the actual ratio modified by multipliers for effects of local conditions inside and outside the urban area.

RHCUM = RHCU * HDMI * HDMX -1

where

RHCU = actual ratio of demand to supply of upper skilled housing
HDMI = housing demand multiplier due to internal conditions within the city
HDMX = housing demand multiplier due to external conditions

In this formulation, the only factor within the city, other than the housing supply and demand, which is assumed to affect the ratio is the rate of unemployment of the upper skilled population. As is shown in Figure 15, this factor is assumed to depress the demand only in cases of extreme unemployment (greater than 5%), and it did not significantly affect most of the runs. The external multiplier for demand HDMX was a time dependent exogenous input to the model whose primary function was to shut off the construction of housing during WW I and WW II. It could also be used to incorporate the effects on demand of fluctuating interest rates, material prices, etc., but this was not done in this work. (For a summary of other factors which have been suggested as influencing housing construction and a general review of housing models, see Grebler and Maisel.[10]

The Federal home mortgage programs are an obvious ommission from the discussion thus far of factors influencing new construction. As was shown in Figure 7 of Chapter 3,

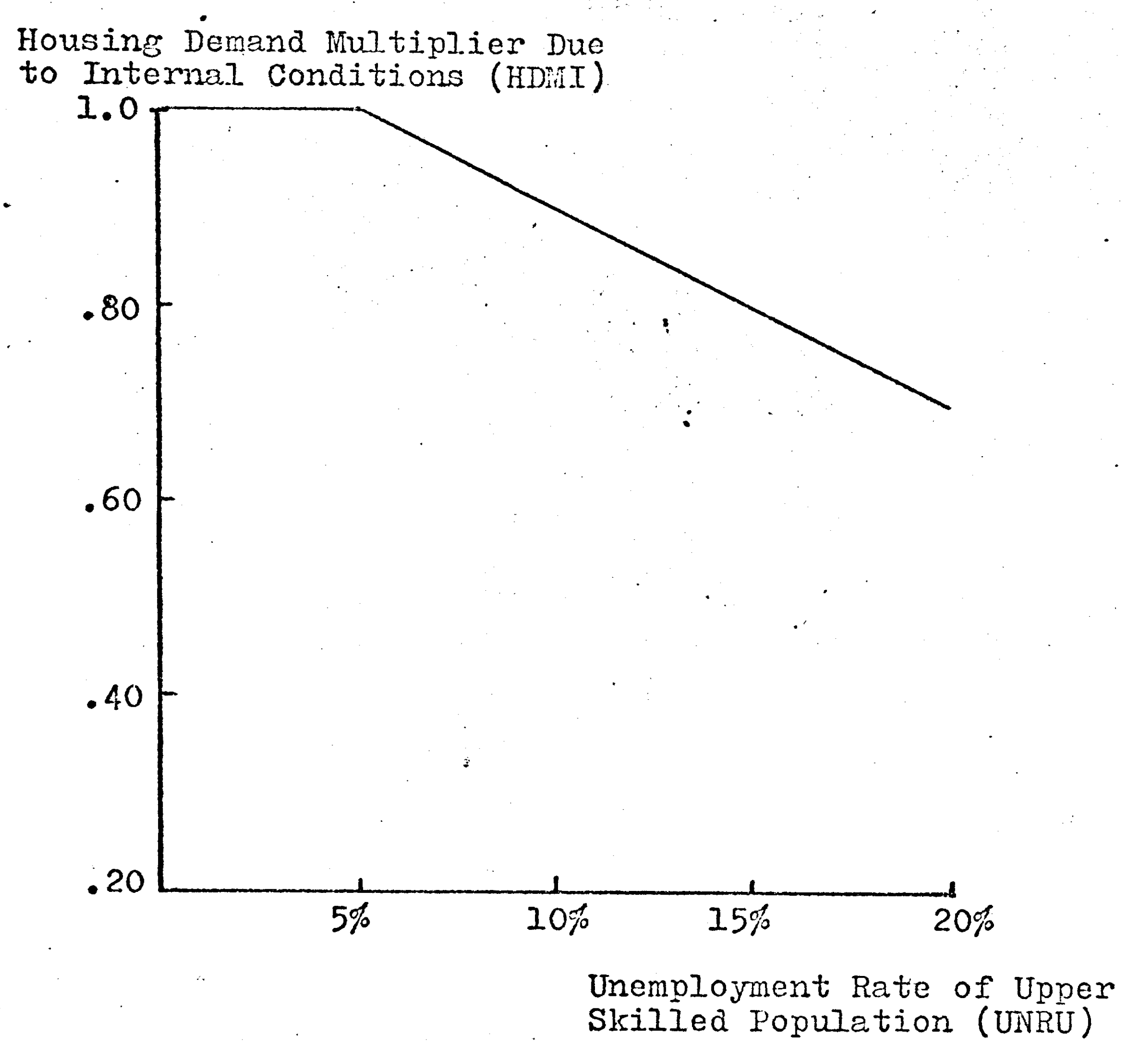


Fig. 15 Influence of Unemployment of the Upper Skilled Labor Force on the Demand for New Upper Skilled Housing.
The modified demand driving the construction of new upper skilled housing is the actual demand multiplied by HDMI and one other term (see text).

since beginning in the mid-thirties these programs have supported as much as 50% of the new non-farm housing in a given year, and have usually financed between 20% and 30% of the new housing starts in any given year. Although large in terms of the fraction of homes affected, the programs are very restricted in terms of the types of housing they influence. They almost exclusively support moderate income home-owners (in 1967 only 1.5% of the home-owners they affected had incomes of less than $4800 per year) and single family detached housing (as of 1967, 96% of the existing FHA units were single family, and 97% of those were detached housing).[11]

The influence of these programs could have been included in this urban development model in two primary ways--first, as an influence on the total volume of housing construction and second, as an influence on the distribution of that construction between central city and suburb. Neither of these influences have been included because of the inability of this model to translate financial support programs into the number of additional units produced or demanded.[12] This housing model includes only the effects of direct construction programs initiated by the government, e.g. the addition of public housing.

b) Filtering of upper skilled housing to lower skilled

Filtering of housing as used in this work refers to units of housing which were originally built for upper skilled population becoming available to lower skilled population because of a decline in prices or rents. Of the many definitions of filtering which have been proposed, Lowry's "change in the real value (price in constant dollars) of an existing dwelling unit" comes closest to the meaning used here.[13] Over the time spans being dealt with in the model, the real incomes and thus the ability to pay of the population have increased substantially, but the redistribution of demand this implies is treated through the demand side of the formulation rather than in the filtering of the housing supply.

In the model the driving force for filtering is the tightness of the market for upper skilled housing as measured by the ratio of demand to supply of upper skilled housing.

> As demand for units at a given price (or rent) declines relative to supply, the units will either fall in price (or rent) or the proportion that stand vacant will rise, or both. Thus the same factors which create a potential for filtering create a potential for increased vacancies.[14]

The exact formulation of the filtering rate in the model is given by

HCFR = NHFR * HFMC * HCU

where

HCFR = the filtering of upper skilled housing to lower skilled in units per year
NHFR = the normal rate of filtering of the units (fraction of HCU per year)
HFMC = the housing filter multiplier for the core city based on the tightness of the housing market in the core city (Figure 5)

The formulation interprets filtering as an aging or deterioration process which is slowed or accelerated by the tightness of the housing market. Under 'normal' conditions, i.e. supply equal to demand in the upper skilled housing market, the multiplier HFMC is equal to 1.0. The normal filtering rate (NHFR) of 3% makes the average life of upper skilled housing to be 33 years. In other words, each year 3% of the stock filters into lower skilled housing, exactly matching the 3% new construction under these conditions. If supply is greater or less than demand, the filtering increases or decreases as shown by the multiplier in Figure 16. With 20% excess supply, the housing filtering multiplier increases the rate of deterioration by a factor of 4 to 12% per year, decreasing the average life of upper skilled housing to slightly over 8 years. With 20% excess demand, i.e. a tight market,

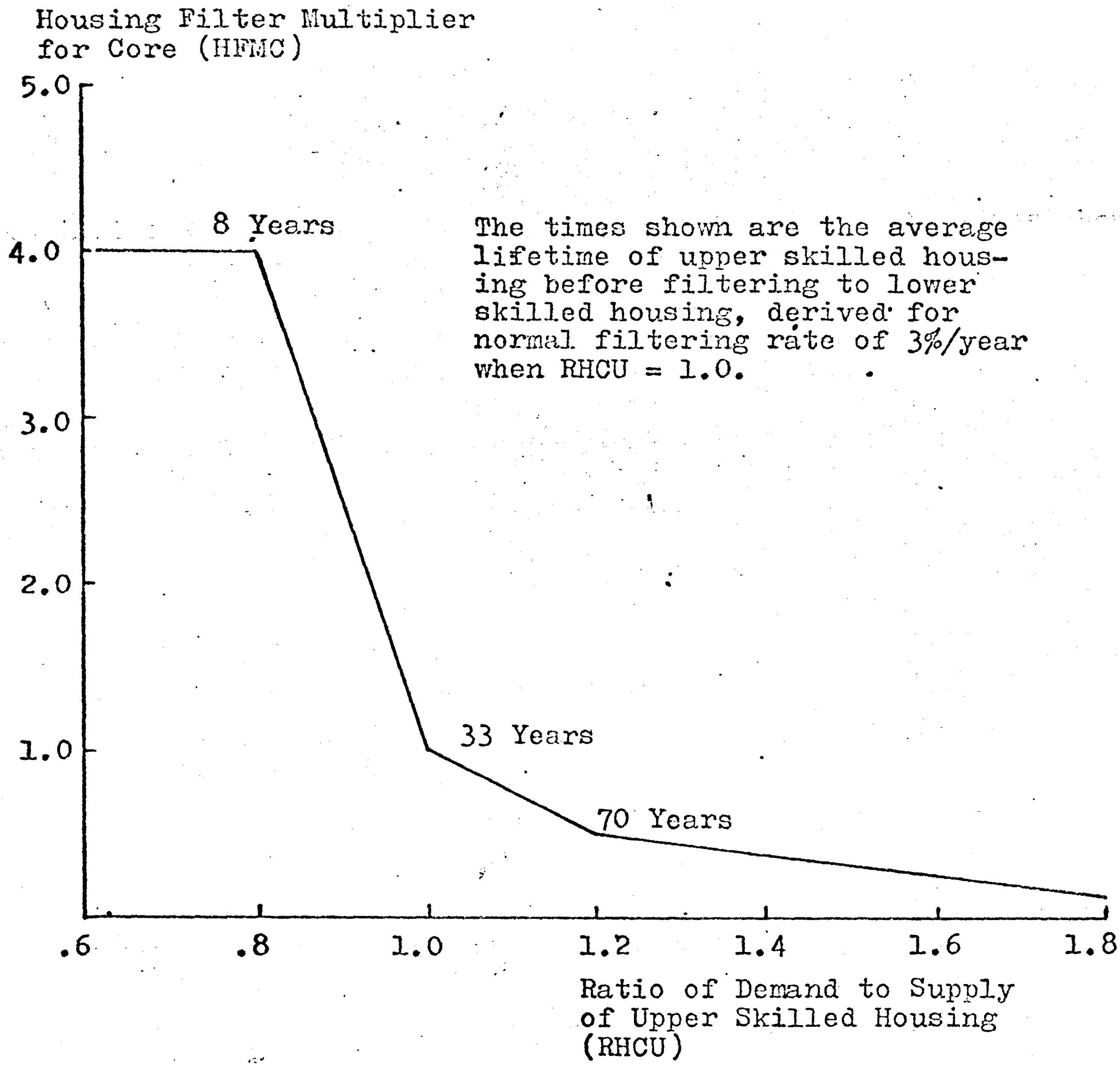


Fig. 16 Affect of Ratio of Demand to Supply of Upper Skilled Housing on the Filtering Rate of Upper Skilled Housing Down to Lower Skilled Housing. The actual filtering rate is calculated by multiplying the normal filtering rate (NHFR) by the multiplier HFMC.

the filtering rate has been cut by a factor of two to 1.5%, and the lifetime of the housing increased to just under 70 years.

The filtering rate and construction rate act together to keep the upper skilled housing stock in equilibrium with demand. When RHCUM = RHCU, the behavior is straightforward. An excess of demand over supply increases construction and decreases filtering, thus raising supply to meet demand. An excess of supply decreases construction and increases filtering, thus causing a net loss in the housing stock. For constant demand the upper skilled housing stock does have an equilibrium point with supply equal to demand and the filtering equal to the construction rate. If the modified ratio of housing demand to supply is different from the actual ratio, the equilibrium housing stock is shifted, but the behavior is essentially the same. This formulation is reasonable from the standpoint of the upper skilled housing stock, but what are the implications for the lower skilled stock?

2. Housing for the Lower Skilled Population

Figure 12 shows four rates affecting the stock of lower skilled housing--HCFR, the filtering of housing down from the upper skilled stock; HCLCU, the conversion of lower to upper; HCAR, the abandonment of lower skilled housing; and HCLCR, the government construction programs. Figure 17 shows the interactions which determine these rates and the interactions between them.

a) Additions to the supply

One of the basic assumptions in this formulation of the lower skilled housing market is that the flows of housing into the lower skilled housing stock, HCL, are independent of the ratio of demand to supply in that market, i.e. there is no feedback in either direction between HCL and the two rates which add to it. One of the rates controlling the outflow of units from HCL is a function of the ratio of demand to supply, so some control is exercised, but the effectiveness of this control is questionable.

The normal way for the supply to demand ratio to affect the increase in HCL is through new construction of HCL by the private sector. However, several factors, e.g. the social reforms in building and sanitation codes in the late nineteenth and early twentieth century,[15] have eliminated the participation of the private sector. These standards,

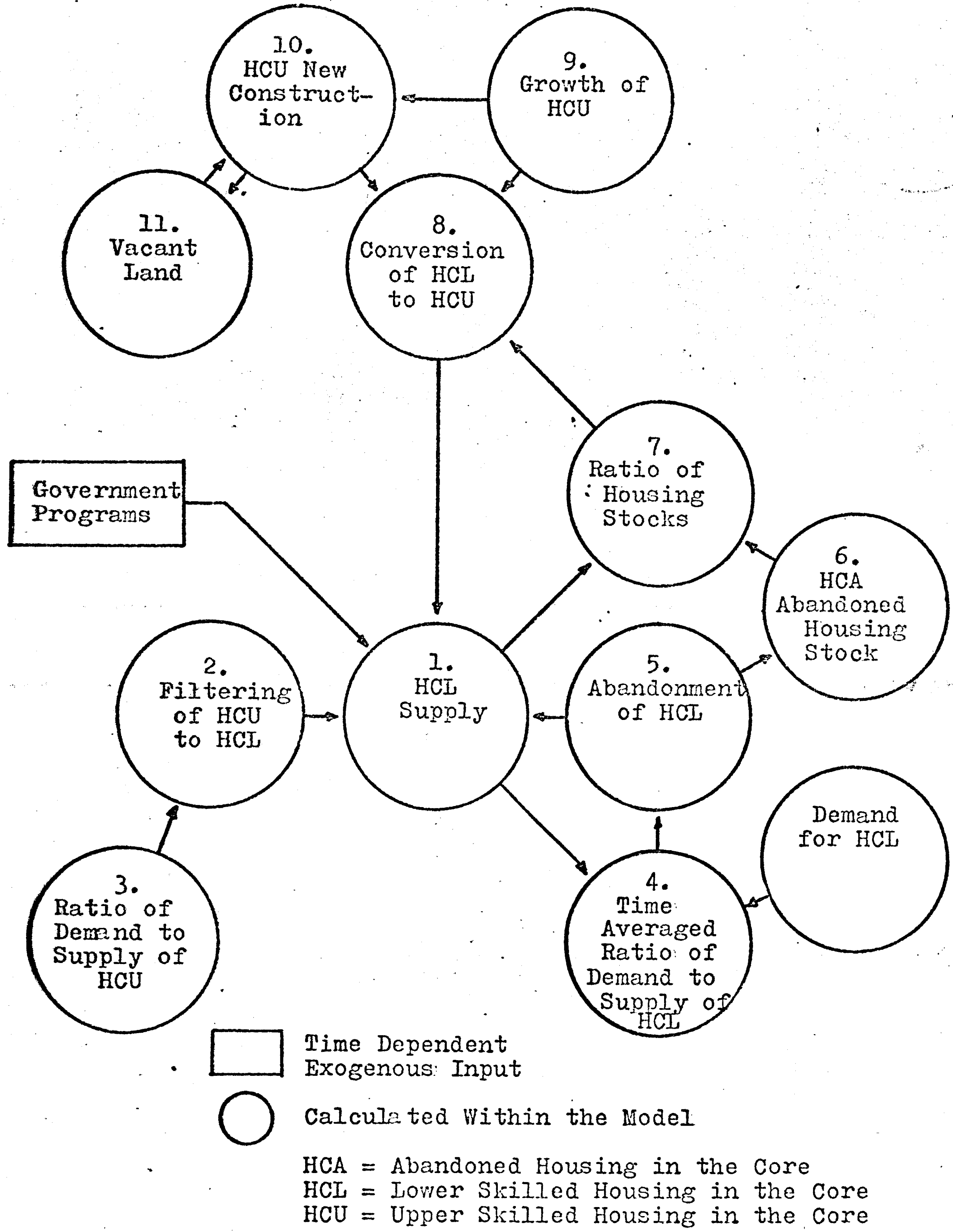


Fig. 17 Interaction Controlling the Changes in the Housing for the Lower Skilled Population in the Core City. (The structure of the suburban housing market is identical.)

together with the normal costs of land in urban areas and the interest rates of long term loans, have raised the costs of building housing above the level that can be paid by the low skilled population of the U.S. This is not a new problem of the 1950's and 1960's. The tenements built during the late nineteenth century before the reform laws were enacted or enforced were the last major expansion of low income housing in urban areas by the private sector. In 1934 Edith Wood wrote that "Supply and demand do not reach it [the housing problem] because the cost of new housing and the distribution of income are such that approximately two-thirds of the population cannot present an effective demand for new housing."[16]

If new construction by the private sector is not present, it could be argued that the public sector, i.e. government, will respond, but the experience thus far is that in general this has not been the case.[17] To some extent there is feedback between the need for housing and government action (if there is no problem there is no action), but public policy programs have been formulated here as exogenous inputs (Figure 17). No decision rules have been built into the model--one of its functions is to examine the alternatives of different interventions.

With both sources of new construction eliminated, the only remaining way in which HCL could influence the flow of additional units into it is through the filtering rate HCFR. However, HCFR has been formulated as a function of only the tightness of the upper housing market, and not the lower. (LOOP 1-5-4-1 in Figure 13, CHAIN 3-2-1 in Figure 13.) The justification for this is the difference in the ability to pay of the two population classes, i.e. property owner will always be able to earn a larger return on his property by dealing in the upper skill housing market than in the lower. The tightness of the lower market does not affect the potential return from dealing in the upper market. If the upper market is tight (demand greater than supply), the owner will clearly want to maintain his property in the upper market independent of how tight the lower market may be. If the upper market is loose (supply greater than demand), the upper supply will filter down because of the opportunity to attract tenants. The upper skilled housing offers 'more housing' at the same price when it first filters down, thus it can displace the marginal components of lower skilled housing stock independent of the tightness of the lower market.

No direct feedback exists between the degree of housing need in the lower level and the filtering rate from the upper level. However, there is an interaction through the shifts in demand due to the influence of population composition on residential location decisions which can serve an equivalent function in some situations. As will be discussed in the next section, the attraction of an area for upper skilled population is a function of the composition of the population living in that area. If the shortage of housing in the lower market is due to an influx of low skilled population, while the upper skilled population remains relatively fixed, the area becomes less attractive, and the upper skilled population moves out. The flight of the upper class causes an excess of housing supply, i.e. the filtering of housing to the lower level increases in 'response' to the increase in demand. In general, however, the lower skilled housing market must depend upon the feedback in the outflow of units to attempt to balance supply and demand. The basic problems of this type of control in dealing with a growing lower skilled population should be clear--they will be discussed in the following chapter.

b) Depletion of units due to conversion and abandonment

The expansion of the housing in the upper stock HCU which was discussed previously can occur through either construction on vacant land or construction on occupied land after demolishing the existing land use (the reverse filtering of lower units directly to upper units has been assumed to be negligible). The latter process is described by the 'conversion rates' HCLCU and HCACU (see Figure 12) of lower skilled and abandoned housing respectively. Conversion of other land uses to residential was not included because studies of land use transitions indicate that the residential to residential conversions dominated the total conversions to residential use.[18]

The rate HCLCU is determined by two factors. First, the volume of conversion (HCUC) required to meet the expansion of the upper housing stock (HCU) is calculated on the basis of the total expansion of HCU and the amount of vacant land available (CHAIN 9-10-11-10-8 in Figure 17). Second, the number of units to be converted are allocated between the low skilled stock (HCL) and the abandoned stock (HCA) (LOOP 8-1-7-8 in Figure 17). The volume of conversion is given by

HCUC = HCER * HCU * (1.0 - FHCV) * RHDC

where

HCUC = total number of units converted from HCL and HCA to HCU
HCER = rate of growth of HCU
HCU = existing stock of upper skilled housing
FHCV = fraction of the increment in HCU constructed on vacant land, i.e. not coming from conversion of existing units
RHDC = ratio of the average density of existing units in the core to the density of the new units being added

The product of the first two terms on the right hand side is the number of units added to HCU, multiplying by the third term, yields the number of units which have to be supplied from conversion, and the final term corrects for the change in density between the units being displaced and the units added.

The fraction of units constructed on vacant land (FHCV) is a function of the fraction of the land in the area which is occupied (Figure 18). When less than 40% of the land is occupied, all of the housing construction is assumed to take place on vacant land and there are no conversions. (FHCV = 1.0). As the fraction of land occupied increases from 40% to 100%, FHCV drops sharply to zero, i.e. to having all the construction take place on converted land.

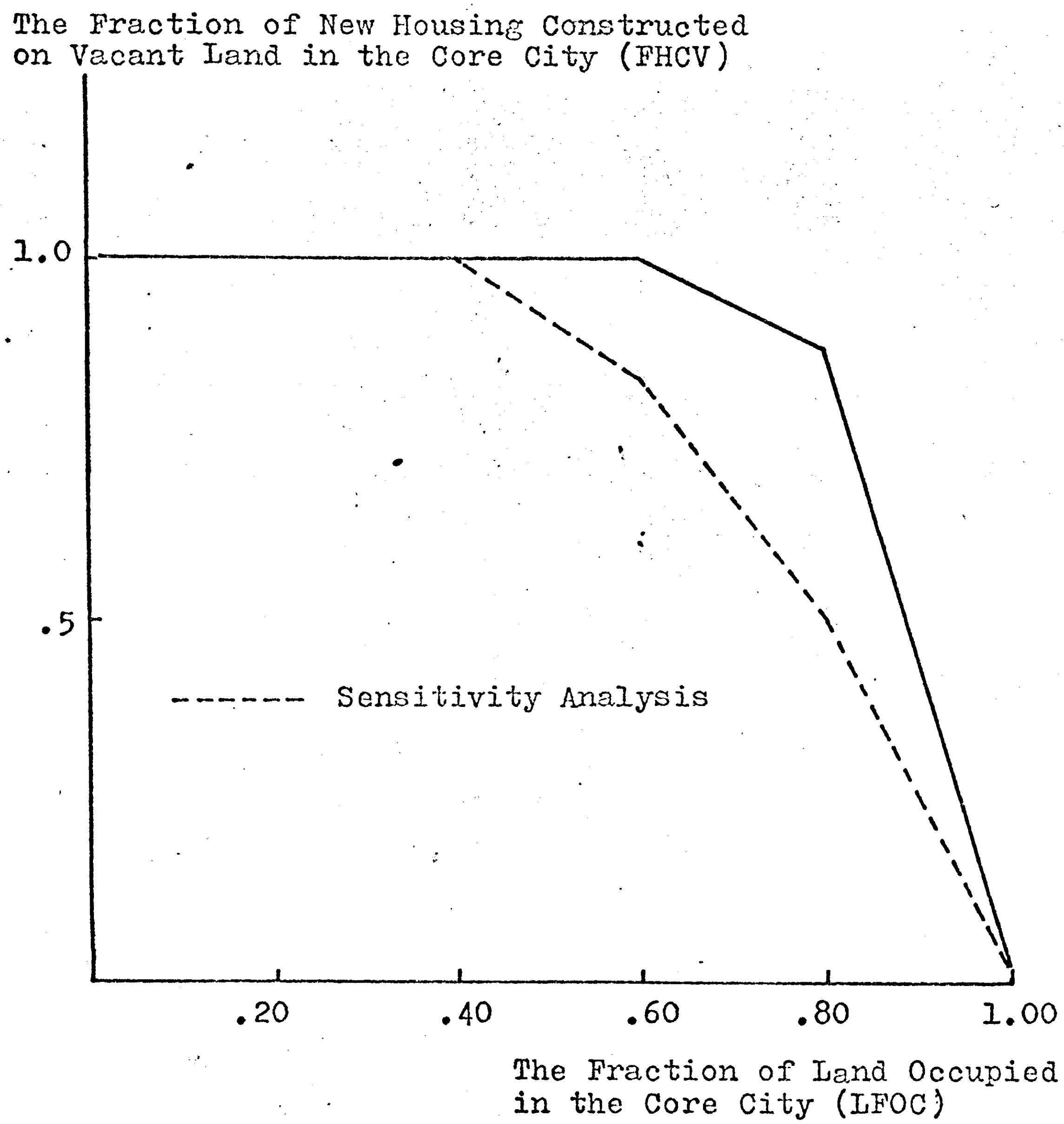


Fig. 18 The Fraction of New Units of Upper Skilled Housing Which are Constructed on Vacant Land as a Function of the Fraction of Land in Use in the Core City.
(Housing units not constructed on vacant land require demolition of an existing land use before they can be constructed.)

Given HCUC, the total number of existing units which need to be converted, the allocation of the units to be demolished between lower skilled and abandoned is simply proportional to the available stocks in those two classes.

$$HCLCU = HCUC * (1.0 - RHSC)$$
$$HCACU = HCUC * RHSC$$
$$RHSC = \frac{HCA}{HCA + HCL}$$

where

HCACU = the number of HCA units converted to HCU
HCLCU = the number of HCL units converted to upper skilled housing
RHSC = the ratio of housing stocks in the core city
HCL = lower skilled housing supply in the core
HCA = the abandoned housing in the core
HCUC = the total number of units needed for conversion

Abandonment is the second way of depleting the lower housing stock. Abandoned housing is distinguished from vacant housing by the severe deterioration which makes habitation impossible and rehabilitation to even minimum standards prohibitively costly. Although firm statistics are difficult to obtain, there appears to have been a sharp rise in the abandonment of buildings in the older central cities during the last five years. The appearance of "half forgotten neighborhoods with a bombed out, end of a war appearance" has received increasing attention by both the press and professional analysts.[19] It is possible to formulate abandonment as occurring primarily as an economic response to an increase in vacancies in a housing market which imposes fixed costs (e.g. real estate taxes, and minimum standards of maintenance). As vacancies increase, rental income decreases, the cash flow on the property becomes negative, and at some point the owner abandons the property rather than continue to take the operating loss.[20] However, the preliminary studies on abandonment carried out thus far have shown that the problem is also strongly influenced by social, psychological and political forces.[21]

This model will simplify the processes involved in abandonment and formulate it as driven solely by the vacancy rate, i.e. by the ratio of demand to supply in the lower skilled housing market (LOOP 4-5-1-4 in Figure17). In the model, the abandonment of lower skilled housing (HCAR) is given by

$$HCAR = NHAR * HAMC * HCL$$

Where

HCAR = the number of units abandoned per year
NHAR = the fraction of units in HCL abandoned each year when supply equals demand, i.e. no vacancies
HAMC = the housing abandonment multiplier for the core which increases the normal rate of abandonment as vacancies increase (Figure 19)
HCL = the stock of lower skilled housing

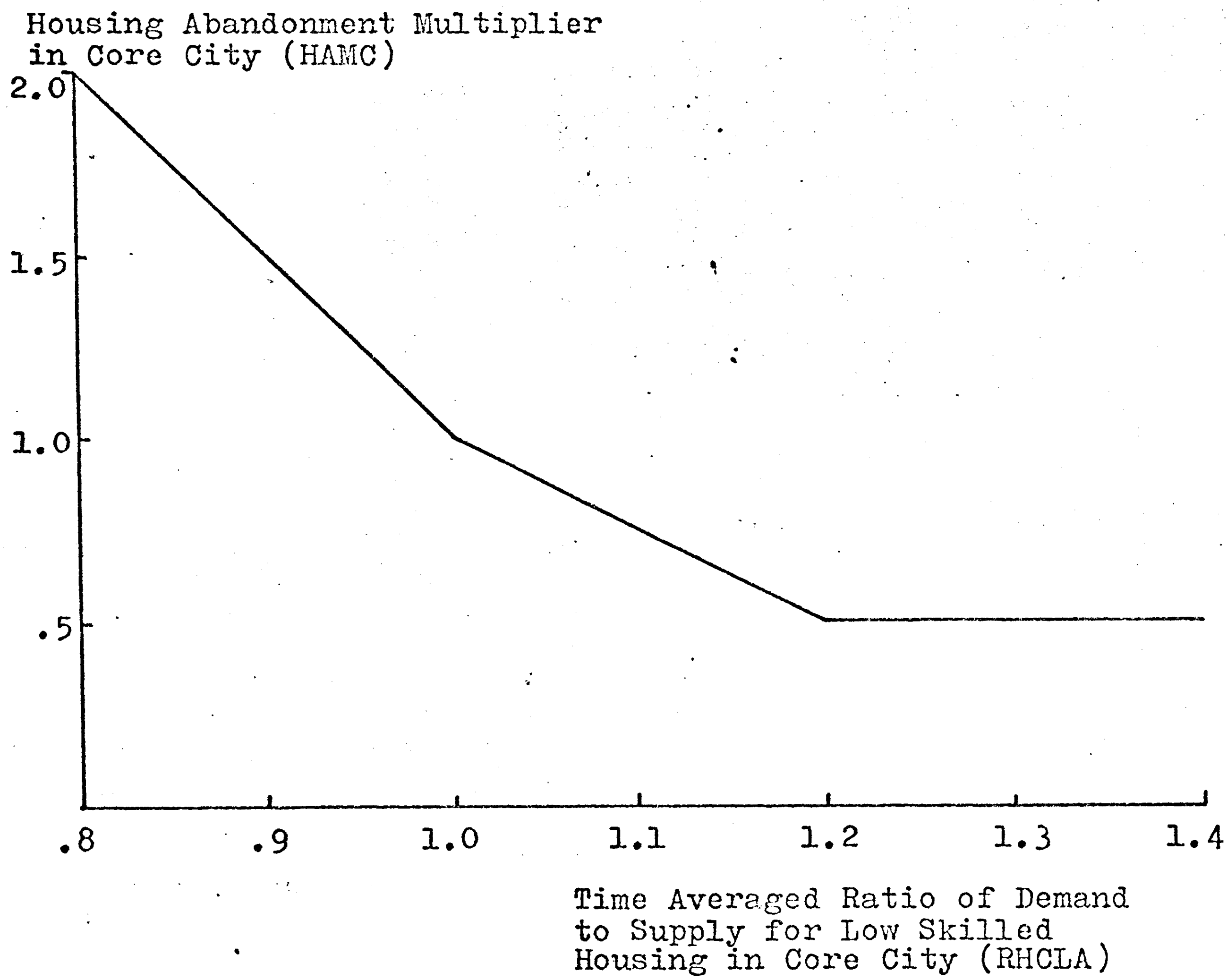


Fig. 19 The Multiplier of the Rate of Abandonment of Lower Skilled Housing as a Function of the Time Averaged Ratio of Demand to Supply in the Lower Skilled Housing Market
(The rate of abandonment is the normal rate (NHAR) times the multiplier HAMC.)

The housing abandonment multiplier (HAMC) is a function of the vacancy rate averaged over time rather than the instantaneous rate. Although in extreme cases vandalism can reduce vacant buildings or even individual units within buildings to an uninhabitable state within days after vacancies occur, the normal process is one of deterioration over a period of years. Extended periods of high vacancy reduce cash flow and expenditures for maintenance and upkeep. The model has assumed that the high rate of vacancies must be maintained for several years before the decline in maintenance significantly increases the flow of abandonments.

The scale of the rate of abandonment is set by the constant NHAR, the 'normal' housing abandonment rate when supply equals demand, while the range of variation of the rate is determined by the housing abandonment multiplier HAMC shown in Figure 19. The normal rate was set at 1% of the lower stock and range of variation set at approximately a factor of 4 on the basis of the limited data available in the studies cited in notes 19 and 21.[22]

3. The Stock of Abandoned Housing

Figure 12 shows that in the model the changes in the stock of abandoned housing (HCA) are governed by the three rates HCAR, the inflow of abandoned housing from the lower skilled stock HCL, HCACU, the removal of abandoned units to supply space for construction of upper skilled housing, and HCDR, the demolition of abandoned housing. Figure 20 shows the interaction of these rates with the abandoned housing stock HCA. The first two rates have already been discussed in part 2, and their interactions shown in Figure 20 are virtually identical to those in Figure 17.

The annual demolition rate has been formulated as removing a constant fraction of the abandoned housing present at the beginning of the year. As the number of abandoned units increases, the volume of demolition increases (LOOP 1-2-1 in Figure 20), but the proportion of the units being removed remains fixed.

The equation for the demolition rate HCDR is

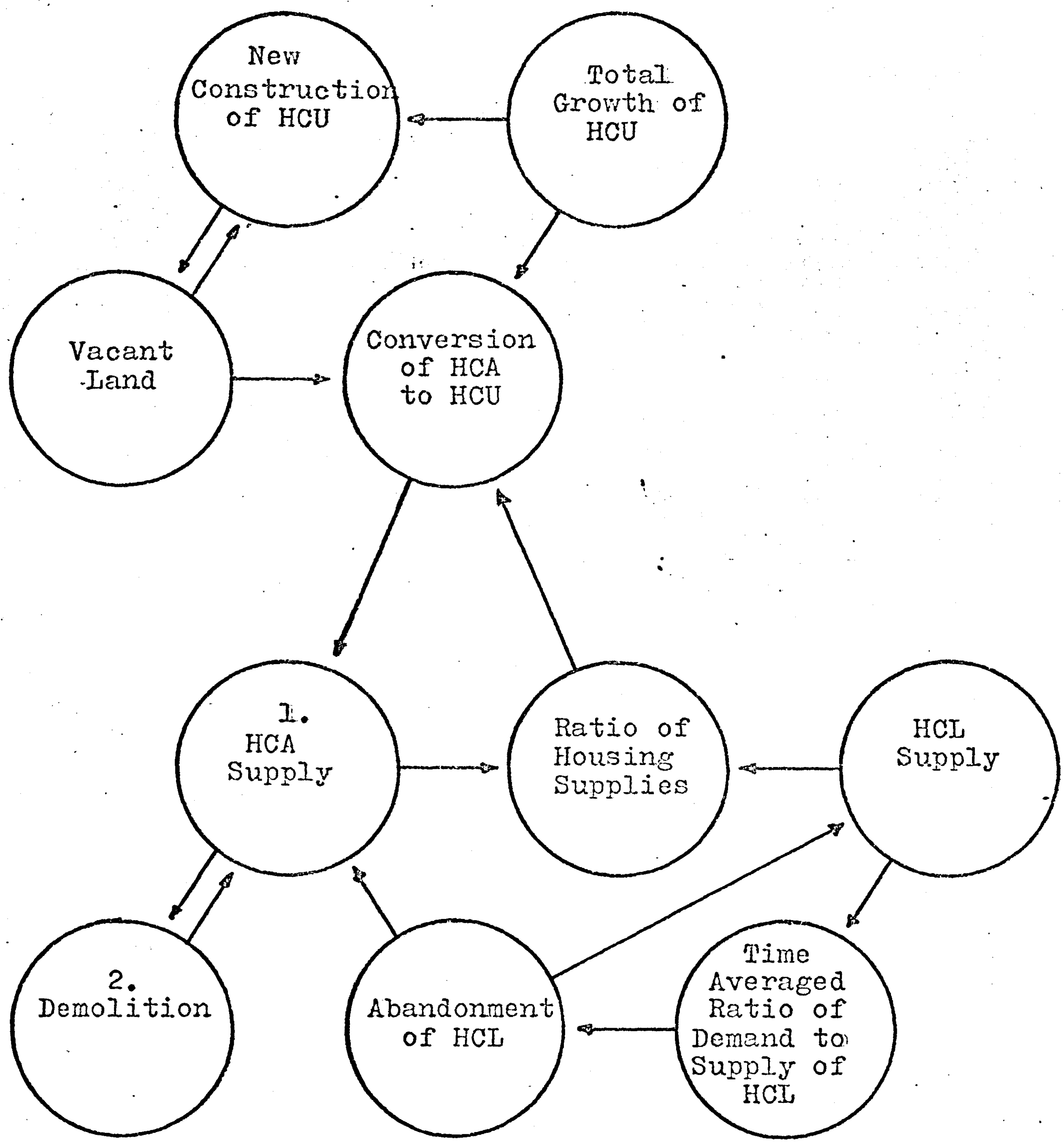
$$HCDR = NHDR * HCDP * HCA$$

where

NHDR = the normal housing demolition rate expressed as a fraction of the abandoned units removed per year

HCDP = a switching function which produces a step change in NHDR at a specified time during the simulation. It is equivalent to instituting a special housing demolition program

HCA = the stock of abandoned housing



HCA = Abandoned Housing in Core
HCL = Lower Skilled Housing in Core
HCU = Upper Skilled Housing in Core

Fig. 20 The Interactions Controlling the Changes in Abandoned Housing in the Core City. (The structure of the suburban market is identical.)

The constant NHDR was set equal to .20, i.e. one-fifth of the abandoned housing is assumed to be removed each year on the basis of the studies by Grebler and the report of the Kaiser Commission.[23]

4. Residential Land Use and Housing Densities

If new housing were always added at the same density, then the land in residential use could be calculated simply by dividing the number of housing units at any given time by the density of housing. However, on the time scales being dealt with in this model, the density of residential development increases drmatically as the fraction of the land occupied increases from less than .25 to values approaching 1.0. The time dependent density implies that the residential land use must be calculated by integrating the changes in housing stock over time, as represented by the equation

LHC.k = LHC.j + DT * (LHCG.jk + LHCD.jk)

where

LHC.k = the land used for housing in the core at the time k
LHC.j = the land use for housing in the core at the time j
DT = the time period between calculations, i.e. between j and k
LHCG.jk = the growth rate of LHC between time periods j and k due to the addition of housing
LHCK.jk = the decline in LHC between times j and k due to the demolition of housing

The growth rate of residential land due to housing additions if given by the equation

$$\text{LHCG} = \frac{\text{(total number of units constructed)} \quad \text{(fraction constructed on vacant land)}}{\text{(density of housing units being added)}}$$

$$= \frac{(\text{HCLP} * \text{HCL} + \text{HCER} * \text{HCU}) * \text{FHCV}}{\text{DMHC}}$$

where

HCLP * HCL = the number of lower skilled housing units added by government programs

HCER * HCU = the number of upper skilled housing units added

FHCV = the fraction of new units constructed on vacant land

DMHC = the marginal density of housing, i.e. the density at which new units are added (Figure 21)

All of the variables in this equation except the last have been discussed previously. The marginal density of housing is 'marginal' in the sense that it is the density of housing units in the increments of land to residential use. The marginal density is determined by the fraction of land which is occupied (LFOC) by any use (Figure 21). When the land fraction occupied is less than .20 the marginal density is assumed to be 2 dwelling units (DU) per acre. As the fraction of land occupied increases to 1.0, the marginal density increases to a maximum of 45 DU/acre. These marginal densities can be interpreted as a distribution of housing

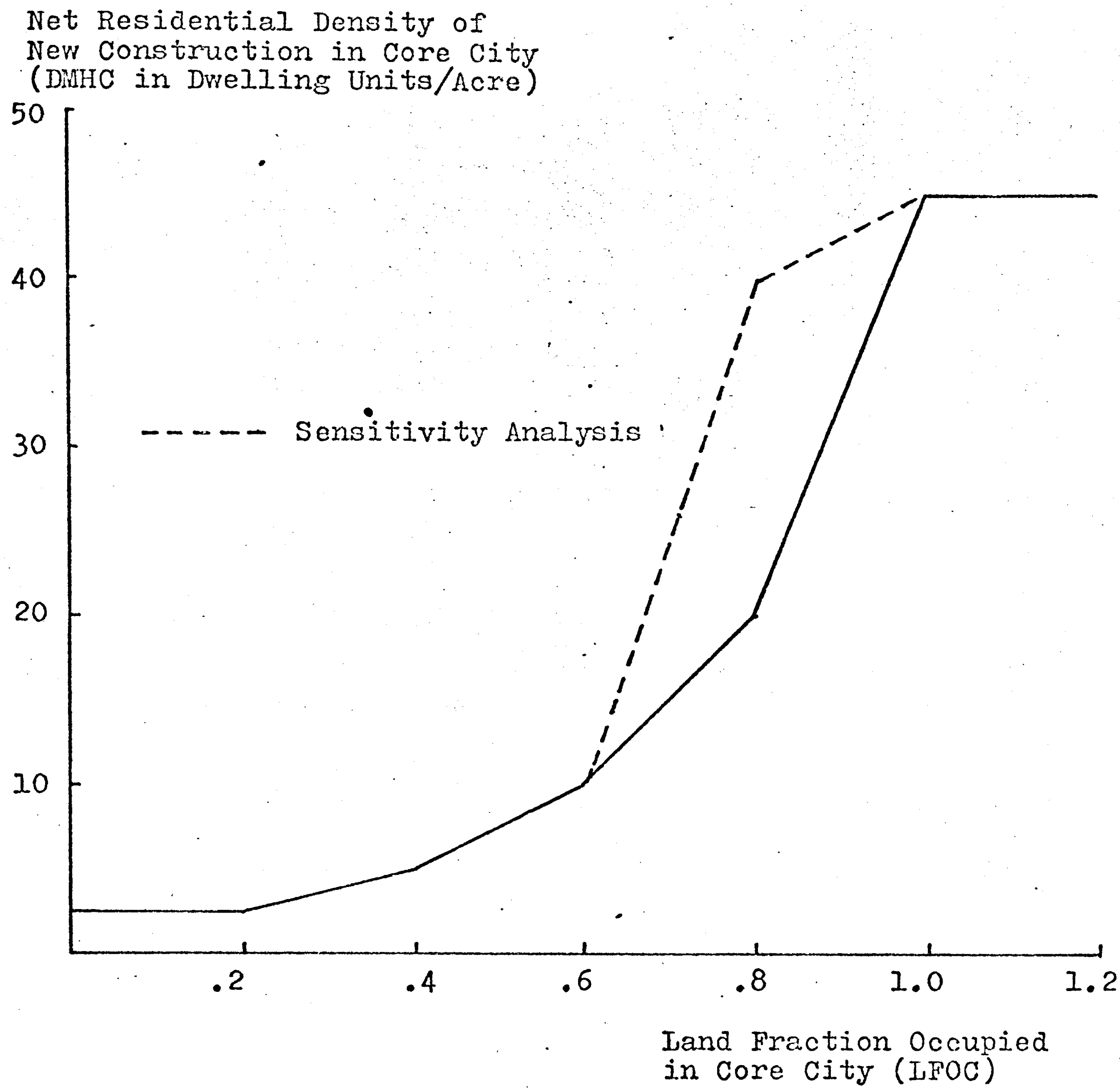


Fig. 21 The Net Residential Density of New Housing Construction as a Function of the Fraction of Land Occupied in the Central City (For an interpretation of these densities in terms of distributions between four types of residential construction, see Table 1.)

additions among several types of construction--single family detached, row housing, low rise apartments, and high rise apartments. An interpretation of the marginal densities of Figure 21 in terms of such a distribution among four classes of housing construction is given in Table 6. For example, a marginal density of 5 DU/acre would be entirely single family detached housing, while a marginal density of 40 DU/acre would have no detached housing and a predominance (60% of total units) of moderate rise apartments.

The second rate appearing in the equation governing land in residential use is the decline in residential land due to demolitions. (Note that the conversions of abandoned and lower skilled housing to upper skilled are simply shifts in the type of residential land use and do not appear in equation . The land subtracted from residential use by demolitions is equal to the number of units demolished divided by the average density of residential units. The average density is the total number of units in the area divided by the land in residential use. Since the marginal density increases over time, the average density will always be lower than the margin.

TABLE 6. Example of Distribution of Types of Housing Units for Four Different Average Residential Densities

Type of Housing	Single family Detached	Single story Row housing	3 story	13 story
Recommended net density of type housing* (DU/acre)	5	16	40	85
Marginal residential density (DU/acre)				
5	100%	00%	00%	00%
12	50%	40%	10%	00%
24	10%	50%	40%	00%
40	00%	25%	60%	15%

* The source for the recommended densities in Chapin, Stuart, Urban Land Use Planning (University of Illinois Press, Urbana, 1965), p. 430.

5. Policy Options

The housing policy options have already been described at various points in the preceding discussion of the housing model, but for convenience they are summarized here. The three options built directly into the model are a low skilled housing construction program in the core city, a similar program in the suburbs, and an abandoned housing demolition program in the core city. The magnitude of the construction program in the core city is specified as a fraction of the total lower skilled housing supply by the constant HCLPC, and the timing of the beginning of the program is specified by the switching time SWHLC. For example, HCLPC = .05 and SWHLC = 60 implies that a lower skilled housing construction program in the core city of 5% of the existing core city supply begins 60 years into the simulation. The low skilled housing construction program in the suburbs is specified in a similar way by the constants HSLPC and SWHLS.

The magnitude of the demolition program is specified as a multiple of the existing rate of demolition by the constant HCOPC, and the timing of the beginning of the program by switching constant SWHDP. For example, if HCDPC = 2 and SWHDP = 60, abandoned housing is demolished at twice the normal rate (as determined by the constant NHDR), beginning at 60 years into the simulation.

The values of the constants specifying the housing policies are the last entry in the exogenous inputs to the model. (See Appendix III.) As was noted in the introduction, the model can also incorporate other types of housing policies, such as financial incentives and supports, once those policies have been translated into changes in either the demand for or supply of housing.

D. Location and Redistribution Submodel

The location and redistribution model simulates two similar processes. First, it allocates the growth in four classes of population and three classes of industry, which is produced by the growth submodel, to the two areas of the city. As will be described below, the allocation between the two areas is based on the relative attraction as measured by several factors important to the population or industrial class being located, e.g., availability of housing and jobs for upper skilled white population or availability of labor and land for export industries. Second, the model calculates the redistribution and relocation of population and employment which had previously located in an area, but now want to move. This relocation is done on the basis of the relative attraction of the two areas as determined by the same factors governing the location of new growth.

In the case of both relocation of past growth and location of new growth, the allocation is determined by the local availability of or the access to activities which are vital to the quantity distributed. For population these vital activities are common to all four groups and include employment, which need not be in the same area, housing, and some measures of the local physical amenities as measured by the intensity of development and the degree of deterioration of this area. For industries, the vital activities vary with the function of the industry. Export industries, being predominantly manufacturing, are dependent upon land, labor force, and availability of supporting services such as long distance transportation. Residential services are much more closely tied to their local markets and thus to the distribution of population.

The first two parts of this section describe the location and redistribution process for population and industries respectively. The third part discusses the calculation of land use and densities of development (the residential land use and densities have already been discussed in part 4 of Section C). The fourth part describes the different types of accessibilities which were used in calculating the attractiveness of the suburbs and central city, and the chapter concludes with a summary of the alternative policies influencing location which can be tested by the model. The literature on previous work in location land redistribution models has already been reviewed in detail in Chapter 5, and that review will not be repeated here.

Virtually all of the discussion in all parts of this section deals with the processes and attraction functions of location in the central city. The calculation of the attraction functions for the suburbs is identical to that for the central city -- only the entries have been changed. For example, the demand to supply ratio of housing used to calculate the attraction of housing is based on the population and housing supply of the core city when calculating the attraction of the core city, but on the population and housing supply of the suburbs when calculating the attraction of the suburbs. Normally the name of the variable used in the calculation for the suburb can be determined from that for the core simply by changing a C to S, e.g., PBC is the black population in the core, PBS is the black population in the suburbs.

Before beginning the discussion of the location model, an explanatory note about the table functions in the location model should be added. These table functions - two describing the allocation of industry and population as a function of the relative attraction of the core city and suburbs, three describing the attraction of land, labor and accessibility for industry, and five describing the attraction of housing, jobs, racial composition, and land for population - are crucial parts of the location model. However, they represent relationships which have not previously been qualified and whose exact form is uncertain. An important part of the analysis of the model discussed in Chapter 8 will be the consequences of 'experiments' with alternative formulations of these table functions. As will be discussed in that chapter, all of the 10 table functions mentioned above, as well as others in the remainder of the model, have been varied. Some of the alternative forms of the table functions are indicated in the figures in this chapter but they will not be discussed until Chapter 8.

1. Population

Each of the four population groups--black lower skilled, black upper skilled, white lower skilled, and white upper skilled--are considered separately in the location and redistribution model. The model allocates the adult population in each of these groups, then distributes black children and white children in proportion to the distribution of the black adults and white adults respectively. Figure 22 is a schematic of the process used to allocate and redistribute each population group. The structures of the process for all four groups are so identical they will not be discussed separately. The differences in constants and attraction function because of differences in race or skill level will be

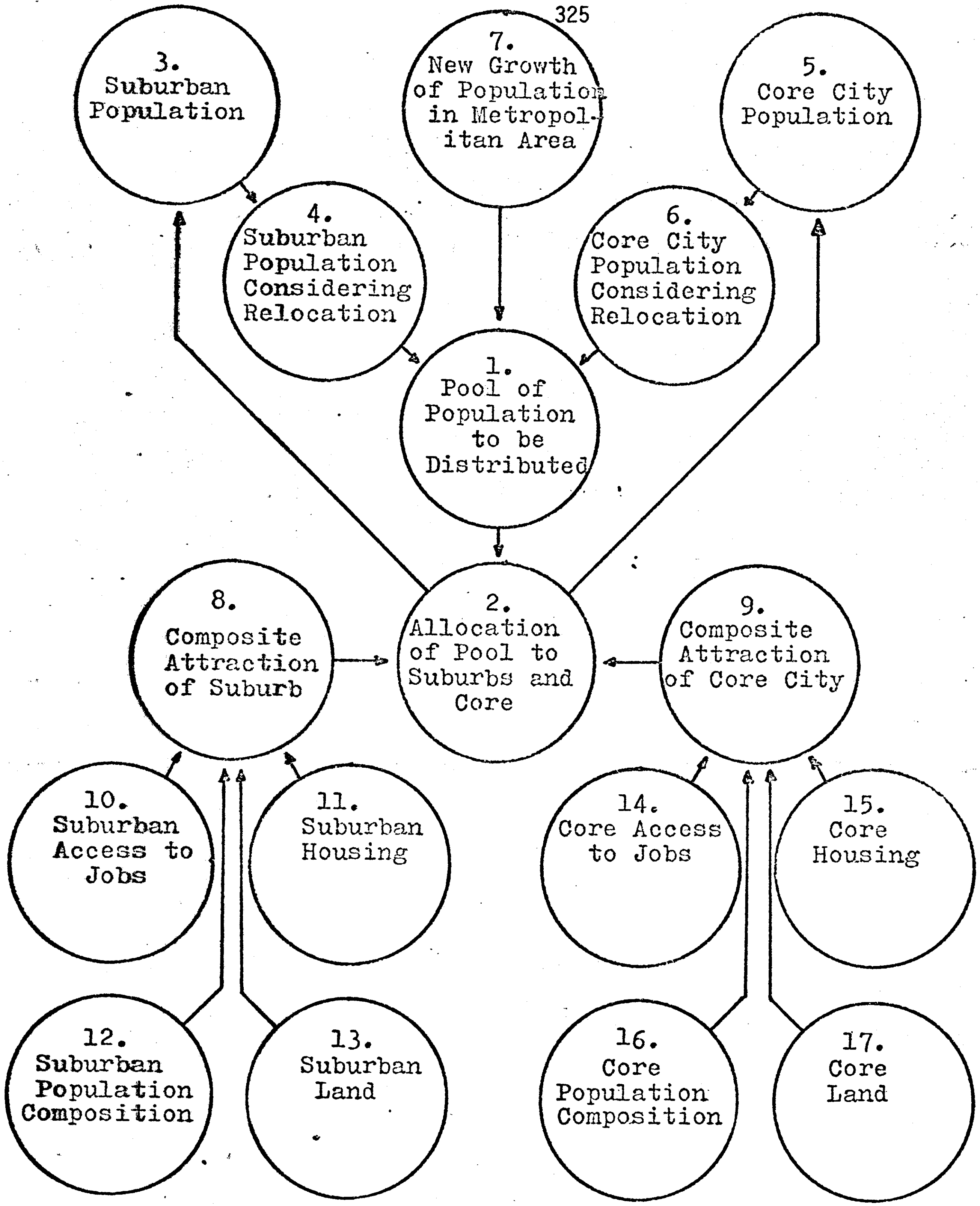


Fig. 22 Schematic of Redistribution and Location Process for Population in the Metropolitan Area.
The model has four such structures- one for each of the four types of population- with the only difference being the factors which determine the attractions. The location and redistribution of export industry also follows an identical process, but with different components determining the composite attraction.

pointed out as they occur.

a. The allocation of the population 'pool'

The essentials of the process shown in Figure 22 are first the calculation of a 'pool' (item #1) of one of the classes of population, e.g., upper skilled whites, which has to be allocated between the central city and suburbs, and the allocation of this pool (item #2) on the basis of the relative attractions of the two areas (items #8 and #9). The first element in the pool is the growth in the adult upper skilled white population because of the aging of children within the city or because of the immigration of adults from outside the city as calculated in the growth model. The second component of the pool is the redistribution of upper skilled white adults already living in both the central city and suburbs. This redistribution is calculated on the assumption that a constant fraction of the population in each area is moving each year. The variable WUCDR is the number of white upper skilled adults in the suburb who move within the metropolitan area each year and WUSDR is the corresponding variable for the suburban population. They are defined by the equations:

WUCDR = PWUC / TPM
WUSDR = PWUS / TPM

where

PWUC = white upper skilled adults in the core city
PWUS = white upper skilled adults in the suburbs
TPM = the average time between moves for the population
= five years

The constant TPM, the average time between intrametropolitan moves for the population, is the inverse of the average rate of moving. (The intermetropolitan moves are calculated in the outmigration rate from the city. See Section B of this chapter.) TPM has been assumed to be the same for all four groups of population on the basis of U.S. Bureau of Census data, which showed no significant differences in the rate of moving on the basis of either race or occupation.[24] TPM has also been assumed to be constant in time on the basis of mobility data over the 18 year period 1947 - 1965.[25] The alternative of formulating TPM as a function of the local conditions within each area of the city, e.g., of the level of central city deterioration, was considered. However, a comparison of the rate of population moves of residents of central cities vs. suburbs revealed no significant differences.[26]

The population pool obtained from growth and relocation is allocated to the two areas on the basis of the relative composite attraction of the core city and suburbs (8 and 9 in Figure 22). The components of the composite attraction for each four classes of population will be discussed below, but essentially they include the effects of housing, accessibility to employment, population composition, and land characteristics. For example, the fraction of the white upper skilled population distributed to the core, FWUDC, is determined by the ratio of attractions for white upper skilled population, RAWU, as shown in Figure 23. RAWU is given by:

$$RAWU = \frac{CCUW}{CCUW + CSUW}$$

where

CCUW = composite attraction of core for upper skilled whites

CSUW = composite attraction of suburbs for upper skilled whites

The function dependence of the allocation on this ratio is shown in Figure 23 and is the same for all four classes of population; in other words, all the population groups are assumed to have the same sensitivity to differences in attraction, when those attractions are expressed in terms of the appropriate factors. The always important question of the degree of sensitivity to differences is aggravated by the

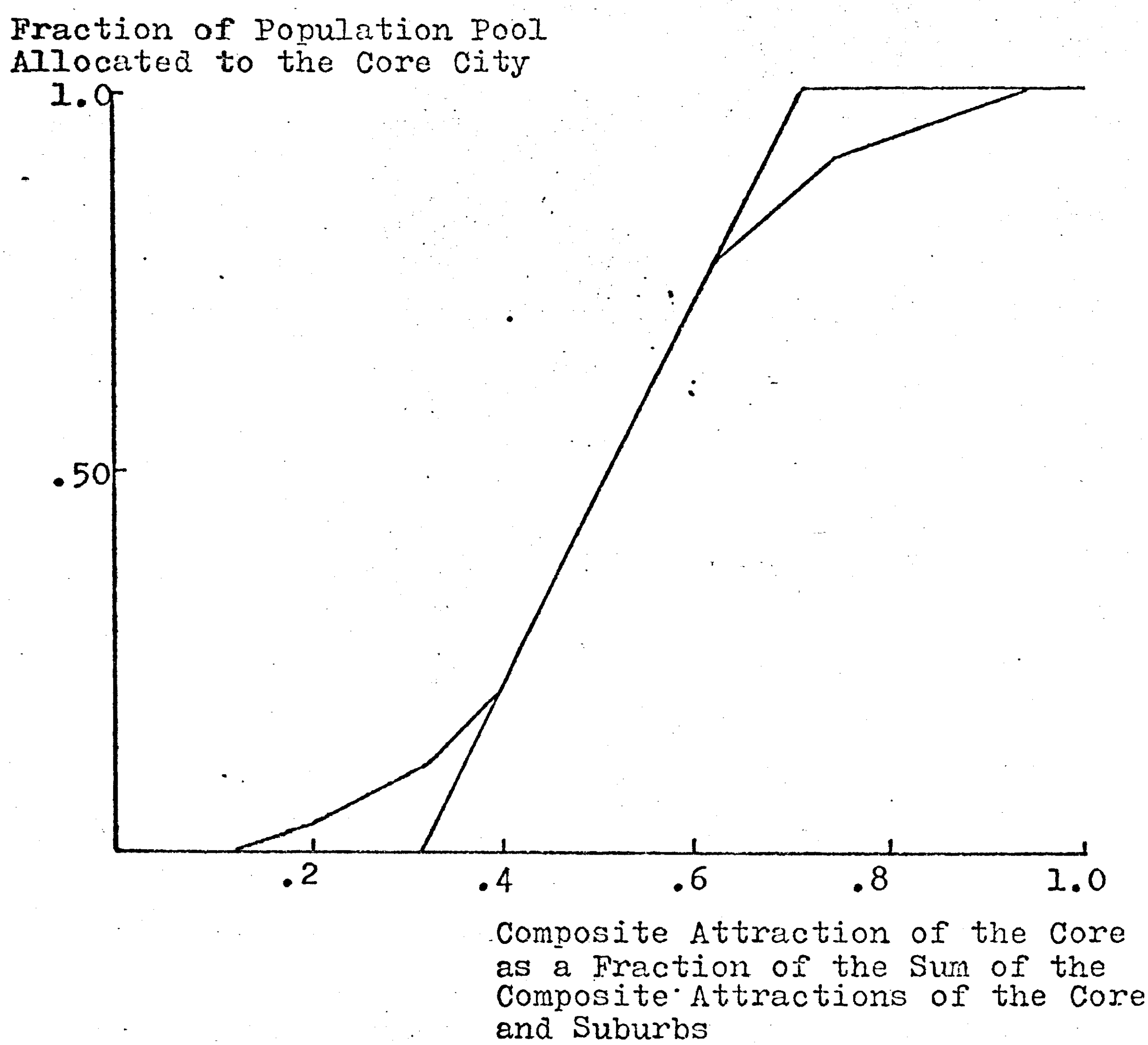


Fig. 23 Functional Dependence of the Distribution Multipliers for Population (FBUDC, FBLDC, FWUDC, and FWLDC) upon the Attraction of the Core City Relative to the Suburbs. A different composite attraction function, and thus a different ratio, is used for each of the population groups.

absence of data and formal analyses. The general form of the relationship in Figure 23 is clear--the curve has a positive slope, an upper limit of 1.0, a lower limit of 0, and should be equal to .5 when RAWU = .5. (If RAWU = .5, the two areas are equally attractive, and the population pool should be split equally between them.) Figure 23 shows just two of the infinite possible relations between the distribution of population and the ratio of attractions which meet these conditions. The first, the dotted line, assumes that the distribution is proportional to RAWU. The second, the solid line, assumes that if one area is twice as attractive as the other, then it will attract all of the growth. Determining the sensitivity of the behavior of the model to alternative functions of the relationship in Figure 23 will be an important part of the analysis of the model in Chapter 8.

b. The components of attraction for population of an urban area

Chapter 5 has already reviewed the types of characteristics of an area which have been assumed to influence residential location in previous models of urban development. This model uses the relatively standard characteristics of housing supply, employment and intensity of land use, and adds to them measures of the racial composition of the population and the degree of deterioration of the housing and industry in the area. Although the value of the components of attraction may vary with the skill level and race of the population group, the same five types of attraction are used to determine the composite attraction of all four classes of population. For example, the composite attraction of the core city used to allocate white upper skilled population is given by

CCUW = AJCWU * AHCWU * ARC (AVC + ADC * RWDV)

where

AJCUW = attraction of jobs in the core city to upper skilled whites
AHCWU = attraction of housing in the core city to upper skilled whites
ARC = attraction of racial composition of the core city to both skill levels of white population
AVC = attraction of vacant land in the core to all four population classes
ADC = attraction of deteriorated land in the core to all four population classes
RWDV = weighting of abandoned land relative to vacant land

Table 7 summarizes the components of attraction for each of the four population classes. It shows what population characteristics, i.e., skill, race, or both, are important in determining the attraction of a component for each population adds to them measures of the racial composition of the population and the degree of deterioration of the housing and industry in the area. Although the value of the components of attraction may vary with the skill level and race of the population group, the same five types of attraction are used to determine the composite attraction of all four classes of population. For example, the composite attraction of the core city used to allocate white upper skilled population is given by

CCUW = AJCWU * AHCWU * ARC (AVC + ADC * RWDV)

where

AJCUW = attraction of jobs in the core city to upper skilled whites
AHCWU = attraction of housing in the core city to upper skilled whites
ARC = attraction of racial composition of the core city to both skill levels of white population
AVC = attraction of vacant land in the core to all four population classes
ADC = attraction of deteriorated land in the core to all four population classes
RWDV = weighting of abandoned land relative to vacant land

Table 7 summarizes the components of attraction for each of the four population classes. It shows what population characteristics, i.e., skill, race, or both, are important in determining the attraction of a component for each population

TABLE 7. Influences on Residential Location for the Four Types of Population

POPULATION GROUP	WHITE LOWER SKILL	WHITE UPPER SKILL	BLACK LOWER SKILL	BLACK UPPER SKILL
COMPONENT OF ATTRACTION				
1. Housing Supply	R, S	R, S	R, S	R, S
Central City	AHCL, (Eq.334)	AHCU, (Eq.333)	AHCBL, (Eq.330)	AHCBU, (Eq.329)
Suburb	AHSL, (Eq.336)	AHSU, (Eq.335)	AHSBL, (Eq.332)	AHSBU, (eq.331)
2. Job Access	R, S	R, S	R, S	R, S
Central City	AJCL, (Eq.369)	AJCU (Eq.368)	AJCBL, (Eq.365)	AJCBU, (Eq.364)
Suburb	AJSL, (Eq.371)	AJSU (Eq.370)	AJSBL, (Eq.367)	AJSBU, (Eq.366)
3. Racial Composition	R	R	R	R
Central City	ARC, (Eq.397)	ARC, (Eq.397)	1.0	1.0
Suburb	ARS, (Eq.398)	ARS, (Eq.398)	1.0	1.0
4. Open Space	Identical Preferences For All Four Groups			
Central City	AVC (Eq.402)			
Suburb	AVS (Eq.403)			
5. Physical Deterioration	Identical Preferences For All Four Groups			
Central City	ADC (Eq.404)			
Suburb	ADS (Eq.405)			

S Indicates that different ratios are used for each of the skill levels

R Indicates that a racial discrimination multiplier is included

The variables listed are the names of the parameters for each location factor in each area. The equation number refers to the equation in the model which calculates that location parameter.

group, and identifies the equation in the model which calculates each attraction function. For example, the attraction of the housing supply and job supply depends upon both the race and skill level, while the effect of physical deterioration is assumed to be the same for all population classes. The relations used to calculate these components of attraction of the core city will now be discussed. As was noted before, the relations for the suburb are identical, but the independent variables are the conditions in the suburbs rather than in the core city. The relations do not have a firm base from previous analytical studies, and an analysis of the sensitivity of the population distribution to changes in the relations shown here is an important part of the analysis of the model in Chapter 8.

i. Attraction of housing

As Table 7 has shown, the attraction of the housing in the core city has been assumed to depend upon the skill level and population of the population group. The distinction due to skill level comes from the difference in the ability to pay for housing and the type of housing desired, i.e., the upper skilled population of either race is assumed to be attracted only by upper skilled housing, and the lower skilled population only by lower skilled housing. The distinction due to race comes from discrimination in the housing market which decreases the supply of housing available to meet the housing needs of the black population of either skill level.

The attractiveness of the core city for a population group is formulated in terms of the ratio of the demand of housing by the population with the same skill level of that group to the supply of housing units in the area available to that group. For example, the ratios of housing demand to supply determining the attraction of the housing in the core city to the white upper skilled population and black upper skilled population are

$$RHCU = \frac{(PBUC/AHB) + (PWUC/AHW)}{HCUZ}$$

$$RHCUB = \frac{RHCU}{HDMC}$$

where

RHCU = ratio of housing demand to supply in the core city for upper skilled whites

RHCUB = ratio of housing demand to supply in the core city for upper skilled blacks

PBUC = upper skilled black adults in the core city

PWUC = upper skilled white adults in the core city

AHB = the average number of adults per black household

AHW = the average number of adults per white household

HCUZ = the upper skilled housing supply in the core city

HDMC = the housing discrimination multiplier for the core city

The numerator of RHCU is the number of housing units demanded by upper skilled population in the core, the denominator is the upper skilled housing supply in the core. The number of adults per household used in calculating the housing demand is the ratio of the workers per household (WPHB, WPHW) to the labor force participation rate (LFPR). The LFPR has been estimated from data on the US labor force (see Section B of this chapter) and the number of workers per household has been assumed to have a constant value of 1.5 for both black and white families.

For the white population, all the housing supply is assumed to be available in the market, but for the black population the housing supply is diminished proportional to a discrimination multiplier, HDMC. HDMC is expressed as a function of the ratio black population to total population of the core city in Figure 24. The model includes a policy

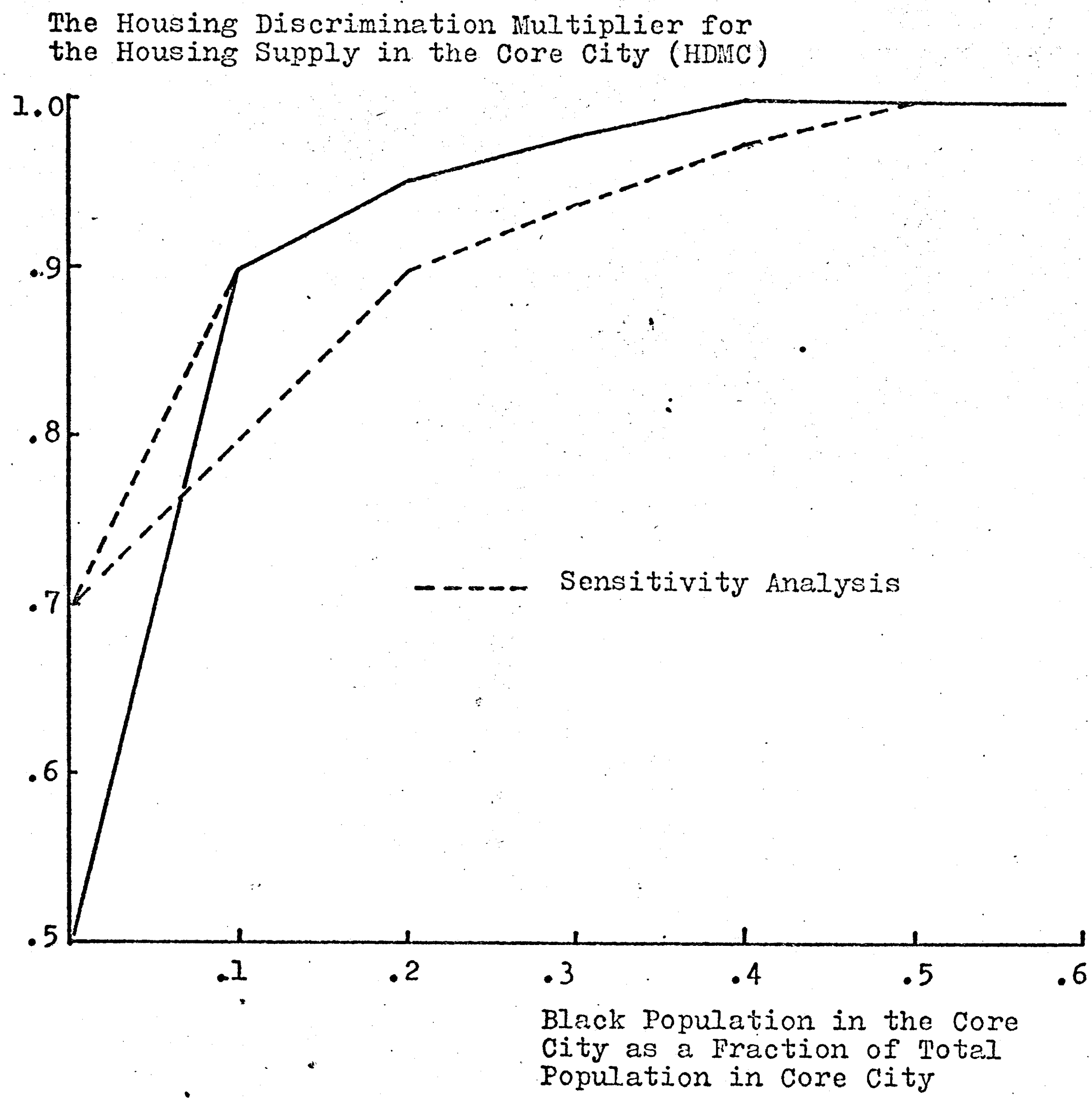


Fig. 24 The Influence of Racial Discrimination in Housing on the Housing Supply in the Core City. The housing supply used in the calculations of the ratio of housing demand to supply in each of the two classes is the product of the actual supply and the discrimination multiplier HDMC.

option of eliminating this discrimination through a switching function which will be discussed in the last part of this section..

The variation of the attraction of the core city with the appropriate ratio of demand to supply is shown in Figure 25. Excess housing supply has been assumed to have some affect in increasing the attraction of the area, but a deficit of housing has stronger effect in decreasing the attractiveness.

ii. Attraction of job supply.

Like the housing attraction, the attraction of the job supply available to residents of the central city depends upon both the skill level and race of the population class. The job attraction is formulated as a function of the ratio of the supply of jobs both within and accessible from the area to the total metropolitan job supply in each skill level. only of the skill level of the population. For example,

RJCU = JSCU / JU

where

RJCU = the ratio of the job supply accessible to the upper skilled population in the core to the total upper skilled job supply

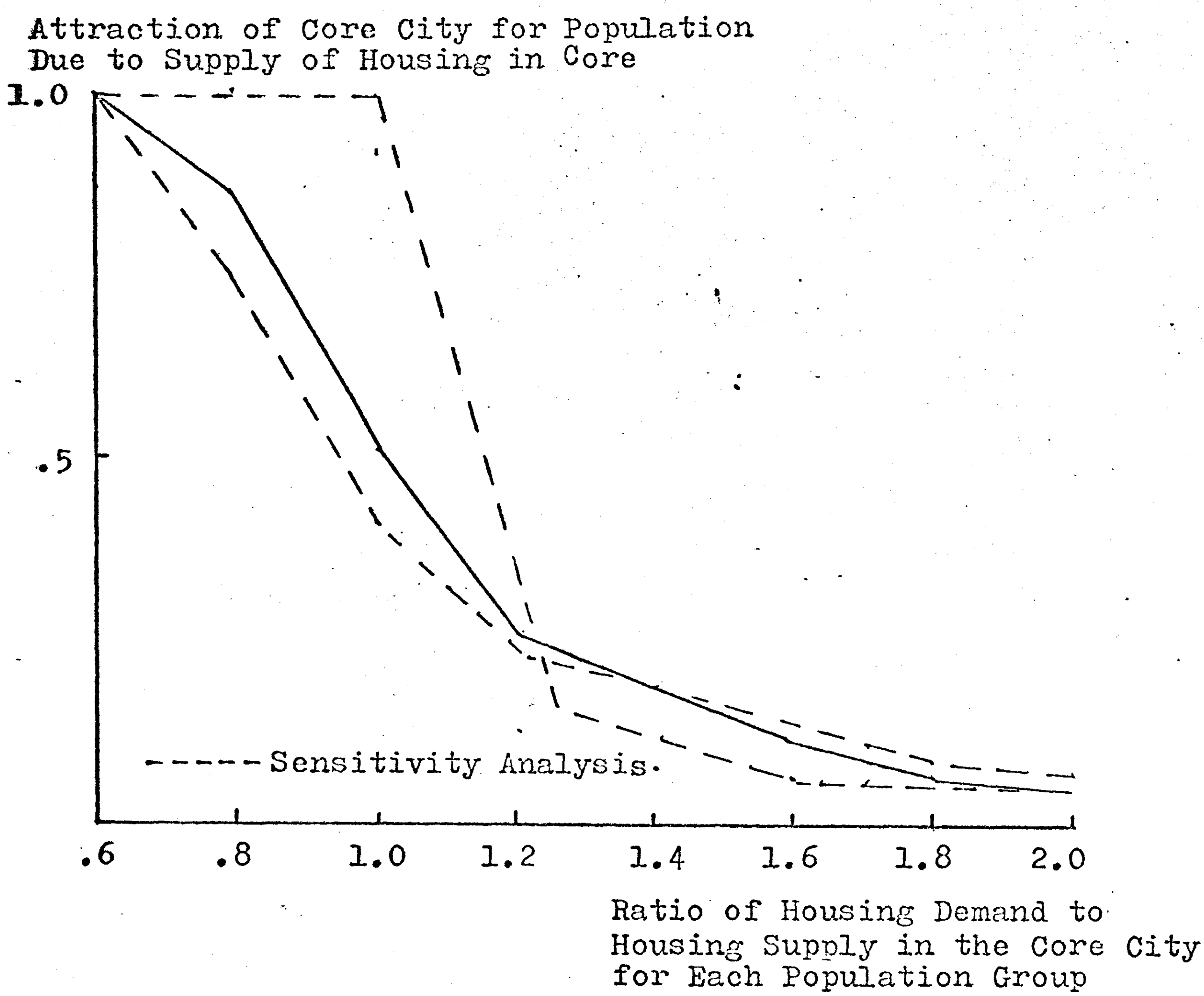


Fig. 25 The Influence of Housing Supply in the Core City on the Attraction of the Core City to the Population

JSCU = the upper skilled job supply accessible from the core

JU = the total upper skilled job supply in the metropolitan area

Skill level has two effects on the accessible job supply. First, only the jobs in the appropriate skill level are included in the supply for each population group. Second, the mobility of the population used to calculate the accessibility of jobs outside the area is assumed to be a function of skill level. For example,

JSCU = JCU*AKUCC + JSU*AKUCS

JSCL = JCL*AKLCC + JSL*AKLCS

where

JSCU = job supply accessible from core city for upper skilled labor

JSCL = job supply accessible from core city for lower skilled labor

JCU = number of upper skilled jobs actually in the core city

JCL = number of lower skilled jobs actually in the core city

JSU = number of upper skilled jobs actually in the suburbs

JSL = number of lower skilled jobs actually in the suburbs

AKUCC = accessibility of upper skilled population within core city, i.e., from core to within core

AKUCS = accessibility of upper skilled population from core city to suburbs

AKLCC = accessibility of lower skilled population within the core city

AKLCS = accessibility of lower skilled population from core city to suburbs.

Thus, JSCU is the sum of the upper skilled job supply in the core city modified by the accessibility of the upper skilled to those jobs, plus the upper skilled job supply in the suburbs modified by the accessibility of the upper skilled to the suburbs. The formulation of the differences in accessibility from one area to another for the different population groups will be discussed in Part 4 below. The modification due to race of the accessible job supply is similar to that of the housing supply. The accessible job supply for each skill level and area is decreased proportional to a job descrimination multiplier for that skill level (JDMU for the upper skill, JDML for the lower skill). The multipliers are constants which are set exogenously and which can be controlled by the policy options discussed in the last part of this section.

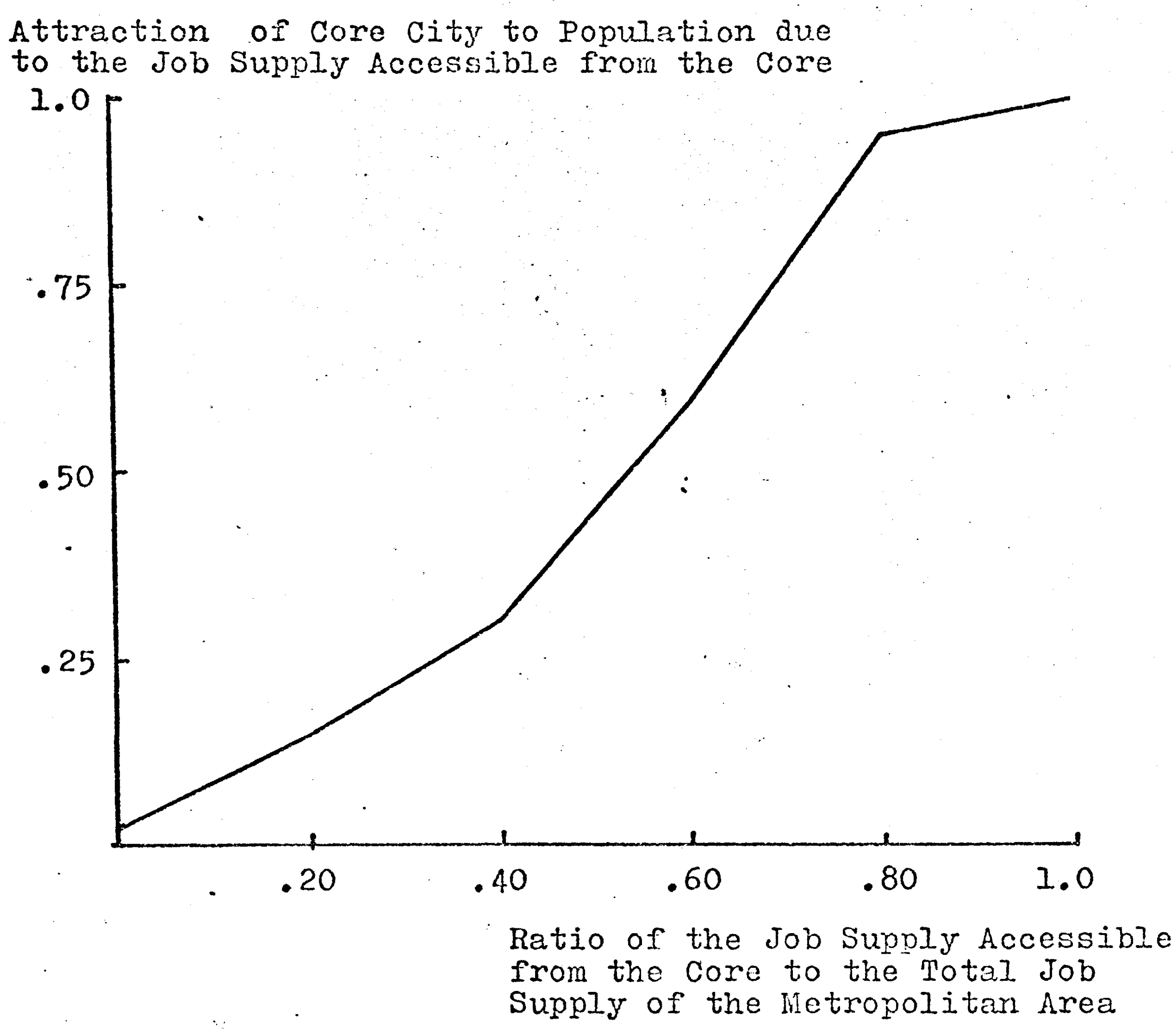
The attraction of the central city for each class of population is calculated on the basis of the appropriate ratio of job demand to supply using the relation shown in

Figure 26. An excess supply increases the attraction by one-third, but the strongest effect is the sharp decline in attraction with increasing shortage of jobs.

iii. Racial Composition of the Population

The effects of the population composition of the area are formulated solely in terms of racial characteristics. Income and ethnic characteristics are also determinants of location but the former was assumed to be small effect compared to racial discrimination, while the latter could not be treated using the simple population disaggregation of this model.

The racial composition of the area is formulated as affecting the location decisions of only the white population. The effects of racial discrimination in housing and jobs on the location blacks has already been included through the discrimination multipliers in the attraction functions for housing and jobs. Although positive discrimination forces, e.g., blacks wishing to live with blacks, also exist,[27] they have not been included in this formulation. Thus, the attraction due to racial composition for both skill levels of black population is set identically equal to 1.0 (see Table 7). The effect on whites has been formulated in terms of the ratio of black population as shown



Note: This graph plots the general functional dependence of attraction upon the ratio of jobs accessible from each area. As is disclosed in the text, a different ratio is calculated for each combination of area, skill level, and race which leads to a different attraction of each area for each of the four population groups.

Fig. 26 The Influence of Job Supply Accessible from the Core City on the Attraction of the Core for Population for each area in Figure 27. The sharpness of the decline in attraction with increasing black population in the area arises from the neighborhood 'tipping' process described by Mayer[28] and modelled by Schelling.[29]

iv. Attraction of Vacant and Deteriorating Land.

The influence of 'amenities' and intensity of development have been formulated in terms of the effects of vacant land and land with abandoned housing and industry on it. The effect of these factors is assumed to be the same for all four classes of population. Also, as was shown in the equation for the composite attraction, their individual effects are additive, i.e., direct substitution of one for the other is allowed. (The rate of substitution is the constant RWDV in equation.) The effect of vacant land is expressed as a function of the land fraction occupied in the central city (LFOC), with the attraction decreasing as LFOC tends toward 1.0 (Figure 28). The effect of deterioration is expressed as decreasing the attraction of the core city as the fraction of land with abandoned buildings on it increases (Figure 29). The calculation of these two land use fractions from the land use in the city is discussed in Part 3 below.

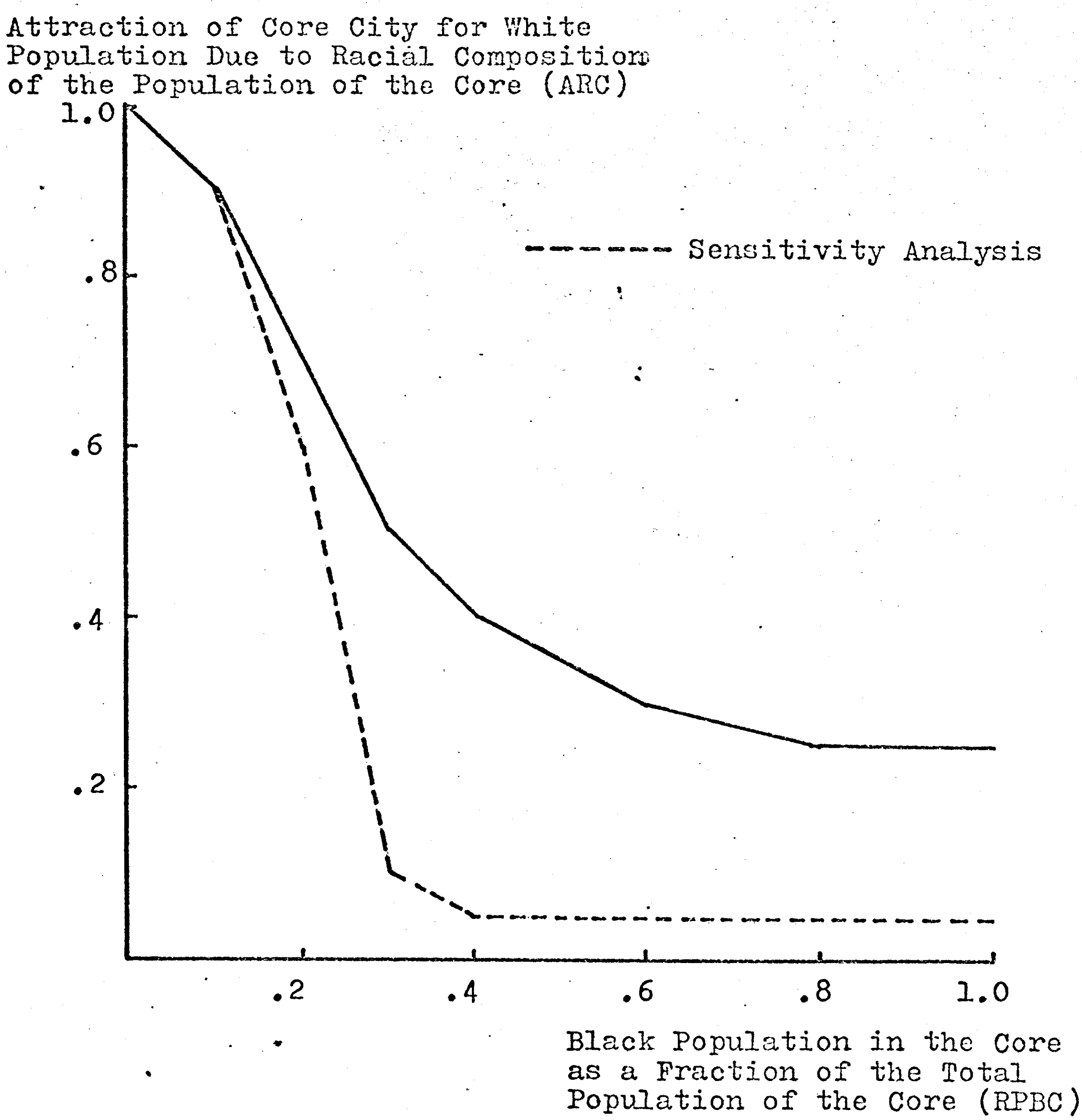


Fig. 27 Influence of Racial Composition of the Core City on the Attraction of the Core City for White Population

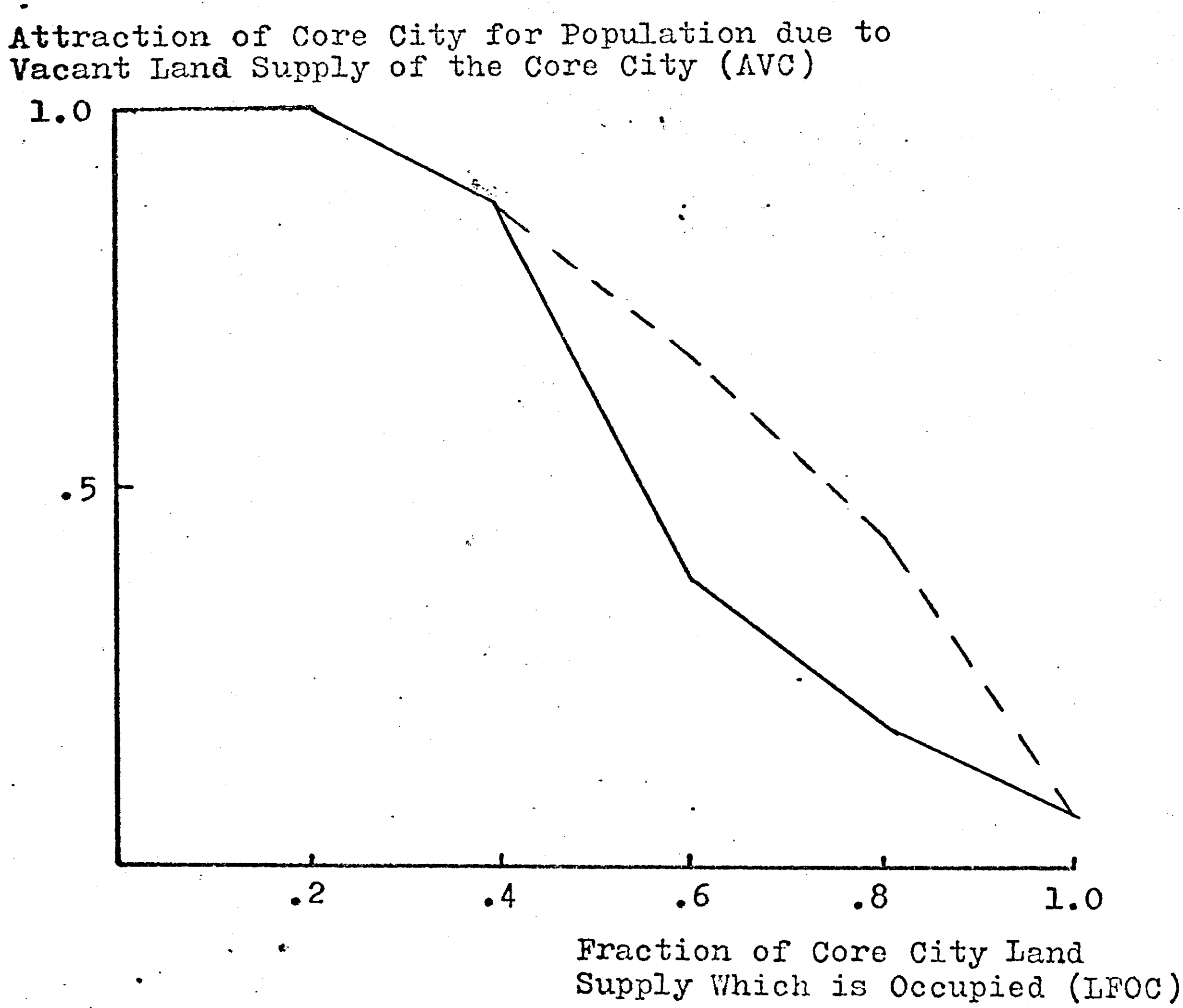


Fig. 28 The Influence of Vacant Land Supply in the Core City on the Attraction of the Core City for Population

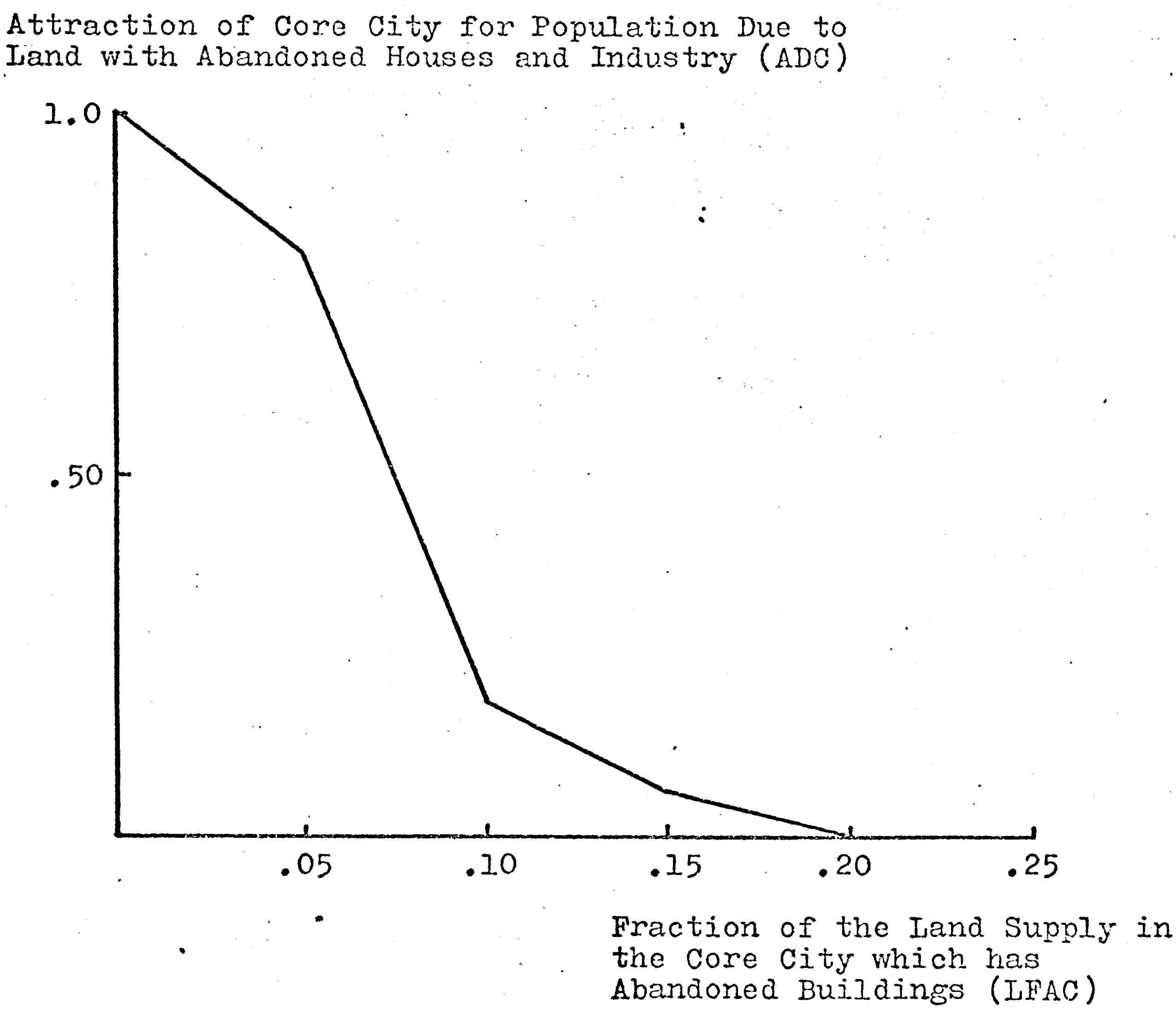


Fig. 29 The Influence of Land Supply with Abandoned Buildings in the Core City on the Attraction of the Core City for Population

2. Industry

The process of location and redistribution for each of the three classes of industry is quite different and they will be discussed separately.

a. Export Industries.

This class of industry is primarily manufacturing and its location has been formulated in terms of the attraction of each area due to land supply, labor supply, and the access to supporting services and industries. The actual process used for distribution and relocation is identical to that for population illustrated in Figure 22. A pool of industry to be allocated is created by adding new growth to those industries previously allocated but now moving. The rate of relocation of industry is determined by assuming an average time between moves of 20 years. This pool is allocated on the basis of the ratio RAIX involving the composite attraction of suburbs and central city for export industries rather than population.

$$RAIX = \frac{CCAIX}{CCAIX + CSAIX}$$

RAIX= ratio of composite attractions for export industries

CCAIX= the composite attraction of the core for export industries

CSAIX= the composite attraction of the suburbs for export industries

The fraction of the pool allocated to the core city is shown as a function of RAIX in Figure 30.

The composite attractions are given by the product of three components. For example, for the core,

$$CCAIX = ACXS * ACXL * ACXA$$

Where

ACXS= the attraction of the core for export industries due to space available

ACXL= the attraction of the core for export industries due to labor supply

ACXA= the attraction of the core for export industries due to supporting services and other manufacturing activities

i. Attraction of Space.

The attraction ACXS of the core city due to the space available is determined by the ratio RSXC of the land supply available for use by industry in the core city to the land demanded by the export industries in the pool. The demand for land is the product of the number of employees in the industries in the pool (IXPL) divided by the average marginal density (DMAX in units of employees per acre) of the export industries being allocated. The average marginal density is specified as an exogenous input

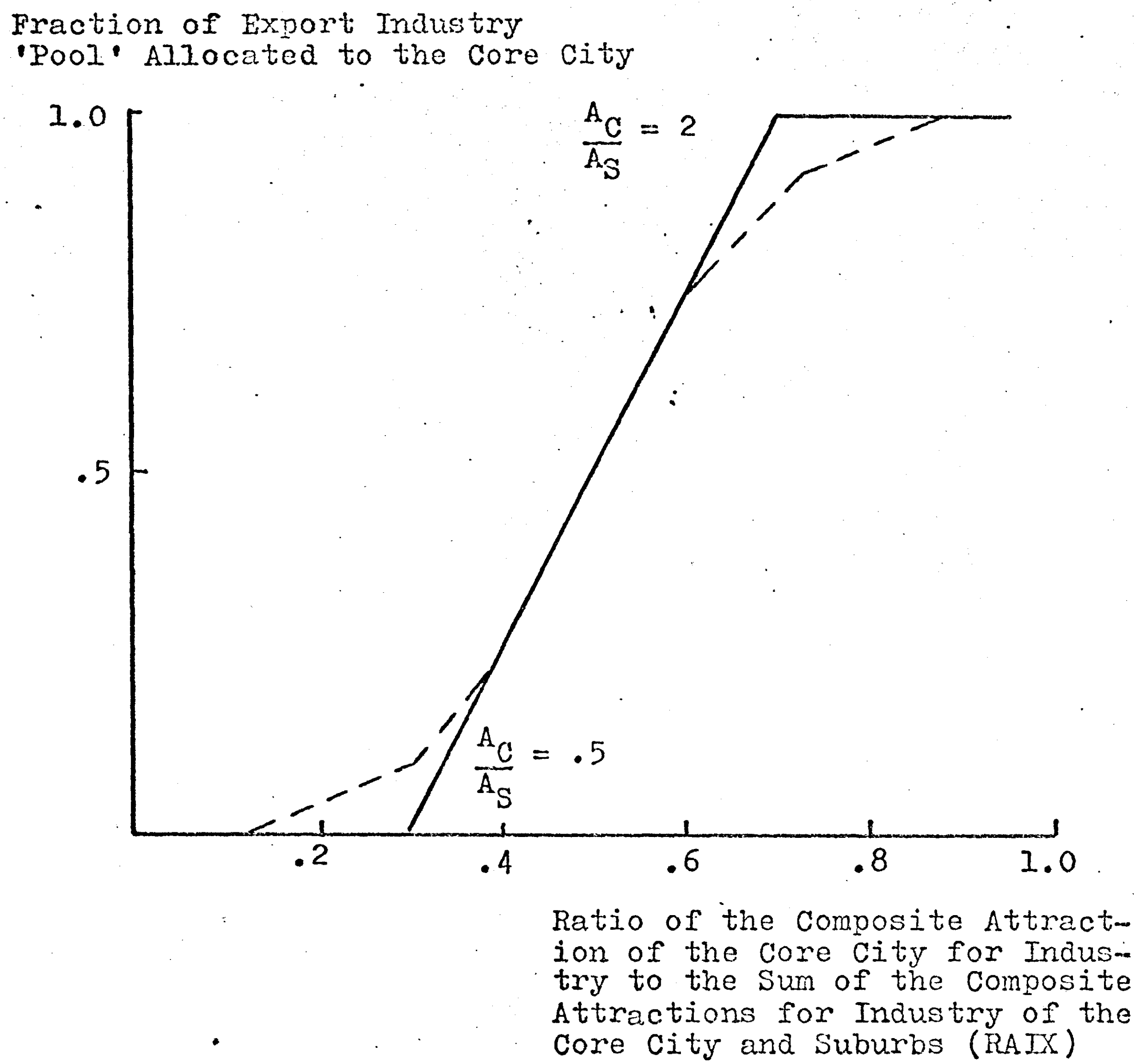


Fig. 30 The Fraction of the Export Industry Pool Allocated to the Core City as a Function of the Composite Attractions for Industry of the Core City and Suburbs

which decreases over time because of the shift to horizontal production line techniques which need more land (see Chapter 3).

The land supply LSXC available for industrial use in the core comes from two sources and is given by

$$LSXC = FLRXC * \left(\frac{IEXC * DT + LIAC}{TIM * DAXC} \right) + LVC$$

Where

FLRXC= fraction of previously occupied land reusable by export industries

IEXC= number of export industry employees currently located in the core

DAXC= the average density of employees for export industries now located in the core

LIAC= land now occupied by abandoned export industries in the core

LVC= vacant land in the core

TIM= the average time between moves for export industry

DT= the time interval of this calculation

The first term in the brackets is the land in the core coming available during this time interval because of the industrial moves. The second term in the brackets is the abandoned industrial land which has accumulated during previous time intervals because of the failure to reoccupy sites abandoned in previous time periods. These two quantities of land are multiplied by a factor accounting for the unsuitability of the old small high density sites for industries now operating at significantly lower densities of employees. This factor, FLRXC, is a function of the ratio of average density DAXC of export industry employees now located in the central city to the average marginal density DMAX of export industry employees in the industries now being located (Figure 31). For values of the ratio less than or near one, FLRXC is near one but it drops sharply and asymtopically approaches .25 as the ratio of densities increases. (This form of FLRXC is equivalent to assuming that(1) the distribution of employee densities of the export industries in the core is uniform between 0 and DAXC and(2) any sites with a density greater than DMAX are unusable.)

The final source of land for industries is the vacant land supply available in the city LVC.

The attractiveness of the central city for export industries due to the land supply available is given as a

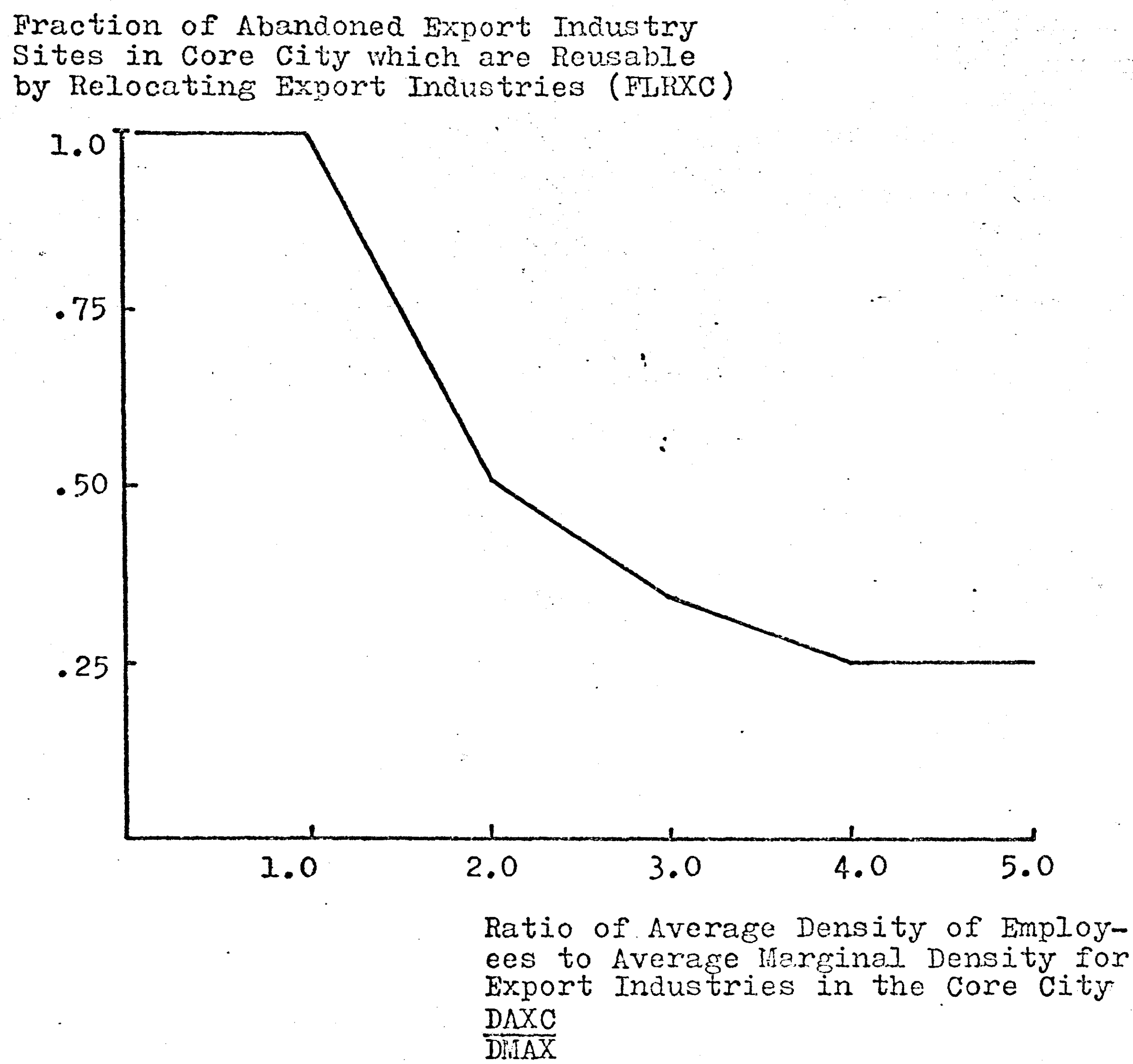


Fig. 31 Influence of Changing Density of Export Industry Employment on Reuse of Export Industry Sites in the Core City

function of the ratio RSXC of land supply to demand in the core in Figure 32. Since RSCX is the ratio of marginal supply to demand an area with RSCX=1 is not particularly attractive because strong competition results. The attraction increases as the marginal supply becomes several multiples of the demand and this competition eases.

ii. Attraction of Labor Supply.

The attraction ACXL of the central city for export industry due to the labor supply is based on the ratio RLXC of the labor supply available to all industries from the central city itself and from commuters to the total labor supply of the metropolitan area. Although the industries require two different skill levels of employees, the two labor markets have been combined in determining their effect on location of export industry. The numerator of RLXC is LSIC, the sum of the labor force in the central city plus the labor force in the suburbs modified by the mobility of the labor force to each area.

LSIC= JDCU * AKUCC + JDCL* AKLCC+ JDSU* AKUCS + JDSL * AKLCS

Where

JDCU= the jobs demanded by upper skilled labor in the core, i.e., the adult upper skilled population times the labor force participation rate

JDCL= the jobs demanded by lower skilled labor in the core

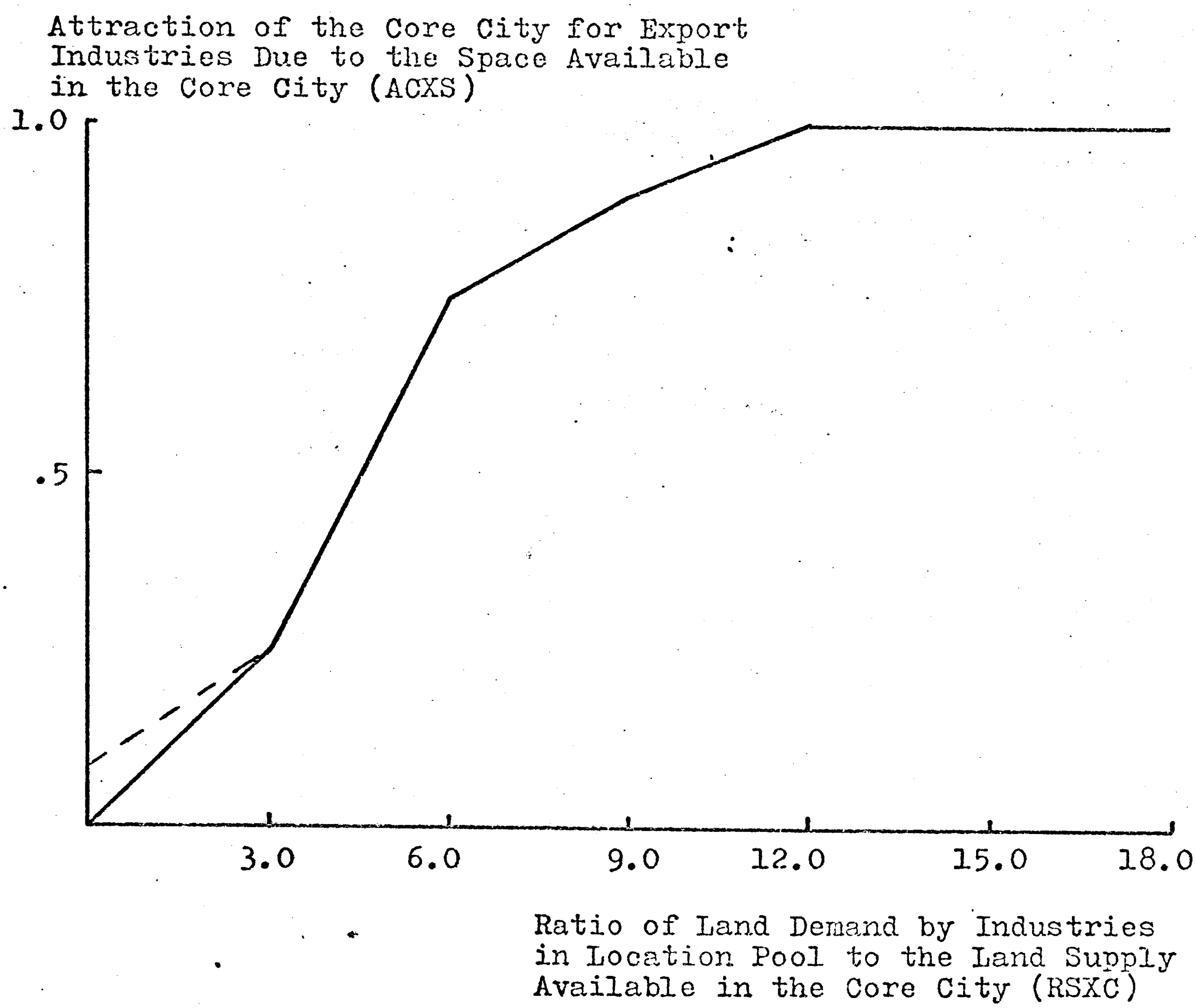


Fig. 32 The Influence of the Land Available for Export Industries in the Core City on the Attraction of the Core City for Export Industry

JDSU= the jobs demanded by upper skilled labor in the suburbs

JDSL= the jobs demanded by the lower skilled labor in the suburbs

AKUCS= the mobility of the upper skilled labor force between core and suburbs

AKLCS= the mobility of the lower skilled labor force between core and suburbs

AKUCC= the mobility of the upper skilled labor force within the core city

AKLCC= the mobility of the lower skilled labor force within the core city

The mobility factors are identical to the accessibility factors used in locating population. They will be discussed below in Part 4. The denominator of RLXC is just the total labor supply in the city.

The attraction of the core city due to its labor supply is shown as a function of the ratio RLXC of labor demand to supply in Figure 33.

iii. Attraction due to access to Supporting Services and Industries.

The attraction factor ACXA accounts for the dependence of export industries upon complementary industries and services, particularly intra-city freight transportation. This factor has been formulated in terms of access to other

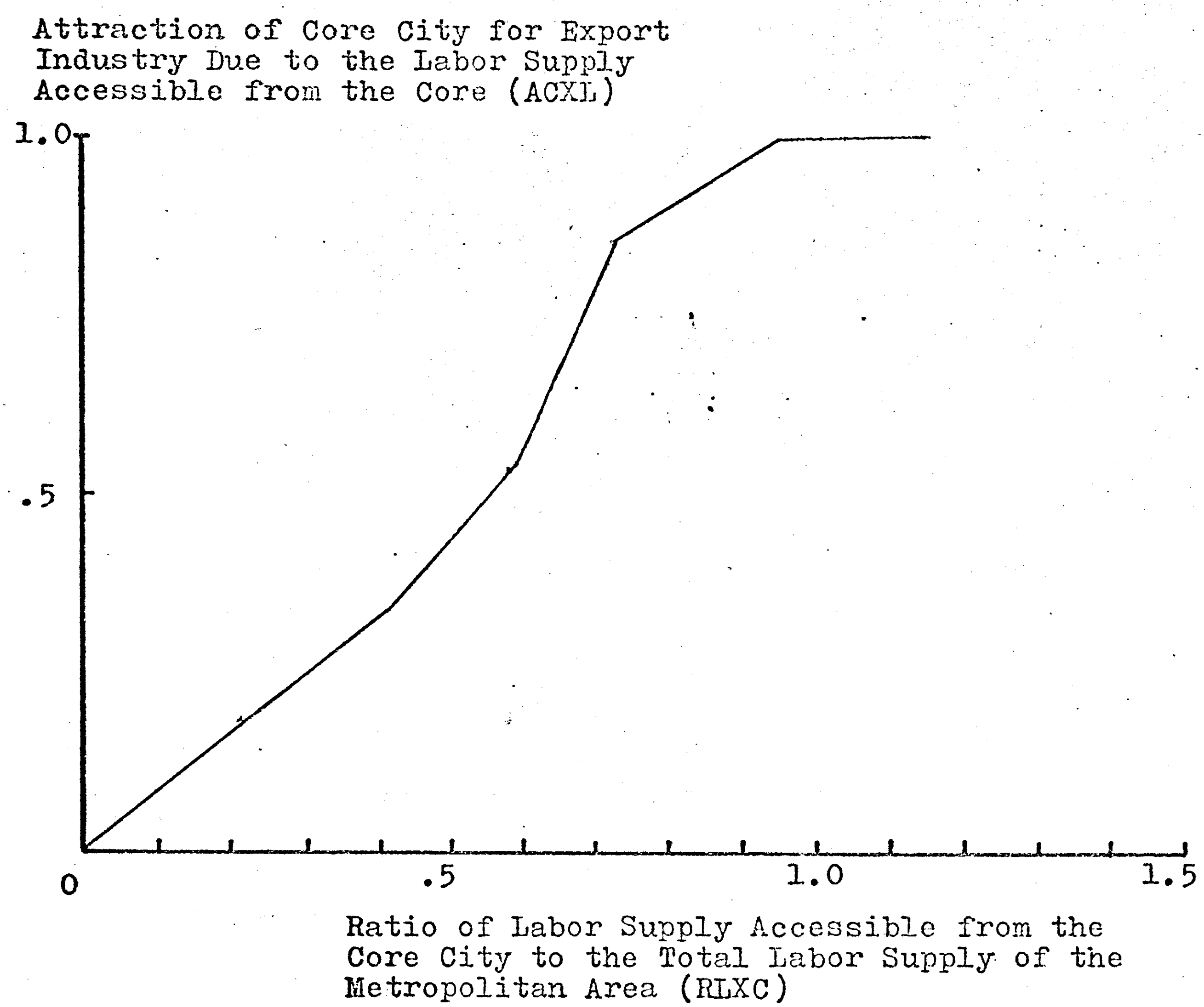


Fig. 33 The Influence of the Labor Supply Accessible from the Core City on the Attraction of the Core City to Export Industry

export industries and to business services. The access to business services reflects the availability of supporting activities. The access to other export industries reflects the dependence upon both complementary activities which produce inputs and utilize outputs of the export industry, but also access to the inter-regional transportation links which become more diffuse throughout the city as their users disperse. Specifically, ACXA is formulated as a function of the fraction RXBC of export industry and business service activities which are accessible from the core city.

$$RXBC = \frac{(IEXC + IBSC) * AKUCC + (IEXS + IBSS) * AKUCS}{IEX + IBS}$$

Where

IEXC= the export industry employment in the core city

IEXS= the export industry employment in the suburbs

IBSC= business service employment in the core city

IBSS= business service employment in the suburbs

IEX= total export industry employment

IBS= total business service employment

AKUCC= accessibility between industries within the core

AKUCS= accessibility between industries in core city and those in suburbs

The accessibility factors represent the access by intra-city freight and, as is discussed below, is the same as the mobility of upper skilled population (i.e., trucks are assumed to have the same mobility as private automobiles).

Figure 34 gives the variation of the attraction due to industrial accessibility as a function of the fraction RXBC. The curve rises extremely sharply and has saturated by the point where one quarter of the industries are accessible.

b. Residential Service and Business Industries.

The residential service employment is dominated by trade and services which are extremely sensitive to shifts in their market, i.e., shifts in population. Also, they characteristically do not absorb much land and are able to outbid other potential users of locations with good market potential. Thus, the residential service employment has been formulated as remaining in equilibrium with the distribution of its market. Since, as was discussed in Chapter 3, the market for services is assumed to be independent of the income distribution of the population, the fraction of residential service employment in the core is assumed to be equal to the proportion of the population living in

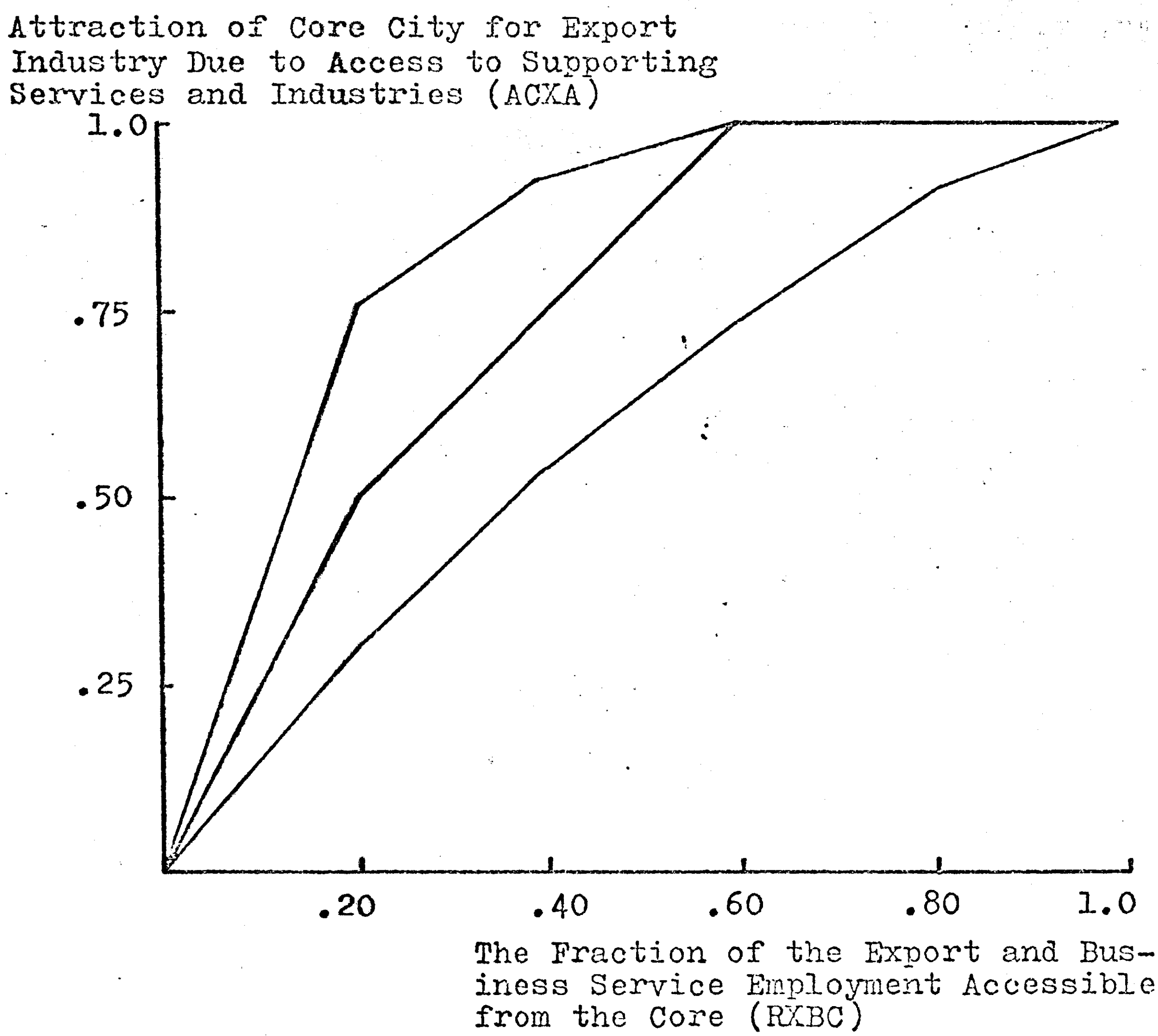


Fig. 34 The Influence of Access to Supporting Services and Complementary Industries On the Attraction of the Core City for Export Industries

the core.

Similarly, the distribution of business service employment is assumed to remain in equilibrium with the distribution of export industries and residential services. The fraction of business services in the core city is equal to the fraction of residential service and export industry employment in the core.

3. Land Use, Land Densities, and Total Land Supply.

This part discusses the calculation of the land uses within the core city and the densities which determine the absorption of land by expanding population and employment. (As usual, the procedures for the suburb are identical.) The land absorbed by housing and the determination of the density of housing units has already been treated in Part 4 of the previous section. The remaining uses are industrial, transportation and public, vacant, and abandoned. These land uses account for all the land in the city and are mutually exclusive except for abandoned land which is also included in the industrial and residential uses. The different land use markets are isolated from one another because the only way in which conversion from one use to another occurs, e.g., residential to industrial, is through the normal process of demolition to reduce the land back to completely vacant state.

a. Industrial Land

The industrial land use in the core city, LIC, is the sum, of three components--LISC, the land used by the two classes of service industries, LIXC, the land used by the export industry in the core, and LIAC, the abandoned industrial land in the core. The land used by the service industries is equal to the employment in these residential and business service classes of industry divided by the average density of service employees in the core (DASC). The average density is the density (DAS) of service employees at low intensities of development multiplied by a factor DMC which increases the density of employees as the fraction of land occupied in the core city increases (Figure 35). Both the average density and its range of increase with increasing intensity of surrounding land use is consistent with the marginal and average densities reported by Neidercorn and Kain.[30]

The land used by export industries in the core LIXC is accounted for by a "level" equation which integrates the increases and decreases in land use by export industries over time. This is necessary because of the rapidly declining

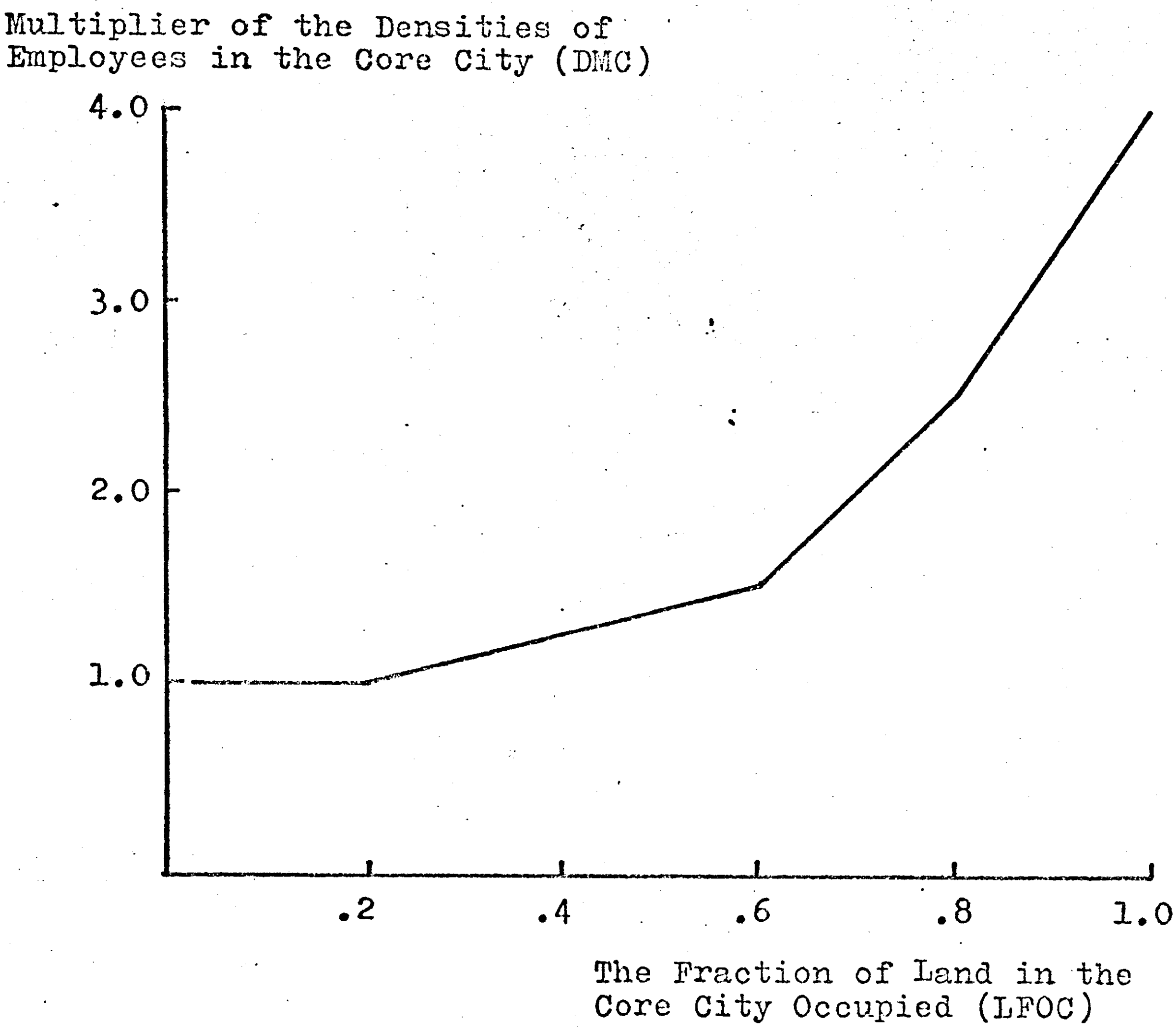


Fig. 35 The Influence of the Level of Land Use in the Core City on the Density of Employees of Industries Locating There
(The densities of newly locating service industries and export industries are proportional to DMC.)

<u>average</u> density of export industry employees (see Chapter 3) which makes old sites obsolete and leads to abandonment. If the sites are reused by a replacement industry, the replacement industry has a density several times that of the previous user. 3½ Since export industries is a broad class of industrial types, the employee densities within it cover a relatively broad distribution. Some of these will have employee densities high enough to justify reuse, but the declining average of the distribution implies that the number of such industries is declining at the same time that the number of reuseable sites is increasing. The abandoned or vacant sites which result were assumed to be important enough in the deterioration process to account for them explicitly.

The equation for land for export industry in the core LIXC is

LIXC.k=LIXC.j+DT* (LXCC.jk+LXCR.jk+LXCO.jk)

where

LIXC.k = the value of LIXC at time k
LIXC.j = the value of LIXC at time j
DT = the time interval between times k and j
LXCC.jk = the rate of industrial land being added by construction of export industries on vacant land between j and k
LXCR.jk = the rate of industrial land being added by reuse of abandoned sites between time periods j and k

LXCO.jk = the rate of transfer of land from active use for export industries to abandoned due to the relocation of export industries between times s j and k

The first two rates essentially split the export industries allocated to the core in each period between abandoned sites and sites on completely vacant land. The split is made solely on the basis of the distribution of available land between the two categories.

$$LXCC = \frac{IXPL * FIXDC}{DMXC} * (1.0-FRLC)$$

$$LXCR = \frac{IXPL * FIXDC}{DMXC} * FRLC$$

$$FRLC = \frac{LIAC}{LIAC + LVC}$$

where

IXPL = pool of export industry being allocated
FIXDC = the fraction of the pool allocated to the core
DMXC = the marginal density of export industries allocated to the core
FRLC = the fraction of reusable land for export industries in the core
LIAC = abandoned industrial land in the core
LVC = vacant land in the core

The first term on the right hand side of the equations for LXCC and LXCR is the total land required by the export industries which have been allocated to the core city. The variable

FRLC allocates this required land between reuse of existing abandoned sites and construction on vacant land on the basis of the land available from each of these two sources. Note that the decision on how much of the export industry pool has been made in the location and distribution equations discussed in Part 2. The equations for LIXC merely keep track of the land used by the industries allocated through this process. If no land is available from either source, the land multiplier in the composite attraction for export industries goes to zero and cuts off the distribution of export industries to the core city.

The density DMXC used to calculate the land needed by the export industries allocated to the core is given by

DMXC = DMAX * DMC

where

DMAX = the average density in areas of low intensity of land use of employees at the new sites of the export industries moving or locating in the city for the first time

DMC = the density multiplier for the core city which increases the density due to the intensity of surrounding land use

DMAX is an input of the model which is assumed to increase over time as manufacturing industries shift to horizontal production line techniques, require increased land for employee parking, etc. (Figure 36.) The multiplier DMC is the same as that for the density of service employees in Figure 35. The combined effects of the change in DMAZ over time and the difference in the multiplier DMC for the core and its counterpart DMS for the suburbs are consistent with the changes in the density of manufacturing employment reported by Hoover and Vernon,[32] Niedercorn and Hearle,[33] and Chapin.[34]

The last term in the equation for changes in industrial land use in the core is LXCO, the rate of transfer of land from active use for export industries to abandoned because of the relocation of the export industries.

$$LXCO = \frac{IEXC}{TIM} * \frac{1}{DAXC}$$

where

IEXC = the export industry employment in the core
TIM = the average time between moves for export industries
DAXC = the average density of export industries currently located in the core

The first term is just the number of employees relocating to another site. The second term is the density of export industries presently in the core, i.e., the number of export industry employees in the core IEXC divided by the land use for export industries in the core LIXC.

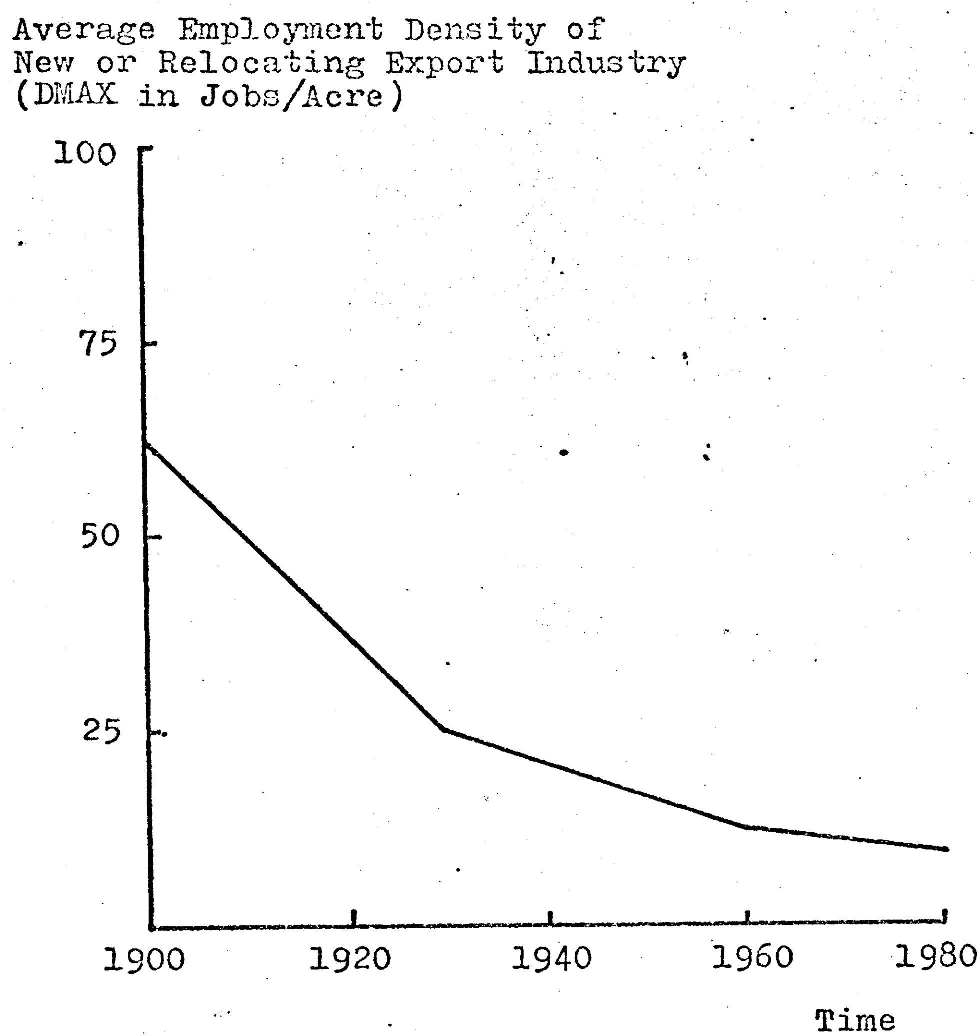


Fig. 36 Changes in the Average Marginal Density of Export Industry Employees in Time

The final component of industrial land use is the abandoned industrial land in the core city LIAC.

LIAC.k = LIAC.j + DT * (LXCO.jk - LSCR.jk - LSCD.jk)

where the time notation is standard, and all the rates except LXCD, the demolition of abandoned export industry sites, have already been discussed (LSCO is the inflow of abandoned sites from active use, LXCR is the conversion to active use once again). The demolition rate LXCD simply assumes that a constant fraction of the abandoned sites are demolished each year. The fraction is the inverse of the expected industrial clearance time TLXC which has been assumed to be 5 years, i.e., 20% of the abandoned sites are cleared each year.

b. Other Land Uses and the Total Land Supply of the Core City and of the Suburbs.

The land LTC absorbed by transportation, public, and other miscellaneous uses in the core has been calculated as a fraction of the land in industrial and residential uses in the core.

LTC - LCT * (LIC = LHC)

where

LCT = the land coefficient for transportation and miscellaneous uses
LIC = the total land in industrial land use in the core
LHC = the total land used for housing in the core

The coefficient LCT was estimated from the data of Niedercorn and Hearle [35] and has a value of approximately six tenths (.6).

The land abandoned in the core LAC is the sum of the land occupied by abandoned housing and LIAC, that occupied by abandoned industries.

$$LAC = \frac{HCA}{DAHC} + LIAC$$

where

HCA = the number of abandoned housing units in the core city
DAHC = the average density of housing in the core city

The land remaining vacant in the core LVC is calculated as the difference between the total land in the core city LTOTC and the land used for housing, industry, and transportation and miscellaneous. The total land supply of the core city is a constant specified as an initial input of the model in terms of the radius of the core city. The area in acres is calculated in the model by assuming that the core city is a perfect circle.

The total land supply in the suburbs LTOTS is assumed to increase in time due to improvements in both the average speed and degree of network coverage of the transportation system. The radius of the outer boundary of the city is assumed to be the distance traveled in one half an hour by the upper skilled population (see next part of this section for

for discussion of velocities). The difference in the area of a circle with this radius and the area of the core city is the potential land supply of the suburbs. The actual land supply available is this potential supply multiplied by a factor (FSLT-see Figure 37) which accounts for the degree of coverage of the upper skilled transportation network. For example, in the early twentieth century, trolleys to the suburbs had a relatively high average speed leading to a large radius. The actual amount of suburban land accessible by this means of transportation was limited because of the limited number of lines extending outward (see for example [36] the 'finger development' of Boston described by Warner). This FSLT at this time is low, [37] decreasing by a factor of five the land actually available in the suburbs. In contrast, modern highways currently provide more uniform coverage of the suburban land, the construction of the highway network required time, so the improvement in degree of coverage, i.e., FSLT, occurs gradually, but by 1950 it was assumed to be complete.

4. Accessibilities.

The accessibilities of jobs, labor force, and industrial supporting services are calculated in the model on the basis of the average travel times within the city. The travel times

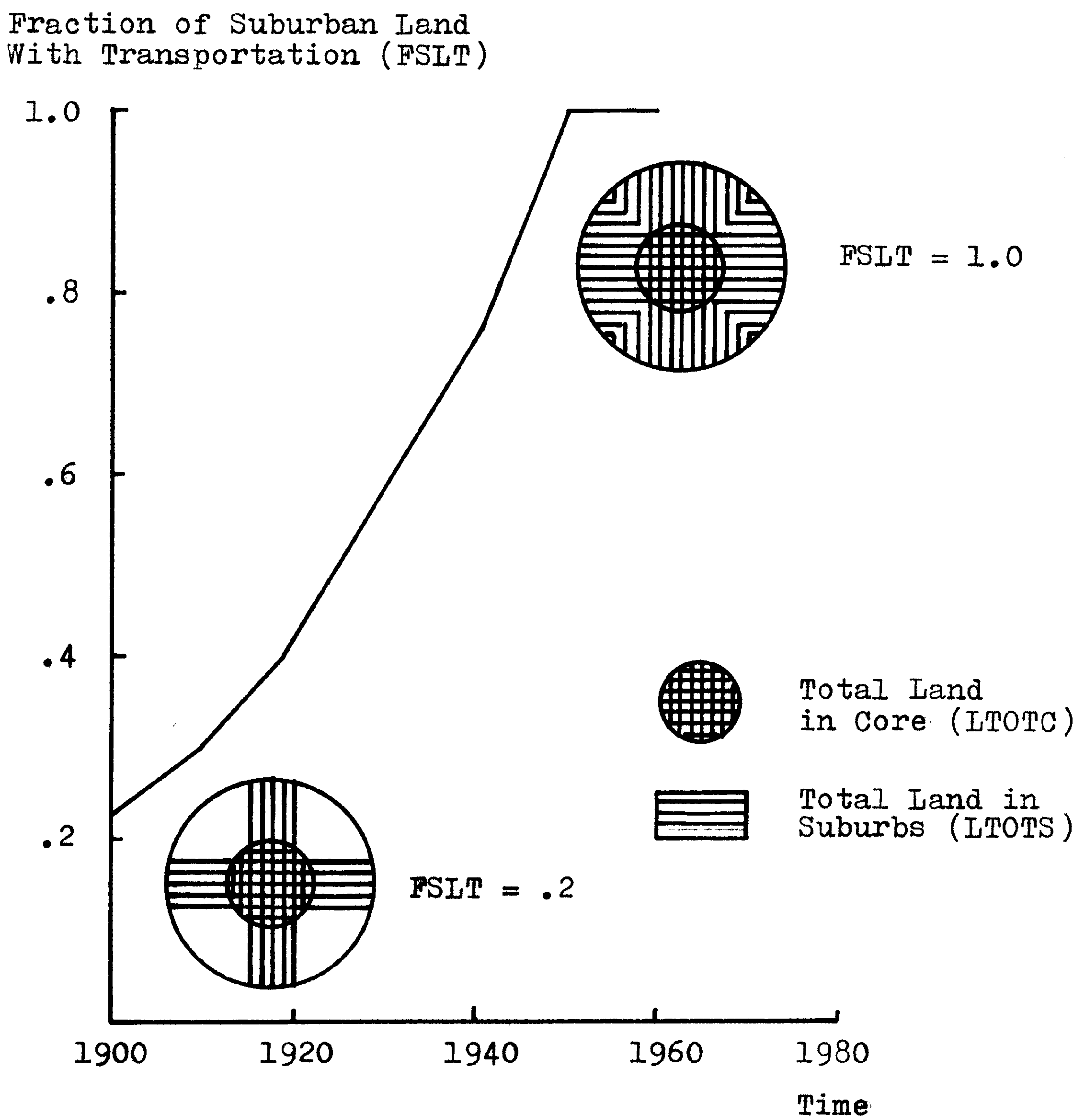


Fig. 37 The Fraction of Suburban Land With Transportation as a Function of Time from 1900 to 1960. The diagrams indicate the difference in network coverage in the suburbs implied by FSLT = .2, such as occured with the finger development generated by trolley lines, versus FSLT = 1.0, such as occured with the development of a much more uniformly distributed network of suburban roads.

are a function of the average speed of the mode of transportation being used and the distance traveled. The average speed varies with time as technology changes,[38] with the user at a given point in time because of the differences in the ability to use different modes of transportation, and with the origin and destination of the user. The distance traveled is a function of the origin and destination of the trip. With only two areas, or origin and destination 'zones,' the model can include only a gross characterization of the differences in these distances and thus the travel times.

The model includes two modes of transportation--one for upper skilled population, the other for lower skilled. The characteristics of the mode used for freight distribution rather than movement of people are assumed to be equivalent to those of the upper skilled mode at this level of aggregation. The three different networks considered for each mode are the intra-central city network, the intra-suburban network, and the network linking the central city to the suburb. The average velocities for each of the two modes on each of the three networks which have been assumed in the model are shown in Figures 38 and 39. The lower skilled mode for the intra-suburban, and suburban--central city networks is initially assumed to be walking and shifts to buses in the thirties (see Figure 12 in Chapter 3). The intra-central city mode

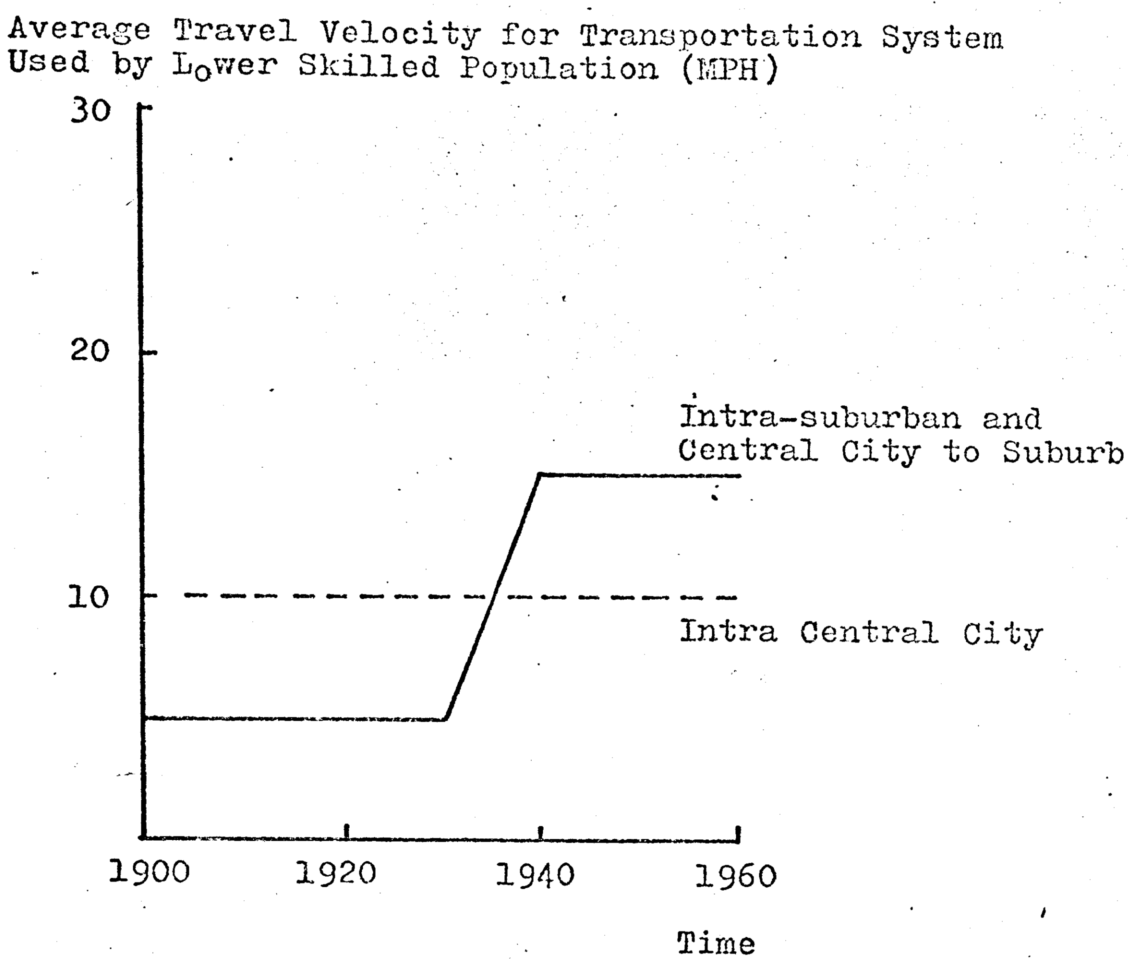


Fig. 38 The Average Travel Velocities for the Lower Skilled Population on Three Different Transportation Networks Between 1900 and 1960

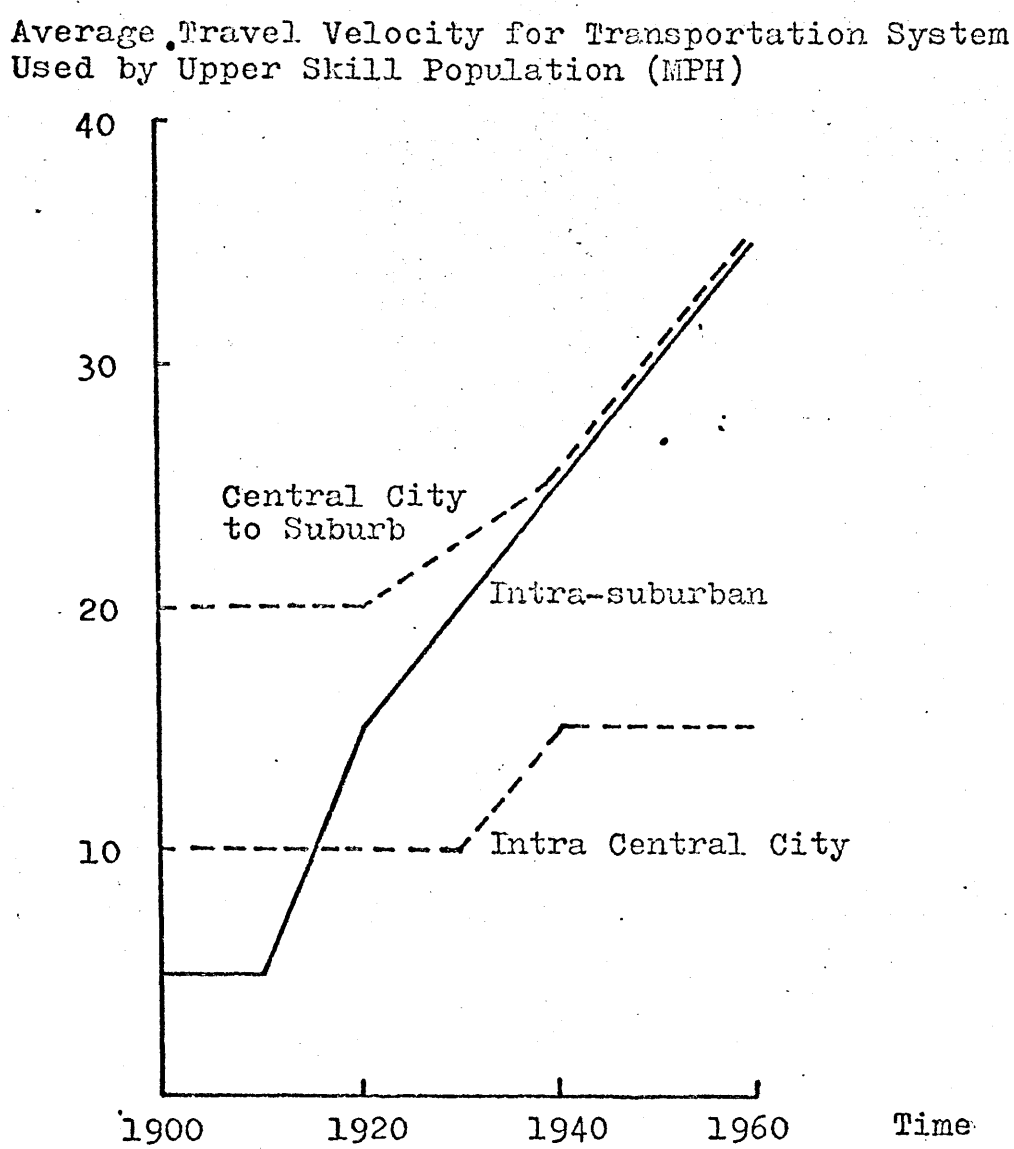


Fig. 39 The Average Travel Velocities for the Upper Skilled Population on Three Different Networks Between 1900 and 1960

shifts from trolleys to buses, but the average is assumed to be constant. For the upper skilled population (Figure 39), the intra-city mode shifts from trolley to private car during the thirties, but without a major improvement in average speed. The intra-suburban mode shifts from walking to private car operating on a steadily improving highway network. The central city-suburban mode is initially trolleys but also shifts to private auto.

The distance used in calculating average travel times, inside and between the two areas were just gross representations of the scale of distances involved. The distances are interpreted as an average, but they were not formally derived by assuming a distribution of population and employment over the two areas and calculating an average. The average distances assumed in the model were [39]

RCC = .75 * RCORE
RCS = .5 * (RCORE + RSUB)
RSS = .75 * (RCORE + RSUB)

where

RCC = the average intra-central city distance
RCS = the average core to suburban distance
RSS = the average intra-suburban distance
RCORE = the radius of the core city (an input to the model)
RSUB = the radius of the outer boundary of the suburbs of the city (the distance traveled in one-half an hour at the average speed between central city and suburb.)

Using these distances and the average velocities shown in Figures 38 and 39, the average travel times within the central city and suburb and between the central city and suburb were calculated for the two skill classes of population. These six travel times were used to calculate a set of six accessibility multipliers which modified the supplies of jobs in the calculation of the attraction function for population location and the supply of labor in the attraction function for export industry location.

AKUCC = accessibility multiplier for upper skill level within the core
AKUCS = accessibility multiplier for upper skill level from core to suburb
AKUSS = accessibility multiplier for upper skill level within suburbs
AKLCC = accessibility multiplier for lower skill level within core
AKLCS = accessibility multiplier for lower skill level from core to suburb
AKLSS = accessibility multiplier for lower skill level within suburb

The function used to calculate these multipliers is shown in Figure 40. The range of travel times in Figure 40 was estimated from the study by Lansing and Mueller [40] and the linear function was used following the BASS study. [41] The intra-suburban accessibilities calculated on the basis of travel times from the function shown in Figure 40 were

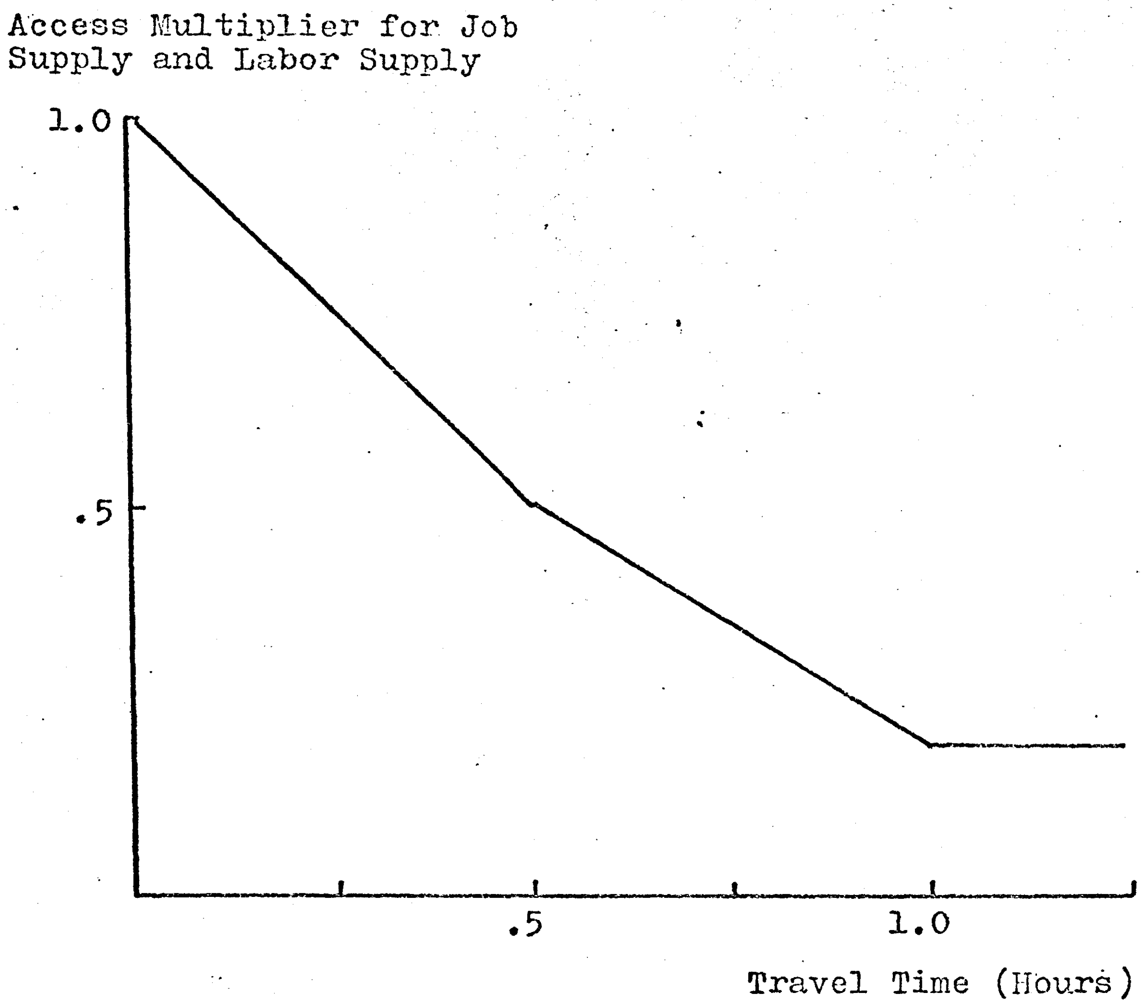


Fig. 40 The Influence of Travel Time on the Accessibility of the Labor Supply for Export Industries and the Job Supply for the Labor Force
The access multipliers modify the number of jobs present to determine the number of jobs actually accessible. The same functional dependence of accessibility on travel time is used for all six multipliers, but the travel time varies with the population group and the network being considered.

multiplied by FSLT, the fraction of suburban land with transportation, before use in the calculations of available labor and employment.

5. Policy Options in the Location and Redistribution Sub-model.

The model contains five policy options dealing with the problem of racial discrimination against blacks in housing, employment, and location of white population. The two options concerning housing discrimination specify the elimination of housing discrimination in the suburbs and/or in the core city. The two options dealing with employment discrimination eliminate the discrimination in upper skilled jobs in all parts of the city and/or the lower skilled jobs in all parts of the city. The final option eliminates race as a consideration in the location of white population. All five options can be exercised completely independently of one another at any point during the simulation.

The final policy option gives the lower skilled population of both races the same mobility as the upper skilled population.

E. The Linkages Between Major Components of the Model.

1. The Linkages Between the Three Submodels.

Figure 41 shows the linkages between the three submodels for population and employment growth, housing supply, and population and employment location which have been described individually above, The loops from each submodel directly back to itself indicate that each submodel is dependent upon 'inputs' which are calculated within itself; for example, the amount of population redistributed in the location submodel is calculated from the existing spatial distribution of population. The closed loops passing from one submodel, through another, then back to the original submodel indicate interactions between processes in urban development which have normally been ignored in past models of urban development (See Chapter 5). For example, the interaction loop between the growth model and location model arises from (1) the increases in population and employment being inputs for the location model, and (2) the existing distribution of population and employment from the location model being inputs for the calculation of the rate of skill upgrading of the labor force in the growth model. Note that there are no interactions directly between the growth model.

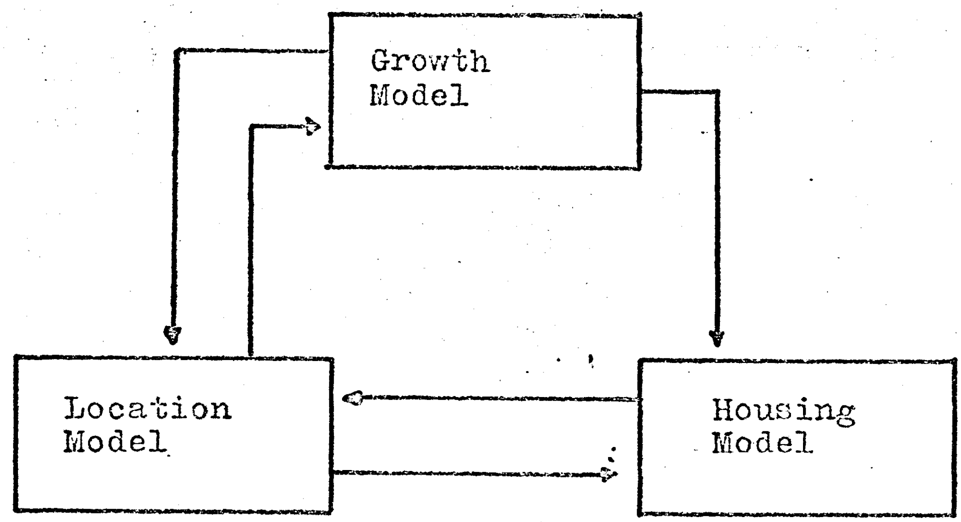


Fig. 41 Schematic of the Linkages Between the Three Submodels

and the housing model, i.e., growth affects the housing model only through its specific spatial distribution and housing supply influences growth only through the effect of housing on location. This part of Section E will briefly review the variables which create the links shown in Figure 41.

a) Growth submodel to location submodel

The only connection is the increase in population and employment being an input to the 'pools' which are allocated in the location model.

b) Location model to growth model

The rate of upgrading of lower skilled population to upper skilled in the growth model is a function of (1) the accessibility of lower skilled population in each area to the supply of upper skilled jobs (Figure 5) and (2) the distribution of lower skilled population between central city and suburb.

c) Growth model to housing model

The rate of expansion of the upper skilled housing in each area is a function of the demand for housing modified by the correction for unemployment among the upper skilled population (Figure 15). The relative size of the total demand for upper skilled and lower skilled housing is influenced by the fraction of total population classified as upper skilled, i.e., of the coefficient JUC (Figure 11 in Chapter 3).

d) Housing Model to growth model

There are no linkages.

e) Housing model to location model

The housing supply in each area influences the location of all four classes of population through the effect of the appropriate ratios of housing demand to supply on the attraction of the area due to housing (Figure 25).

f) Location model to housing model

The demand for housing created by the allocation of population to each area by the location model influences the ratio of housing demand to supply and thus the rate of expansion of upper skilled housing (Figure 14), the rate of filtering of upper skilled housing to lower skilled (Figure 16) and the rate of abandonment of lower skilled housing (Figure 19).

2. Linkages between the central city and suburb

The structures of the interactions in the growth and development of the central city and suburb have been formulated as virtually identical, and operating in parallel. To some extent they can be considered as separate regions having their own set of interactions and having a simple phase lag in their relative development due to the central city's starting to grow first. However, the combination of important differences in the characteristics of the two areas and close ties through their mutual accessibility imply that the structures, while parallel, are not isolated from one another. The differences between the two areas include their intensity of development, as expressed in terms of the fraction of land occupied, residential densities, and employment densities, their spatial extent and degree of separation between complementary activities, and the composition of their population and employment. The interactions between the two areas arise from

a) the aggregate growth of population and employment being a function of the composite properties of the city rather than the properties of any single piece of it. For example, the migration of population is a function of the total size of the city, and the inflow of industry is affected by the labor force of the metropolitan region rather than the central city or suburb alone.

b) the allocation of the aggregate growth on the basis of the <u>relative</u> attraction of the two areas, where the attractions are closely coupled by the sharing of the same aggregate increase in population and employment. A decline or increase in one area decreases or increases the share of the total growth going to that area, and thus influences the development of the other area.

c) the total employment and population of the city having to balance on a metropolitan scale rather than a local scale. The mobility of the labor force today implies that the population in any part of the city no longer has to balance with the employment available there and vice-versa. Commuters can, and do, pass freely across arbitrary political and sociological boundaries. It may be decided that a local balance within parts of the city is desirable, but it can no longer be considered a necessary constraint on urban growth.

These interactions between the central city and suburb are two way, i.e., they establish feedback interactions between the two areas. If any of these feedback loops are important in the dynamics of the growth of the parts of the city, then it is impossible to formulate a model of the growth of just one area within the city. In other words, the boundaries of the urban 'system' must be expanded to include the entire city. The analysis of the model in the following chapter will demonstrate that this is indeed the case.

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12. See for an example of the work in this area the analysis by George Break, "The Sensitivity of Housing Demand to Changes in Mortgage Credit Terms", in The Economic Impact of Federal Loan Insurance," (National Planning Association, Washington, D.C., 1961) or the Page and Seyfried reader (note 9).

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19. For example, see "In the Inner City: Acres of Abandoned Buildings", US News and World Report, January 26, 1970, or "Urban Paradox: Dwellings Abandoned Despite Housing Shortage", New York Times, Feb. 9, 1970, or "Slide in Profit from Slum Housing Spurs Many Landlords to Abandon Properties", The Wall Street Journal, Sept. 19, 1969.

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22. The approximate rates of abandonment for the central cities of Cleveland, Detroit and Chicago ranged from just under 1% to slightly over 2% during the late 1960's. In Grebler's study of one part of Manhattan with a strong decline in population, the rate ranged from 1% to 5% between 1934 and 1940.

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Grebler's data imply a rate of removal fluctuating from a high of 50% during special programs to a low of 10% or less during WW II. The Kaiser Commission study projects a demolition rate of .6 % of total housing stock which converts to approximately 15% to 30% of the abandoned stock. The choice of a value of 20% is consistent with the observations of abandoned buildings remaining standing for periods of 10 to 15 years.

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39. The distances were determined as follows:
    - RCC- the average distance from a point on the outer edge of the core city to a set of activities distributed uniformly over the core city is RCORE (by symmetry). The average distance from a point at the center to a uniform distribution of activities is .67 *RCORE. The value of .75 *RCORE was chosen as an intermediate between these two extremes.
    - RCS- this is the distance from the center of the core city to halfway between the inner and outer boundary of the suburbs.
    - RSS- this is one quarter of the circumference of the city at a radius halfway between the inner and outer boundaries of the suburb.

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Chapter 8

THE ANALYSIS OF SOME EXPERIMENTS WITH THE SIMULATION MODEL

The simulation model described in Chapter 7 represents a precise formulation of a specific set of assumptions about how activities within the city interact with one another in the development and growth of the city. The results of each run of the model are an equally precise statement (to as many significant figures as one could desire) of the exact consequences of those set of assumptinns under the influence of a specified set of external driving forces, for example a constant rate of national economic growth of one percent per year and "normal" amounts of migration. However, as has been mentioned repeatedly above, many of the interactions which have been formulated so precisely in the equations, constants, and table functions of the model are in reality quite uncertain. By varying the formulation and strength of the interactions, e.g., through changing the table functions relating one set of variables to another, and varying the external driving forces, one can use the model to conduct experiments on the consequences of alternative sets of assumptions and thus the sensitivity of the model to these uncertainties.

The testing of the model under a variety of strengths of interactions and in a variety of external driving forces is critical to understanding the nature of the interactions within the model and, through this understanding, to some confidence in the structure of the model and an awareness of its limitations. When dealing with a model of moderate complexity, such as the urban development model of this thesis, this testing and improvement in understanding are never really completed. The number of possible combinations of changes is infinite. The selection of future changes is continuously modified and enlarged by the understanding arising from the analysis of past changes. Thus, although this chapter summarizes the results of approximately two hundred runs of the model, the exploration of the model has really only begun.

Section A of this chapter discusses the behavior of the individual submodels of the urban development model under changes in 1) the initial conditions of the submodel, 2) the table functions of the model, 3) the external driving forces, and 4) the variables which link each submodel to the other submodels. Section B discusses the behavior of the complete model, first in response to a similar set of variations, then to various interventions through the 'policy options' discussed in Chapter 7. Section C analyzes the conclusions drawn from the behavior of the model in terms of some of the questions posed in Chapters 1, 3 and 5. Section D compares the basic structure, behavior, and use of this simulation to the <u>Urban Dynamics</u> model of Forrester. Finally, Section E discusses some questions about the formulation of model developed in this thesis.

Only the output of the submodels and the complete model directly relevant to the discussion have been included in the text of the chapter. A sample of the complete output of the urban growth model is included in Appendix 3.

A. The Individual Submodels

Slightly simplified versions of the growth and housing submodels were created which run independent of the other models and allow the analysis of separate parts of the full model. These models were simplified from the ones incorporated in the full development model as follows: The growth model did not have the skill upgrading of population because that upgrading is dependent upon the location of activities. The housing model assumed that the land fraction occupied (LCOF), the unemployment rate of the upper skilled population (URU), and the distribution of demand between upper and lower skilled (JUC) were constant parameters of the model. These are normal variables which are input from the other submodels and part of the purpose of the analysis was to determine the influence of these interactions between submodels. The demand for housing, instead of being determined by the location model, was either assumed to be constant, or to increase exponentially in time. The housing model was just the model of housing in one area (the core city) but this did not affect the dynamics because there are no direct connections between the housing stocks in the core city and suburb. (In the following discussion, the words models and submodels are used interchangeably. It should be clear from the text whether the full model, composed of three submodels, or an individual submodel is being referred to.)

1. The growth of population and employment

a) Structure and Behavior

Figures 1 and 2 show a sample of the output of the growth submodel. Figure 1 plots as a function of time the total population (P), total employment (J), black population as a fraction of total population (B), black children and white children as a fraction of their respective total populations (C and D), the employment in the export industry as a fraction of the total employment (X), and the lower skilled employment as a fraction of the total employment (F). Figure 2 plots as a function of time the immigration of whites to the city (M), the immigration of blacks to the city (N), the rate of unemployment of the total labor force (T), the rate of unemployment of the upper skilled labor force (U), and the excess

PAGE 2

P=P,J=J,PBR=B,CBR=C,CWR=D,EXR=X,FEL=F

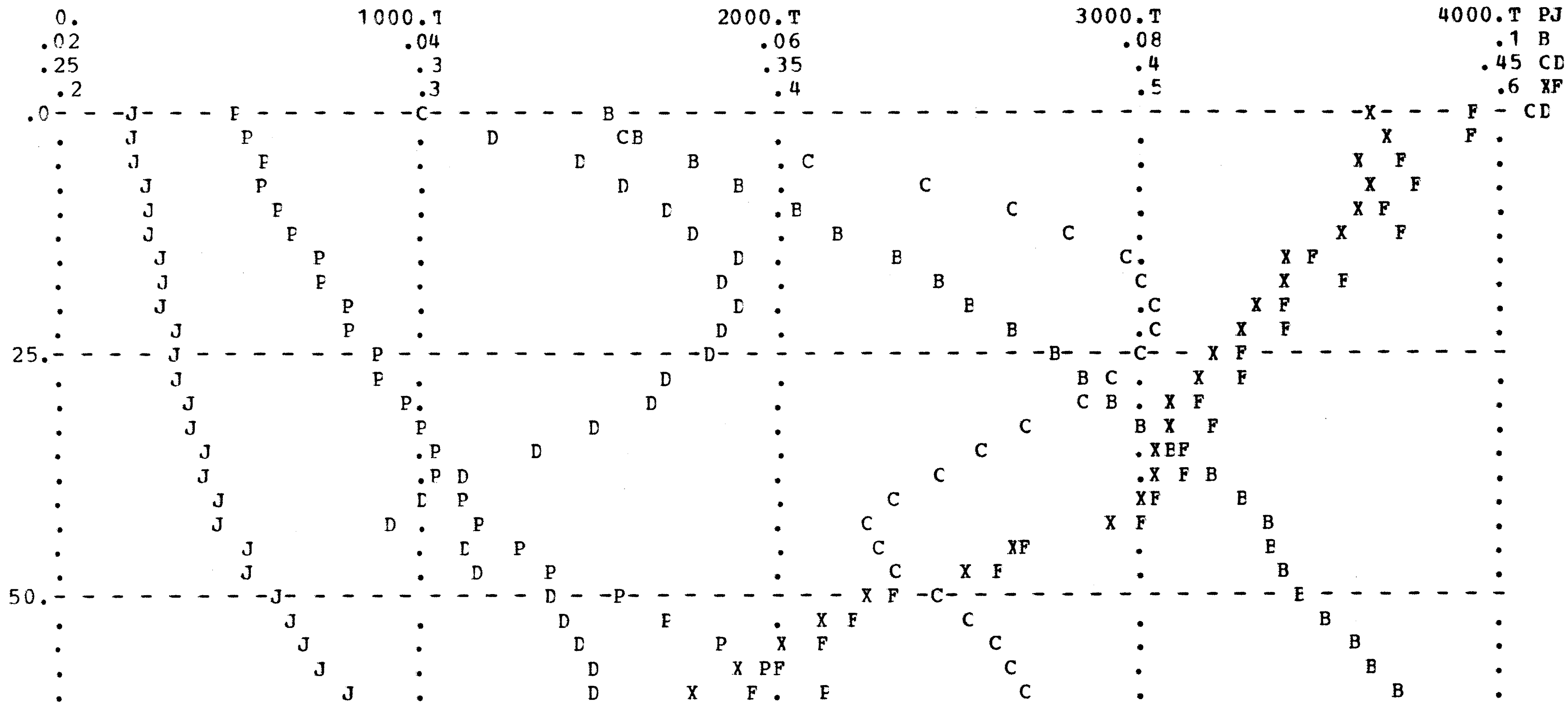

FIGURE 1 SAMPLE OUTPUT OF GROWTH SUBMODEL --- SEE TEXT FOR AN EXPLANATION OF THE VARIABLES AND THE PLOTS.

PAGE 3

FWMIG=M,FBMIG=N,UNR=T,UNRU=U,ELRAT=L

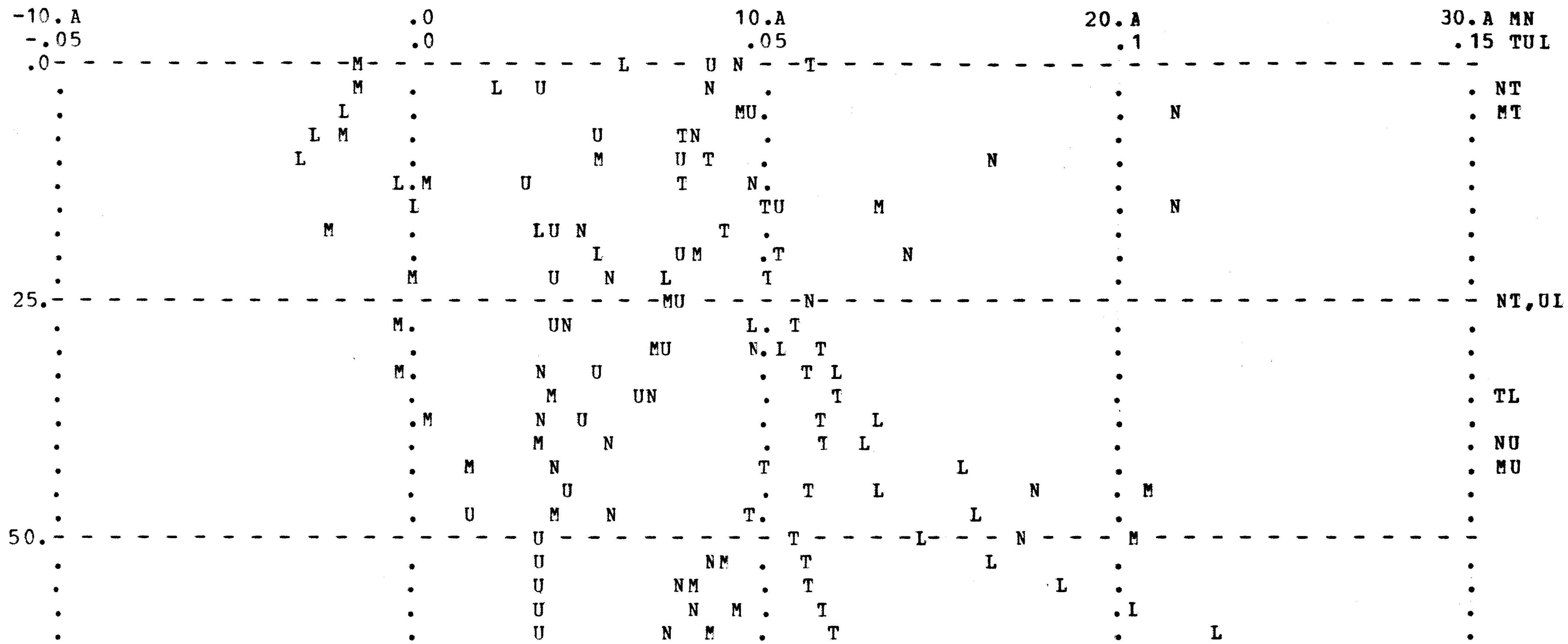

FIGURE 2 SAMPLE OUTPUT OF THE GROWTH SUBMODEL (CONTINUED).

supply of lower skilled labor relative to lower skilled jobs. Time zero on all plots is equivalent to 1900, so the plots of Figure 1 are from 1900 to 1960. The scale for each of the variables is indicated on the left hand side of the figure. For example, population varies from 0 to 4 million (the symbol T stands for thousands. The symbol A, e.g., as used in M in Figure 2, stands for thousandths (.001). Thus, M varies from 0 to .030).

As was discussed in Chapter 7, the growth model has a separate sector for employment growth and population growth which is linked through the rate of unemployment of the labor force (Figure 10 in Chapter 7). The formulation of the population sector in terms of adult populations and children with time dependent birth and death rates produces 'waves' of increases in the labor force over time which are indicated by fluctuations in the fraction of the total population which is children. These waves are delayed with respect to the changes in birth and death rates producing them because of the 18 year aging time (DAG) of children into adults. The timing and magnitude of changes in the distribution of population between adults and children in the model because of the depression dip in birth rates and baby boom of WWII is in agreement with those occurring in the United States.

The employment sector is relatively simple, consisting of only one difference equation (or integration) for employment in export industries. The employment in the other industries are proportional to the population and other employment.

b) Sensitivity

The population sector is influenced by the employment sector through the effect of unemployment rate on migration (Figure 3 in Chapter 7). The employment sector is influenced by population through the effect of excess labor supply upon the rate of expansion of export industry (Figure 8 in Chapter 7). The sensitivity of these connections between the two sectors to imbalances in population and employment determine the 'pull' which excess labor has on new industrial growth, and the pull of excess jobs on population growth. These relative pulls (which are the local slopes of the curves in Figures 3 and 8 in Chapter 7) need not be equivalent, as will be discussed below. The coupling between the two sections is such that the behavior of the growth submodel is very stable, i.e., the smooth exponential growth in population and employment shown in Figure 1 is typical of the behavior under a wide variety of growth condition. The submodel was also relatively insensitive to moderate mismatches in the initial values of population and employment.

The rates of unemployment and immigration fluctuated in time (Figure 2) due to the population waves generated by the population sector and to changes in external driving forces, but no instabilities were observed. The response to the internal population waves could be 'washed out', by driving the growth hard enough by external forces, e.g. by increasing the rate of growth of export industry to 3% per year.

The coupling of the population to employment through unemployment has been comparatively well established by Lowry's work (see Chapter 7), but the sensitivity of coupling in the other direction, from employment to population through the excess labor supply, is much less certain. In particular, the base curve (solid line) in Figure 8 of Chapter 7 implies an insensitivity of industry to excess labor supply, i.e., the slope of the curve for excess labor is low relative to that for a labor deficit. In contrast, the slope of the curve in Figure 3 at high rates of unemployment is much higher, once the corrections for changes in scale are made.

The implication of this insensitivity is that rate of industrial growth expands very little to match the labor force provided by high immigration rates of population. This keeps the unemployment high, which in turn decreases the rate of immigration. In other words the insensitivity of Figure 3 increases in excess labor supply and makes the export industries resist increases in the expansion of the city due to population migration. Table 1 shows this resistance and how it is modified by a change in the curve in Figure 3 of Chapter 7 from the base curve to one with a higher slope of positive excess labor supplies. The relatively small change in Figure 3 almost doubles the increase in population caused by a factor of three increase in the migration potential.

Using the base curve of Figure 3 in Chapter 7, it was impossible to have the model reproduce the high sustained growth rates (5% to 8% per year for several decades) which have been observed in cities driven primarily by population migration. Thus, either the original curve must be made much more sensitive to increases in excess labor supply or some other aspect of the formulation must be changed.

For contrast, the effects of 2.5 increase in the growth of export industry are also included in Table 1 for both curves in Figure 3. Note that when growth of the city is being driven by an increase in the export industries rather than by migration, the labor market is tight and unemployment low in order to increase population migration. Thus, a city is expanding faster than usual because of high immigration, is in a basically different state than one expanding due to high industrial growth. The former has a loose labor market and high unemployment, while the latter has a tight labor market and low unemployment.

Table 1: The effects of change in the attraction of excess labor for export industry (Figure 3 of Chapter 7) on the influence of increases in the multipliers of population immigration rate and in the growth rate of export industry.

	Ratio of Industrial growth rates	Ratio of Population Migration Rates	Ratio of final population
1) Basic curve in Figure 3	1	1	1
	1	3	1.3
	2.5	1	2.2
2) Modified Curve in Figure 3	1	1	1
	1	3	1.6
	2.5	1	1.8

The ratio of final population is the ratio of the population after 60 years of growth using the changes in migration and export industry growth shown, to the final population after 60 years growth using the 'normal' growth rates.

The effect of this difference on the housing submodel will be discussed later.

The only input from the other submodels to the growth model occurs through the dependence of skill upgrading on the location of employment and lower skilled population, as was discussed in the concluding section of Chapter 7. The growth model which ran separately did not incorporate the spatial inputs and their influence was not tested.

2. The Housing Submodel

a) Behavior and Structure

Figures 3 and 4 are samples of the output of the housing model. Figure 3 plots as a function of time the housing stocks for upper skilled (U), for lower skilled (L), and abandoned (A); the ratio of housing demand to supply in the upper skilled market (R), and the same ratio for the lower skilled market (P); the construction rate of upper skilled units per year (C), the filtering of upper skilled units per year (F), the abandonment of lower skilled units per year (E), and the demolition of lower skilled housing units per year (D). Figure 4 plots the land in residential use for all three housing stocks (C), the average density of housing (D), and the marginal density of housing (M). (The marginal density remains constant because the land fraction occupied is assumed to be constant, i.e., the

PAGE 1

```
HCU=U,HCL=L,HCA=A,RHCU=R,RHCL=P,HCUCR=C,HCFR=F,HCAR=E,HCDR=D
          .0                         50.T                         100.T                         150.T                         200.T ULA
         .98                         1.01                          1.04                          1.07                           1.1 R
          .0                           1.                            2.                            3.                            4. P
          .0                          5.T                          10.T                          15.T                          20.T CF
          .0                         200.                          400.                          600.                          800. ED
        .0A - - C - - - - - -R- -U- -P- - L - - - - - - - - - - - - - - - - - - - - - - - - - E - - - - - - - - - - - - - - - - CF,AD
          .A    F                 C  U  . DP  L                       .                          E  .              R              .
          .A     F                    C U     L P           D         .          E                  .                   R         .
          .A      F                     . CU   L      P E        D    .                             .                   R         .
          .A       F                    .     CL U       E PD         .                             .                   R         .
          .A         F                  .       L   C U   E      P    .                             .                   R         .  ED
          .A          F                 .       L        DCE U        . P                           .                   R         .
          .A           F                .        L       D  E    C   U.        P                    .                   R         .
          .A              F             .          L     D    E       . C   U         P             .                   R         .
          .A                F           .            L    D     E     .           C   U     P     .                   R         .
       20.-A- - - - - - - - - -F- - - - - - - - - - - -L- D - - E - - - - - - - - - - - - - C - -U- -P- - - - - - - - R - - - - -
```

FIGURE 3 SAMPLE OUTPUT OF THE HOUSING MODEL.

PAGE 2

LHC=C,DAHC=D,DMHC=M

```
 .0          5.T         10.T         15.T         20.T C
13.5         14.         14.5          15.         15.5 DM
.0D - - - - - - - --C- - - - - - - - - - - - - - - - M
 . D          .      C     .            .            M
 .    D       .        C   .            .            M
 .        D   .         C  .            .            M
 .           D.          C .            .            M
 .            . D          C            .            M
 .            .    D       . C          .            M
 .            .       D    .   C        .            M
 .            .          D .      C     .            M
 .            .            . D       C  .            M
20.- - - - - - - - - - - - - --D- - -  C - - - - - M
```

FIGURE 4 SAMPLE OF THE HOUSING MODEL (CONTINUED).

housing model alone cannot simulate changes in other land uses). The scales for time and other variables are as described for the growth submodel.

The behavior of the housing model was explored primarily in terms of the behavior of the ratio of demand to supply for the two housing markets. The demand for housing, which is normally an input from the location model, was assumed to be constant or to increase exponentially in time. The dynamics of the response of the demand to supply ratios were thus determined solely by the dynamics of the changes in the stocks of upper skilled and lower skilled housing.

As was shown in Figure 13 of Chapter 7, the upper skilled housing stock is controlled by the rate of housing construction and the rate of filtering. Both of these rates are functions of the ratio of demand to supply in the upper skilled market. In the full model, the housing construction rate is also affected by the rate of unemployment in the upper skilled labor and the external demand multiplier (see Chapter 7) but these have both been assumed to be constant parameters of the housing model when it runs independently. Assume temporarily that these constants are chosen so they have no effect, i.e., the modified housing demand to supply ratio of Chapter 7 is equal to the actual ratio. (If this is not true, then the same discussion holds true, but the scale of the rate of upper skilled housing expansion in Figure 14 of Chapter 7 merely has to be shifted by some constant value.) Under this assumption both the expansion and filtering of upper skilled housing are a function of only the ratio of demand to supply. They can be combined into one rate, the net rate of housing expansion and the changes in upper skilled housing are governed by only a single feedback loop. Figure 5 shows this combined rate derived from the curves of Figures 14 and 16 of Chapter 7.

With no growth in housing demand, as is the case in Figures 3 and 4, the passing of the net expansion curve of Figure 5 through the origin implies that the model has an equilibrium point at supply equal to demand. If the supply is displaced from this equilibrium, it approaches its equilibrium exponentially with a time constant determined by the slope of the curve in Figure 5. If the supply grows at a constant rate, the model still has an equilibrium but at a demand to supply ratio greater than one. The demand to supply ratio increases until the net rate of housing expansion in Figure 5 is equal to the rate of expansion of supply. Because the upper skilled housing involves only one state of level variable, the system is stable and does not oscillate (A system mustbe at least second order, i.e., involve two first order difference equations, before it can have internally generated oscillations.) In other words, as the rate of expansion of housing demand increases,

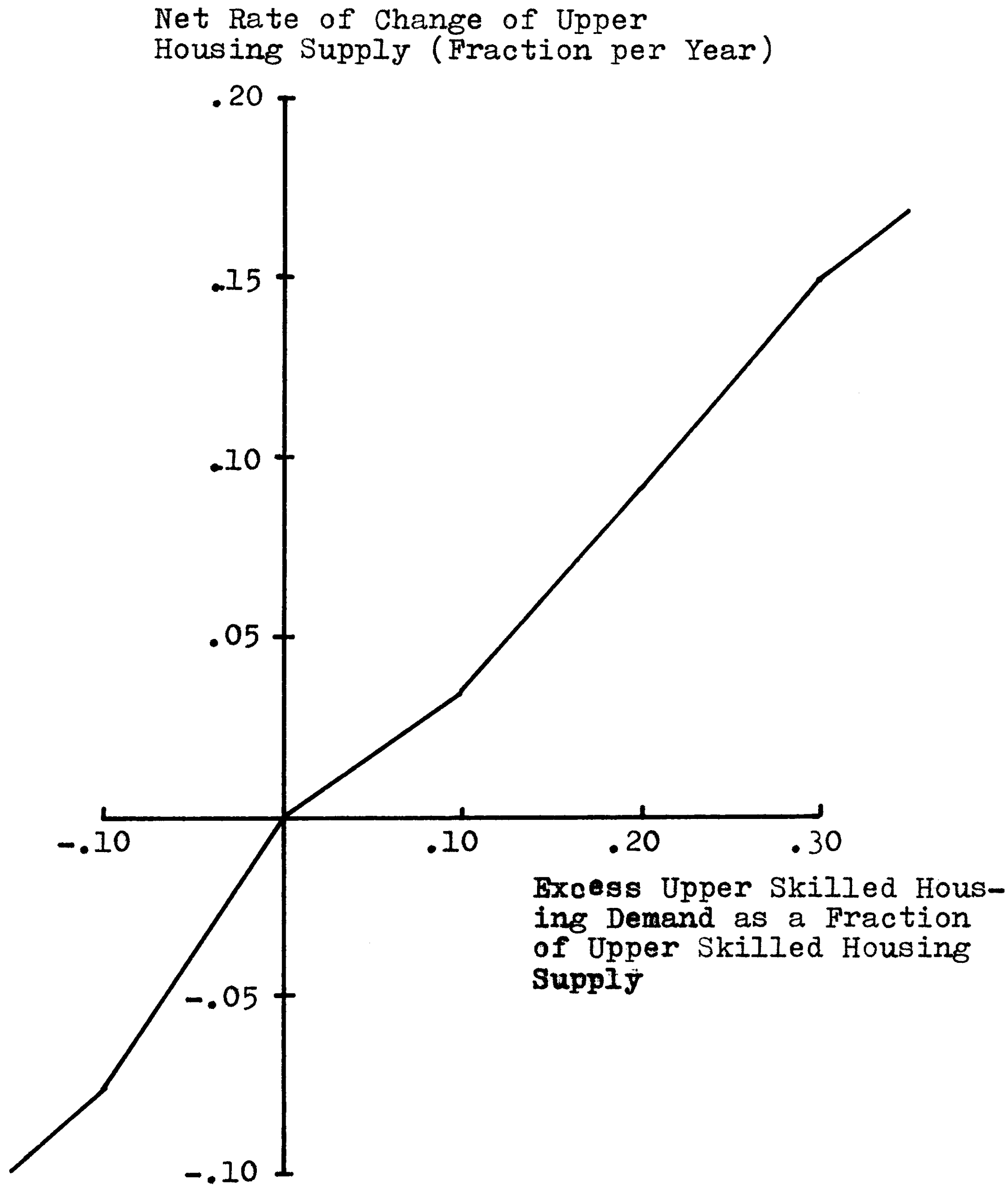

Fig. 5 **Net Rate of Expansion of the Upper Skilled Housing Supply as a Function of Excess Demand**

the equilibrium ratio of demand to supply and thus the degree of housing shortage increases. Thus the formulation of this housing model implies that the city will never eliminate its housing shortage as long as it is growing. The only way to avoid such a shortage is to make the curve in Figure 5 absolutely flat and following the origin, i.e., an infinitely responsive market.

For the filtering rates used here, the net expansion curve is dominated by the housing construction curve for growth rates of more than about 5% per year. Thus, changes in the responsiveness of the housing market (the slope of Figure 14 as was discussed in Chapter 7) are reflected directly in the net expansion curve. For example, if the responsiveness of the housing market is doubled, the net expansion essentially doubles and the housing shortage required to have equilibrium in the housing market at a constantly demand declines. (Table 2).

The lower skilled housing supply is changed by the filtering of the upper skilled housing, the abandonment of the lower skilled, and the conversion of lower skilled to upper skilled. The first is independent of the lower skilled supply and demand. If the fraction of land occupied is small, all new construction occurs on vacant land and the number of building conversions is zero. Then the low skilled housing supply is determined by the balance between

Table 2: **The effect of doubling the response of the upper skilled housing market (Figure 14 in Chapter 7) on equilibrium shortage of upper skilled housing at a constant rate of growth of housing demand.**

1)

Responsiveness of housing market (in years to adjust to constand demand)	Annual rate of growth of housing demand	Equilibrium Shortage of Housing Supply
2 years	3%	8%
2 years	7%	18%
2 years	10%	23%
1 year	7%	9%
1 year	10%	12%

The responsiveness of the housing market is described in Section C of Chapter 7.

the rates of filtering and abandonment, i.e, by the number of units in each of the two supplies and the ratio of supply to demand which determines the fraction of units filtering and being abandoned. As the ratio of the number of upper skilled units to lower skilled units decreases, it becomes progressively more difficult to achieve such a balance. As the fraction of land occupied increases, the fraction of upper skilled units being built by conversion of lower skilled housing sites land increases, the rate of decrease increases and a further drain on the low skilled housing supply is added.

b) Sensitivity

The behavior of the upper skilled market was insensitive to initial imbalances in demand because of the relatively high responsiveness. The model corrected for both a fifty percent housing shortage and excess within five to ten years. The lower skilled housing supply was much more sensitive to initial discrepancies between housing demand and supply, requiring 40 to 50 years to correct for the same 50% shortage. This sensitivity of the lower skilled market could be greatly reduced (a factor of two to three) by changing the ratio of upper skilled housing to lower skilled housing from approximately 2:1 to 1:2.

The calculation from other models which are used as inputs to the housing model are the demand for housing, the land fraction occupied, the size of the demand for lower skilled housing relative to the demand for upper skilled housing, and the unemployment rate of the upper skilled population. The third quantity, the relative size of the lower skilled housing demand, does not appear explicitly in the equations of the housing model, but is effectively determined by the fraction of the total labor force classified as upper skilled, i.e., the time dependent coefficient JUC in the growth model (see Figure II of Chapter 3). The effects of this relative size of demand, the rate of change of demand, and the land fraction occupied have already been discussed. The unemployment rate of the upper skilled population decreases the effective demand in the upper skilled housing market. This is equivalent at a shift to the left on the horizontal scale of Figure 14 of Chapter 7 and thus of Figure 5, i.e., unemployment further aggrevates the housing shortages created by growth of demand.

3. Location of population and employment

No separate runs of the location submodel alone were made because of the dependence of location on shifts in housing supply. The runs of the housing and location models without the growth model, i.e., for constant population and employment, are treated in the next section.

The analysis of the location model was conducted using the full urban growth model, because it was felt that the consequences of alternate forms of the distribution functions and the attraction functions could only be tested fairly under conditions of growth. Virtually all of the tests in this analysis were made using the simulation of the development of a high density city, i.e., a city with an initial population density of 12,000 people per square mile in the core city and an initial size of 600,000 people in 1900.

The discussion here will focus on the alternative formulations of the distribution functions which allocate population and industry to the core on the basis of its attractiveness relative to the suburbs, and of the functions which determine that composite attraction. It should be emphasized that both of the distribution functions and every one of the attraction functions have been varied either by changing their table function or by reformulating the interactions. The alternative forms of the table functions have been included in the figures in Chapter 7. and only the more important of them will be discussed here. The alternative formulations which led to those used in Chapter 7 will be briefly reviewed here.

The sensitivity of the behavior of the model to changes in the external driving forces such as rate of migration, and in the initial conditions are treated in the discussion of the full model in Section B. As for the sensitivity of the location model to changes in the inputs from the other models, the only input to the location model from the growth model is the new growth of population and employment which enter the pools to be allocated to the core city and suburbs. The variation in this input is handled in the discussion of the sensitivity of the full model to changes in growth rates in the following section. The only inputs from the housing model are the housing supplies used to calculate the ratio of housing demand to supply, and thus to determine the attraction of the area due to housing. This same ratio is extremely important in the housing model as will be discussed in Section B.

a) Changes in the formulation of population location

The fraction of the population pool allocated at the core city is determined by the distribution function shown in Figure 23 of Chapter 7. Initially this function was formulated as shown by the solid line. However, this formulation completely cuts off the allocation of any part of the people to the area once the attraction of the other area is twice as great. This sharp cutoff of growth created erratic behavior in the growth of population and employment. The simple change of easing the transition to zero growth by adding the dotted lines smoothed these fluctuations. The slope of the body of the curve was not experimented with because the change in allocation for a given change in ratio of attractions was commensurate with one another as formulated. An entirely equivalent formulation using a distribution multiplier which was much more sensitive to changes in attraction, but attraction functions which changed much more gradually with changes in their dependent variable should have given equivalent results.

The sensitivity of the location model to any individual component of attraction, e.g., housing or jobs, is one of the basic assumptions of the model. Flattening the attraction curves for housing makes the attraction of an area independent of the housing supply and effectively eliminates housing from the location model. The relative steepness of the attraction functions for two variables in the region of operation of the model determines the tradeoffs between two location factors. These tradeoffs, and thus the shapes of the curves are assumptions of the model, and the model can do no more than show whether those assumptions produce results which seem 'reasonable' and consistent in the light of observed behavior. The slope of the attractions functions which govern the behavior of the location model is not the simple geometric slope. Since the relative attraction of the two areas appears only as a ratio, the ratio of the attraction functions at different values of the dependent variable in the crucial characteristic of the attraction curves. Multiplication of the attraction by a constant, i.e., changing its scale, has no effect whatsoever on the model because the ratio of attractions remains unaffected. This is why the attraction functions in Chapter 7 were all normalized to one.)

As was mentioned before each of the five attraction functions influencing the location of population were varied or reformulated in terms of the ratio of job demand in the area to job supply accessible from the area. This formulation gave much too high an attraction to the suburbs during the early stages of development when the suburbs had low population and access to the entire job supply of the central city. The effect of racial discrimination in the housing supply available to blacks was originally formulated as strictly proportional to the fraction of blacks in the area, but this seemed to under-emphasize strong transition in an area once it becomes partially black.

The attraction function for housing supply has a key role in the link between the housing and location model and several variations were necessary to produce 'reasonable' behavior, particularly in the trends of the' location of black population relative to whites. The formulation of the attraction function for housing had to assume that black population was just as sensitive to an increase in housing shortage as whites even though the degree of the shortage was much higher for blacks because of racial discrimination. In other words, no diminishing effects in increasing housing shortage are assumed through the point where demand equals twice the available housing supply. A ten percent increase in housing shortage when the base shortage is 80% has almost the same effect as a ten percent increase when the base shortage is 20%.

b) Changes in the formulation of industrial location

The changes which were made in the distribution function for industry are the same as the changes made in the distribution function for population. The original formulation of the attraction of labor supply on industrial location was similar to that for population, i.e., it was based on the ratio of the demand for labor by industries located in the area to the supply of labor available in the area. This formulation encountered difficulties similar to those of the attraction of jobs for population and it was changed to the present formulation in terms of the fraction of labor supply accessible from the area.

B. The Behavior of the Complete Systems Model of Urban Growth

The complete model will first be discussed in terms of its behavior under constant and 'actual' rates of export industry expansion for the two cases of 1) city with an initial population of 100,000 and an initial residential density in the core city of 3,000 people per square mile, and 2) a city with an initial population of 600,000 and an initial density of 12,000 people per square mile. The rates of technological change in transportation and production, and the 'actual' rate of export national industry growth are those of the United States between 1900 and 1960 which were discussed in Chapter 3. The behavior of the model is in reasonable agreement with the data on the distribution of population and industrial growth in large metropolitan areas in the United States during this period, which was presented in Figures 3, 4 and 5 of Chapter 2.

Second, the effects of three policy interventions in the model are discussed. The relative effects of the interventions are quite different and represent useful inputs to the evaluation of alternative approaches to relieving some of the problems of the urban crisis, However, as is discussed in part 3 of Section D below, a formal evaluation of the alternatives is beyond both the scope and capability of this research.

The figures in this section are only the basic plots of distribution of population and employment and the ratios of growth rates developed as indicators of dispersal in Chapter 2. A sample of the complete output of the full model is included in Appendix 3 for the case of a high density city.

1. Development without policy interventions

a) Development of a High Density City

Figure 6 plots the changes in total population in the core city (O); population in the suburbs (P), black population in the core (A) and in the suburbs (B), white population in the core (W) and in the suburbs (U), the export industry employment in the core both in magnitude (K) and as a fraction of the total export employment in the city (1), and the total employment in the core as a fraction of the total metropolitan employment (J). Figure 7 plots the growth rates of four activities for the metropolitan area as a whole. These ratios for total population (P), black population (B), white population (W), and total employment (J), were developed in Chapter 3 as indicators of the rate of dispersal. Although Figure 7 plots the same variables over time as the figures in Chapter 3, the plots should not be confused with one another. Figure 7 follows the development of a particular city as it grows in time; Figure 4 in Chapter 3 follows the development of a changing sample of cities which have the same core city density. However, since the 'city' of the simulation in Figure 7 happens to stay in the same density class (high), the behavior of its growth rate ratios should be similar to those for high density cities in Figure 4 of Chapter 3.

PAGE 2 RUN - LE

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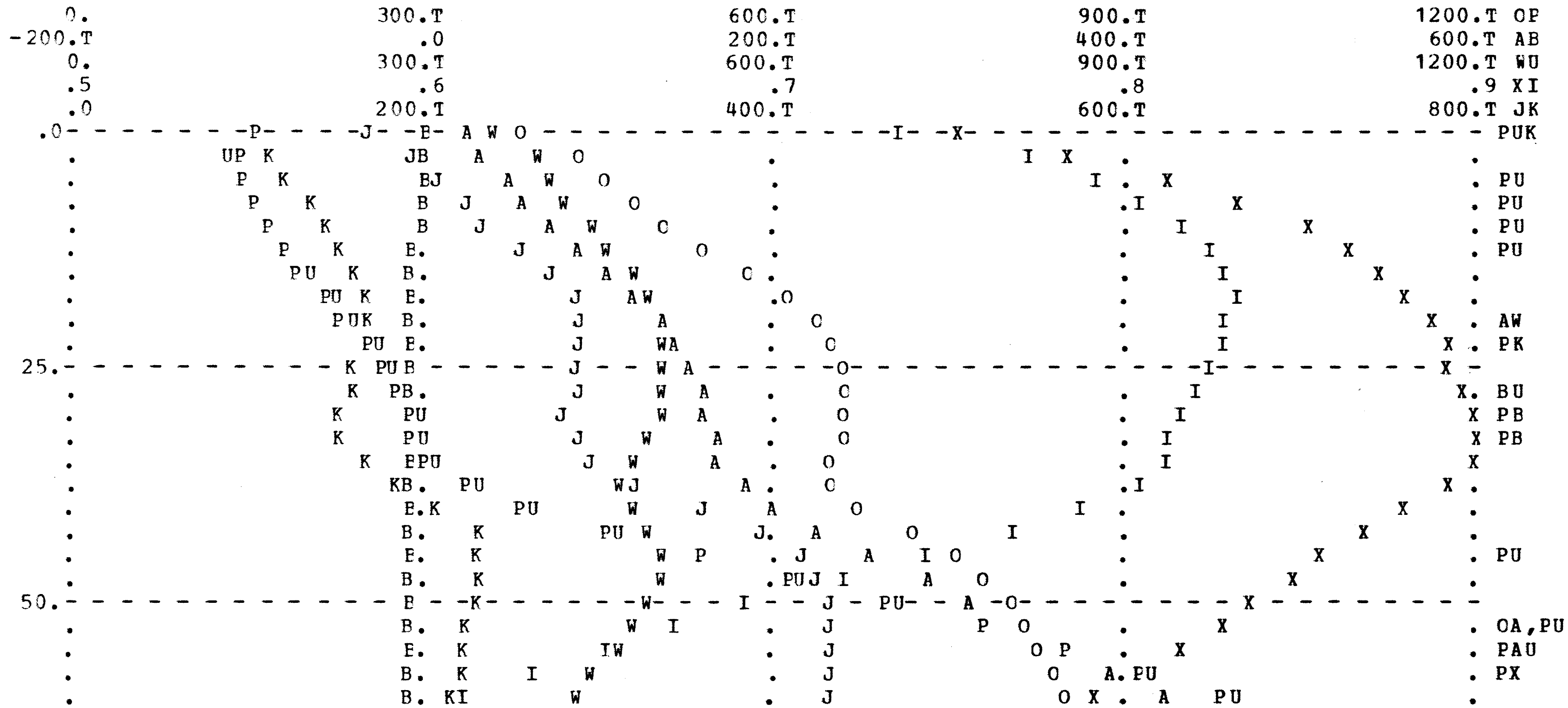

FIGURE 6 THE SIMULATION OF THE DEVELOPMENT OF A HIGH DENSITY CITY UNDER CONSTANT NATIONAL GROWTH RATE OF EXPORT INDUSTRY.

PAGE 3 RUN - LE

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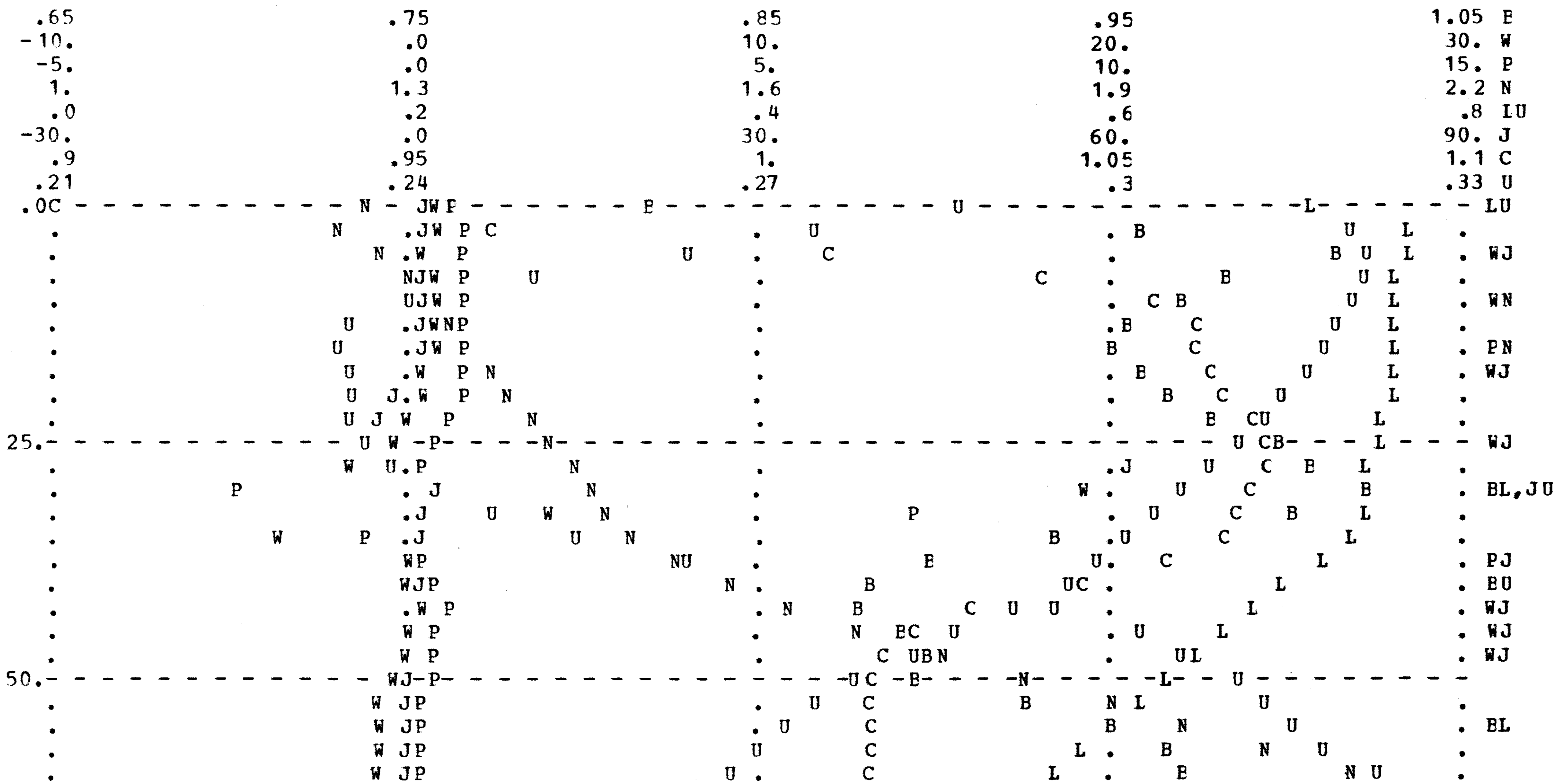

FIGURE 7 CONTINUATION OF THE OUTPUT OF THE SIMULATION OF FIGURE 6.

The simulation in Figures 6 and 7 is of a city which has an initial population of 600,000 and residential density of 12,000 people per square mile in its core in 1900. Over the sixty year simulation, the population in core (O) increases steadily to slightly over one million people (Figure 6). The scale of each variable is specified at the top of the figure; the letter T stands for thousands. In the plot, time increases from the top of the page to the bottom and the time scale is indicated in the left hand scale. The absolute rate of population growth decreases over the last ten to twenty years and Figure 7 shows that the ratio of population growth rate in the core to growth rate of the metropolitan area (P) is declining almost continuously for the sixty year period from 1900 to 1960. There are some fluctuations in the rate in the simulation, but the general trend and total change in the ratio of growth is quite similar. The relative roles of the upper and lower skilled populations in this decline is indicated by the trends in the fraction of upper skilled population in the core (U) and the fraction of lower skilled population in the core (L) in Figure 7. The decline in upper skilled population in the core leads that of the lower skilled by about ten to fifteen years.

The black population in the core (A in Figure 6) grows steadily while that in the suburbs (B) remains virtually constant. This is also shown by the ratio of core growth to metropolitan growth (B in Figure 7) remaining close to one for most of the simulation. The rise in suburban black population during the last ten years continued to accelerate when the simulation was extended but this 'trend' will be described later.

The export industries in the core as a fraction of the total export employment in the city, (X) declines during the simulation. The ratio of growth rates in the core and metropolitan area also declines from a value greater than one (i.e., an increasing concentration of export industries in the core) to approximately one tenth. As will be seen below, if the rate of national expansion of export industries declines in time as it did between 1940 and 1960, this relative decline in export industries in the core becomes an absolute decline.

Figures 8 and 9 show the results of a simulation of the same city but assuming that the national rate of expansion of export industry varied as shown in Figure 6 of Chapter 3. The 'Great Depression' has added a dip in the growth of the central city during the thirties. The decline in the rate of expansion in export industries in the late forties and fifties has been translated into an absolute decline in the export employment of the core city.

A fundamental change has also occurred in the location of black population. Instead of beginning to move into the suburbs during the fifties, they continue to concentrate in the core. Even when the simulation was

PAGE 13 RUN - LE1

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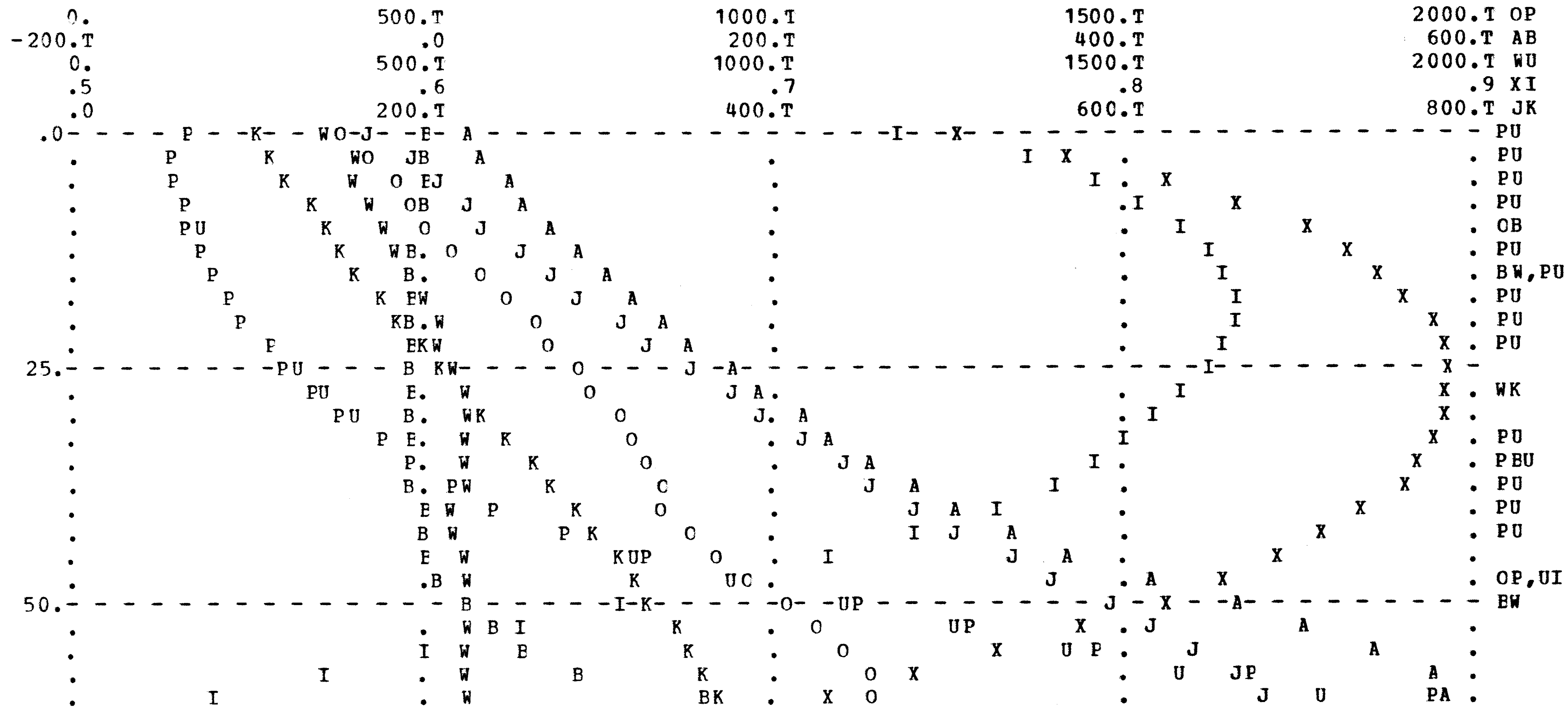

FIGURE 8 SIMULATION OF THE DEVELOPMENT OF A HIGH DENSITY CITY UNDER THE NATIONAL GROWTH RATE OF EXPORT INDUSTRY VARYING AS IN THE UNITED STATES BETWEEN 1900 AND 1960.

PAGE 14 RUN - LE1

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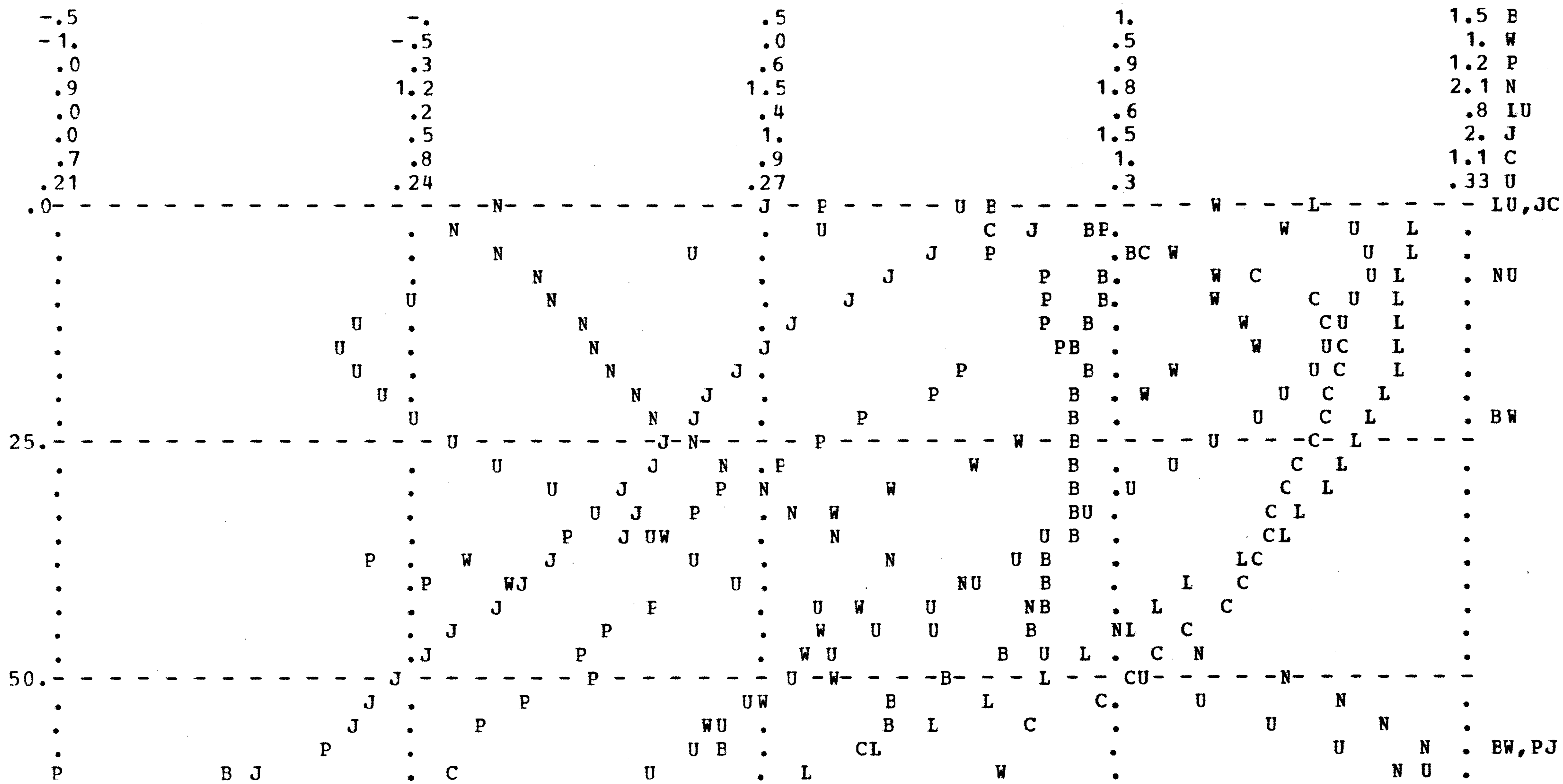

FIGURE 9 CONTINUATION OF THE OUTPUT OF FIGURE 8.

extended another twenty years (assuming the external inputs remained constant at their 1960 values), the redistribution of black population occurring in Figure 6 did not appear. The cause of this difference lies in the strong influence of the depression of the thirties on unemployment and thus changes in both of the housing stocks. As was discussed in the section on the behavior of the housing submodel, the equilibrium imbalance between supply and demand is a strong function of the rate of growth. The depression of the thirties cut off the expansion of housing demand. The downward filtering of housing, although slowed by the increasing shortage of housing in the upper skilled market, was able to improve somewhat the growing housing shortage for lower skilled in the core city. The shortage was never reduced to less than 15% of the total demand so the improvement was relative rather than absolute.) Under the assumptions incorporated in the housing submodel, the respite from continuous population growth caused by the depression dip in birth rates and the high unemployment produced conditions basically different from those which would have existed if growth had continued steadily. The increased attraction of the core due to the changes in the housing supply keeps the black population in the central city, and also retards the outflow of upper skilled and lower skilled whites.

b) The Development of a Low Density City

The simulation of the low density city began with a total population of 100,000 in the metropolitan area and a density of 3,000 people per square mile in the core city in 1900. Figures 10 and 11 show the results of the simulation for the 'actual' national rates of expansion of export employment. At the end of sixty years, the total population had grown to over 300,000 and the central city population density had reached a density of approximately 8,000 people per square mile.

Although the rate of central city growth was still a significant fraction of the rate of total metropolitan growth (P = .5 at 1960 in Figure 11) it had begun to drop following the recovery from the perturbation during the depression. When the simulation was extended another twenty years, the decline in P continued steadily to a value of two tenths (.2). If the national rate of expansion of export industries is assumed to be constant, rather than fluctuating, the decline in the growth rate ratios is almost completely smooth, so the economic depressions following WW I and in the thirties are having a major effect on the oscillations of these ratios. Comparing the values and trends of the ratio of growth rates of total population (P in Figure 11) to those of the city in

PAGE 2   RUN - SE

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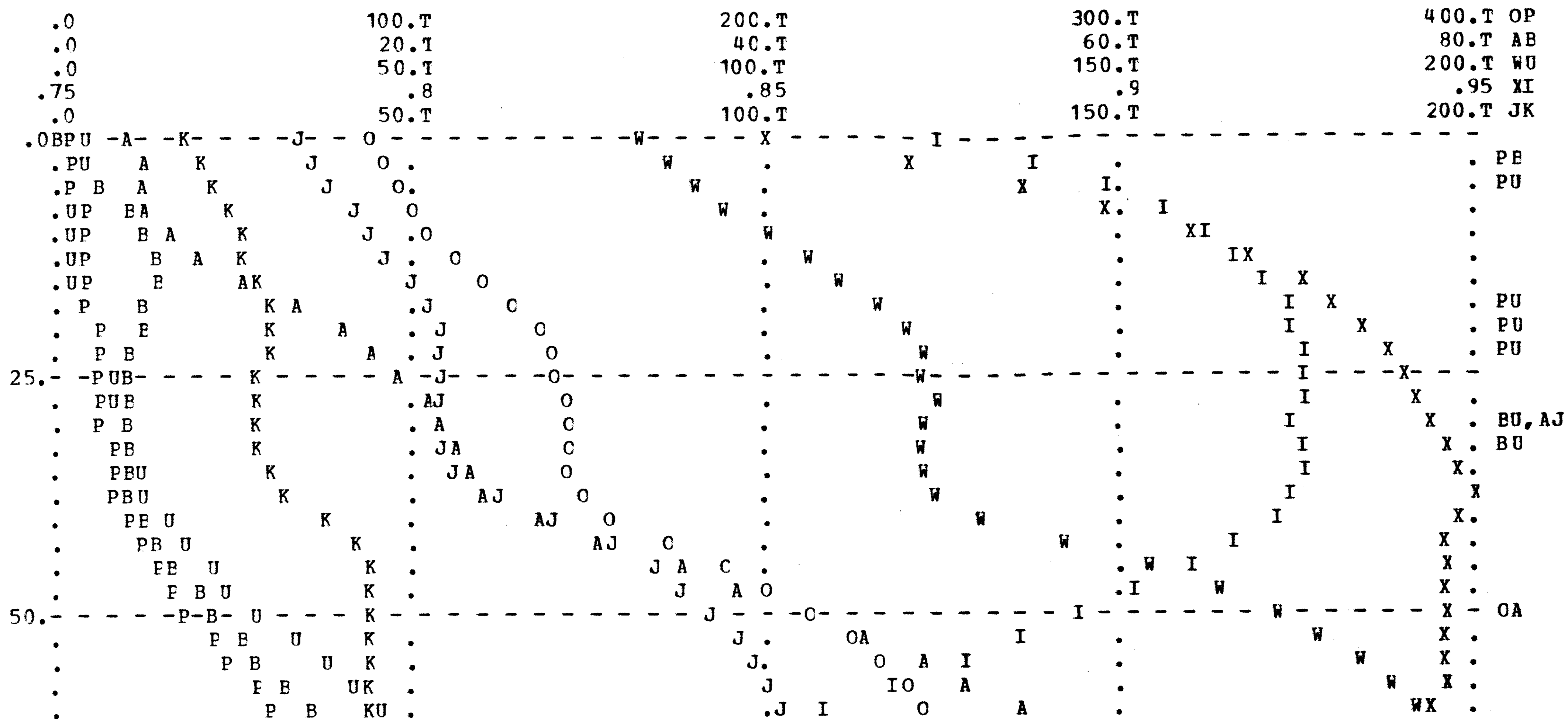

FIGURE 10   SIMULATION OF THE DEVELOPMENT OF A LOW DENSITY CITY UNDER VARIATION OF NATIONAL GROWTH RATE OF EXPORT INDUSTRY AS ACTUALLY OCCURRED IN THE UNITED STATES BETWEEN 1900 AND 1960.

PAGE 3 RUN - SE

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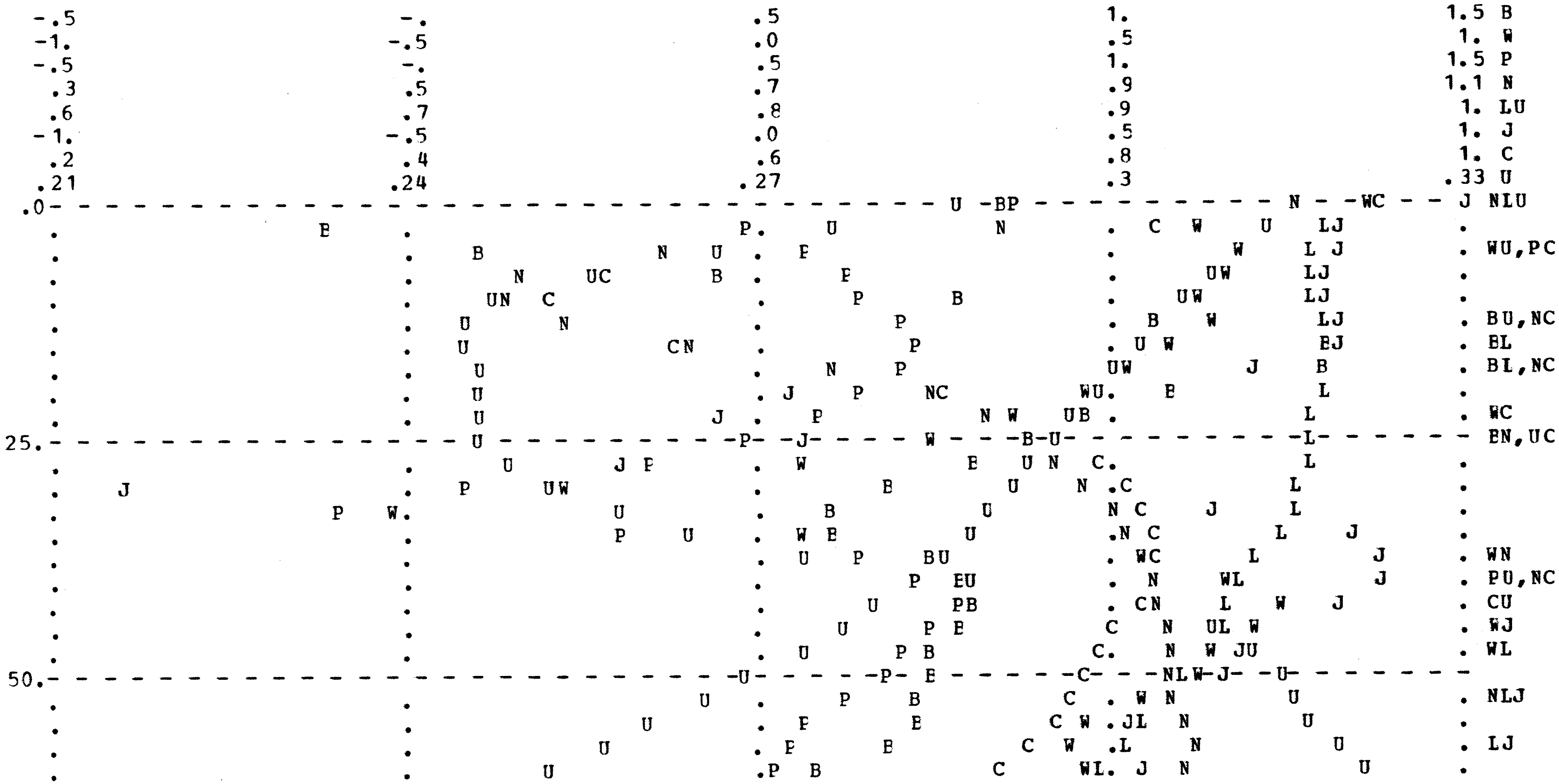

FIGURE 11 CONTINUATION OF OUTPUT OF FIGURE 10.

the moderate density class in Figure 4 of Chapter 3, the initial values of P are low but the basic trends are similar, particularly if the decline through the extra twenty years of the simulation is considered.

Considering the components of population, the lag between the decline in low skilled population in the core has increased and the concentration of black population in the core city, while strong, is not nearly as high as in the larger city. The strong fluctuations in the ratio of the growth rates of core city and metropolitan area black population (B in Figure 11) during the first twenty years of the simulation are not entirely understood, but are partially due to mismatches in the initial distributions of black population. Except for these fluctuations the general level of the ratio of growth rates of the black population are above .6 to .7 throughout the simulation.

As is discussed below, the export industry remains concentrated in the central city, primarily because of the continued availability of land there. (In 1960 the fraction of central city land occupied is still less than .75).

c) The General Trends in the Attraction Functions

The trends in the attraction functions which determine the location behavior described above cannot be completely generalized, but the following discussion will attempt to give some insight into the forces operating in the simulation of development of a high density city. The trends in the low density city are essentially the same. For population location, the attraction of the core is decreasing because of 1) the continuing decrease in the supply of available land (the land fraction occupied shifting from .75 to roughly .9 to 1.0)., the decline in the fraction of jobs in the core city (shown in the figures), and for the white population, the continued concentration of blacks in the core city.

In the suburbs, the fraction of jobs accessible remains about the same, very few blacks are moving in so the attraction due to job access and racial composition remain the same.

The fraction of land occupied is increasing, but very slowly because of the expansion of the land supply caused by improvements in transportation. If the transportation technology is assumed to remain constant at its 1900 values, thus fixing the suburban land supply, the pattern of development is quite different. The suburbs quickly 'fill up',the attraction due to suburban land declines, and the core continues to share in the growth. Under typical growth rates of a couple of per cent per year, this simulation reaches the point where the land supply of both areas is saturated. The model breaks down as the continued growth must be allocated somewhere and fractions of land occupied greater than one occur. If transportation technology were fixed, the model would have to be modified either by incorporating a shutoff on total growth or by increasing the marginal densities when the fraction of land occupied is high. The former case is equivalent to the development of traditional cities (see the study by Abu-Lughod of the transition of Cairo from medieval city to modern metropolis[1]). The latter case corresponds to a city, such as Hong Kong, where special pressures maintain population immigration, even in the face of densities of population inconceivable to urban Americans (Abrams reported densities of over 2000 people per acre - over a million people per square mile - in Hong Kong.[2])

The effects of housing, and in particular housing shortages, in each of the two areas is a strong function of population growth rates, the distribution of that growth, whether the city is growing by expansion due to export industry growth or by population migration, etc., and can thus not be generalized. The interaction between population and housing markets as modified by the economic conditions produced by the growth submodel is one of the most important ones in the model. In particular, the attraction due to housing is the key determinant to the difference between the distribution of growth of white and black population as the model is now formulated.

For industrial location, the attraction of the core due to access to other industries is declining while the attraction of the suburbs due to access is increasing as industries and population relocate. The same is true for the labor supply - the redistribution of the population decreases the attraction of the core and increases the attraction of the suburbs. While both of these effects influence the outflow of industry, by far the dominant factor is the availability of land in the suburbs. This was shown by the run of the small city in which land continued to be available within the central city for the duration of the simulation. In this case the core city did not dominate industrial growth (the growth rate of export employment in the core was the same or slightly lower than that of metropolitan area as a whole), but neither did its role decline.

2. Development under Policy Interventions

This part discusses the behavior of the model under three different interventions in the structure of the city - 1) the construction of low income housing in the suburbs, 2) the elimination of racial discrimination in housing and jobs, and 3) the upgrading of the mobility of the lower skilled population to a level equal to that of the upper skilled population. Some of the difficulties in converting these alternative impacts into a formal evaluation of different programs needed to draw conclusions on urban policy are discussed in D below. The programs were 'tested' using the simulation for a high density city under the influence of 'actual' expansion of export industries.

a) Construction lf low skilled housing in the suburbs

A program constructing 5% of the low skilled housing stock in the suburbs as long as there was a housing shortage was added in 1940 (i.e. forty years into the simulation). At this time the outflow of the lower skilled population to the suburbs had begun. The program, accentuated that outflow for approximately ten years, but after twenty years the distribution of population with the program was the same as without. During the first ten years of the program, the lower skilled population was increased by almost 50% in the suburbs and decreased by about 15% in the core city over what the distribution would have been without the program. However, this redistribution decreased the housing shortages in the core city and increased it in the suburbs, thus slowing the redistribution of population during the last twenty years.

The upper class housing supply, the job distribution and the upper skilled population distribution are not noticeably affected. The changes in the housing market are too slight to influence the concentration of blacks in the core under the presence of radial discrimination in housing.

The net effect of the program is to reduce the peak housing shortage in the suburbs by about a factor of two (from 20% to 10% for about 10 years.

b) Upgrading of lower skilled transportation

The upgrading of the mobility of the lower skilled at 50 years into the simulation has a result similar to that for the housing program - it does not produce a major shift in the distribution of population and employment twenty, or in this case, even ten years later. The increase in mobility generates a flow of lower skilled population to the suburbs. This flow quickly (within 5 years) changes the conditions in the housing markets of the core and suburbs so as to balance the attractions of the areas and thus to return flows of population to what they would have been without the transportation program. However, in this case the change in housing markets acts to raise the attraction of the core city because of the decline in housing shortage as people move out. Although the final distributions of population and unemployment are not different, the final attractions of the core and the suburbs are more than twice as high than without the program.

c) Elimination of racial discrimination in jobs and housing

The elimination of racial discrimination in jobs and housing immediately produced a turn-around in the distribution of growth of black population. Where before the program, the black population in the core increased by 20% (100,000 out of 500,000) in ten years, the addition of the program caused a decline of 100,000 in the black population in ten years. This redistribution of black population out of the core city represented a basic change in the behavior of the model. An equilbrium distribution of black population and white population in the core city was not reached in twenty years, but that equilibrium was going to involve a much lower concentration of black population in the core city.

C. Conclusions Drawn from the Model

This section briefly reviews the conclusions drawn from the behavior just discussed, with special emphasis on the questions posed in the discussion of trends in urban development in Part 1 and the review of previous models in Part 11.

1. Interaction of the city with outside driving forces

The behavior of the model has provided several examples of the types of interaction between technological change and the structure of urban growth. The basic one has been the continuous expansion of the land supply of the city which has prevented the attraction of the suburbs from declining in the response to the flows of employment and population to it. The increased number of population and jobs in the suburbs have in turn increased that area's attraction for growth, thus continuously accelerating the dispersal process. The increased mobility of the population has been the 'cause' of the increased land supply, but this model has not found it necessary to formulate the basic effect of the mobility in terms of the highly disaggregated small area models used in transportation systems analysis. In this model the changes in transportation have effectively relaxed a constraint on the system - the response of the city to that relaxed constraint has been determined by the other interactions in the model, and not primarily by accessibility. The role of accessibility in previous urban development models has been clearly overemphasized. This conclusion has been reached by many others, but this work is the first to formulate an alternative set of location influences in a model which explicitly incorporated the dynamic behavior of those influences, e.g. the housing market, and their interactions with growth and location.

The changes in production technology have enhanced the effect of increasing land supply in the suburbs on industrial location. This effect has been noted before, and this model simply provides a formulation of it. However, an unexpected second consequence of the change in production technology occured through the role of the increase in the fraction of population classed as upper skilled in the dynamics of the housing market. As the fraction of the population in the upper skill level increases the increasing size of the upper skilled housing stock relative to the lower skilled makes it easier for natural filtering precesses to deal with shortages of low skilled housing. This influence is greatly modified by the location and rate of growth of the demand, but it is an example of technological change shifting the nature of the structural interactions within the city.

The interaction of the housing market of the city with the fluctuations in national rate of export industry development provide an example of the influence of non-technological driving forces on the development of the city. The important roles of both types of forces outside the city have provided numerous examples of how the city is not the 'master of its own fate.'

2. The interactions within the city

The strong coupling between the growth model, the housing model, and the location model, which were outlined at the conclusion to Chapter 7 and have been mentioned repeatedly in the discussion of the behavior above, make it impossible to formulate urban location, the urban housing markets, and urban growth independent of one another. This thesis has provided a number of examples of the way in which these processes are linked. The dynamics of their behavior cannot be formulated over time spans of more than a few years unless those links are explicitly considered.

The same conclusion is true for the formulation of the interactions between different parts of the city on the development of any single part of it. The behavior of any piece of the city cannot be formulated without explicitly including the role of the rest of the city in that development. Again, the behavior above has provided several examples where changes in the suburbs induced flows from the central city which in turn have changed the attraction of both the central city and suburb. The presence of such interactions due to the mutual accessibility of the areas of the city to the same labor force and job supply, and their sharing of the same growth makes an independent formulation of one part of the city impossible.

D. Comparison with the Urban Dynamics Model of Forrester

The simulation model of urban growth developed by Forrester and published as the book Urban Dynamics [3] was the initial stimulas for this thesis. The model in this thesis was formulated in the same simulation language as Forrester's work and involves attraction functions which appear to be quite similar to those used by him. However, there are major differences between the Urban Dynamics model and this thesis in terms of the formulation of the model, the behavior those formulations produce, and the use of the results of the model.

1. Differences in the formulation of the model

The formulation of the urban growth model in this thesis is different from that in Urban Dynamics in three types of ways - the boundaries of the system being studied, the role of the world outside the city in the dynamics of the growth of the city, and the particular mechanisms of growth and development. The system boundaries are different in that Forrester assumes that the growth of one part of the city can be modeled without explicitly incorporating the effects of the other parts of the city on that growth.

The Urban Dynamics model focuses on the development of the older core area of the city, and lumps the rest of the city together with the outside world. The discussion above of the simulation model in this thesis has made it clear that several important mutual interactions exist between the growth and development of the core city and that of the suburb. As was just stated, one of the conclusions of this thesis is that in general the interactions between parts of the city are strong enough that the growth of any single part of it cannot be considered independent of the remainder of the city.

The second major type of difference in the formulation of the two models is the role of changes in the world outside the city on the dynamics of the development of the city. The Urban Dynamics model assumes that

> ... the urban area is represented as a living, self-controlling system that regulates its own flows of people to and from the outside environment. This approach does not assume that either the area or the outside world is static. It assumes that the technology, the living standards, and the nature of economic activity in the area change to keep pace with the outside. The changing outside environment is not pertinent to this book.[4]

The Urban Dynamics model allows the outside world to change, but those changes are irrelevent for the dynamics of the behavior of the model. This assumption is in direct conflict with the conclusions just reviewed. Chapter 3 has presented in detail the types of changes in driving forces influencing the rate of growth of the city and internal structure of the interactions of the city. The basic theme of this thesis is that the structure governing the development of the city has changed radically because of changes in the world outside the city.

The third major difference is in the choice of the variables included in the model and in the specification of the interactions between them. The basic variables - population, employment, and housing - are the same, but the specific breakdown of those variables, particularly industry is quite different. The interactions between these variables particularly industry is quite different. The interactions between these variables, particularly those driving the growth of the urban area are quite different. For example, unemployment rate is the only internal variable which influences inmigration while Urban Dynamics assumes that housing, public expenditures, population composition and upward mobility influence the inflow of 'underemployed' population. The other differences are too numerous to detail here, but a general cause of the difference in specific interactions is the failure of the Urban Dynamics model to even consider the previous work done in analyzing and simulating urban growth, and to consider the results of the model in the light of any actual data on urban growth. Forrester noted this in the prefact to Urban Dynamics,

> Several reviewers of the manuscript criticized the absence of ties to the literature on the assumption that such ties must exist but had not been revealed. Actually the book comes from a different body of knowledge, from the insights of those who know the urban scene firsthand, from my own reading in the public and business press, and from the literature on the dynamics of social systems for which references are given. There are indeed relevant studies on urban dynamics, but to identify these is a large and separate task...[5]

One of the aims of this thesis was to begin the task of relating the 'relevant' literature to a dynamic model of urban development by incorporating parts of it into an alternative model.

2. Comparison of the behavior of the models

The first difference between the behavior of the two models is that whereas the Urban Dynamics model reaches an equilibrium, the model in this thesis does not. The difference in the time spans of the analysis of the behavior of the models (centuries in Urban Dynamics, decades here) is a symptom rather than a cause of this difference. The lack of any external driving forces in the Urban Dynamics model implies that the central city can and probably does have an equilibrium state (the alternatives of explosive growth or of undamped oscillations would be inconsistent with the observed behavior of the city). Given that equilibrium state, it is reasonable to explore the implications of changes in the city on the equilibrium, although not necessarily rational to base policy decisions on those equilibrium conditions (see the following section). The formulation of urban development independent of the changes in the 'outside world' eliminates all uncertainties in the development which arise from unknown future developments and leaves only the uncertainties in the formulation of the interactions within the city. The dependence of the model in this thesis upon outside forces which vary abruptly in time implies that the model, and thus the parts of the city, never reaches an equilibrium. The analysis of future growth and the influence of alternative policies becomes dependent upon conditional projections of those outside forces.

If only the fifty years or so period in which the Urban Dynamics model is stagnating is considered the gross behavior of total population and total employment is similar. However, the structure of the interactions generating that behavior is radically different. For example, the labor force and employment are balanced on a metropolitan scale in this thesis, but on a local scale in Urban Dynamics. Urban Dynamics includes a formulation of the economics of the city - tax rate, services, welfare, etc., which this thesis has ignored. Although the Urban Dynamics model is smaller than this one in terms of the number of equations and level variables involved, the Urban Dynamics model has a much more tightly coupled set of interactions. In general, the set of interactions included within Urban Dynamics, and the exlusion of the interaction within the suburb makes the behavior of the Urban Dynamics model much more 'counterintuitive' than the behavior of the model of this thesis.

3. Comparison of applications of the model - a note on the uses of systems models

Models of urban development at best given information on what will happen under a set of assumed external conditions and policy interventions. The model itself can make no judgments as to what results are desirable or undesirable. It is absolutely imperative to distinguish between the 'system' analysis' practiced by someone creating a model of a system and the 'systematic policy analysis' required to evaluate the results of that model and translate them into policy recommendations. The former, the analysis of the interactions within the system which'cause' its behavior, can in some sense be thought of as an objective process in which the analyst seeks the 'true' causal relations driving the system. The analysis can be carried out with at least an attempt to reduce observer bias and normative judgments on the formulation of the interactions. The creation of the model is simply an attempt to 'tell it like it is'.

In contrast, the use of the model in a systematic analysis of policy alternative to develop recommendations for external intervention in the system is at the opposite extreme of the objective/subjective scale. Such an analysis cannot be carried out without a set of extremely subjective judgments on the relative values of the different results of the model. The types of value judgments which need to be made and some of the approaches to dealing with recurrent problems, such as the value of benefits in the near future versus those occurring many years from now, are discussed in many of the standard references in the 'systems analysis' and cost-benefit analysis literature and will not be treated here.[6]

Although evaluation 'models' are being developed to generate optimum policies and to aid in the analysis of the volume of output generated by systems simulation models, evaluation and simulation models are radically different from one another and must not be confused.

Both types of models simulation and evaluation - involves _a priori_ judgments and assumptions. The crucial difference is that the former attempts to say what will happen given a specific set of external influences and a specific policy, while the latter says, given a set of alternative policies and a set of alternative policies and a set of values, which policy gives the 'best' results. Any effort which makes policy recommendations, particularly for urban areas, must carefully separate and distinguish between these two processes. One of the major components of the 'urban problem' is the different sets of values held by the diverse groups.

Urban Dynamics included an evaluation of several alternative urban policies which comprise the city. This thesis presents no policy conclusions because these differing sets of values cannot be reconciled to a universal, monolithic set which applies to all areas at all times. The determination of the values and priorities to be used in evaluating alternative programs can only be done through the political processes of each area and with the active involvement of the people who are directly involved. The problems inherent in such a reconciliation and involvement are real, as is evident from the experiences of 'advocacy' planning groups [7] and attempts to institutionalize the participation of the poor. [8]

But even putting aside the problem of diversity of values, the problem remains of what criteria to use in evaluating alternative policies. For example, as was noted above, the interactions between the different parts of the city react to an improvement in the attraction of one area by generating flows which shift the attractions into balance once again. Thus, a specific policy may not have a dramatic effect on the levels of population and employment in the areas, but the new balance of attraction between the areas can be at a much higher level than before. For example, in the case of the improvement of lower skilled mobility discussed above, the housing supply reacted to eliminate the discrepancy which the improvement created between the attractions of the core and suburb so the final distribution of population was not modified very much. Yet, the final levels of attractions of both the core and suburb with the transportation change were several times those without the change. Supply had been upgraded so that the improvement in mobility and housing availability represented by these increases in attraction could be considered as desirable an impact as changes in population distribution and composition.

Finally, another basic problem in making evaluations is the time span over which the evaluation is carried out. The time span cannot be extended indefinitely into the future for political reasons, but also because of the increasing degree of uncertainty in the results of projections as they are extended further into the future.

Footnotes Chapter 8

1. Abu-Lughod, Janet, Cairo: Evolution of a Middle Eastern Metropolis, PhD thesis available at the Joint Center for Urban Studies, Cambridge, Mass., to be published in 1971.

2. Abrams, Charles, Man's Struggle for Shelter in an Urbanizing World, (MIT Press, Cambridge, 1964), p.6.

3. Forrester, Jay, Urban Dynamics, (MIT Press, Cambridge, Mass., 1969),

4. Ibid, p. 18.

5. Ibid, p. X.

6. The literature is voluminous but some good introductions are de Neufvxille, Richard, and Stafford, Joeseph, Systems Analysis for Engineers and Managers, (McGraw-Hill, New York, in press), McKean, Roland, Efficiency in Government Through Systems Analysis, (John Wiley and Sons, New York, 1958), and Marglin, Steven, Public Investment Criteria, (MIT Press, Cambridge, 1967). For some case studies in applications of the techniques see Dorfman,Robert, (ed) Measuring Benefits of Government Investments, (Brookings Institution, Washington, DC 1965).

7. See for example, Peatie, Lisa, "Reflections on Advocacy Planning", Journal of the American Institute of Planners, Vol. 34, 1968, pp. 80-87.

8. See the special issue of the Journal of the American Institute of Planners on citizen involvement, Vol. 35, July, 1969.

Chapter 9

SUMMARY AND CONCLUSIONS

A. Summary

This thesis formulated a simulation model of the development of a large metropolitan area in the United States during the period 1900 to 1960. In Part I of the thesis, Chapter 2 presented data on the trends during this period in the distribution of growth between central city and suburbs for three types of cities classified by density of central city. The data sample was all cities in the United States with a population greater than 250,000. The trends in total population and black population were presented in terms of an indicator of dispersal formed from the growth rates of the central city relative to that of the metropolitan area. This data showed clearly that the process of dispersal of population had begun during the early part of the twentieth century for all cities in all three density classes. Consistent data on the trends in the distribution of employment growth between central city and suburb were not available, but a comparison of limited data at the beginning of the period with that for the last fifteen years indicated a similar trend.

The remainder of Part I (Chapter 3) presented the trends in the forces outside the city which influence the development of the city. Two types of external forces were identified, one simply changing the base growth rate of the city, e.g., fluctuations in the national rate of economic growth, the second acting to change the structure of the interactions within the city, e.g., technological change in transportation and production. The simulation model developed in the thesis was formulated to test a set of assumptions on how these changes in forces outside the city, particularly technological change, interacted with the structure of the city to produce the trends toward urban dispersal.

Part II of the thesis first identified five processes in urban development which need to be incorporated in the formulation of such a model of urban growth in Chapter 4. These processes are: 1) growth driven from within the city, 2) growth driven from outside the city, 3) the internal shifts between classes in the city, e.g., from one housing type to another or from one skill class of population to another, 4) the location and redistribution of activities in the city, and

5) the expansion of the land supply of the city. Chapter 5 reviewed literature on the previous attempts to model these processes and established the need for a 'systems' model which formulated the interactions between these processes in the city.

Chapter 6 then described the simulation language (DYNAMO) used to formulate the finite difference equations of the model, and discussed the assumptions inherent in the use of this language. The problems of specifying the structure, estimating parameters, and validating the model in general were discussed in terms of comparing dynamic simulations to formal econometric estimation techniques. A simple econometric model was converted to DYNAMO to facilitate this discussion.

Part III discussed the formulation and behavior of the computer simulation model developed in this thesis. The model is divided into three submodels simulating growth of total population and employment, the location of population and employment, and the changes in the housing market. The model simulates the changes in four classes of population (white upper skilled, white lower skilled, black upper skilled, and black lower skilled), three classes of industry (export, residential services, and industrial services), three classes of housing (upper skilled, lower skilled, and abandoned), and five types of land use (residential, industrial, transportation and public, vacant, and abandoned) in the central city and in the suburban ring of a large metropolitan area. Chapter 7 discussed in detail the structure of each of the three major submodels and the assumptions inherent in their structure. Chapter 8 discussed the behavior of the individual submodels and the systems model as a whole under a variety of growth conditions. First, the sensitivity of each of the submodels to changes in initial conditions, external growth rates, internal relations, and linkages to the other models was explored. The complete model simulated the development of 1) a city which initially has a high density central city (12,000) people per acre) and 2) a city with a low density central city (3,000) people per acre) over the sixty year time period from 1900 to 1960. The behavior of these simulations was compared to the observed behavior of metropolitan growth as a function of density and time developed in Chapter 2 and found to be in reasonable agreement. The formulation, general behavior, and use of the model was then compared to that of Urban Dynamics model developed by Forrester.

B. Conclusions

The model developed in this thesis represents a set of assumptions about the interactions both within the city and between the city and its outside environment. Each run of the simulation model represents an experiment to determine the consequences of the set of assumptions so that they may be tested against observed behavior and against the general criteria of 'are the results reasonable?' As was discussed in detail in Chapter 6, the validity of any given set of assumptions can never be established as representing the 'true' causes of the behavior of the system--alternative formulations which produce exactly the same results are always available.

Two essential parts of the laboratory 'apparatus' used to experiment with alternative formulations of the model were the DYNAMO language and the CP/67 CMS time sharing system of the Information Processing Center of MIT. The DYNAMO language allowed major changes in the interactions in the model and produced the results of the simulation in the initially confusing, but soon very readable, plots shown in Chapter 8. The time sharing system allowed a much closer interaction between the experimenter and his apparatus, giving essentially instantaneous response (the typical run time was tens of seconds), eliminating the frustration of long turnaround and lost days due to the usual human errors, and providing a vital continuity to the interaction between man and machine. In addition, the modeling strategy of constructing submodels of major parts of the main model and experimenting with the behavior of those submodels with the links to the other models held constant was absolutely essential to unraveling the behavior of even the moderately complex systems model of this thesis.

The consequences of the assumptions formulated in the model of urban development have been tested in this thesis and found to produce behavior which is in reasonable agreement with the observed behavior of large urban areas. These assumptions lead to the following conclusions about the processes involved in the development of large urban areas over time spans of more than a few years:

1. The development of the city is strongly affected by the interactions of the city with the world outside it. The form of these interactions is determined by

the internal structure of the city, but actual growth and development of an urban area is continuously being driven and modified by the conditions in the region, nation and world outside it.

2. The development of any part of a metropolitan area, for example its central city or suburbs, is strongly influenced by the remainder of the city. The nature of these interactions between parts of the city is fundamentally different from those between the urban area as a whole and its outside environment. In the latter, the city does not significantly influence the changes in the driving forces acting on it. In the former, the parts of the city do mutually interact with one another due to their high mutual accessibility. This mutual interaction implies that any model of even part of the city must include the variables and interactions of the entire city within the model. No part of the city can be modeled independently.

3. No single process in urban development dominates the others to the extent that the linkages between such processes as growth of the total population in the

city, filtering of the housing supply, and location of population and employment can be neglected. These processes, particularly the changes in the housing market and location of activities, have strong mutual influences on one another and interact strongly. The usual tendency to oversimplify these interactions between processes and let one characteristic, such as accessibility in many of the models developed for transportation systems analysis, cannot be justified in the light of these interactions.

C. Future Work

The purpose of this thesis has been to explore and point new directions for work in the modeling of urban development, rather than to definitely map and fix the formulation of the processes of urban development. One of the objectives of this thesis has been to stimulate others to explore a broader terrain and the paths between areas which have already been tentatively explored, instead of following what seemed to be the trend of remaining isolated and developing the formulations of the processes of urban development independent of one another. Much remains to be done in improving our understanding of individual processes in urban development. The influence of racial discrimination on location in this thesis, the causes of abandonment of housing in the central city, and the processes underlying the upgrading of the population are just three examples of the processes which have been incorporated in this model, but only in a highly tentative form.

However, the investigation of the nature of the interactions between these processes needs to continue. The question of the level of detail of the disaggregation of variables, such as population and, particularly, land appropriate for the formulation of such interactions, is still open. The role of explicit economic forces in the interaction was ignored in this work and is a glaring omission. For example, wage differences are important determinants of migration, prices in housing market should strongly influence the rates of change there, and there are questions about the role of local variations in costs (such as tax rate) on the location of population and industry.

APPENDICES I, II, and III

Appendix I

Data on Growth and Annexation of Large U.S. Cities from 1900 to 1960

A. Tables on Central City Growth and Annexation

In the tables below the metropolitan areas are grouped into three classes on the basis of the residential density of their central cities:

1. High density - gross residential densities greater than 10,000 people per square mile.
2. Moderate density - gross residential densities between 5,000 and 10,000 people per square mile.
3. Low density - gross residential densities less than 5,000 people per square mile.

Figure A-1 shows how the total number of cities in each density class and the total number of cities changed over time because of the continuing growth of urban areas in the United States.

In the tables the cities in a given density class are listed for each decade in order of declining central city density. The legend for the symbols used in the tables is given on the following page. Table A-1 provides a summary of the changes for all cities in each of the three classes for each decade 1900 and 1960. The data sources for the tables presented here are listed in Section C of this appendix. The method used to correct population growth due to area annexations is discussed in Section B.

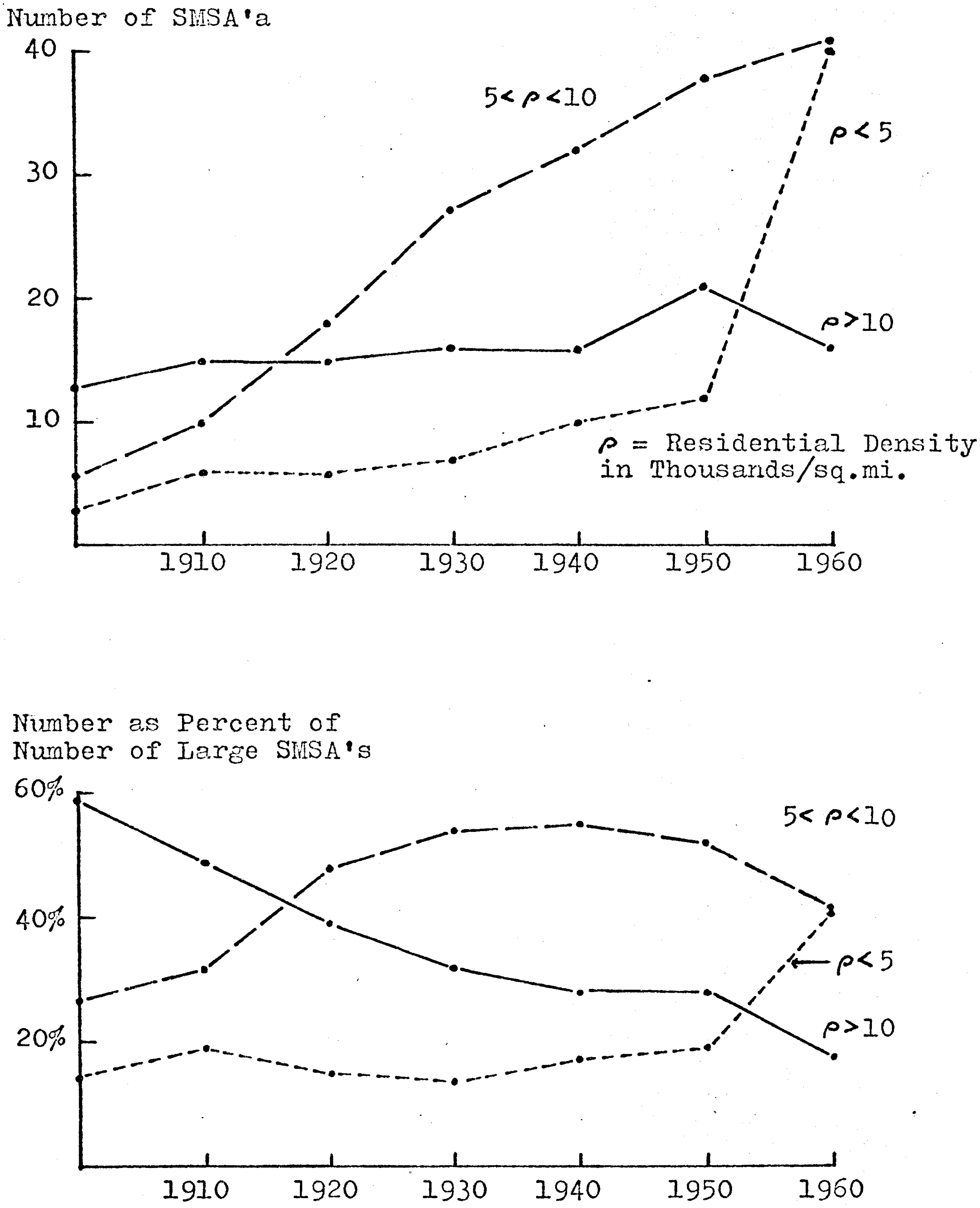

Fig.A-1 Distribution of Large SMSA's (Population 250,000) Disaggregated by Density of Central City 1900-1960

Legend for Notation in Tables of Appendix I

The following data is provided for each decade from 1900 to 1960 for each metropolitan area in the U. S. with a population greater than 250,000 at the beginning of a decade.

D_c	=	Gross residential density of central city (thousands/sq. mi.)
P_t	=	Total metropolitan area population at the beginning of the decade (thousands)
dP_t	=	Change in total population during decade (thousands)
P_c	=	Population of the central city at the beginning of the decade (thousands)
A_c	=	Land area of the central city at the beginning of the decade (square miles)
dA_c	=	Change in A_c over the decade
dP_c	=	Change in the population of the central city during the decade including corrections for area annexation (thousands)
dP_a	=	Estimated population annexations during the decade which was used to calculate dP_c (thousands). Note that the 1960 U. S. Census provided data on annexed population for the decade 1950-60, so no estimates were necessary for that period.
dP_b	=	Change in the black population of the metropolitan area during the decade.
dP_w	=	Change in the white population of the metropolitan area during the decade.
dP_{cb}	=	Change in the black population of the central city during the decade.
dP_{cw}	=	Change in the white population of the central city during the decade.

Table A-1

Summary of Changes in Metropolitan and Central City Population for Three Density Classes from 1900-1960

I. Metropolitan Areas with Low Density Central Cities (D_c less than 5,000/sq. mi.)

	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960
P_t	1146	2208	2764	4537	6108	10169
P_c	932	1546	1938	2955	3641	5924
P_c/P_t	.81	.68	.70	.65	.60	.58
dP_t	283	859	1716	850	2499	4650
dP_b	20	34	97	80	259	554
dP_w	263	835	1619	770	2240	4096
dP_c	255	346	900	394	999	1081
dP_{cb}	22	30	83	67	209	493
dP_{cw}	233	316	817	327	790	588

Table A-1 (continued)

Summary of Changes in Metropolitan and Central City Population for Three Density Classes from 1900-1960

II. Metropolitan Areas with Moderate Density Central Cities (D_c between 5,000 and 10,000 /sq. mi.)

	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960
P_t	2559	4254	8377	12680	14729	18534
P_c	1546	2776	5763	8536	9510	10792
P_c/P_t	.60	.65	.69	.67	.65	.58
dP_t	605	839	1822	1108	4134	5765
dP_b	29	68	206	177	388	643
dP_w	576	771	1616	931	3746	5122
dP_c	299	563	628	321	1297	-48
dP_{cb}	19	59	172	152	293	537
dP_{cw}	280	494	456	169	1004	-585

Table A-1 (continued)

Summary of Changes in Metropolitan and Central City Population for Three Density Classes from 1900-1960

III. Metropolitan Areas with High Density Central Cities (D_c greater than 10,000/ sq. mile)

	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960
P_t	15069	20379	24667	31950	34123	42335
P_c	10557	14394	17036	20851	21813	25129
P_c/P_t	.70	.71	.69	.65	.64	.60
dP_t	4610	4799	6377	1653	4750	7398
dP_b	126	356	745	356	1319	2016
dP_w	4484	4443	5632	1297	3431	5382
dP_c	3011	3141	2820	550	1353	-1097
dP_{cb}	102	312	608	316	1155	1728
dP_{cw}	2909	2829	212	234	198	-2825

I. Metropolitan Areas with Low Density Central Cities (D_c less than 5,000/sq.mi.)

	D_c POP. sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a 000's
A. 1900 - 1910								
1. Washington, D.C.	4900	379	67	279	52	60	-	-
2. Minneapolis/ St. Paul	3800	460	161	366	151	101	.7	-
3. New Orleans	1500	307	5	287	52	196	-	-
Total		1146	283	932	255	357		
B. 1910 - 1920								
1. Kansas City	4200	422	107	248	76	58	-	-
2. Seattle	4200	344	113	237	78	57	-	-
3. Denver	3700	277	54	213	43	58	-	-
4. Los Angeles/ Long Beach	3200	539	459	337	29	99	266	266
5. Springfield/ Holyoke/ Chicopee	2500	263	75	172	72	58	-5.2	18
6. New Orleans	1700	363	51	339	48	196	-	-
Total		2208	859	1546	346	526		
C. 1920 - 1930								
1. Denver	4400	331	54	256	31	58	-	-
2. Portland	4100	373	82	258	44	63	-	-
3. Birmingham	3700	310	121	179	81	49	1.5	-
4. Springfield/ Holyoke/ Chicopee	3600	338	39	226	24	53	-	-
5. New Orleans	1900	414	92	387	72	196	-	-
6. Los Angeles/ Long Beach	1600	998	1328	632	648	365	75	100
Total		2764	1716	1938	900	784		

	D_c $\frac{POP}{sq.mi.}$	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a 000's
D. 1930 - 1940								
1. Portland	4800	455	46	302	4	63	-	-
2. Utica/Rome	4800	263	-	134	20	21	-5.4	-19
3. Springfield/ Holyoke/ Chicopee	3900	377	-5	250	-5	53	-	-
4. Houston	4100	359	170	292	92	71	1.0	-
5. Los Angeles/ Long Beach	2800	2327	589	1380	260	440	8.0	28
6. New Orleans	2340	505	47	459	24	196	3.4	12
7. Duluth/Superior	1600	251	3	138	-1	62	-	-
Total		4537	850	2955	394	906		
E. 1940 - 1950								
1. Atlanta	4809	559	168	305	68	64	.6	-
2. Akron	4600	339	71	245	30	54	-	-
3. Oklahoma City	4100	299	93	204	39	50	1.0	-
4. Springfield/ Holyoke/ Chicopee	3860	372	42	203	21	53	-	-
5. Fort Worth	3600	256	137	178	40	50	44	61
6. Los Angeles/ Long Beach	3355	2916	1452	1504	545	448	2.6	8
7. New Orleans	2480	552	133	494	76	200	-	-
8. Tampa/ St. Petersburg	2400	272	137	169	52	71	-	-
9. San Diego	2100	289	267	203	124	95	4	14
10. Duluth/Superior	1600	254	-1	136	4	99	-	-
Total		6108	2499	3641	999	1184		
F. 1950 - 1960								
1. Knoxville	4900	337	31	125	-13	25.4	-	-
2. Oklahoma City	4800	392	119	244	11	51	272	70
3. Los Angeles/ Long Beach	4400	4368	2375	2221	535		-	67

	D_c POP./sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a 000's
F. 1950 - 1960 (cont.)								
4. Springfield/ Holyoke/ Chicopee	4100	413	65	266	22	53	-	-
5. Dallas	3900	744	340	434	52	112	112	193
6. Memphis	3800	492	145	396	32	104	24	69
7. Houston	3700	807	436	596	99	85	247	251
8. Salt Lake City	3400	275	108	182	3.5	54	2.2	3.5
9. San Diego	3400	557	476	334	173	99	93	66
10. Fort Worth	3000	393	181	279	21	94	47	57
11. Tacoma	3000	276	46	144	4	48	-	-
12. New Orleans	2900	685	183	570	57	200	.4	-
13. St. Petersburg	1800	177	120	97	84	52	1.8	.6
14. Duluth/Superior	1400	253	24	140	1	99	1	-
Total		10169	4649	5928	1081	1076		

II. Metropolitan Areas with Moderate Density Central Cities
(D_c between 5,000 and 10,000 sq.mi.)

	D_c POP./sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a 000's
A. 1900 - 1910								
1.Buffalo	9100	509	112	352	71	42	-2.4	-
2.Cincinnati	9000	327	63	326	-7	37	13	45
3.Albany/Schenectady/Troy	8900	395	51	186	38	21	7.2	25
4.San Francisco/Oakland	7600	543	231	410	157	46.5	-	-
5.Syracuse	7200	280	31	108	29	16	1.4	-
6.Kansas City	6800	305	117	164	11	25	33	74
Total		2559	605	1546	299	187		
B. 1910-1920								
1.Albany/Schenectady/Troy	8800	446	23	250	8	28	5	18
2.Syracuse	7900	311	41	137	34	17	1	-
3.Cincinnati	7300	590	39	364	-7	50	21	45
4.Indianapolis	7100	264	84	234	44	33	11	37
5.Scranton	6700	260	27	130	8	19	-	-
6.San Francisco/Oakland	6200	774	235	567	170	92	-4	-14
7.Atlanta	6000	273	75	155	46	26	.5	-
8.Dallas	5700	270	82	92	44	16	6.6	23
9.Washington, D.C.	5500	445	126	331	107	60	-	-
10.Minneapolis/St. Paul	5000	621	107	516	99	102	-	-
Total		4254	839	2776	553	443		
C. 1920 - 1930								
1.Dayton	9700	289	69	153	20	16	8.0	28
2.Syracuse	9400	352	49	172	13	18	7.0	25
3.Baltimore	9300	902	135	734	71	79	-.5	-

	D_c POP/ sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a 000's
C. 1920 - 1930 (cont.)								
4.Akron	9100	286	58	208	-5	23	14.8	52
5.Toledo	8600	276	72	243	31	28	4.8	17
6.Albany/ Schenectady/Troy	8300	469	51	274	3	33	5.3	19
7.San Francisco/ Oakland	8300	1009	338	723	170	8	7.5	26
8.Atlanta	7700	349	114	201	40	26	8.5	30
9.Washington, D.C.	7300	572	100	438	42	60	2.0	7
10.Indianapolis	7200	348	75	314	17	44	9.4	33
11.Scranton	7200	286	24	138	6	19	-	-
12.Dallas	7000	351	107	159	34	23	19	67
13.Minneapolis/ St. Paul	6100	728	154	615	14	102	5.5	19
14.Cincinnati	5700	629	127	401	50	71	-	-
15.Kansas City	5600	529	137	324	75	58	-	-
16.Seattle	5400	457	85	315	15	59	10	35
17.Omaha	5300	275	38	192	22	37	2.5	-
18.Youngstown/ Warren	5300	270	89	159	20	25	9.1	32
Total		8377	1822	5763	628	809		
D. 1930 - 1940								
1.Rochester	9600	424	14	328	-3	34	.6	-
2.San Francisco/ Oakland	9600	1348	114	918	18	95	2.2	-
3.Toledo	8800	348	-3	291	-22	33	4.1	14
4.Louisville	8600	421	31	308	11	36	2.0	-
5.Syracuse	8300	401	5	209	-3	25	-	-
6.Atlanta	7800	462	96	270	32	35	-	-
7.Washington, D.C.	7800	672	296	487	176	62	-	-
8.Albany/ Schenectady/Troy	7700	520	11	296	-7	38	-	-
9.Columbus	7600	361	28	291	16	38	.5	-
10.Scranton	7400	310	-9	143	-3	19	-	-
11.Akron	6800	344	-5	255	-58	38	15.9	48
12.Kansas City	6800	666	21	400	-1	58	-	-

	D_c POP./sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a 000's
D. 1930 - 1940 (cont.)								
13. Minneapolis/ St. Paul	6800	892	84	736	44	108	-	-
14. Indianapolis	6700	423	38	364	23	54	-	-
15. San Antonio	6500	293	46	232	22	36	-	-
16. Tulsa	6500	299	-9	141	1	22	-.2	-
17. Cincinnati	6400	756	31	451	4	71	1.0	-
18. Dallas	6200	459	69	260	34	42	-1.2	-
19. Oklahoma City	6100	273	24	185	-38	30	19.5	57
20. Allentown	5800	392	5	185	-12	32	4.7	16
21. Memphis	5500	306	52	253	40	46	-	-
22. Omaha	5500	313	12	214	10	39	-	-
23. Seattle	5300	542	51	366	3	68	-	-
24. Birmingham	5200	431	28	260	8	50	-	-
25. Worcester	5200	276	4	194	-2	37	-	-
26. Denver	5000	385	60	288	35	58	-	-
27. Youngstown/ Warren	5000	359	13	211	-1	34	-1.0	-
Total		12680	1108	8536	321	1237		
E. 1940 - 1950								
1. Hartford	9600	337	70	166	11	17	-	-
2. San Francisco/ Oakland	9600	1462	779	936	223	97	-	-
3. Rochester	9300	438	49	325	8	35	1.2	-
4. Richmond	9000	266	62	193	-18	21	15.7	53
5. Dayton	8900	384	135	211	33	24	1.3	-
6. Atlanta	8700	559	168	302	29	35	2.2	-
7. Louisville	8400	451	125	319	50	50	2.0	-
8. Syracuse8	8100	406	59	206	15	25	-	-
9. Columbus	7800	389	115	306	70	39	.4	-
10. Nashville	7600	237	64	167	7	22	-	-
11. Toledo	7600	344	51	282	21	37	1.2	-
12. Albany/ Schenectady/Troy	7500	531	58	288	11	38	-	-
13. Minneapolis/ St. Paul	7400	967	184	780	53	106	-	-
14. Dallas	7300	527	216	295	41	41	71	99

E. 1940 – 1950 (cont.)

	D_c POP/sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a sq.mi.
15. Indianapolis	7200	461	91	387	40	54	1.6	-
16. Scranton	7200	301	-44	140	-34	19	5.4	19
17. San Antonio	7100	338	162	254	80	36	34	71
18. Kansas City	6800	687	128	399	11	59	22	46
19. Tulsa	6600	290	38	142	22	21	5.3	19
20. Memphis	6400	358	124	192	22	46	58.6	81
21. Utica/Rome	6400	263	21	135	8	16	-	-
22. Cincinnati	6300	787	117	456	48	72	-	-
23. Omaha	5800	325	41	224	27	39	-	-
24. Miami	5700	268	227	172	63	30	3.9	14
25. Norfolk/ Portsmouth	5700	259	187	195	84	34	4.0	14
26. Denver	5600	445	167	322	63	58	8.6	30
27. Seattle	5400	594	251	368	99	68	2.3	-
28. Birmingham	5300	460	99	268	5	50	15	53
29. Houston	5300	529	278	385	168	72	12.6	44
30. Worcester	5200	276	27	194	10	37	-	-
31. Allentown	5100	397	41	189	20	37	-2.3	-
32. Youngstown/ Warren	5100	373	44	211	8	33	-	-
Total		14729	4134	9510	1297	1358		

F. 1950 – 1960

	D_c POP/sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a sq.mi.
1. Dayton	9750	519	176	244	-14.3	25	8.6	32.8
2. Columbus	9500	503	180	376	19.7	39	49.6	75.6
3. Louisville	9200	577	148	369	-40.7	40	18.2	62.2
4. New Haven	9200	270	42	164	-12	18	-	-
5. Rochester	9200	488	99	332	-14	36	.4	-
6. Atlanta	9000	727	290	331	-15	37	92.3	172
7. Peoria	8700	251	38	112	-11	13	2.3	2.2
8. Syracuse	8700	465	99	221	-5	25	-.3	-
9. Canton	8300	283	57	117	-3	14	.2	-
10. Sacramento	8100	277	226	138	1.4	17	29.2	52.7
11. Nashville	7900	322	78	174	-10.7	22	7.0	7.3
12. Toledo	7900	457	61	304	-4.8	38	9.9	19.2
13. Albany/ Schnectady/Troy	7800	589	68	299	-20	38	-	-

	D_c POP./sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a sq.mi.
F. 1950 - 1960 (cont.)								
14. Minneapolis/ St. Paul	7800	1151	331	833	-37	106	2.7	-
15. Indianapolis	7700	552	146	427	1.6	55	16	47.4
16. Norfolk/ Portsmouth	7600	446	132	294	3	38	29.6	124
17. Grand Rapids	7500	288	75	177	1	23	1.0	-
18. Jacksonville	6800	304	151	205	-3	30	-	-
19. Miami	7300	495	440	249	42	23	-	-
20. Tulsa	6800	328	91	183	-22	27	21	101
21. Cincinnati	6700	904	167	504	-8.8	75	2.2	7.4
22. Seattle	6600	845	263	468	3.4	71	17.7	86.1
*23. Tampa	6600	332	243	179	10	19	66	140
24. Utica/Rome	6400	284	47	143	8.5	16	1.2	.5
25. Denver	6200	612	317	416	40	67	4.2	38
26. Omaha	6200	366	91	251	10	41	10.5	40.2
27. Phoenix	6200	332	332	107	-	17	170	332
28. Richmond	6200	328	80	230	-10	37	-	-
29. Fresno	6100	277	89	92	-2.3	15	13.6	44
30. San Antonio	5900	500	187	408	40	70	91	139
31. Portland	5800	705	117	374	-12	64	3.1	11.0
32. Kansas City	5700	814	225	457	-23	81	49	42
33. Flint	5600	271	103	163	34	29	.6	-
34. San Jose	5600	291	252	95	9.5	17	37.5	99
35. Worcester	5500	303	20	203	-17	37	-	-
36. Akron	5100	410	104	275	16	54	.2	-
37. Youngstown/ Warren	5100	417	92	218	4	33	.4	4
38. Allentown	5000	438	54	209	7	34	2.1	-
39. Birmingham	5000	559	76	326	2.1	65	9.2	12.7
40. Scranton	5000	257	-23	126	-14	25	.4	-
Total		18534	5765	10792	-48	1542		

* Tampa and St. Petersburg were split because of the factor of 3 difference in densities.

III. Metropolitan Areas with High Density Central Cities
(D_c greater than 10,000/sq.mi.)

	D_c POP/sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a 000's
A. 1900 - 1910								
1. Baltimore	17700	690	81	509	30	30	-	-
2. Milwaukee	14800	365	105	285	89	21	1.6	-
3. Boston	13800	1321	281	561	110	43	-	-
4. Wilkes-Barre	13100	257	86	66	27	5.0	-	-
5. Pittsburgh	12100	1084	388	452	36	284	13	46
6. Cleveland	12000	461	200	382	149	35	9.0	30
7. Providence/ Pawtucket	11800	408	115	215	61	16	1.8	-
8. New York/ Jersey City/ Newark/ Patterson	11500	4957	1939	4028	1500	362	-31	-100
9. Detroit	10800	427	187	286	136	28	12.4	44
10. Philadelphia	10700	1892	376	1294	255	128	-	-
11. Chicago	10600	2085	618	1699	487	177	-	-
12. Louisville	10000	295	29	205	19	20	.3	-
13. St. Louis	10000	827	205	575	112	62	-	-
Total		15069	4610	10557	3011	1211		
B. 1910 - 1920								
1. Baltimore	18500	770	132	558	75	30	49	100
2. Boston	17400	1602	267	671	59	39	5.0	18
3. New York/ Jersey City/ Newark/ Patterson	17200	6896	1385	5574	1120	331	-34	-137
4. Milwaukee	16500	470	112	374	83	23	2.5	-
5. Wilkes-Barre	13400	343	48	92	14	5.0	✓	-
6. Pittsburgh	13000	1472	288	534	54	41	-1.5	-
7. Providence/ Pawtucket	12800	523	65	276	26	18	-	-
8. Cleveland	12200	660	312	561	216	45.7	5.7	20
9. Chicago	11800	2702	693	2185	484	185	9	32
10. Philadelphia	11800	2268	446	1549	285	131	-3.0	-10
11. Detroit	11400	614	692	466	450	41	37	78
12. St. Louis	11200	1032	135	687	86	61	-	-

	D_c	P_t	dP_t	P_c	dP_c	A_c	dA_c	dP_a
	POP. / sq.mi.	000's	000's	000's	000's	sq.mi.	sq.mi.	sq.mi.
B. 1910 - 1920 (cont.)								
13. Buffalo	11000	621	132	424	83	39	.2	-
14. Rochester	10900	283	69	218	95	20	9.4	33
15. Louisville	10800	323	23	224	11	21	1.7	-
Total		20379	4799	14394	3141	1031		
C. 1920 - 1930								
1. New York/ Jersey City/ Newark/ Patterson	22700	8280	2302	6559	1200	292	51	179
2. Milwaukee	18100	582	196	457	65	25	16.1	56
3. Boston	17200	1869	300	748	33	44	-	-
4. Cleveland	15500	972	271	797	37	51	19.4	67
5. Pittsburgh	14700	1760	263	588	41	40	11.4	40
6. Philadelphia	14300	2714	423	1824	127	128	-	-
7. Chicago	14000	3395	1055	2702	650	194	7	25
8. Providence/ Pawtucket	13300	588	89	302	28	26.4	-	-
9. Buffalo	13000	753	158	507	66	39		
10. St. Louis	12700	1186	221	773	49	61	-	-
11. Johnstown	12300	280	4	67	-	5.5	-	-
12. Detroit	12100	1306	872	944	491	78	60.1	84
13. Columbus	10500	284	77	237	-9	23	15.9	56
14. Louisville	10500	346	74	235	26	22	13.5	47
15. Rochester	10000	352	72	296	16	30	4.7	16
Total		24667	6377	17036	2820	1058		
D. 1930 - 1940								
1. New York/ Jersey City/ Newark/ Patterson	23200	10543	787	7921	498	343	1.3	-
2. Boston	17800	2169	41	781	-10	44	2.2	-

	D_c POP/sq.mi.	P_t 000's	dP_t 000's	P_c 000's	dP_c 000's	A_c sq.mi.	dA_c sq.mi.	dP_a sq.mi.
D. 1930 - 1940 (cont.)								
3. Chicago	16700	4450	120	3397	-5	201	7	25
4. Philadelphia	15200	3157	63	1951	-20	128	-	-
5. Buffalo	14700	912	47	573	3	39	.5	-
6. Providence/ Pawtucket	14200	677	18	330	-1	26	-	-
7. Milwaukee	14000	778	52	578	9	41	2.0	-
8. St. Louis	13500	1387	77	822	-6	61	-	-
9. Pittsburgh	13000	2023	59	670	2	51	.8	-
10. Cleveland	12700	1243	24	900	-22	71	2.3	-
11. Wilkes-Barre	12500	445	-4	123	1	*7.0	-	-
12. Johnstown	12300	284	15	67	-	5.5	-	-
13. Detroit	11375	2177	200	1569	-10	138	-	-
14. Dayton	11100	358	26	201	-10	18	5.6	20
15. Hartford	10300	312	25	164	2	16	1.5	-
16. Baltimore	10200	1037	103	805	54	79	-	-
Total		31950	1653	20851	550	1268		
E. 1940 - 1950								
1. New York/ Newark/ Jersey City/ Patterson	24900	11369	1178	8436	400	345	14.7	56
2. Boston	16700	2210	201	771	31	46	1.7	-
3. Chicago	16400	4570	608	3397	224	207	.8	-
4. Philadelphia	15200	3200	471	1931	140	127	-	-
5. Buffalo	14600	958	131	576	4	39	-	-
6. Providence/ Pawtucket	14200	695	65	329	1	26	-	-
7. Harrisburg	13500	252	40	84	6	6.2	.1	-
8. St. Louis	13400	1464	255	816	41	61	-	-
9. Pittsburgh	12900	2083	131	672	2.1	52	2.1	-
10. Milwaukee	12700	830	127	587	27	43	6.6	23
11. Wilkes-Barre	12500	442	-49	124	-12	7.0	-	-
12. Cleveland	12000	1267	198	878	36	73	1.9	-

* Area in 1950; earlier data not available

	D_c	P_t	dP_t	P_c	dP_c	A_c	dA_c	dP_a
	POP. / sq.mi.	000's	000's	000's	000's	sq.mi.	sq.mi.	sq.mi.
E. 1940 - 1950 (cont.)								
13. Johnstown	11900	298	-7	67	-3	5.6	-	-
14. Detroit	11800	2377	639	1623	226	138	1.7	-
15. Baltimore	10900	1140	266	859	91	79	-	-
16. Washington, D.C.	10800	968	496	663	139	61	-	-
Total		34123	4750	21813	1353	1315		
F. 1950 - 1960								
1. New York/ Jersey City/ Newark/ Patterson	25000	12547	1634	8892	-149	360	-	-
2. Chicago	17450	5178	1043	3621	-77	207	16.5	7
3. Boston	16800	2411	179	801	-104	48	-	-
4. Philadelphia	16300	3671	672	2072	-69	127	-	-
5. Buffalo	14700	1089	218	580	-47	39	-	-
6. Harrisburg	14200	292	53	90	-10	6.3	1.3	-
7. St. Louis	14000	1719	341	857	-107	61	-	-
8. Providence/ Pawtucket	13900	760	56	330	-42	26	-	-
9. Detroit	13200	3016	746	1850	-179	140	-	-
10. Washington, D.C.	13100	1464	538	802	-38	61	-	-
11. Milwaukee	12700	957	237	637	-20	50	41	124
12. Pittsburgh	12500	2213	192	677	-72	54	-	-
13. Redding	12400	256	20	109	-11	8.8	-	-
14. Cleveland	12200	1466	331	915	-39	75	6.2	-
15. Baltimore	12100	1405	322	950	-11	79	-	-
16. San Francisco/ Oakland	11900	2241	543	1160	-64	98	3.0	12
17. Johnstown	11300	291	-11	228	-9	5.6	-	-
18. Wilmington	11300	268	98	110	-15	9.8	-	-
19. Akron	11100	410	104	112	-17	6.9	-	-
20. Bridgeport	10900	274	61	159	-2	15	3.3	-
21. Hartford	10200	407	119	177	-15	17	-	-
Total		42335	7398	25129	-1097	1558		

B. Method of Estimating Population Corrections Due to Area Annexations

The change, dA_c, in the area of the central city of each metropolitan area during each decade was calculated as the difference between its area at the beginning and end of the decade as given in the references in Section C below. The change, dP_a, in population due to annexations was calculated by multiplying this change in area by an average density, D_a, of the annexed area. Since no data on these averaged densities was available, they were estimated as a function of the size of the annexation and the overall density of the suburban area as follows:

1. dA_c 2.9 sq. mi. – the change in area was ignored and the annexed population assumed to be 0.
2. 3 dA_c 20 – D_a was assumed to be 3,500 people per square mile.
3. 20 dA_c 50 – D_a was assumed to be equal to the average density of the suburban area as a whole.
4. dA_c 50 – D_a was assumed to be two thirds of the density of the suburban area as a whole.

Since some of the suburban areas have unusually low densities due to large annexations of vacant land, the minimum suburban density was assumed to be 2,000 per square mile. If the density of the suburban area was listed as being less than two thousand it was assumed to be 2,000

Corrections in population growth due to area annexations were made only for the white population. At all times, the fraction of the black population living outside the central city was small enough that changes in black population due to annexations to the central city were assumed to be zero. The changes in black population in the metropolitan area as a whole and in the central city were taken directly from reference I in Section C below.

C. References

The general sources for historical data on the changes in population by race and area were references 1 and 2. The general guide to Bureau of the Census data on areas of metropolitan area in the United States is reference 3. The specific references used in this work and for the year which they provided data are given in references 4 through 15.

1. US Bureau of the Census, US Census of Population: 1960. Selected Area Reports. Standard Metropolitan Statistical Areas. Final Report PC(3) - 1D (US Government Printing Office, Washington, D.C. 1963).

2. Bogue, Donald J., Population Growth in SMA's 1900-1950, Housing and Home Finance Agency, Housing Research Division, 1953.

3. Kerlin, T.C., and Klove, Robert C., "Area Measurements Published in Census Reports," to be published by the Geography Division of the Bureau of the Census, Suitland, Maryland.

4. (1890) "Report on the Social Statistics of Cities in the US at the 11th Census: 1890," Department of the Interior, Census Office, pp. 9-12, 53.

5. (1900) "Financial Statistics of Cities Having a Population of Over 25,000 in 1902 and 1903," Department of Commerce and Labor, Bureau of the Census, Bulletin 20, Table #1, pp. 65-67.

6. (1910) "Financial Statistics of Cities Having a Population of Over 30,000: 1910," Special Reports, Department of Commerce and Labor, Bureau of the Census, (Government Printing Office, Washington, D.C.), p. 90.

7. (1910) 13th Census of the U.S., 1920, Vol I, Table 50.

8. (1920) 14th Census of the U.S., 1930, Vol I, p. 63.

9. (1930) 15th Census of the U.S.: 1930 Metropolitan District: Population and Area, pp. 10-13.

10. (1940) _16th Census of the U. S.: 1940 Population, Vol I, Number of Inhabitants_, p. 58.

11. (1940) 16th Census of the U. S.: 1940, Areas of the U. S., (US Government Printing Office, 1942).

12. (1950) "Land Area and Population of Incorporated Places of 2,500 or More, April 1, 1950," _Geographic Report_ #5, Jan 1953.

13. (1950) _U. S. Census of Population: 1950, Vol I, Number of Inhabitants, pp. 1-21 to 1-29._

14. (1960) "1960 Area Measurement Reports," _Geographic Report_, Series GE-20, pp. 1-51.

15. (1960) _U. S. Census of Population: 1960, Vol I, Characteristics of Population, Part A, Number of Inhabitants_, pp. 1-40, to 1-49 and Table 9.

Appendix II

ANNOTATED BIBLIOGRAPHY ON URBAN SPATIAL GROWTH MODELS

TITLE

BIBLIOGRAPHY

I. REVIEW ARTICLES ON THE STATE OF THE ART IN URBAN MODELING

1. Artle, Roland, The Structure of Stockholm's Economy, Chapter 6, "On Locational patterns. A Progress Report on Further Research" Business Research Institute, Stockholm School of Economics, 1959. A good review of location theory through the middle of the 1950's including a very complete bibliography.

2. Center for Real Estate and Urban Economics, Jobs, People and Land - The Bay Area Simulation Study (BASS), Berkeley: University of California Printing Department, 1968. A good review of techniques for 1) projection of aggregate growth, 2) location of residences, 3) location of manufacturing and 4) location of commerce, services, etc. The main effort in the book is the development of an extremely interesting location model.

3. Crecine, John P. "Computer Simulation in Urban Research," Public Administration Review, vol. 27, 1968, pp. 67-77. Not very useful. It contains a good summary of political science models but just paraphrases Lowery's review of urban land use models.

4. Harris, Britton. "Quantitative Models of Urban Development -- Their Role in Metropolitan Policy Making," Issues in Urban Economics, ed. by Harvey Perloff and Lowdon Wingo, Resources for the Future, Inc., John Hopkins Press, 1968. An excellent overview of methods and problems in modelling the location of 1) population, 2) manufacturing, 3) retail and 4) other employment. It contains no equations and is an extremely readable and comprehensive review.

5. Harris, Britton (ed.) "Urban Development Models: New Tools for Planning," AIP Journal, Special Issue, #31, 1965. A set of eight articles, each on a promising model or set of models. It does not include a separate article reviewing the state of the art, and does not have a bibliography.

6. Highway Research Board, Urban Development Models, Special Report #97, Washington, D.C. 1968. The best and most current summary of the problems and issues in urban modeling. See particularly Harris' summary, Lowry's review article, and Hemmens' review of planning agency experiences.
   a. Harris, Britton, "Conference Summary and Recommendations."
   b. Hemmens, George C. "Survey of Planning Agency Experience with Urban Development Models, Data Processing, and Compu-

ters." pp. 219-230, and Appendix A, Agency Descriptions of Urban Development Models, pp. 253-262.

c. Lowry, Ira S., "Seven Models of Urban Development - A Structural Comparison," pp. 121-163.

7. Irwin, N.A. A Review of Existing Land Use Forecasting Techniques, Highway Research Board Record #88, 1963.
Excellent description of 15 models divided into 1) operational, 2) research oriented, and 3) conceptual techniques. Excellent bibliography for both the models discussed and other work published by 1963.

8. Kilbridge, Maurice, O'Block, Robert, and Teplitz, Paul. "A Conceptual Framework for Urban Planning Models," Urban Analysis Project, Harvard University, Management Science, February 1969.
A poorly organized but still interesting and useful comparison of 20 urban models, including an excellent bibliography.

9. Lamb, Donald, "Research of Existing Land Use Models, " SW Pennsylvania Regional Planning Commission, 1967.
Reviews: 1) Hamberg & Lathrop's Opportunity-accessibility Model, 2) Schlager's Land Use Simulation, 3) Lowry, 4) Industrial Impact Model (INIMP) from Pittsburgh CRP, 5) TOMM from Pittsburgh CRP, 6) DVRPC's activities allocation model, 7) Connecticut Land Use Model, 8) EMPIRIC, 9) San Francisco CRP. Contains a general description of each model, its major equations and variables, and operating sequence, but little critical evaluation.

10. Meyer, John, "Regional Economics: A Survey," American Economic Review, vol. 53, 1963, pp. 19-54.
An excellent critical and comparative review of four theoretical foundations of regional economics--1) location theory, 2) multiplier analysis, 3) input-output theory, and 4) mathematical optimization techniques.

11. Putnam, Stephen H. "Intra-Urban Industrial Location Model Design and Implementation," Papers and Proceedings of the Regional Science Association, vol. XIX, 1966.
Includes a short (3 pages) but good review of four models for intra-urban industrial location. 1) LINTA sub model of the Activities Allocation Model (Penn Jersey), 2) EMPIRIC (Boston), 3) Southwestern Wisconsin Regional Planning Commission Model and, 4) Federal Employment Center Location Model.
(Limited bibliography).

12. Rogers, A. "An Investigation of Retail Land Use Forecasting Models," Bay Area Transportation Study, Berkeley, California, 1966.
Was not obtained in time for review.

13. Silver, J. and Stowers, J. "Population, Economic, and Land Use Studies in Urban Transportation Planning - An Evaluation of Current Practices and Recommendations for a Future Program," Bureau of Public Roads, May 3, 1963.

14. Stevens, Benjamin, "A Review of the Literature on Linear Methods and Models for Spatial Analysis," AIP Journal, August, 1960, pp. 253-259.
A good, but now dated, explanation of techniques and bibliography of work using input-output and linear programming techniques. Only a few references deal with intra-urban analysis.

15. Voorhees, A.M. (ed.), "Land Use and Traffic Models: A Progress Report," AIP Journal, Special Issue, #25, 1959.
The first review of urban modeling - now very dated and not too useful.

16. Wilson, A.G., Models in Urban Planning: A Synoptic Review of Recent Literature," Urban Studies, November, 1968, pp. 249-276.

17. Zettel, Richard M. and Carli, Richard R. "Summary Review of Major Metropolitan Area Transportation Studies in the US," Special Report Institute of Transportation and Traffic Engineering, University of California, Berkeley, 1962.
A summary of 12 studies, most of which had not been completed at the time. Good source for information on the scale of the studies and their original goals and organization. Includes a bibliography of original proposals.

II. SUMMARY OF THE MAJOR COMPREHENSIVE STUDIES CURRENTLY IN USE OR UNDER DEVELOPMENT

(An * indicates the more important documents. Where no documents are listed at all for a study, the information about it was obtained from Hemmens' review in reference #6 of Section 1, or by private interviews and correspondence.)

A. Baltimore Regional Planning Council

Developing its own set of models to allocate seven categories of land use, vacant land, and employment in sequential iterative periods. One major phase identified optimum locations for multi-purpose community centers using gravity models.

1. Lakshmanan, Tiruvarur R. "An Approach to the Analysis of Interurban Location," Regional Science Association, November 1963, Representation to Southeastern Section, Roanoke, Virginia.

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3. Lakshmanan, R. "Simulation and Modelling Methods and Techniques at Regional Planning Council, Baltimore: Review and Prospects," January 15, 1968.
   Good overview of Baltimore's modeling efforts, including REGRO (the residential location model); the retail potential model, an outdoor recreation model, and a manufacturing location model.

4. "Manufacturing Industries: Projections of Location Decisions" 1967.

5. Munzert, Ken. "REGRO, The Rimberg Model," November 4, 1968.

6. "Outdoor Recreation in the Baltimore Region." 1967.

7. "Projections and Allocations for Regional Plan Alternatives," 1965.

8. "A Projection of Planning Factors for Land Use and Transportation," Tech Report #9, 1963.

9. "Retail Market Alternatives in the Baltimore Region, The Technical Record, July 1967.
Basically a gravity model of market potentials allocating consumer expenditures on the basis of size of facilities and distance as measured by driving time.

10. Rose, James, Interim Industrial Allocation Model: Structure and Analysis, October, 1968.
Describes an analytic model to identify relevant industrial location behavior, and a linear programming allocation model for projecting industrial location. Contains a good discussion of issues in this part of location theory.

B. Bay Area Simulation Study (BASS) (San Francisco)

11. Center for Real Estate and Urban Economics, Jobs, People, and Land - The Bay Area Simulation Study (BASS), Institute of Urban and Regional Development, University of California, Berkeley, 1968.
Excellent discussion of a set of models for the nine county San Francisco Bay Area. Includes 1) aggregate growth of population and employment obtained by combination of both economic and population projections, 2) allocation of industrial employment on basis of modified index obtained from regression equations, 3) allocation of retail employment by a modified market potential model considering both demand and supply (or site) factors, 4) residential location on the basis of both housing supply as determined by filtering and construction in a 6 sector model, and demand based on access to employment.

C. Cleveland - Seven County Transportation - Land Use Study

Uses the location models developed by New York State Department of Public Works (see below H)

D. Delaware Valley Regional Planning Commission (DVRPC)

Formerly the Penn Jersey Transportation Study; only the more important documents are listed here.

12. "Allocation of Urban Activities," DVRPC, Technical Report #1, 1967.

13. Chevan, Albert, "Population Projection System," Technical Report #3, Penn-Jersey Study, June, 1965.

14. Fagin, Henry. "The Penn Jersey Transportation Study, AIP Journal, February 1963, pp. 9-18.

15. Harris, Britton. "Linear Programming and the Projection of Land Uses," PJ Paper #20, PJ Transportation Study, 1962. Good discussion of the issues in residential location models and the modifications of the original Herbert - Stevens linear programming theory.

16. Harris, Britton. "A Model of Locational Equilibrium for Retail Trade," Institute of Environmental Studies, University of Pennsylvania, Philadelphia, October 1964.

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*18. Seidman, David R. "The Construction of an Urban Growth Model," DVRPC Plan Report #1, Technical Supplement, vol. A, 1969.
Excellent documentation of the development and final results of the models produced by the Penn Jersey Study.

19. Seidman, David R. "Report on Activities Allocation Model," Penn Jersey Paper #22, Penn Jersey Transportation Study. 1964.

20. "1985 Regional Projections for the Delaware Valley," DVRPC Plan Report #1, 1967.

E. Detroit Transportation and Land Use Study (TALUS)

21. CONSAD Research Corporation, "Urban Regional Model of Small Area Change for Southeastern Michigan," July 1969. (Study headed by Donald Lamb).
A highly disaggregated model allocating approximately 70 population and household variables broken down by income (6 classes); stage in life (7 classes); age, sex, race (a 10 x 2 x 2 matrix); and auto ownership (10 classes). Allocations are made to 1500 zones on basis of 328 independent variables, including 12 types of accessibility. The model consists of 99 regression equations calibrated using two point (1953 and 1965) time series data.

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23. Polk, Lon, "Employment Allocation Model Report," TALUS Report, November 1969.
Allocates 10 classes of employment on the basis of relative attractiveness index calculated from set of regression equations.

F. Connecticut Interregional Planning Program

24. Voorhees and Assoc. "Summary: A Model for Allocating Economic Activities into Sub-areas of a State." Memo prepared for the Connecticut Interregional Planning Program, November 1963.

25. Lakshmanan, T.R. "A Model for Allocating Urban Activities in a State," Socio-economic Planning Science, vol. I, 1968, pp. 283-295.

G. Eastern Massachusetts Regional Planning Project (Empiric Model)

26. Brand, Daniel, Barber, Brian and Michael Jacobs. "Techniques for Relating Transportation Improvements and Urban Development Patterns," Highway Research Record #207, Urban Land Use: Concepts and Models, 1967.

27. Hill, Donald M., et al. "Prototype Development of Statistical Land Use Prediction Model for Greater Boston Region." Highway Research Record, #114, pp. 51-70, 1965.

28. Traffic Research Corporation. "EMPIRIC Land Use Forecasting Model: Final Report," February 1967.
Good documentation of a nine equation simultaneous regression model for projecting 4 classes of population (disaggregated by income) and 5 classes of employment. Good bibliography of EMPIRIC reports.

H. Los Angeles City Planning Department

29. "The Mathematical Model Development Program: Introduction and Proposed Program," RM-SD-00200-01, 1966.

30. "The Mathematical Model Development Program: Residential Location Models, RM-SD-00202-01, 1966.
Brief description of the Herbert - Stevens model as modified by Harris at the University of Pennsylvania.

31. "Residential Location Model Multivariate Analysis," Department of City Planning, Los Angeles, June, 1967, RM-SD-00202-02.
Analyzes rent as a function of household, housing, and access characteristics, using both a) multivariate analysis, b) factor analysis.

32. "Population Projection Model Application," RM-SD-00203-01, January, 1967.
Uses Chevan's model from PJ and cohort analysis with policy sensitive migration rates.

I. New York State Department of Public Works (Models originally developed for Buffalo)

33. Fidler, Jere. "Commercial Activity Location Model," Public TPOO - 332-01, Subdivision of Transportation Planning and Programming, New York State Department of Public Works, Albany, New York, 1967.

34. Fidler, Jere. "Commercial Activity Location Model," Highway Research Record #207, Urban Land Use Concepts and Models, 1967.

35. Lanthrop, George T. and John R. Hamburg. An Opportunity--Accessibility Model for Allocating Regional Growth," AIP Journal, Vol. XXXI, 1965, pp. 95-103.

J. Northeast Corridor Transportation Project

This effort does not deal with intraurban development, but the development of models predicting the intra-regional economic and demographic impacts of changes in the transportation system in the Northeast Corridor having many similar problems. The models include 1) an interregional input output model for projecting aggregate growth, 2) an intra-regional location model based on state of the art theories and techniques as of early 1966, and 3) a second phase location model based on a much more complete conceptual development.

36. Bruck, Henry W., Putnam, Stephen H., and Wilbur A. Steger. "Evaluation of Alternative Transportation Proposals: The North-

east Corridor," AIP Journal, November 1966, Vol. 32, pp. 322-334.

37. Consad Research Corporation, Impact Studies: Northeast Corridor Transportation Project.
   Vol. I: "Background, Overview and Summary," June 1967
   Vol. II: "Models, Results and Technical Discussion," January 1968
   Vol. III: Phase II Modeling Efforts, January 1969

K. Pittsburgh Community Renewal Program (CRP)

The Lowry model, allocating residences on the basis of access to work and retail employment on the basis of access to population, is the basic foundation of this work. The TOMM model made the allocation dynamic with growth distributed over time, and also disaggregated population. Work at Pittsburgh has ceased, but the TOMM model was revised and its running time significantly reduced by Teplitz.

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39. Department of City Planning, Pittsburgh, CRP Technical Bulletins
   #5 "Industrial Location Model," December, 1963
   #6 "Time Oriented Metropolitan Model (TOMM)," January, 1964
   #17 "TOMM - Time Oriented Metropolitan Model, 1965.
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   Describes the INIMP Industrial Location Model.

41. Steger, Wilbur A. "The Pittsburgh Urban Renewal Simulation Model," AIP Journal, Vol. XXXI, May 1965, pp. 144-150.

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L. Puget Sound Regional Transportation Study

Has developed its own set of multiple regression models to project population changes and employment shifts. A set of non-simultaneous regression equations for distributing population growth, population declines, manufacturing employment, retail employment, office services employment, and other employment.

43. Graves, C.H. "Forecasting the Distribution of 1985 Population and Employment to Analysis Zones," Puget Sound Regional Transportation Study, Staff Report #15, Seattle, Washington, Revised March, 1967.

M. Regional Plan Association (New York City)

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N. San Juan, Puerto Rico

44. "Design of Analytical Models for the San Juan Metropolitan Area," Consad Research Corporation, May, 1968.
Descriptions of a program proposed to "fill the gap between public policy analytical requirements and the current available techniques."

O. Southeastern Wisconsin Regional Planning Commission (SWRPC)

45. Schlager, K.J. "Simulation Models in Urban and Regional Planning," The Technical Record – SWRPC, Vol. II, #1, October, 1964.

46. SWRPC. "Land Use Plan Design Model," Technical Report #8, Waukesha, Wisconsin, 1968.

P. Southwestern Pennsylvania Regional Planning Commission (SWRPC)

Uses the location models developed by the New York State Department of Public Works. (see above)

47. Lamb, Donald, "Research of Existing Land Use Models," 1967.

48. "Provisional Employment and Population Forecasts," 1968.
Aggregate projections only.

Q. Twin Cities Metropolitan Planning Commission

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III. SPECIFIC MODELS AND TECHNIQUES

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12. Tiebout, Charles M. The Community Economic Base Study, Committee for Economic Development Supplementary Paper #16, 1962.

13. Wingo, Lowdon. "An Economic Model of the Utilization of Urban Land for Residential Purposes," Papers and Proceedings of the Regional Science Association, Vol. VII, 1961, pp. 192-205.

14. Wingo, Lowdon. "Transportation and Urban Land," Resources for the Future, Inc. 1961.

B. Manufacturing Employment Location (also see Baltimore and BASS studies)

15. C-E-I-R, Inc. An Analytical Technique for the Selection of Federal Employment Center Locations in the National Capital Region, Arlington C-E-I-R Center, Arlington, Virginia, 1961.

16. Center for Real Estate and Urban Economics, Jobs, People and Land -- The Bay Area Simulation Study, (BASS), Institute of Urban and Regional Development, University of California, Berkeley, 1968. (see Chapter III)

17. Pittsburgh Community Renewal Program (CRP), Industrial Location Model, Department of City Planning, Pittsburgh, Pennsylvania, December, 1963.

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C. Non-Manufacturing Employment Location

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D. Residential Location

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Appendix III

The Listings of the Equations of the Model and the Submodels

The first part of this appendix is the listings of the models developed in the thesis. The listing of each model first describes the external inputs to the model, then gives the equations. The external inputs are listed in the following sequence: initial conditions, constants, table functions, and policy inputs. The number of each equation is the last three digits on the right hand side.

The second part of the appendix gives the remainder of the output of the complete model for a simulation of the development of a high density city. The first two pages of the output are Figures 6 and 7 of Chapter 8.

A. Listings of Models

```
NOTE     FILE EXGML
NOTE     THIS FILE CONTAINS THE EXTERNAL INPUTS FOR THE GROWTH
NOTE     MODEL WHICH RUNS SEPARATELY.
NOTE      THE INITIAL CONDITIONS ARE FOR A LARGE CITY.
NOTE
NOTE      A. INITIAL CONDITIONS
NOTE
C  PT=500000
C  FPB=.05                               FRACTION OF POP BLACK
C  FPU=.41                               FRACTION OF POP IN UPPER SKILLED
C  FC=.30                               FRACTION OF POP IN CHILDREN
C  RSPN=.11                              RATIO OF RES SERVICE EMP TO POP
NOTE
N  PBU=(1-FC)*FPB*FPU*PT
N  PBL=(1-FC)*FPB*PT*(1-FPU)
N  CB=FC*FPB*PT
N  PWU=(1-FC)*(1-FPB)*FPU*PT
N  PWL=(1-FC)(1-FPB)(1-FPU)*PT
N  CW=FC*(1-FPB)*PT
N  IEX=PT*((((1-FC)*LFPR)/(1+BSR))-RSPN)
NOTE
NOTE     B. CONSTANTS
NOTE
C  DAG=18 YEARS                          DELAY IN AGING
C  OMRL=.009                             OUTMIGRATION RATE, LOW SKILL
C  OMRU=.031                             OUTMIGRATION RATE, HI SKILL
C  IRBL=.00078                           BLACK IMMIGRATION, LOW SKILL
C  IRBU=.00052                             "       "        HI SKILL
C  IRWL=.0039                            WHITE     "        LOW SKILL
C  IRWU=.0078                              "       "        HI  SKILL
C  LFPR=.58                              LABOR FORCE PARTICIPATION RATE
C  CPM=.70                               CHILDREN PER MIGRANT
C  BSR=.22                               BUSINESS SERVICE EMP RATIO
NOTE
NOTE      C. TABLE FUNCTIONS
NOTE       THE EXTERNAL DRIVING FORCES OF TWO MIGRATION POTENTIALS AND
NOTE       NATIONAL ECONOMIC GROWTH RATE ARE CONTROLLED BY THE SWITCHES
NOTE       BELOW.  IF THE SWITCH IS SET TO 0, THE DRIVING FORCE
NOTE       IS CONSTANT AT THE VALUE INDICATED.
NOTE
C  SWBM=0                                MIGRATION POTENTIAL FOR BLACKS
C  SWWM=0                                MIGRATION POTENTIAL FOR WHITES
C  SWNX=0                                NATIONAL EXPORT GROWTH
C  MBPOC=1
C  MWPOC=1
C  NXGRC=.02 PER YEAR
NOTE
T  BRBTAB=.039/.039/.038/.037/.035/.031/.028/.026/.026/.029/.033/.032/.0
X  32/.032/.032/.032/.032
T  BRWTAB=.030/.03/.029/.028/.026/.024/.021/.018/.019/.023/.023/.023/.02
X  3/.023/.023/.023/.023
T  DRBTAB=.025/.0217/.0185/.0155/.013/.011/.010/.0095/.0095
T  DRWTAB=.017/.0145/.0125/.0108/.01/.0095/.0095/.0095/.0095
T  MBTAB=1.0/1.0/1.0/1.0/1.0/1.0/1.0/1.0/1.0
```

```
T  MWTAB=1.0/1.0/1.0/1.0/1.0/1.0/1.0/1.0/1.0                              GRO00560
T  UALTAB=4./4./2./1.4/1./.82/.67/.56/.47/.38/.3/.22/.14/.07/.0          GRO00570
T  UAUTAB=4./4./2./1.4/1./.82/.67/.56/.47/.38/.3/.22/.14/.07/0           GRO00580
T  UNTAB=0/.02/.04/.06/.08/.12/.16                                        GRO00590
T  UNUTAB=0/.008/.014/.02/.035/.048/.06/.08/.1/.12/.14/.16                GRO00600
T  IEXTAB=1./1./1./1./1./1./1./1./1.                                      GRO00610
T  EATTAB=0/.2/.4/.6/.8/.86/.93/1.0                                       GRO00620
T  NEXTAB=.03/.03/.03/.03/-.015/-.008/-.011/.038/.075/-.0003/.0018/-.002GRO00630
X  /.001/.001/.001/.001/.001                                              GRO00640
T  RSPTAB=.1/.1/.106/.115/.123/.151/.165/.175/.180                        GRO00650
T  JUCTAB=.41/.42/.46/.49/.51/.59/.64/.68/.70                             GRO00660
T  RDRTAB=1.0/.52/.21/.21                                                 GRO00670
NOTE                                                                      GRO00680
NOTE      D. POLICY INPUTS -NONE                                          GRO00690
                                                                          GRO00700
NOTE      FILE EQGM                                                       GRO00710
NOTE      THIS FILE CONTAINS THE EQUATIONS FOR THE GROWTH MODEL           GRO00720
NOTE      A. MODEL EQUATIONS                                              GRO00730
NOTE  BLACK CHILDREN                                                      GRO00740
L  CB.K=CB.J+(DT)(CBBR.JK+(CPM)(PBLMR.JK+PBUMR.JK)-CBDR.JK-CBAR.JK)       GRO00750
R  CBBR.KL=(PB.K)(BRB.K)                                                  GRO00760
A  BRB.K=TABLE(BRBTAB,TIME.K,0,80,5)                                      GRO00770
R  CBDR.KL=(CB.K)(DRB.K)(RDR.K)                                           GRO00780
A  RDR.K=TABLE(RDRTAB,TIME.K,0,90,30)                                     GRO00790
A  DRB.K=TABLE(DRBTAB,TIME.K,0,80,10)                                     GRO00800
R  CBAR.KL=CB.K/DAG                                                       GRO00810
A  CBR.K=CB.K/PB.K                                                        GRO00820
NOTE  LOW SKILLED BLACK ADULTS                                            GRO00830
L  PBL.K=PBL.J+(DT)((FBPL.J)(CBAR.JK)+PBLMR.JK-PBLDR.JK)                  GRO00840
R  PBLDR.KL=PBL.K*DRB.K                                                   GRO00850
R  PBLMR.KL=(P.K)(MBPOT.K)(MLAT.K)(IRBL)-(PBL.K)(OMBL)                    GRO00860
A  FBPL.K=(PBL.K)/(PBL.K+PBU.K)                                           GRO00870
A  P.K=PB.K+PW.K                                                          GRO00880
A  PBR.K=PB.K/P.K                                                         GRO00890
A  PW.K=PWL.K+PWU.K+CW.K                                                  GRO00900
A  PB.K=PBL.K+PBU.K+CB.K                                                  GRO00910
A  FWMIG.K=(PWLMR.JK+PWUMR.JK)/PW.K                                       GRO00920
A  FBMIG.K=(PBLMR.JK+PBUMR.JK)/PB.K                                       GRO00930
A  MBPQT.K=TABLE(MBTAB,TIME.K,0,80,10)                                    GRO00940
A  MBPOT.K=SWITCH(MBPOC,MBPQT.K,SWBM)                                     GRO00950
A  MLAT.K=TABHL(UALTAB,UNR.K,0,.14,.01)                                   GRO00960
A  UNR.K=TABHL(UNTAB,ERAT.K,-.08,.16,.04)                                 GRO00970
A  ERAT.K=(E.K-J.K)/E.K                                                   GRO00980
A  E.K=EL.K+EU.K                                                          GRO00990
A  EL.K=(PBL.K+PWL.K)(LFPR)                                               GRO01000
A  EU.K=(PBU.K+PWU.K)(LFPR)                                               GRO01010
A  ELRAT.K=(EL.K-JL.K)/EL.K                                               GRO01020
A  EURAT.K=(EU.K-JU.K)/EU.K                                               GRO01030
A  FEL.K=EL.K/E.K                                                         GRO01040
NOTE  BLACK UPPER SKILLED ADULTS                                          GRO01050
L  PBU.K=PBU.J+(DT)((1-FBPL.J)(CBAR.JK)+PBUMR.JK-PBUDR.JK)                GRO01060
R  PBUDR.KL=PBU.K*DRB.K                                                   GRO01070
R  PBUMR.KL=(P.K)(MBPOT.K)(MUAT.K)(IRBU)-(PBU.K)(OMBU)                    GRO01080
A  MUAT.K=TABHL(UAUTAB,UNRU.K,0,.14,.01)                                  GRO01090
A  UNRU.K=TABHL(UNUTAB,EURAT.K,-.06,.16,.02)                              GRO01100
```

```
NOTE  WHITE CHILDREN
L  CW.K=CW.J+(DT)(CWBR.JK+(CPM)(PWLMR.JK+PWUMR.JK)-CWDR.JK-CWAR.JK)
R  CWBR.KL=(PW.K)(BRW.K)
A  BRW.K=TABLE(BRWTAB,TIME.K,0,80,5)
R  CWDR.KL=(CW.K)(DRW.K)(RDR.K)
A  DRW.K=TABLE(DRWTAB,TIME.K,0,80,10)
R  CWAR.KL=CW.K/DAG
A  CWR.K=CW.K/PW.K
NOTE  WHITE LOWER SKILLED ADULTS
L  PWL.K=PWL.J+(DT)((FWPL.J)(CWAR.JK)+PWLMR.JK-PWLDR.JK)
R  PWLDR.KL=PWL.K*DRW.K
A  FWPL.K=PWL.K/(PWL.K+PWU.K)
R  PWLMR.KL=(P.K)(MWPOT.K)(MLAT.K)(IRWL)-(PWL.K)(CMRL)
A  MWPQT.K=TABLE(MWTAB,TIME.K,0,80,10)
A  MWPOT.K=SWITCH(MWPOC,MWPQT.K,SWWM)
NOTE  WHITE UPPER SKILLED ADULTS
L  PWU.K=PWU.J+(DT)((1-FWPL.J)(CWAR.JK)+PWUMR.JK-PWUDR.JK)
R  PWUDR.KL=PWU.K*DRW.K
R  PWUMR.KL=(P.K)(MWPOT.K)(MUAT.K)(IRWU)-(PWU.K)(CMRU)
NOTE  INDUSTRIAL GROWTH
L  IEX.K=IEX.J+DT*IEXG.JK
R  IEXG.KL=IEXPOT.K*EAT.K*NIEXGR.K*IEX.K
A  IEXPOT.K=TABLE(IEXTAB,TIME.K,0,80,10)
A  EAT.K=TABHL(EATTAB,ERAT.K,-.12,.09,.03)
A  NIEXGQ.K=TABLE(NEXTAB,TIME.K,0,80,5)
A  NIEXGR.K=SWITCH(NXGRC,NIEXGQ.K,SWNX)
A  IBS.K=(IEX.K+IRS.K)(BSR)
A  IRS.K=(P.K)(RSPR.K)
A  RSPR.K=TABLE(RSPTAB,TIME.K,0,80,10)
A  J.K=IEX.K+IBS.K+IRS.K
A  JU.K=(J.K)(JUC.K)
A  JL.K=(J.K)(1-JUC.K)
A  JUC.K=TABLE(JUCTAB,TIME.K,0,80,10)
A  EXR.K=IEX.K/J.K
NOTE
NOTE     B. MODEL OUTPUTS AND RUN SPECIFICATIONS
PLOT  P=P,J=J/FBR=B/CBR=C,CWR=D/EXR=X,FEI=F
PLOT  FWMIG=M,FBMIG=N/UNR=T,UNRU=U,ELRAT=L
SPEC  DT=2.5/LENGTH=60/PLTPER=2.5
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```
NOTE      A.  LARGE CITY INITIAL CONDITIONS FOR HOUSING MODEL            INH00010
NOTE         (FILE EXHML)                                                 INH00020
NOTE                                                                      INH00030
NOTE                                                                      INH00040
C  PT=500000                          TOTAL POPULATION                    INH00050
C  FRPC=.75                           FRACTION OF POPULATION IN CORE      INH00060
C  LFOC=.71                           LAND FRACTION OCCUPIED IN CORE      INH00070
C  NDAHC=13.5 DU/ACRE                  AVERAGE DENSITY OF HOUSING         INH00080
C  FNCU=1.0                           FRAC OF NEEDED UPPER CORE HOUSINGINH00090
C  FNCL=1.0                           FRAC OF NEEDED LOWER CORE HOUSINGINH00100
C  UNRU=.04                           UNEMP RATE OF UPPER SKILL LABOR     INH00110
C  JUC=.41                            COEF OF UPPER SKILLED LABOR         INH00120
C  APH=2.6                            NUMBER OF ADULTS PER HOUSEHOLD      INH00130
N  PCU=(FRPC)(JUC)(PT)(.7)                                                INH00140
NOTE                                                                      INH00150
NOTE                                                                      INH00160
N  HCU=(FNCU)(PCU)/APH                UPPER SKILLED HOUSING IN CORE       INH00170
N  HCL=(FNCL)(PCL)/APH                LOWER    "      "     "    "        INH00180
N  HCA=0                              ABANDONED HOUSING IN CORE           INH00190
N  LHC=(HCU+HCL+HCA)/NDAHC             LAND USED FOR HOUSING IN CORE      INH00200
N  RHCLA=1.0                          AVERAGED RATIO OF HOUSING D/S       INH00210
NOTE        FILE EXH                                                      INH00220
NOTE        SPECIFIES THE CONSTANTS, TABLE FUNCTIONS,AND EXTERNAL         INH00230
NOTE        FORCES FOR BOTH THE HOUSING MODEL AND SUBROUTINE.             INH00240
NOTE                                                                      INH00250
NOTE         AS IS EXPLAINED BELOW, THE SWITCH "SWHX" CONTROLS            INH00260
NOTE        THE EXTERNAL DRIVING FORCE ON THE HOUSING SUPPLY.             INH00270
NOTE                                                                      INH00280
NOTE       B. CONSTANTS                                                   INH00290
NOTE                                                                      INH00300
C  NHFR=.03                           NORMAL HOUSING FILTERING RATE       INH00310
C  NHAR=.01                            "       "      ABANDONMENT RATE    INH00320
C  TARHL=4 YEARS                     TIME FOR AVERAGING LOWER D/S         INH00330
C  NHDR=.20                           NORMAL DEMOLITION RATE              INH00340
NOTE                                                                      INH00350
NOTE                                                                      INH00360
NOTE     C. TABLE FUNCTIONS AND EXTERNAL DRIVING FORCES                   INH00370
NOTE                                                                      INH00380
T  HERT=0/3/10/20/27/30/30              HOUING EXPANSION RESPONSE         INH00390
T  HDMIT=1/1/.9/.8/.7/.6           HOUSING DEMAND MULT FOR INTERNAL COND.INH00400
T  FHVT=1/1/1/1/.8/0                  FRAC OF NEW HOUSING ON VACANT LAND  INH00410
T  HFMT=4/4/1/.5/.37/.23/.10           HOUSING FILTERING RATE MULTIPLIERINH00420
T  HAMT=2/1.5/1/.75/.5/.5/.5           HOUSING ABANDON. RATE MULT.        INH00430
T  DMHT=2.5/2.5/5/10/20/45             MARGINAL HOUSING DENSITY           INH00440
NOTE                                                                      INH00450
T  HDMXT=1/1/1/1/.8/1/1/1/1/.6/1/1/1/1/1/1/1     EXTERNAL DEMAND MULT    INH00460
NOTE  THE SWITCH "SWHX" CONTROLS WHETHER THE EXTERNAL HOUSING DEMAND     INH00470
NOTE  MULTIPLIER VARIES AS GIVEN IN HDMXT (SWHX=1) OR REMAINS CONSTANT   INH00480
NOTE  AT THE VALUE EQUAL TO HDMX (SWHX=0).                                INH00490
C  SWHX=0                                                                 INH00500
C  HDMXC=1                                                                INH00510
NOTE                                                                      INH00520
NOTE         D. POLICY INPUTS                                             INH00530
NOTE            1. LOW INCOME HOUSING CONSTRUCTION PROGRAM                INH00540
C  HCLPC=.05                            PROGRAM AS FRACTION OF SUPPLY     INH00550
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C  SWHLC=100 YRS                         TIMING OF INITIATION OF PROGRAMINH00560
NOTE                                                                  INH00570
NOTE       2. ABANDONED HOUSING DEMOLITION PROGRAM                    INH00580
C  HCDPC=2                              MULTIPLIER OF NORMAL DEMO RATE   INH00590
C  SWHDP=100 YRS                         TIME OF INITIATION OF PROGRAM   INH00600
NOTE                                                                  INH00610
                                                                      INH00620
                                                                      INH00630
NOTE    EQUATIONS FOR HOUSING MODEL                                   INH00640
NOTE     FILE EQHM                                                    INH00650
NOTE     EQUATIONS FOR HOUSING MODEL TO RUN INDEPENDENT OF OTHER MODELS INH00660
NOTE    (THE FILE ALSO CONTAINS THE REMAINING INPUTS,RUN SPECIFICATIONS,INH00670
NOTE     AND OUTPUT SPECIFICATIONS.)                                  INH00680
NOTE                                                                  INH00690
NOTE     A. EQUATIONS FOR HOUSING MODEL                               INH00700
NOTE          1.   HOUSING STOCKS                                     INH00710
NOTE                                                                  INH00720
L  HCU.K=HCU.J+(DT)(HCUCR.JK-HCFR.JK)                                 INH00730
L  HCL.K=HCL.J+(DT)(HCLCR.JK+HCFR.JK-HCLCL.JK-HCLCU.JK-HCAR.JK)       INH00740
L  HCA.K=HCA.J+(DT)(HCAR.JK-HCACU.JK-HCACL.JK-HCDR.JK)                INH00750
                                                                      INH00760
                                                                      INH00770
NOTE       2. RATES OF NEW CONSTRUCTION                               INH00780
R  HCUCR.KL=(.01)(HCER.K)(HCU.K)      CONSTRUCTION OF UPPER HSG IN COREINH00790
A  HCER.K=TABHL(HERT,RHCUM.K,.9,1.5,.1)                               INH00800
R  HCLCR.KL=(HCLP.K)(HCL.K)           CONSTRUCTION OF LOWER HSG IN COREINH00810
A  HCLP.K=CLIP(HCLPC,0,TIME.K,SWHLC)                                  INH00820
NOTE     THIS FUNCTION INITIATES A LOW INCOME HOUSING PROGRAM         INH00830
NOTE     IN THE CORE OF HCLP OF THE SUPPLY AT T=SWHLC.                INH00840
A  RHCUM.K=(RHCU.K)(HDMI.K)(HDMX.K)                                   INH00850
A  HDMI.K=TABHL(HDMIT,UNRU,0,.25,.05)                                 INH00860
A  HDMXQ.K=TABLE(HDMXT,TIME.K,0,80,5)                                 INH00870
A  HDMX.K=SWITCH(HDMXC,HDMXQ.K,SWHX)   CUTOFF FOR EXTERNAL HSG MULT.  INH00880
NOTE                                                                  INH00890
NOTE                                                                  INH00900
NOTE       3. CONVERSIONS, FILTERING, AND DEMOLITION                  INH00910
NOTE                                                                  INH00920
R  HCLCU.KL=(HCUC.K)(1-RHSC.K)        LOWER CONVERSIONS TO UPPER      INH00930
R  HCACU.KL=(HCUC.K)(RHSC.K)          ABANDONED CONVERSIONS TO UPPER  INH00940
A  HCUC.K=(.01)(HCER.K)(HCU.K)(1-FHCV.K)(RHDC.K)                      INH00950
A  FHCV.K=TABLE(FHVT,LFOC,0,1,.2)    FRAC CONST ON VACANT LAND        INH00960
A  RHDC.K=DAHC.K/DMHC.K               AVG/MARGINAL HOUSING DENSITIES  INH00970
A  RHSC.K=HCA.K/(HCL.K+HCA.K)                                         INH00980
R  HCACL.KL=(HCLC.K)(RHSC.K)          ABANDONED CONVERSIONS TO LOWER  INH00990
R  HCLCL.KL=(HCLC.K)(1-RHSC.K)        LOWER CONVERTED TO NEW LOWER    INH01000
A  HCLC.K=(HCLP.K)(HCL.K)(1-FHCV.K)(RHDC.K)                           INH01010
R  HCFR.KL=(NHFR)(HFMC.K)(HCU.K)      FILTERING UPPER TO LOWER        INH01020
A  HFMC.K=TABLE(HFMT,RHCU.K,.6,1.8,.2)                                INH01030
R  HCAR.KL=(NHAR)(HAMC.K)(HCL.K)      ABANDONMENT RATE                INH01040
A  HAMC.K=TABHL(HAMT,RHCLA.K,.8,1.4,.1)                               INH01050
L  RHCLA.K=RHCLA.J+DT*(RHCL.J-RHCLA.J)/TARHL                          INH01060
R  HCDR.KL=(NHDR)(HCDP.K)(HCA.K)      DEMOLITION RATE                 INH01070
A  HCDP.K=CLIP(HCDPC,1.0,TIME.K,SWHDP)                                INH01080
NOTE   SWHDP IS THE TIME OF THE BEGINNING OF A HOUSING DEMOLITION     INH01090
NOTE   PROGRAM IN THE CORE OF HCDP TIMES THE NORMAL RATE.             INH01100
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NOTE        4. IAND USED FCR HOUSING                                                  INH01110
L   LHC.K=LHC.J+(DT)(LHCG.JK-LHCD.JK)                                                  INH01120
R   LHCG.KL=((HCLP.K)(HCL.K)+(.01)(HCER.K)(HCU.K))(FHCV.K)/DMHC.K                      INH01130
R   LHCD.KL=(NHDR)(HCDP.K)(HCA.K)/DAHC.K                                               INH01140
A   DAHC.K=(HCU.K+HCL.K+HCA.K)/LHC.K   AVERAGE HOUSING DENSITY IN CORE                 INH01150
A   DMHC.K=TABLE(DMHT,LFCC,0,1,.2)    MARGINAL HOUSING DENSITY IN CORE                 INH01160
NOTE        5. SPECIAL FUNCTIONS FCR MODEL TO RUN SEPARATELY                           INH01170
NOTE                                                                                   INH01180
A   RHCU.K=PCU.K/(HCU.K*APH)                                                           INH01190
A   RHCL.K=PCL.K/(HCL.K*APH)                                                           INH01200
A   PCL.K=PCU.K*(1-JUC)/JUC                                                            INH01210
L   PCU.K=PCU.J+DT*GR*PCU.J                                                            INH01220
C   GR=.07                                                                             INH01230
NOTE                                                                                   INH01240
NOTE      B. RUN SPECIFICATIONS AND OUTPUTS                                            INH01250
SPEC    DT=1/LENGTH=20/PLTPER=2                                                        INH01260
PLOT    HCU=U,HCL=L,HCA=A/RHCU=R/RHCL=P/HCUCR=C,HCFR=F/HCAR=E,HCDR=D                   INH01270
PLOT    LHC=C/DAHC=D,DMHC=M                                                            INH01280
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NOTE     FILE EXGSL
NOTE     THIS FIIE CCNTAINS THE EXTERNAL INPUTS FOR THE GRCWTH
NOTE     SUBRCUTINE OF THE PHASE2 MOCEL.
NOTE      THE INITIAL CONDITIONS ARE FOR A LARGE CITY.
NOTE
C  PT=600000
C  FPB=.05                               FRACTION OF POP BLACK
C  FPU=.41                               FRACTION CF POP IN UPPER SKILLEC
C  FC=.30                               FRACTION OF POP IN CHILDREN
C  RSPN=.11                              INITIAL RATIO OF RES EMP TO POP
NOTE
N  PBU=(1-FC)*FPB*FPU*PT
N  PBL=(1-FC)*FPB*PT*(1-FPU)
N  CB=FC*FPB*PT
N  PWU=(1-FC)*(1-FPB)*FPU*PT
N  PWL=(1-FC)(1-FPB)(1-FPU)*PT
N  CW=FC*(1-FPB)*PT
N  IEX=PT*((((1-FC)*LFPR)/(1+BSR))-RSPN)
NOTE     B. CONSTANTS
C  DAG=18 YEARS                          DELAY IN AGING
C  OMRL=.009                             CUTMIGRATION RATE, LCW SKILL
C  OMRU=.031                             OUTMIGRATION RATE, HI SKILL
C  IRBL=.00078                           BLACK IMMIGRATICN, LOW SKILL
C  IRBU=.00052                             "        "       HI SKILL
C  IRWL=.0039                            WHITE      "       LOW SKILL
C  IRWU=.0078                              "        "       HI  SKILL
C  LFPR=.58                              LABOR FORCE PARTICIPATION RATE
C  CPM=.70                               CHILDREN PER MIGRANT
C  BSR=.22                               BUSINESS SERVICE EMP RATIO
C  UPL=.01                               UPGRADING RATE OF LOW SKILLED
NOTE
NOTE      D. TABLE FUNCTIONS
NOTE      THE EXTERNAL DRIVING FORCES OF TWO MIGRATION POTENTIALS AND
NOTE      NATIONAL ECONOMIC GROWTH RATE ARE CCNTRCLLED BY THE SWITCHES
NOTE      BELCW.  IF THE SWITCH IS SET TO 0, THE DRIVING FORCE
NOTE      IS CONSTANT AT THE VALUE INDICATED.
NOTE
C  SWBM=0                                MIGRATION POTENTIAL FOR BLACKS
C  SWWM=0                                MIGRATION PCTENTIAL FOR WHITES
C  SWNX=1                                NATIONAL EXPORT GROWTH
C  MBPOC=3
C  MWPOC=3
C  NXGRC=.03 PER YEAR
NOTE
T  BRBTAB=.039/.039/.038/.037/.035/.031/.028/.026/.026/.029/.033/.032/.0
X  32/.032/.032/.032/.032
T  BRWTAB=.030/.03/.029/.028/.026/.024/.021/.018/.019/.023/.023/.023/.02
X  3/.023/.023/.023/.023
T  DRBTAB=.025/.0217/.0185/.0155/.013/.011/.010/.0095/.0095
T  DRWTAB=.017/.0145/.0125/.0108/.01/.0095/.0095/.0095/.0095
T  MBTAB=1.0/1.0/1.0/1.0/1.0/1.0/1.0/1.0/1.0
T  MWTAB=1.0/1.0/1.0/1.0/1.0/1.0/1.0/1.0/1.0
T  UALTAB=4./4./2./1.4/1./.82/.67/.56/.47/.38/.3/.22/.14/.07/.0
T  UAUTAB=4./4./2./1.4/1./.82/.67/.56/.47/.38/.3/.22/.14/.07/0
T  UNTAB=0/.02/.04/.06/.08/.12/.16
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T  UNUTAB=0/.008/.014/.02/.035/.048/.06/.08/.1/.12/.14/.16
T  IEXTAB=1./1./1./1./1./1./1./1./1.
T  EATTAB=0/.2/.4/.6/.8/.86/.93/1.0
T  NEXTAB=.03/.03/.03/.03/-.015/-.008/-.011/.038/.075/-.0003/.0018/-.002
X  /.001/.001/.001/.001/.001
T  RSPTAB=.1/.1/.106/.115/.123/.151/.165/.175/.180
T  JUCTAB=.41/.42/.46/.49/.51/.59/.64/.68/.70
T  RDRTAB=1.0/.52/.21/.21
T  UMUT=3/2.5/1/.5/0                      UPGRADING MULTIPLIER FOR UNEMPLOY
T  UMJT=0/.5/1/1.5/2                         "       "      FOR JOB ACCESS

NOTE  FILE EXLSL
NOTE  THIS FILE CONTAINS THE EXTERNAL INPUTS FOR THE LOCATION SUBROUTINE
NOTE     IT INCLUDES THE INTIAL CONDITIONS FOR A LARGE CITY, CONSTANTS
NOTE      TABLE FUNCTIONS AND EXTERNAL DRIVING FORCES, AND POLICY INPUTS
NOTE      A. LARGE CITY INTIAL CONDITIONS FOR LOCATION MODEL
NOTE
NOTE
C  FBC=.9                                  FRAC OF BLACKS LIVING IN CORE
C  FWC=.7                                   "  "  WHITES   "     "   "
C  FXC=.75                                  "  "  EXP. INDUSTRY  "   "
C  RCORE=3.46 MILES                        RADIUS OF CORE CITY
NOTE
N  PBUC=FBC*PBU                            UPPER BLACKS IN CORE
N  PBLC=FBC*PBL                            LOWER BLACKS IN CORE
N  PWUC=FWC*PWU                            UPPER WHITES IN CORE
N  PWLC=FWC*PWL                            LOWER WHITES IN CORE
N  IEXC=FXC*IEX                            EXPORT INDUSTRY IN CORE
N  LIXC=1150 ACRES                         LAND FOR EXP. IND. IN CORE
N  LIXS=550 ACRES                          LAND FOR EXP IND IN SUBURBS
N  LIAS=0 ACRES                            ABANDONED IND LAND
N  LIAC=0 ACRES                            ABANDONED IND LAND IN CORE
N  LFOCD=.71
N  LFOSD=.28
NOTE
NOTE
NOTE       B. CONSTANTS
NOTE
C  TPM=5 YRS                               TIME BETWEEN MOVES OF POPULATION
C  WPHW=1.5                                WAGE EARNERS PER WHITE HOUSEHOLD
C  WPHB=1.5                                WAGE EARNERS PER BLACK HOUSEHOLD
C  TIM=20 YEARS                            TIME BETWEEN MOVES OF EXP. IND.
C  LCT=.6                                  LAND COEFFICIENT FOR TRANS, ETC
C  TLXC=5 YRS                              TIME FOR CLEARING INDUSTRIAL LAND
C  RDRM=2                                  RATIO OF REUSE DENS TO MARG DENS
C  DAS=15 EMP/ACRE                         LOW INTENSITY DENSITY OF SERV EMP
N  TIEL=DT                                 DUMMY TIME DELAY FOR LFOCD,
C  LZI=.2                                 LAND ZONED FOR INDUSTRY
NOTE                                       LFOSD, AND ALL Q LEVELS
C  RWDV=.2                                 RELATIVE WEIGHT OF DETERIORATING
NOTE                                       LAND TO VACANT LAND.
NOTE
NOTE
NOTE     C. TABLE FUNCTIONS  AND EXTERNAL DRIVING FORCES
NOTE        AS IS EXPLAINED BELOW, THE SWITCH "SWTR" CONTROLS
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NOTE        THE CHANGE IN TRANSPORTATION TECHNOLOGY AND NETWORKS.
C  SWTR=1              SWTR=0 IMPLIES CONSTANT TECH. AND NETWORKS
NOTE
T  FPDT=0/0/.05/.1/.25/.5/.75/.9/.95/1/1      POPULATION DISTRIBUTION
T  AHTAB=1/.75/.4/.25/.15/.09/.054/.032      ATTRACTION OF HOUSING
T  RDMHT=.5/.9/.95/.97/1/1                RACIAL DISCRIMINATION IN HOUSING
T  AJTAB=.01/.15/.3/.6/.9/1                JOB ATTRACTION
T  ARTAB=1/.9/.7/.52/.4/.35/.30/.27/.25  ATTRAC. OF RACIAL COMP
T  AVTAB=1/1/.87/.65/.4/.1                ATTRACTION OF VACANT LAND
T  ADTAB=1/.8/.2/.05/0/0                   ATTRACTION OF DETERIORATED LAND
T  FIDT=0/0/.05/.1/.25/.5/.75/.9/.95/1/1      EXPORT INDUSTRY DISTRIBUTIO
T  ASXT=.5/.63/.75/.9/1/1                   ATTRACTION OF SPACE FOR IND
T  ALXT=0/.15/.3/.5/.8/1        ATTRACTION OF LABOR FOR IND
T  AAXT=.01/.3/.5/.7/.9/1                     ATTRACTION OF ACCESS FOR IND
T  FRXT=1/1/.75/.6/.5                    FRACTION OF LAND REUSABLE FOR IND
T  DMIT=1/1/1.25/1.5/3/6                DENSITY MULT FOR INTENSIVE USE
T  TTPT=1/.4/.2                          TRAVEL TIME PREFERENCES OF LABOR
NOTE
NOTE      EXTERNAL DRIVING FORCES
T  DMXT=62/50/37/25/21/17/15/15/15/15/15  MARGINAL DENSITY OF EXP IND
C  SWDX=1
NOTE  IF SWDX=0, DMXT HAS THE CONSTANT VALUE DMXTC
C  DMXTC=62 EMP/ACRE
T  FSLTT=.23/.3/.4/.6/.75/1/1/1/1/1/1      FRAC. OF SUB LAND  WITH TRANS
NOTE     IF SWTR=0, FSLT HAS CONSTANT VALUE = FSLTC
C  FSLTC=.23
NOTE
T  VUCCT=10/10/10/10/15/15/15/15/15/15/15    AVG MPH UPPER: INTRA CORE
T  VUCST=20/20/20/22/25/30/35/35/35/35/35   AVG MPH UPPER:CORE-SUB
T  VUSST=5/5/15/20/25/30/35/35/35/35/35   AVG MPH UPPER: INTRA SUB
T  VLCCT=10/10/10/10/10/10/10/10/10/10/10    AVG MPH LOWER: INTRACORE
T  VLCST=5/5/5/5/15/15/15/15/15/15/15        AVG MPH LOWER: CORE-SUB
T  VLSST=5/5/5/5/15/15/15/15/15/15/15        AVG MPH LOWER:INTRA-SUB
NOTE     IF SWTR=0, THE SIX VELOCITY TABLES ABOVE HAVE A CONSTANT
NOTE     VALUE DEFINED BELOW.
C  VUCCC=10 MPH
C  VUCSC=20 MPH
C  VUSSC=5 MPH
C  VLCCC=10 MPH
C  VLCSC=5 MPH
C  VLSSC=5 MPH
NOTE
NOTE
NOTE      D. POLICY INPUTS
NOTE        1. RACIAL HOUSING DISCRIMINATION IN CORE: SWHDC=TIME WHEN
NOTE            DISCRIMINATION ENDS
C  SWHDC=100 YEARS
NOTE          2. RACIAL HOUSING DISCRIMINATION IN SUBURBS:
NOTE             SWHDS=TIME WHEN DISCRIMINATION ENDS.
C  SWHDS=100 YRS
NOTE        3. RACIAL JOB DISCRIMINATION FOR UPPER SKILLED JOB:
NOTE            SWJDU= TIME OF ELIMINATION OF DISCRIMINATION
NOTE            JDMU= FRACTION OF UPPER SKILLED JOBS ORIGINALLY
NOTE            EXCLUDED FROM BLACKS.
C  SWJDU=100 YEARS
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C   JDMUC=.7                                                                GRC01660
NOTE          4. RACIAL JOB DISCRIMINATICN FOR LOWER SKILLEC JOBS:          GRO01670
NOTE             SWJDI=TIME OF ELIMINATION OF DISCRIMINATION                GRO01680
NOTE             JDML= FRACTION OF LOWER SKILLED JOBS ORIGINALLY            GRC01690
NOTE                  EXCLUDED FROM BLACKS.                                 GRO01700
C   SWJDL=100 YEARS                                                         GRC01710
C   JDMLC=.7                                                                GRC01720
NOTE          5. WHITES DISCRIMINATION AGAINST POP RACIAL COMPOSITION       GRO01730
C   SWPD=100 YRS                    TIME OF ELIMINATION OF RACIAL           GRC01740
NOTE                                LOCATION PREFERENCES                    GRO01750
NOTE                                                                        GRO01760
NOTE                                                                        GRC01770
NOTE          6. MOBILITY OF THE LOWER SKILLED POPULATICN                   GRO01780
NOTE             THE SWITCH SWLST CHANGES THE TRANSPORTATION                GRC01790
NOTE             MOBILITY OF THE LOWER SKILLED POPULATICN TC THAT           GRC01800
NOTE             OF THE UPPER SKILLEC POPULATION AT THE TIME TTRAN.         GRO01810
C   TTRANS=100 YEARS                                                        GRC01820
NOTE        FILE EXHSL                                                      GRO01830
NOTE        THIS FILE CONTAINS ALL THEEXTERNAL INPUTS FOR THE HOUSING       GRO01840
NOTE        SUBROUTINE IN THE PHASE2 MODEL.                                 GRC01850
NOTE         A. LARGE CITY INITIAL CONDITICNS FOR HCUSING SUBRCUTINE        GRO01860
NOTE            (FILE INHSL)                                                GRC01870
NOTE                                                                        GRC01880
NOTE                                                                        GRO01890
C   FNCU=1                          S/D OF UPPER HOUSING IN CORE            GRC01900
C   FNCL=1                          S/D OF LOWER HOUSING IN CORE            GRO01910
C   FNSU=1                          S/D OF UPPER HOUSING IN SUBURBS         GRC01920
C   FNSL=1                          S/D OF LOWER HOUSING IN SUBURBS         GRC01930
C   NDAHC=13.5 DU/ACRE               AVG DENSITY OF HOUSING IN CORE         GRO01940
C   NDAHS=5 DU/ACRE                  AVG DENSITY OF HOUSING IN SUBURBGRC01950
NOTE                                                                        GRO01960
NOTE                                                                        GRO01970
N   HCU=(FNCU)((PBUC/AHB)+(PWUC/AHW))      UPPER SKILL HOUSING IN CORE      GRC01980
N   HCL=(FNCL)((PBLC/AHB)+(PWLC/AHW))       LOWER SKILL HOUSING IN CORE     GRO01990
N   HCA=0                           ABANDONED HOUSING IN CORE               GRC02000
N   HSU=(FNSU)((PBUS/AHB)+(PWUS/AHW))       UPPER SKILL HOUSING IN SUB      GRO02010
N   HSL=(FNSL)((PBLS/AHB)+(PWLS/AHW))       LOWER SKILL HOUSING IN SUB      GRO02020
N   HSA=0                           ABANDONED HOUSING IN SUB                GRC02030
N   RHCLA=1.0                       AVG D/S OF LOW HCUSING IN CORE          GRO02040
N   LHC=(HCU+HCL+HCA)/NDAHC          LAND FOR HOUSING IN CORE               GRO02050
N   LHS=(HSU+HSL+HSA)/NDAHS          LAND FOR HOUSING IN SUB                GRC02060
N   RHSLA=1.0                       AVG D/S OF LOW HCUSING IN SUB           GRO02070
NOTE         FILE EXH                                                       GRC02080
NOTE         SPECIFIES THE CONSTANTS, TABLE FUNCTIONS,AND EXTERNAL          GRO02090
NOTE         FORCES FOR BOTH THE HOUSING MODEL AND SUBROUTINE.              GRC02100
NOTE                                                                        GRC02110
NOTE          AS IS EXPLAINED BELOW, THE SWITCH "SWHX" CCNTROLS             GRO02120
NOTE         THE EXTERNAL DRIVING FORCE ON THE HOUSING SUPPLY.              GRC02130
NOTE                                                                        GRO02140
NOTE       B. CCNSTANTS                                                     GRO02150
NOTE                                                                        GRC02160
C   NHFR=.03                        NORMAL HOUSING FILTERING RATE           GRO02170
C   NHAR=.01                         "     "    ABANDONMENT RATE            GRC02180
C   TARHL=4 YEARS                  TIME FOR AVERAGING LOWER D/S             GRC02190
C   NHDR=.20                        NORMAL DEMOLITION RATE                  GRO02200
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NOTE                                                                        GRC02210
NOTE                                                                        GRO02220
NOTE     C. TABIE FUNCTIONS AND EXTERNAL DRIVING FORCES                     GRC02230
NOTE                                                                        GRO02240
T  HERT=0/3/6/10/15/18/18                HOUSING EXPANSION RESPONSE         GRO02250
T  HDMIT=1/1/.9/.8/.7/.6            HOUSING DEMAND MULT FOR INTERNAL COND.GRC02260
T  FHVT=1/1/1/1/.85/0                 FRAC OF NEW HCUSING ON VACANT LAND GRO02270
T  HFMT=4/4/1/.5/.37/.23/.10             HOUSING FILTERING RATE MULTIPLIERGRCO2280
T  HAMT=2/1.5/1/.75/.5/.5/.5             HCUSING ABANDON. RATE MULT.        GRC02290
T  DMHT=2.5/2.5/5/10/20/45               MARGINAL HOUSING DENSITY           GRO02300
NOTE                                                                        GRC02310
T  HDMXT=1/1/1/1/.8/1/1/1/1/.6/1/1/1/1/1/1/1     EXTERNAI DEMANE MULT       GRO02320
NOTE  THE SWITCH "SWHX" CONTROLS WHETHER THE EXTERNAL HOUSING DEMAND        GRO02330
NOTE  MULTIPLIER VARIES AS GIVEN IN HDMXT (SWHX=1) OR REMAINS CONSTANT      GRO02340
NOTE  AT THE VALUE EQUAL TO HDMX (SWHX=0).                                  GRO02350
C  SWHX=0                                                                   GRC02360
C  HDMXC=1                                                                  GRC02370
NOTE        D. PCLICY INPUTS                                                GRO02380
NOTE          1. LOW INCOME HOUSING CONSTRUCTION PROGRAM                    GRC02390
C  HCLPC=.05                               PROGRAM AS FRACTION OF SUPPLY    GRO02400
C  SWHLC=100 YRS                            TIMING OF INITIATION OF PROGRAMGRC02410
C  HSLPC=.05                               SUBURBAN PROGRAM AS FRAC OF SUB SGRC02420
C  SWHLS=100 YEARS                         TIMING OF SUBURBAN PROGRAM       GRO02430
NOTE                                                                        GRC02440
NOTE        2. ABANDONED HOUSING DEMOLITION PROGRAM                         GRO02450
C  HCDPC=2                               MULTIPLIER OF NORMAL DEMO RATE     GRO02460
C  SWHDP=100 YRS                           TIME OF INITIATION OF PROGRAM    GRC02470
NOTE                                                                        GRO02480
NOTE       FILE EQLS                                                        GRO02490
NOTE        THIS FILE CONTAINS THE EQUATIONS FOR THE LOCATION SUBROUTINE    GRO02500
NOTE        OF THE PHASE2 MODEL.                                            GRC02510
NOTE       THE LOCATION MODEL CAN BE RUN WITH THE OTHER TWC MCDELS          GRC02520
NOTE        INACTIVE BY USING THE SWITCHES DESCRIBED BELCW.                 GRO02530
NOTE          1. SWITCH FOR GROWTH MODEL - IF SWZG = 0, POPULATION AND      GRC02540
NOTE             EMPLOYMENT ARE FIXED AT THEIR INITIAL VALUES.              GRO02550
C  SWZG=1                                                                   GRC02560
NOTE                                                                        GRO02570
NOTE         2. SWITCH FOR HOUSING MODEL - IF SWHG=0, HOUSING STOCK         GRC02580
NOTE            REMAINS FIXED AT ITS INITIAL VALUES.                        GRO02590
C  SWHG=1                                                                   GRO02600
NOTE                                                                        GRO02610
NOTE                                                                        GRO02620
NOTE       **********LOCATION MODEL                                         GRC02630
NOTE     A. EQUATIONS FOR POPUIATION LCCATION                               GRO02640
NOTE        1. ALLOCATION OF THE FOUR TYPES OF ADULTS TO CORE CITY          GRC02650
L  PBUC.K=PBUC.J+DT*(BUCGR.JK-BUCDR.JK)      BLACK UPPER SKILLED IN CORE GRO02660
R  BUCGR.KL=BUPL.K*FBUDC.K+PBLC.K*ULRC.K                                    GRC02670
A  BUPL.K=BUPLZ.K+BUCDR.JK+BUSDR.JK                                         GRC02680
A  BUPLZ.K=SWITCH(0,BUGPL.K,SWZG)                                           GRO02690
A  FBUDC.K=TABLE(FPDT,RABU.K,0,1,.1)                                        GRC02700
A  BUGPL.K=((1-FBPL.K)*CB.K/DAG)+PBU.K*PBUMC.K                              GRO02710
A  RABU.K=CCBU.K/(CCBU.K+CSBU.K)                                            GRO02720
R  BUCDR.KL=PBUC.K/TPM                                                      GRC02730
R  BUSDR.KL=PBUS.K/TPM                                                      GRO02740
A  PBUS.K=PBUZ.K-PBUC.K                                                     GRC02750
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A   PBUZ.K=SWITCH(PBUN,PBU.K,SWZG)                                        GRO02760
N   PBUN=PBU                                                              GRO02770
NOTE                                                                      GRO02780
L   PBLC.K=PBLC.J+DT*(BLCGR.JK-BLCDR.JK)      BLACK LOWER SKILLED IN CORE GRO02790
R   BLCGR.KL=BLPL.K*FBLDC.K-PBLC.K*ULRC.K                                 GRO02800
A   BLPL.K=BLPLZ.K+BLCDR.JK+BLSDR.JK                                      GRO02810
A   BLPLZ.K=SWITCH(0,BLGPL.K,SWZG)                                        GRO02820
A   FBLDC.K=TABLE(FPDT,RABL.K,0,1,.1)                                     GRO02830
A   BLGPL.K=(FBPL.K*CB.K/DAG)+PBL.K*PBLMC.K                               GRO02840
A   RABL.K=CCBL.K/(CCBL.K+CSBL.K)                                         GRO02850
R   BLCDR.KL=PBLC.K/TPM                                                   GRO02860
R   BLSDR.KL=PBLS.K/TPM                                                   GRO02870
A   PBLS.K=PBLZ.K-PBLC.K                                                  GRO02880
A   PBLZ.K=SWITCH(PBLN,PBL.K,SWZG)                                        GRO02890
N   PBLN=PBL                                                              GRO02900
NOTE                                                                      GRO02910
L   PWUC.K=PWUC.J+DT*(WUCGR.JK-WUCDR.JK)                                  GRO02920
R   WUCGR.KL=WUPL.K*FWUDC.K+PWUC.K*ULRC.K                                 GRO02930
A   WUPL.K=WUPLZ.K+WUCDR.JK+WUSDR.JK                                      GRO02940
A   WUGPL.K=((1-FWPL.K)*CW.K/DAG)+PWU.K*PWUMC.K                           GRO02950
A   WUPLZ.K=SWITCH(0,WUGPL.K,SWZG)                                        GRO02960
A   FWUDC.K=TABLE(FPDT,RAWU.K,0,1,.1)                                     GRO02970
A   RAWU.K=CCWU.K/(CCWU.K+CSWU.K)                                         GRO02980
R   WUCDR.KL=PWUC.K/TPM                                                   GRO02990
R   WUSDR.KL=PWUS.K/TPM                                                   GRO03000
A   PWUS.K=PWUZ.K-PWUC.K                                                  GRO03010
A   PWUZ.K=SWITCH(PWUN,PWU.K,SWZG)                                        GRO03020
N   PWUN=PWU                                                              GRO03030
NOTE                                                                      GRO03040
L   PWLC.K=PWLC.J+DT*(WLCGR.JK-WLCDR.JK)                                  GRO03050
R   WLCGR.KL=WLPL.K*FWLDC.K-PWLC.K*ULRC.K                                 GRO03060
A   WLPL.K=WLPLZ.K+WLCDR.JK+WLSDR.JK                                      GRO03070
A   WLPLZ.K=SWITCH(0,WLGPL.K,SWZG)                                        GRO03080
A   FWLDC.K=TABLE(FPDT,RAWL.K,0,1,.1)                                     GRO03090
A   WLGPL.K=(FWPL.K*CW.K/DAG)+PWL.K*PWLMC.K                               GRO03100
A   RAWL.K=CCWL.K/(CCWL.K+CSWL.K)                                         GRO03110
R   WLCDR.KL=PWLC.K/TPM                                                   GRO03120
R   WLSDR.KL=PWLS.K/TPM                                                   GRO03130
A   PWLS.K=PWLZ.K-PWLC.K                                                  GRO03140
A   PWLZ.K=SWITCH(PWLN,PWL.K,SWZG)                                        GRO03150
N   PWLN=PWL                                                              GRO03160
NOTE                                                                      GRO03170
NOTE                                                                      GRO03180
NOTE        2. CALCULATION OF MULTIPLIERS USED TO DISTRIBUTE POPULATION GRO03190
A   CCBU.K=AJCBU.K*AHCBU.K*(AVC.K+ADC.K*RWDV)           COMPOSITE ATTRACT.GRO03200
A   CCBL.K=AJCBL.K*AHCBL.K*(AVC.K+ADC.K*RWDV)                             GRO03210
A   CSBU.K=AJSBU.K*AHSBU.K*(AVS.K+ADS.K*RWDV)                             GRO03220
A   CSBL.K=AJSBL.K*AHSBL.K*(AVS.K+ADS.K*RWDV)                             GRO03230
A   CCWU.K=AJCU.K*AHCU.K*ARC.K*(AVC.K+ADC.K*RWDV)                         GRO03240
A   CCWL.K=AJCL.K*AHCL.K*ARC.K*(AVC.K+ADC.K*RWDV)                         GRO03250
A   CSWU.K=AJSU.K*AHSU.K*ARS.K*(AVS.K+ADS.K*RWDV)                         GRO03260
A   CSWL.K=AJSL.K*AHSL.K*ARS.K*(AVS.K+ADS.K*RWDV)                         GRO03270
NOTE                                                                      GRO03280
A   AHCBU.K=TABHL(AHTAB,RHCUB.K,.6,2,.2)         HOUSING ATTRACT.         GRO03290
A   AHCBL.K=TABHL(AHTAB,RHCLB.K,.6,2,.2)                                  GRO03300
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A   AHSBU.K=TABHL(AHTAB,RHSUB.K,.6,2,.2)
A   AHSBL.K=TABHL(AHTAB,RHSLB.K,.6,2,.2)
A   AHCU.K=TABHL(AHTAB,RHCU.K,.6,2,.2)
A   AHCL.K=TABHL(AHTAB,RHCL.K,.6,2,.2)
A   AHSU.K=TABHL(AHTAB,RHSU.K,.6,2,.2)
A   AHSL.K=TABHL(AHTAB,RHSL.K,.6,2,.2)
NOTE
A   RHCU.K=((PBUC.K/AHB.K)+(PWUC.K/AHW.K))/HCUZ.K        HOUSING DEMAND/SUP
A   RHCL.K=((PBLC.K/AHB.K)+(PWLC.K/AHW.K))/HCLZ.K
A   RHSU.K=((PBUS.K/AHB.K)+(PWUS.K/AHW.K))/HSUZ.K
A   RHSL.K=((PBLS.K/AHB.K)+(PWLS.K/AHW.K))/HSLZ.K
A   RHCUB.K=RHCU.K/HDMC.K
A   RHCLB.K=RHCL.K/HDMC.K
A   RHSUB.K=RHSU.K/HDMS.K
A   RHSLB.K=RHSL.K/HDMS.K
NOTE
A   AHB.K=WPHB/LFPR                                   ADULTS PER HOUSEHOLD
A   AHW.K=WPHW/LFPR
NOTE
A   HDMC.K=CLIP(1,HDMCQ.K,TIME.K,SWHDC)               HOUSING DISCRIMINATION
A   HDMS.K=CLIP(1,HDMSQ.K,TIME.K,SWHDS)
A   HDMCQ.K=TABHL(RDMHT,RPBC.K,0,.5,.1)
A   HDMSQ.K=TABHL(RDMHT,RPBS.K,0,.5,.1)
NOTE
A   HCUZ.K=SWITCH(HCUN,HCU.K,SWHG)
A   HCLZ.K=SWITCH(HCLN,HCL.K,SWHG)
A   HSUZ.K=SWITCH(HSUN,HSU.K,SWHG)
A   HSLZ.K=SWITCH(HSLN,HSL.K,SWHG)
N   HCUN=HCU
N   HCLN=HCL
N   HSUN=HSU
N   HSLN=HSL
NOTE
A   AJCBU.K=TABHL(AJTAB,RJCBU.K,0,1,.2)      ATTRACTION DUE TO JOBS
A   AJCBL.K=TABHL(AJTAB,RJCBL.K,0,1,.2)
A   AJSBU.K=TABHL(AJTAB,RJSBU.K,0,1,.2)
A   AJSBL.K=TABHL(AJTAB,RJSBL.K,0,1,.2)
A   AJCU.K=TABHL(AJTAB,RJCU.K,0,1,.2)
A   AJCL.K=TABHL(AJTAB,RJCL.K,0,1,.2)
A   AJSU.K=TABHL(AJTAB,RJSU.K,0,1,.2)
A   AJSL.K=TABHL(AJTAB,RJSL.K,0,1,.2)
NOTE
A   RJCU.K=JSCU.K/JU.K                 FRACTION OF JOBS ACCESSIBLE
A   RJCL.K=JSCL.K/JL.K
A   RJSU.K=JSSU.K/JU.K
A   RJSL.K=JSSL.K/JL.K
A   RJCBU.K=RJCU.K*JDMU.K
A   RJCBL.K=RJCL.K*JDML.K
A   RJSBU.K=RJSU.K*JDMU.K
A   RJSBL.K=RJSL.K*JDML.K
NOTE
A   JDCU.K=(PBUC.K+PWUC.K)*LFPR
A   JDCL.K=(PBLC.K+PWLC.K)*LFPR
A   JDSU.K=(PBUS.K+PWUS.K)*LFPR
A   JDSL.K=(PBLS.K+PWLS.K)*LFPR
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NOTE                                                                   GRC03860
A   JSCU.K=JCU.K*AKUCC.K+JSU.K*AKUCS.K                                 GRO03870
A   JSSU.K=JCU.K*AKUCS.K+JSU.K*AKUSS.K                                 GRO03880
A   JSCL.K=JCL.K*AKLCC.K+JSL.K*AKLCS.K                                 GRC03890
A   JSSL.K=JCL.K*AKLCS.K+JSL.K*AKLSS.K                                 GRO03900
A   JSCUM.K=JCU.K*AKLCC.K+JSU.K*AKLCS.K LOWER SKILL ACCESS TO UPPER JOBS GRC03910
A   JSSUM.K=JSU.K*AKLSS.K+JCU.K*AKLCS.K                                GRO03920
NOTE                                                                   GRO03930
A   JDML.K=CLIP(1,JDMLC,TIME.K,SWJDL)                                  GRC03940
A   JDMU.K=CLIP(1,JDMUC,TIME.K,SWJDU)                                  GRO03950
NOTE                                                                   GRC03960
A   ARC.K=CLIP(ARCZ.K,1,TIME.K,SWPD)     ATTRAC OF PCP. RACIAL COMPOSITIONGRO03970
A   ARS.K=CLIP(ARSZ.K,1,TIME.K,SWPD)                                   GRC03980
A   ARCZ.K=TABLE(ARTAB,RPBC.K,0,.8,.1)                                 GRO03990
A   ARSZ.K=TABLE(ARTAB,RPBS.K,0,.8,.1)                                 GRC04000
NOTE                                                                   GRO04010
A   AVC.K=TABLE(AVTAB,LFOC.K,0,1.0,.2)      ATTRAC. OF VACANT LAND     GRO04020
A   AVS.K=TABLE(AVTAB,LFOS.K,0,1.0,.2)                                 GRC04030
A   ADC.K=TABHL(ADTAB,LFAC.K,0,.25,.05)    ATTRAC. OF DETERIORATED LAND GRO04040
A   ADS.K=TABHL(ADTAB,LFAS.K,0,.25,.05)                                GRC04050
NOTE                                                                   GRO04060
NOTE                                                                   GRC04070
NOTE      B. EQUATIONS FOR INDUSTRIAL LOCATION                         GRO04080
NOTE         1. ALLOCATION OF THE THREE TYPES OF INDUSTRY              GRO04090
L   IEXC.K=IEXC.J+DT*(IXCGR.JK-IXCDR.JK)    EXPORT INDUSTRY IN CORE    GRO04100
R   IXCDR.KL=IEXC.K/TIM                                                GRO04110
R   IXSDR.KL=IEXS.K/TIM                                                GRC04120
A   IEXS.K=IEXZ.K-IEXC.K                                               GRO04130
A   IEXZ.K=SWITCH(IEXN,IEX.K,SWZG)                                     GRC04140
N   IEXN=IEX                                                           GRO04150
R   IXCGR.KL=IXPI.K*FIXDC.K                                            GRO04160
A   FIXDC.K=TABHL(FIDT,RAIX.K,0,1,.1)                                  GRC04170
A   RAIX.K=CCAIX.K/(CCAIX.K+CSAIX.K)                                   GRO04180
A   IXPL.K=IXPLZ.K+IXCDR.JK+IXSDR.JK                                   GRC04190
A   IXPLZ.K=SWITCH(0,IXPLG.K,SWZG)                                     GRC04200
A   IXPLG.K=IEXPCT.K*EAT.K*NIEXGR.K*IEX.K                              GRO04210
NOTE                                                                   GRC04220
A   IRSC.K=IRS.K*PC.K/P.K                RESIDENTIAL SERVICE EMP IN CORE  GRO04230
A   IRSS.K=IRS.K*PS.K/P.K                                              GRO04240
A   IBSC.K=IBS.K*(IRSC.K+IEXC.K)/(IRS.K+IEXZ.K)        INDUSTRIAL SERVICEGRC04250
A   IBSS.K=IBS.K-IBSC.K                                                GRO04260
NOTE                                                                   GRC04270
A   JCU.K=(IEXC.K+IRSC.K+IBSC.K)*JUC.K    UPPER JOBS IN CORE           GRO04280
A   JCL.K=(IEXC.K+IRSC.K+IBSC.K)*(1-JUC.K)                             GRC04290
A   JSU.K=(IEXS.K+IRSS.K+IBSS.K)(JUC.K)                                GRC04300
A   JSL.K=(IEXS.K+IRSS.K+IBSS.K)(1-JUC.K)                              GRO04310
A   JC.K=JCU.K+JCL.K                                                   GRO04320
NOTE                                                                   GRO04330
NOTE                                                                   GRC04340
NOTE         2. CALCULATION OF MULTIPLIERS FOR INDUSTRIAL LOCATION     GRO04350
A   CCAIX.K=ACXS.K*ACXL.K*ACXA.K                                       GRC04360
A   CSAIX.K=ASXS.K*ASXL.K*ASXA.K                                       GRC04370
A   ACXS.K=TABHL(ASXT,RSXC.K,0,15,3)              ATTRACTION OF SPACE  GRO04380
A   RSXC.K=LSXC.K/LDXC.K                                               GRO04390
A   LDXC.K=IXPL.K/DMAX.K                                               GRO04400
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A   LSXC.K=FLRXC.K*((IEXC.K/(TIM*DAXC.K))+LIAC.K)+LZI*LVC.K                  GRO04410
A   FLRXC.K=TABHL(FRXT,RLCXC.K,0,4,1)                                        GRO04420
A   RLCXC.K=DAXC.K/DMAX.K                                                    GRO04430
A   ASXS.K=TABHI(ASXT,RSXS.K,0,15,3)      SUBURBAN SPACE                     GRO04440
A   RSXS.K=LSXS.K/LDXS.K                                                     GRO04450
A   LSXS.K=FLRXS.K*((IEXS.K/(TIM*DAXS.K))+LIAS.K)+LZI*LVS.K                  GRO04460
A   LDXS.K=IXPL.K/DMAX.K                                                     GRO04470
A   FLRXS.K=TABHL(FRXT,RLCXS.K,0,4,1)                                        GRO04480
A   RLCXS.K=DAXS.K/DMAX.K                                                    GRO04490
NOTE                                                                         GRO04500
A   ACXL.K=TABHI(ALXT,RLXC.K,0,1,.2)                ATTRACTION OF LABOR      GRO04510
A   RLXS.K=LSIS.K/LST.K                                                      GRO04520
A   RLXC.K=LSIC.K/LST.K                                                      GRO04530
A   LST.K=JDCL.K+JDCU.K+JDSU.K+JDSL.K                                        GRO04540
A   LSIC.K=JDCU.K*AKUCC.K+JDCL.K*AKLCC.K+JDSU.K*AKUCS.K+JDSL.K*AKLCS.K       GRO04550
A   ASXL.K=TABHI(ALXT,RLXS.K,0,1,.2)                                         GRO04560
A   LSIS.K=JDSU.K*AKUSS.K+JDSL.K*AKLSS.K+JDCU.K*AKUCS.K+JDCL.K*AKLCS.K       GRO04570
NOTE                                                                         GRO04580
A   ACXA.K=TABHI(AAXT,RXBC.K,0,1,.2)                                         GRO04590
A   RXBC.K=((IEXC.K+IBSC.K)*AKUCC.K+(IEXS.K+IBSS.K)*AKUCS.K)/(IEXZ.K+IBS.GRO04600
X1  K)                                                                       GRO04610
A   ASXA.K=TABHL(AAXT,RXBS.K,0,1,.2)                                         GRO04620
A   RXBS.K=((IEXS.K+IBSS.K)*AKUSS.K+(IEXC.K+IBSC.K)*AKUCS.K)/(IEXZ.K+IBS.GRO04630
X1  K)                                                                       GRO04640
NOTE                                                                         GRO04650
NOTE                                                                         GRO04660
NOTE      C. LAND USE                                                        GRO04670
NOTE           1. LAND USE IN CORE CITY                                      GRO04680
A   LVC.K=LTOTC-LTC.K-LHC.K-LIC.K         VACANT                             GRO04690
A   LTC.K=LCT*(LIC.K+LHC.K)               TRANS. AND PUBLIC                  GRO04700
A   LIC.K=LISC.K+LIXC.K+LIAC.K            INDUSTRIAL                         GRO04710
A   LISC.K=(IRSC.K+IBSC.K)/DASC.K         SERVICE EMP                        GRO04720
L   LIXC.K=LIXC.J+DT*(LXCC.JK+LXCR.JK-LXCO.JK)      EXPORT INDUSTRY          GRO04730
R   LXCC.KL=IXPI.K*FIXDC.K*(1-FRLC.K)/DMXC.K       NEW CONSTRUCTION          GRO04740
R   LXCR.KL=IXPI.K*FIXDC.K*FRLC.K/(DMXC.K*RDRM)     REUSE                    GRO04750
R   LXCO.KL=IEXC.K/(TIM*DAXC.K)                       OUTMIGRATION           GRO04760
A   FRLC.K=LIAC.K/(LIAC.K+LVC.K)                                             GRO04770
L   LIAC.K=LIAC.J+DT*(LXCO.JK-LXCR.JK-LXCD.JK)            ABANDONED LAND     GRO04780
R   LXCD.KL=LIAC.K/TLXC                               DEMOLITION RATE        GRO04790
N   LTOTC=3.14*RCORE*RCORE*640 (ACRES)              TOTAL LAND IN CORE       GRO04800
NOTE                                                                         GRO04810
NOTE           2. LAND USE IN SUBURBS                                        GRO04820
A   LVS.K=LTOTS.K-LTS.K-LHS.K-LIS.K                   VACANT                 GRO04830
A   LTS.K=LCT*(LIS.K+LHS.K)                           TRANS AND PUBLIC       GRO04840
A   LIS.K=LISS.K+LIXS.K+LIAS.K                        TOTAL INDUSTRY         GRO04850
A   LISS.K=(IBSS.K+IRSS.K)/DASS.K                     SERVICE EMP            GRO04860
L   LIXS.K=LIXS.J+DT*(LXSC.JK+LXSR.JK-LXSO.JK)      EXPORT IND               GRO04870
R   LXSC.KL=IXPL.K*(1-FIXDC.K)(1-FRLS.K)/DMXS.K                              GRO04880
A   FRLS.K=LIAS.K/(LIAS.K+LVS.K)                                             GRO04890
R   LXSR.KL=IXPI.K*FRLS.K*(1-FIXDC.K)/(RDRM*DMXS.K)  REUSE                   GRO04900
R   LXSO.KL=IEXS.K/(TIM*DAXS.K)                         OUTFLO               GRO04910
L   LIAS.K=LIAS.J+DT*(LXSO.JK-LXSR.JK-LXSD.JK)     ABANDONED IND. LAND      GRO04920
R   LXSD.KL=LIAS.K/TLXC                               DEMOLITION RATE        GRO04930
A   LTOTS.K=(500*VUCS.K*VUCS.K-LTOTC)*FSLT.K       TOTAL SUBURBAN LAND(AC)GRO04940
A   FSLTQ.K=TABLE(FSLTT,TIME.K,0,100,10)                                     GRO04950
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A   FSLT.K=SWITCH(FSLTC,FSLTQ.K,SWTR)                                    GRO04960
NOTE                                                                     GRO04970
NOTE          3. DENSITIES                                               GRO04980
A   DASC.K=DAS*DMC.K                    SERVICE EMP IN CORE              GRO04990
A   DAXC.K=IEXC.K/LIXC.K                AVG. EXP EMP IN CORE             GRO05000
A   DMXC.K=DMAX.K*DMC.K                 MARGINAL EXP EMP IN CORE         GRO05010
A   DMAX.K=SWITCH(DMXTC,DMAXQ.K,SWDX)                                    GRO05020
A   DMAXQ.K=TABLE(DMXT,TIME.K,0,100,10)                                  GRO05030
A   DMC.K=TABLE(DMIT,LFOCD.K,0,1,.2)      DENSITY MULT FOR CORE          GRO05040
L   LFOCD.K=LFOCD.J+DT*(LFOC.J-LFOCD.J)/TDEL                             GRO05050
NOTE                                                                     GRO05060
A   DASS.K=DAS*DMS.K                                                     GRO05070
A   DAXS.K=IEXS.K/(LIXS.K+10)                                            GRO05080
A   DMXS.K=DMAX.K*DMS.K                                                  GRO05090
A   DMS.K=TABLE(DMIT,LFOSD.K,0,1,.2)                                     GRO05100
L   LFOSD.K=LFOSD.J+DT*(LFOS.J-LFOSD.J)/TDEL                             GRO05110
NOTE                                                                     GRO05120
NOTE          4. LAND FRACTIONS                                          GRO05130
A   LFOC.K=1-LVC.K/LTOTC                                                 GRO05140
A   LFOS.K=1-LVS.K/LTOTS.K                                               GRO05150
A   LAC.K=LIAC.K+HCA.K/DAHC.K                                            GRO05160
A   LAS.K=LIAS.K+HSA.K/DAHS.K                                            GRO05170
A   LFAC.K=LAC.K/LTOTC                                                   GRO05180
A   LFAS.K=LAS.K/LTOTS.K                                                 GRO05190
NOTE                                                                     GRO05200
NOTE                                                                     GRO05210
NOTE      D. ACCESSIBILITIES                                             GRO05220
NOTE          1.D                                                        GRO05230
A   AKUCC.K=TABHL(TTPT,TTUCC.K,0,1,.5)          ACCESS PARAMETERS        GRO05240
A   AKUCS.K=TABHL(TTPT,TTUCS.K,0,1,.5)                                   GRO05250
A   ATUSS.K=TABHL(TTPT,TTUSS.K,0,1,.5)                                   GRO05260
A   AKUSS.K=ATUSS.K*FSLT.K                                               GRO05270
A   AKLCC.K=TABHL(TTPT,TTLCC.K,0,1,.5)                                   GRO05280
A   AKLCS.K=TABHL(TTPT,TTLCS.K,0,1,.5)                                   GRO05290
A   ATLSS.K=TABHL(TTPT,TTLSS.K,0,1,.5)                                   GRO05300
A   AKLSS.K=ATLSS.K*FSLT.K                                               GRO05310
NOTE                                                                     GRO05320
A   TTUCC.K=RCC/VUCC.K                 TRAVEL TIMES                      GRO05330
A   TTUCS.K=RCS.K/VUCS.K                                                 GRO05340
A   TTUSS.K=RSS.K/VUSS.K                                                 GRO05350
A   TTLCC.K=RCC/VLCC.K                                                   GRO05360
A   TTLCS.K=RCS.K/VLCS.K                                                 GRO05370
A   TTLSS.K=RSS.K/VLSS.K                                                 GRO05380
NOTE                                                                     GRO05390
N   RCC=(.5)(RCORE)                                                      GRO05400
A   RCS.K=.25*RCORE+.75*RSUB.K                                           GRO05410
A   RSS.K=(.75)(RCORE+RSUB.K)                                            GRO05420
A   RSUB.K=(.5)(VUCS.K)                                                  GRO05430
NOTE                                                                     GRO05440
A   VUCCQ.K=TABLE(VUCCT,TIME.K,0,100,10)        AVERAGE VELOCITIES       GRO05450
A   VUCSQ.K=TABLE(VUCST,TIME.K,0,100,10)                                 GRO05460
A   VUSSQ.K=TABLE(VUSST,TIME.K,0,100,10)                                 GRO05470
A   VLCCQ.K=TABLE(VLCCT,TIME.K,0,100,10)                                 GRO05480
A   VLCSQ.K=TABLE(VLCST,TIME.K,0,100,10)                                 GRO05490
A   VLSSQ.K=TABLE(VLSST,TIME.K,0,100,10)                                 GRO05500
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NOTE                                                                GRO05510
NOTE      IF SWTR=0, THE AVERAGE VELOCITIES ARE SET EQUAL TO THE     GRO05520
NOTE      CONSTANTS DEFINED IN THE INPUTS, INSTEAD OF VARYING OVER TIME GRO05530
NOTE      AS SPECIFIED BY THE TABLE FUNCTIONS ABOVE.                 GRO05540
A   VUCC.K=SWITCH(VUCCC,VUCCQ.K,SWTR)                               GRO05550
A   VUCS.K=SWITCH(VUCSC,VUCSQ.K,SWTR)                               GRO05560
A   VUSS.K=SWITCH(VUSSC,VUSSQ.K,SWTR)                               GRO05570
A   VLCC.K=SWITCH(VLCCC,VLCCX.K,SWTR)                               GRO05580
A   VLCS.K=SWITCH(VLCSC,VLCSX.K,SWTR)                               GRO05590
A   VLSS.K=SWITCH(VLSSC,VLSSX.K,SWTR)                               GRO05600
NOTE   THE CLIPPING FUNCTIONS CHANGE LOWER MOBILITY TO UPPER MOBILITY AT GRO05610
NOTE    TIME TTRANS.                                                GRO05620
A   VLCCX.K=CLIP(VUCCQ.K,VLCCQ.K,TIME.K,TTRANS)                     GRO05630
A   VLCSX.K=CLIP(VUCSQ.K,VLCSQ.K,TIME.K,TTRANS)                     GRO05640
A   VLSSX.K=CLIP(VUSSQ.K,VLSSQ.K,TIME.K,TTRANS)                     GRO05650
NOTE                                                                GRO05660
NOTE                                                                GRO05670
NOTE      E. OUTPUTS FROM LOCATION MODEL                            GRO05680
A   PBC.K=(PBUC.K+PBLC.K) (1+CBR.K)                                 GRO05690
A   PBS.K=(PBUS.K+PBLS.K) (1+CBR.K)                                 GRO05700
A   PWC.K=(PWUC.K+PWLC.K) (1+CWR.K)                                 GRO05710
A   PWS.K=(PWUS.K+PWLS.K) (1+CWR.K)                                 GRO05720
A   PC.K=PBC.K+PWC.K                                                GRO05730
A   PS.K=PBS.K+PWS.K                                                GRO05740
A   RPBC.K=PBC.K/PC.K                                               GRO05750
A   RPBS.K=PBS.K/PS.K                                               GRO05760
A   RLUC.K=(PBUC.K+PWUC.K)/(PBUC.K+PBUS.K+PWUC.K+PWUS.K)            GRO05770
A   RLLC.K=(PBLC.K+PWLC.K)/(PBLC.K+PBLS.K+PWLC.K+PWLS.K)            GRO05780
A   RBUC.K=PBUC.K/PBU.K                                             GRO05790
A   RBU.K=PBU.K/PB.K                                                GRO05800
A   NRPBC.K=RPBC.K/PBRQ.K             BLACKS IN CORE NORMALIZED BY PBR GRO05810
A   PBRQ.K=SWITCH(FPB,PBR.K,SWZG)                                   GRO05820
A   FEXC.K=IEXC.K/IEXZ.K                                            GRO05830
A   FITC.K=JC.K/(JC.K+JSU.K+JSL.K)                                  GRO05840
L   JQ.K=JQ.J+DT*(J.J-JQ.J)/TDEL                                    GRO05850
L   JCQ.K=JCQ.J+DT*(JC.J-JCQ.J)/TDEL                                GRO05860
A   RRJC.K=(JC.K-JCQ.K)*J.K/((J.K+100-JQ.K)*JC.K)                   GRO05870
L   PQBC.K=PQBC.J+DT*(PBC.J-PQBC.J)/TDEL                            GRO05880
L   PQB.K=PQB.J+DT*(PB.J-PQB.J)/TDEL                                GRO05890
L   PQWC.K=PQWC.J+DT*(PWC.J-PQWC.J)/TDEL                            GRO05900
N   JQ=1                                                            GRO05910
L   PQW.K=PQW.J+DT*(PW.J-PQW.J)/TDEL                                GRO05920
L   PQC.K=PQC.J+DT*(PC.J-PQC.J)/TDEL                                GRO05930
L   PQ.K=PQ.J+DT*(P.J-PQ.J)/TDEL                                    GRO05940
N   JCQ=1                                                           GRO05950
N   PQBC=1                                                          GRO05960
N   PQB=1                                                           GRO05970
N   PQWC=1                                                          GRO05980
N   PQW=1                                                           GRO05990
N   PQ=1                                                            GRO06000
N   PQC=1                                                           GRO06010
S   RRPBC.K=PQB.K*(PBC.K-PQBC.K)/((PB.K+100-PQB.K)*PQBC.K)          GRO06020
S   RRPWC.K=PQW.K*(PWC.K-PQWC.K)/((PW.K+300-PQW.K)*PQWC.K)          GRO06030
S   RRPC.K=PQ.K*(PC.K-PQC.K)/((P.K+300-PQ.K)*PQC.K)                 GRO06040
NOTE                                                                GRO06050
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PLOT  PC=0,PS=P/PBC=A,PBS=B/PWC=W,PWS=U/FEXC=X,FITC=I/JC=J,IEXC=K         GRO06060
PLOT  RRPBC=B/RRPWC=W/RRPC=P/NRPBC=N/RLLC=L,RLUC=U/RRJC=J/REUC=C/RBU=U    GRO06070
PLOT  RJCU=J,RJSU=K/RJCL=L,RJSL=M/RSXC=S/RSXS=T/RXBC=A,RXBS=B/RLXS,RLXC   GRO06080
PLOT  LFOC=C,LFOS=S/LFAC=A,LFAS=B/LIC=I,LIXC=X/LIS=J/DAXC=D,DAXS=E        GRO06090
PLOT  CCBU=B,CCBL=C/CSBU=D,CSBL=E/CCWU=W,CCWL=X,CSWL=U,CSWU=Z/CSAIX=1,CCGRO06100
X  AIX=2                                                                   GRO06110
NOTE                                                                       GRO06120
NOTE     E. RUN SPECIFICATIONS FOR PHASE2MODEL                             GRO06130
SPEC  DT=.25/LENGTH=60/PLTPER=2.5                                          GRO06140
NOTE     FILE EQGS                                                         GRO06150
NOTE     THIS FILE CONTAINS THE EQUATIONS FOR THE GROWTH SUBROUTINE        GRO06160
NOTE     A. MODEL EQUATIONS                                                GRO06170
NOTE  BLACK CHILDREN                                                       GRO06180
L  CB.K=CB.J+(DT)(CBBR.JK+(CPM)(PBLMR.JK+PBUMR.JK)-CBDR.JK-CBAR.JK)        GRO06190
R  CBBR.KL=(PB.K)(BRB.K)                                                   GRO06200
A  BRB.K=TABLE(BRBTAB,TIME.K,0,80,5)                                       GRO06210
R  CBDR.KL=(CB.K)(DRB.K)(RDR.K)                                            GRO06220
A  RDR.K=TABLE(RDRTAB,TIME.K,0,90,30)                                      GRO06230
A  DRB.K=TABLE(DRBTAB,TIME.K,0,80,10)                                      GRO06240
R  CBAR.KL=CB.K/DAG                                                        GRO06250
A  CBR.K=CB.K/PB.K                                                         GRO06260
NOTE  LOW SKILLED BLACK ADULTS                                             GRO06270
L  PBL.K=PBL.J+(DT)(FBPL.J*CBAR.JK+PBLMR.JK-PBLDR.JK-PBCUR.JK-PBSUR.JK)    GRO06280
R  PBCUR.KL=PBLC.K*ULRC.K                                                  GRO06290
R  PBSUR.KL=PBLS.K*ULRS.K                                                  GRO06300
A  ULRC.K=URL*UMU.K*UMJAC.K                                                GRO06310
A  ULRS.K=URL*UMU.K*UMJAS.K                                                GRO06320
A  UMU.K=TABHL(UMUT,EURAT.K,-.2,.2,.1)                                     GRO06330
A  UMJAC.K=TABHL(UMJT,RJSDC.K,0,2,.5)                                      GRO06340
A  UMJAS.K=TABHL(UMJT,RJSDS.K,0,2,.5)                                      GRO06350
A  RJSDC.K=JSCUM.K/JDCL.K                        UPPERSKILLED JOB SUP      GRO06360
A  RJSDS.K=JSSUM.K/JDSL.K                                                  GRO06370
R  PBLDR.KL=PBL.K*DRB.K                                                    GRO06380
A  FBPL.K=(PBL.K)/(PBL.K+PBU.K)                                            GRO06390
R  PBLMR.KL=PBL.K*PBLMC.K                                                  GRO06400
A  PBLMC.K=(P.K*MBPOT.K*MLAT.K*IRBL/PBL.K)-OMRL                            GRO06410
A  PZ.K=PB.K+PW.K                                                          GRO06420
A  P.K=SWITCH(PT,PZ.K,SWZG)                                                GRO06430
A  PBR.K=PB.K/P.K                                                          GRO06440
A  PW.K=PWL.K+PWU.K+CW.K                                                   GRO06450
A  PB.K=PBL.K+PBU.K+CB.K                                                   GRO06460
A  FWMIG.K=(PWLMR.JK+PWUMR.JK)/PW.K                                        GRO06470
A  FBMIG.K=(PBLMR.JK+PBUMR.JK)/PB.K                                        GRO06480
A  MBPQT.K=TABLE(MBTAB,TIME.K,0,80,10)                                     GRO06490
A  MBPOT.K=SWITCH(MBPCC,MBPQT.K,SWEM)                                      GRO06500
A  MLAT.K=TABHL(UALTAB,UNR.K,0,.14,.01)                                    GRO06510
A  UNR.K=TABHL(UNTAB,ERAT.K,-.08,.16,.04)                                  GRO06520
A  ERAT.K=(E.K-J.K)/E.K                                                    GRO06530
A  E.K=EL.K+EU.K                                                           GRO06540
A  EL.K=(PBL.K+PWL.K)(LFPR)                                                GRO06550
A  EU.K=(PBU.K+PWU.K)(LFPR)                                                GRO06560
A  ELRAT.K=(EL.K-JL.K)/EL.K                                                GRO06570
A  EURAT.K=(EU.K-JU.K)/EU.K                                                GRO06580
A  FEL.K=EL.K/E.K                                                          GRO06590
NOTE  BLACK UPPER SKILLED ADULTS                                           GRO06600
```

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L   PBU.K=PBU.J+(DT)((1-FBPL.J)(CBAR.JK)+PBUMR.JK-PBUDR.JK+PBCUR.JK+PBSUR
X   .JK)
R   PBUDR.KL=PBU.K*DRB.K
A   MUAT.K=TABHL(UAUTAB,UNRU.K,0,.14,.01)
R   PBUMR.KL=PBU.K*PBUMC.K
A   PBUMC.K=(P.K*MBPOT.K*MUAT.K*IRBU/PBU.K)-OMRU
A   UNRU.K=TABHL(UNUTAB,EURAT.K,-.06,.16,.02)
NOTE  WHITE CHILDREN
L   CW.K=CW.J+(DT)(CWBR.JK+(CPM)(PWLMR.JK+PWUMR.JK)-CWDR.JK-CWAR.JK)
R   CWBR.KL=(PW.K)(BRW.K)
A   BRW.K=TABLE(BRWTAB,TIME.K,0,80,5)
R   CWDR.KL=(CW.K)(DRW.K)(RDR.K)
A   DRW.K=TABLE(DRWTAB,TIME.K,0,80,10)
R   CWAR.KL=CW.K/DAG
A   CWR.K=CW.K/PW.K
NOTE  WHITE LOWER SKILLED ADULTS
L   PWL.K=PWL.J+(DT)(FWPL.J*CWAR.JK+PWLMR.JK-PWLDR.JK-PWCUR.JK-PWSUR.JK)
R   PWCUR.KL=PWLC.K*ULRC.K
R   PWSUR.KL=PWIS.K*ULRS.K
R   PWLDR.KL=PWL.K*DRW.K
A   FWPL.K=PWL.K/(PWL.K+PWU.K)
A   MWPQT.K=TABLE(MWTAB,TIME.K,0,80,10)
R   PWLMR.KL=PWL.K*PWLMC.K
A   PWLMC.K=(P.K*MWPOT.K*MLAT.K*IRWL/PWL.K)-OMRL
A   MWPOT.K=SWITCH(MWPOC,MWPQT.K,SWWM)
NOTE  WHITE UPPER SKILLED ADULTS
L   PWU.K=PWU.J+(DT)((1-FWPL.J)(CWAR.JK)+PWUMR.JK-PWUDR.JK+PWCUR.JK+PWSUR
X   .JK)
R   PWUDR.KL=PWU.K*DRW.K
NOTE  INDUSTRIAL GROWTH
R   PWUMR.KL=PWU.K*PWUMC.K
A   PWUMC.K=(P.K*MWPOT.K*MUAT.K*IRWU/PWU.K)-OMRU
L   IEX.K=IEX.J+DT*IEXG.JK
R   IEXG.KL=IEXPOT.K*EAT.K*NIEXGR.K*IEX.K
A   IEXPOT.K=TABLE(IEXTAB,TIME.K,0,80,10)
A   EAT.K=TABHL(EATTAB,ERAT.K,-.12,.09,.03)
A   NIEXGQ.K=TABLE(NEXTAB,TIME.K,0,80,5)
A   NIEXGR.K=SWITCH(NXGRC,NIEXGQ.K,SWNX)
A   IBS.K=(IEXZ.K+IRS.K)(BSR)
A   IRS.K=(P.K)(RSPR.K)
A   RSPR.K=TABLE(RSPTAB,TIME.K,0,80,10)
A   J.K=IEXZ.K+IBS.K+IRS.K
A   JU.K=(J.K)(JUC.K)
A   JL.K=(J.K)(1-JUC.K)
A   JUC.K=TABLE(JUCTAB,TIME.K,0,80,10)
A   EXR.K=IEXZ.K/J.K
NOTE
NOTE     B.  OUTPUTS FROM LOCATION SUBROUTINE
PLOT  P=P,J=J/PBR=B/UNR=T,UNRU=U,ELRAT=L/CBR=C,CWR=D/EXR=X,FEL=F
PLOT  FWMIG=W,FBMIG=B/ULRC=C,ULRS=S

NOTE      FILE EQHS
NOTE     THIS FILE CONTAINS THE EQUATIONS FOR THE HOUSING SUBROUTINE OF
NOTE     THE PHASE2 MODEL, THE POLICY INPUTS FOR THE HOUSING SECTOR,
NOTE      AND THE SPECIFICATION OF THE OUTPUTS FROM THE HOUSING SECTOR.
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NOTE                                                                    GRO07160
NOTE      EQUATIONS FOR HOUSING SUBROUTINE IN PHASE2 MODEL              GRO07170
NOTE           1.  HOUSING STOCKS                                       GRO07180
NOTE                                                                    GRO07190
L  HCU.K=HCU.J+(DT)(HCUCR.JK-HCFR.JK)                                   GRO07200
L  HCL.K=HCL.J+(DT)(HCLCR.JK+HCFR.JK-HCLCL.JK-HCLCU.JK-HCAR.JK)         GRO07210
L  HCA.K=HCA.J+(DT)(HCAR.JK-HCACU.JK-HCACL.JK-HCDR.JK)                  GRO07220
NOTE                                                                    GRO07230
L  HSU.K=HSU.J+(DT)(HSUCR.JK-HSFR.JK)                                   GRO07240
L  HSL.K=HSL.J+(DT)(HSLCR.JK+HSFR.JK-HSLCL.JK-HSLCU.JK-HSAR.JK)         GRO07250
L  HSA.K=HSA.J+(DT)(HSAR.JK-HSACU.JK-HSACL.JK-HSDR.JK)                  GRO07260
NOTE                                                                    GRO07270
NOTE                                                                    GRO07280
NOTE         2. RATES OF NEW CONSTRUCTION                               GRO07290
R  HCUCR.KL=(.01)(HCER.K)(HCU.K)       CONSTRUCTION OF UPPER HSG IN COREGRO07300
A  HCER.K=TABHL(HERT,RHCUM.K,.9,1.5,.1)                                 GRO07310
R  HCLCR.KL=(HCLP.K)(HCL.K)            CONSTRUCTION OF LOWER HSG IN COREGRO07320
A  HCLP.K=CLIP(HCLPQ.K,0,TIME.K,SWHLC)                                  GRO07330
A  HCLPQ.K=CLIP(HCLPC,0,RHCL.K,1.0)                                     GRO07340
NOTE      THIS FUNCTION INITIATES A LOW INCOME HOUSING PROGRAM          GRO07350
NOTE      IN THE CORE OF HCLP OF THE SUPPLY AT T=SWHLC.                 GRO07360
A  RHCUM.K=(RHCU.K)(HDMI.K)(HDMX.K)                                     GRO07370
A  HDMI.K=TABHL(HDMIT,UNRU.K,0,.25,.05)                                 GRO07380
A  HDMXQ.K=TABLE(HDMXT,TIME.K,0,80,5)                                   GRO07390
A  HDMX.K=SWITCH(HDMXC,HDMXQ.K,SWHX)     CUTOFF FOR EXTERNAL HSG. MULT  GRO07400
NOTE                                                                    GRO07410
R  HSUCR.KL=(.01)(HSER.K)(HSU.K)          SUBURBAN RATES                GRO07420
A  HSER.K=TABHL(HERT,RHSUM.K,.9,1.5,.1)                                 GRO07430
R  HSLCR.KL=(HSLP.K)(HSL.K)                                             GRO07440
A  HSLP.K=CLIP(HSLPQ.K,0,TIME.K,SWHLS)                                  GRO07450
A  HSLPQ.K=CLIP(HSLPC,0,RHSL.K,1.0)                                     GRO07460
A  RHSUM.K=(RHSU.K)(HDMI.K)(HDMX.K)                                     GRO07470
NOTE                                                                    GRO07480
NOTE                                                                    GRO07490
NOTE         3. CONVERSIONS, FILTERING, AND DEMOLITION                  GRO07500
NOTE                                                                    GRO07510
R  HCLCU.KL=(HCUC.K)(1-RHSC.K)          LOWER CONVERSIONS TO UPPER      GRO07520
R  HCACU.KL=(HCUC.K)(RHSC.K)            ABANDONED CONVERSIONS TO UPPER  GRO07530
A  HCUC.K=(.01)(HCER.K)(HCU.K)(1-FHCV.K)(RHDC.K)                        GRO07540
A  FHCV.K=TABLE(FHVT,LFOC.K,0,1,.2)     FRAC CONST ON VACANT LAND       GRO07550
A  RHDC.K=DAHC.K/DMHC.K                 AVG/MARGINAL HOUSING DENSITIES  GRO07560
A  RHSC.K=HCA.K/(HCL.K+HCA.K)                                           GRO07570
R  HCACL.KL=(HCLC.K)(RHSC.K)            ABANDONED CONVERSIONS TO LOWER  GRO07580
R  HCLCL.KL=(HCLC.K)(1-RHSC.K)          LOWER CONVERTED TO NEW LOWER    GRO07590
A  HCLC.K=(HCLP.K)(HCL.K)(1-FHCV.K)(RHDC.K)                             GRO07600
NOTE                                                                    GRO07610
R  HCFR.KL=(NHFR)(HFMC.K)(HCU.K)        FILTERING UPPER TO LOWER        GRO07620
A  HFMC.K=TABLE(HFMT,RHCU.K,.6,1.8,.2)                                  GRO07630
NOTE                                                                    GRO07640
R  HCAR.KL=(NHAR)(HAMC.K)(HCL.K)        ABANDONMENT RATE                GRO07650
A  HAMC.K=TABHL(HAMT,RHCLA.K,.8,1.4,.1)                                 GRO07660
L  RHCLA.K=RHCLA.J+DT*(RHCL.J-RHCLA.J)/TARHL                            GRO07670
NOTE                                                                    GRO07680
R  HCDR.KL=(NHDR)(HCDP.K)(HCA.K)        DEMOLITION RATE                 GRO07690
A  HCDP.K=CLIP(HCDPC,1.0,TIME.K,SWHDP)                                  GRO07700
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NOTE   SWHDP IS THE TIME OF THE BEGINNING OF A HOUSING DEMOLITION        GRO07710
NOTE   PROGRAM IN THE CORE OF HCDP TIMES THE NORMAL RATE.                GRO07720
NOTE                                                                     GRO07730
R   HSLCU.KL=(HSUC.K)(1-RHSS.K)          SUBURBAN RATES                  GRO07740
R   HSACU.KL=(HSUC.K)(RHSS.K)                                            GRO07750
A   HSUC.K=(.01)(HSER.K)(HSU.K)(1-FHSV.K)(RHDS.K)                        GRO07760
A   FHSV.K=TABHL(FHVT,LFOS.K,0,1,.2)                                     GRO07770
A   RHDS.K=DAHS.K/DMHS.K                                                 GRO07780
A   RHSS.K=HSA.K/(HSA.K+HSL.K)                                           GRO07790
R   HSACL.KL=(HSLC.K)(RHSS.K)                                            GRO07800
R   HSLCL.KL=(HSLC.K)(1-RHSS.K)                                          GRO07810
A   HSLC.K=(HSLP.K)(HSL.K)(1-FHSV.K)(RHDS.K)                             GRO07820
NOTE                                                                     GRO07830
R   HSFR.KL=(NHFR)(HFMS.K)(HSU.K)        FILTERING                       GRO07840
A   HFMS.K=TABHL(HFMT,RHSU.K,.6,1.8,.2)                                  GRO07850
NOTE                                                                     GRO07860
R   HSAR.KL=(NHAR)(HAMS.K)(HSL.K)        ABANDONMENT                     GRO07870
A   HAMS.K=TABHL(HAMT,RHSLA.K,.8,1.4,.1)                                 GRO07880
L   RHSLA.K=RHSLA.J+DT*(RHSL.J-RHSLA.J)/TARHL                            GRO07890
NOTE                                                                     GRO07900
R   HSDR.KL=(NHDR)(HSA.K)                DEMOLITION                      GRO07910
NOTE                                                                     GRO07920
NOTE        4. LAND USED FOR HOUSING                                     GRO07930
L   LHC.K=LHC.J+(DT)(LHCG.JK-LHCD.JK)                                    GRO07940
R   LHCG.KL=((HCLP.K)(HCL.K)+(.01)(HCER.K)(HCU.K))(FHCV.K)/DMHC.K        GRO07950
R   LHCD.KL=(NHDR)(HCDP.K)(HCA.K)/DAHC.K                                 GRO07960
NOTE                                                                     GRO07970
NOTE                                                                     GRO07980
L   LHS.K=LHS.J+(DT)(LHSG.JK-LHSD.JK)      SUBURBAN LAND                 GRO07990
R   LHSG.KL=((HSLP.K)(HSL.K)+(.01)(HSER.K)(HSU.K))(FHSV.K)/DMHS.K        GRO08000
R   LHSD.KL=(NHDR)(HSA.K)/DAHS.K                                         GRO08010
NOTE                                                                     GRO08020
A   DAHC.K=(HCU.K+HCL.K+HCA.K)/LHC.K   AVERAGE HOUSING DENSITY IN CORE   GRO08030
A   DMHC.K=TABLE(DMHT,LFCC.K,0,1,.2)   MARGINAL HOUSING DENSITY IN CORE  GRO08040
NOTE                                                                     GRO08050
A   DAHS.K=(HSU.K+HSL.K+HSA.K)/LHS.K    AVERAGE HOUSING DENSITY IN SUBURBGRO08060
A   DMHS.K=TABLE(DMHT,LFOS.K,0,1,.2)    MARGINAL   "      "     "   "    GRO08070
NOTE                                                                     GRO08080
NOTE                                                                     GRO08090
NOTE     HOUSING SECTOR OUTPUTS                                          GRO08100
NOTE                                                                     GRO08110
PLOT  HCU=U,HCL=I,HCA=A/HSU=V,HSL=M,HSA=B/RHCU=R,RHCL=P,RHSU=S,RHSL=T    GRO08120
PLOT  HCUCR=C/HSUCR=D/HCFR=F/HSFR=G/HCAR=A/HSAR=B                        GRO08130
PLOT  LHC=C,LHS=S/DAHC=A,DAHS=B,DMHC=M,DMHS=N                            GRO08140
RUN IE                                                                   RRU00010
CP SWNX=0                                                                RRU00020
C   NXGRC=.03                                                            RRU00030
RUN IE1                                                                  RRU00040
```

B. Sample Output

PAGE 4 RUN - LE

RJCU=J,RJSU=K,RJCL=L,RJSL=M,RSXC=S,RSXS=T,RXBC=A,RXBS=B,RLXS=0,RLXC=1

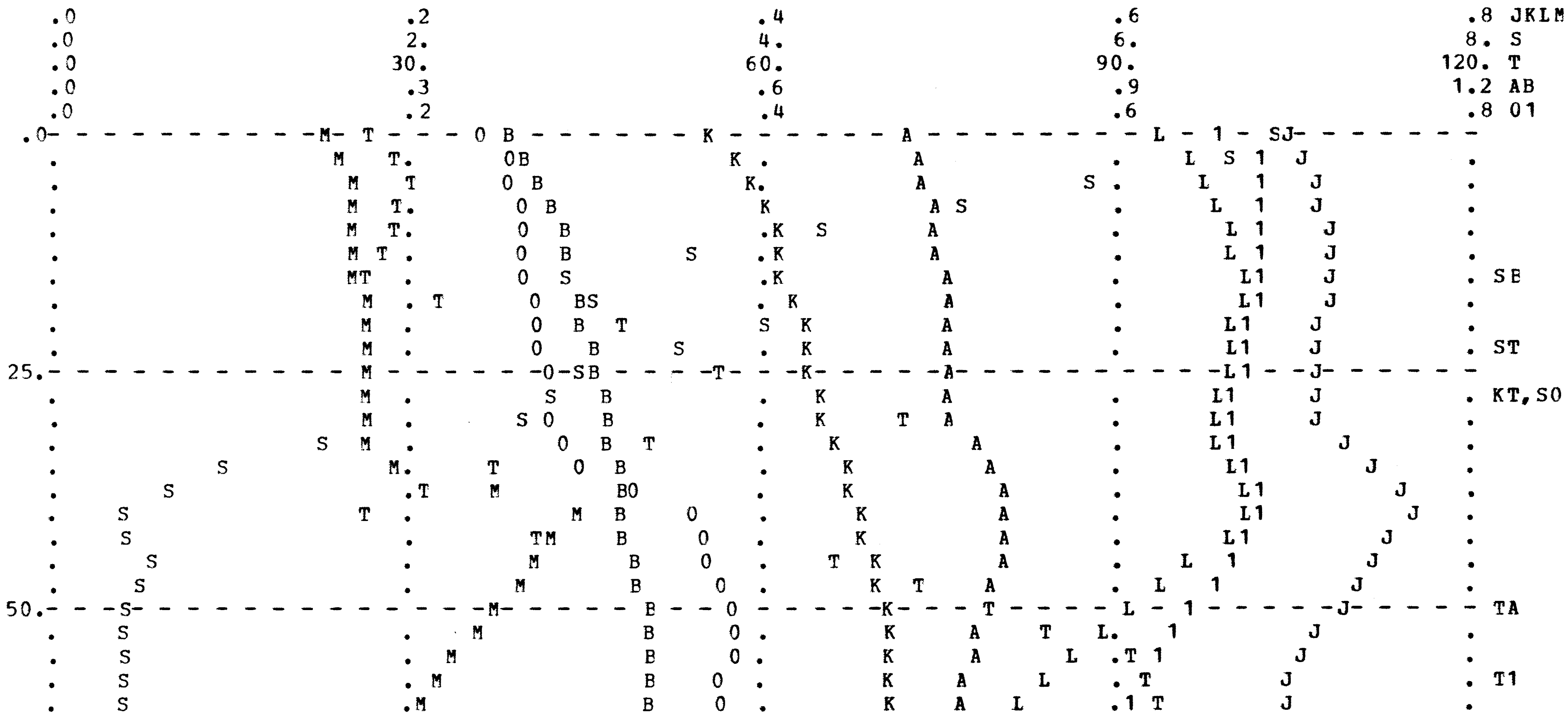


FIGURE A-2 THE FIRST FOUR VARIABLES ARE THE FOUR RATIOS OF JOB SUPPLIES IN A SPECIFIC SKILL LEVEL ACCESSIBLE IN THE METROPOLITAN AREA. THE LAST SIX VARIABLES ARE THE RATIOS OF LAND SUPPLY, LABOR SUPPLY, AND ACCESSIBILITY USED FOR THE CORE AND FOR THE SUBURBS, WHICH ARE USED TO CALCULATE THE COMPOSITE ATTRACTION OF THE AREA FOR INDUSTRY.

PAGE 5 RUN - IE

LFOC=C,LFOS=S,LFAC=A,LFAS=B,LIC=I,LIXC=X,LIS=J,DAXC=D,DAXS=E

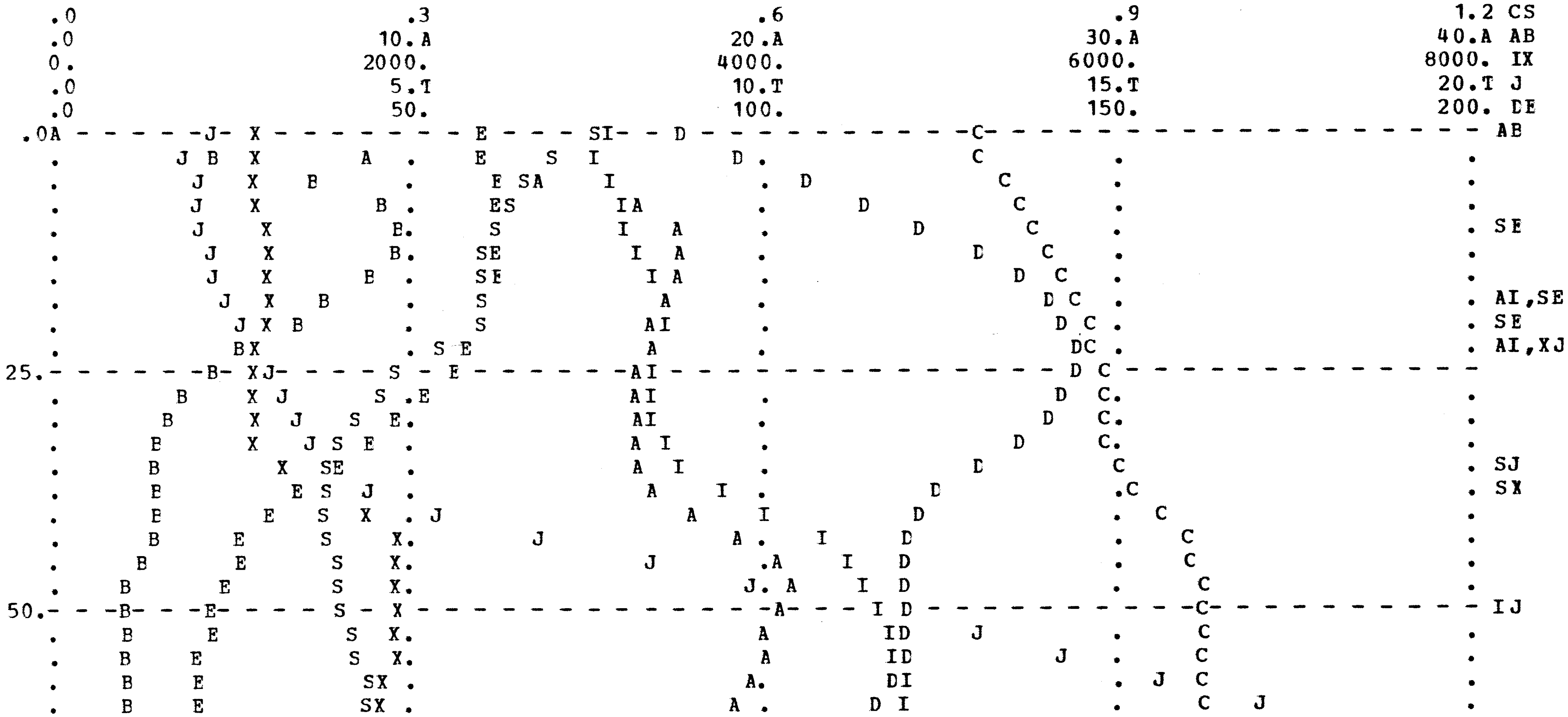
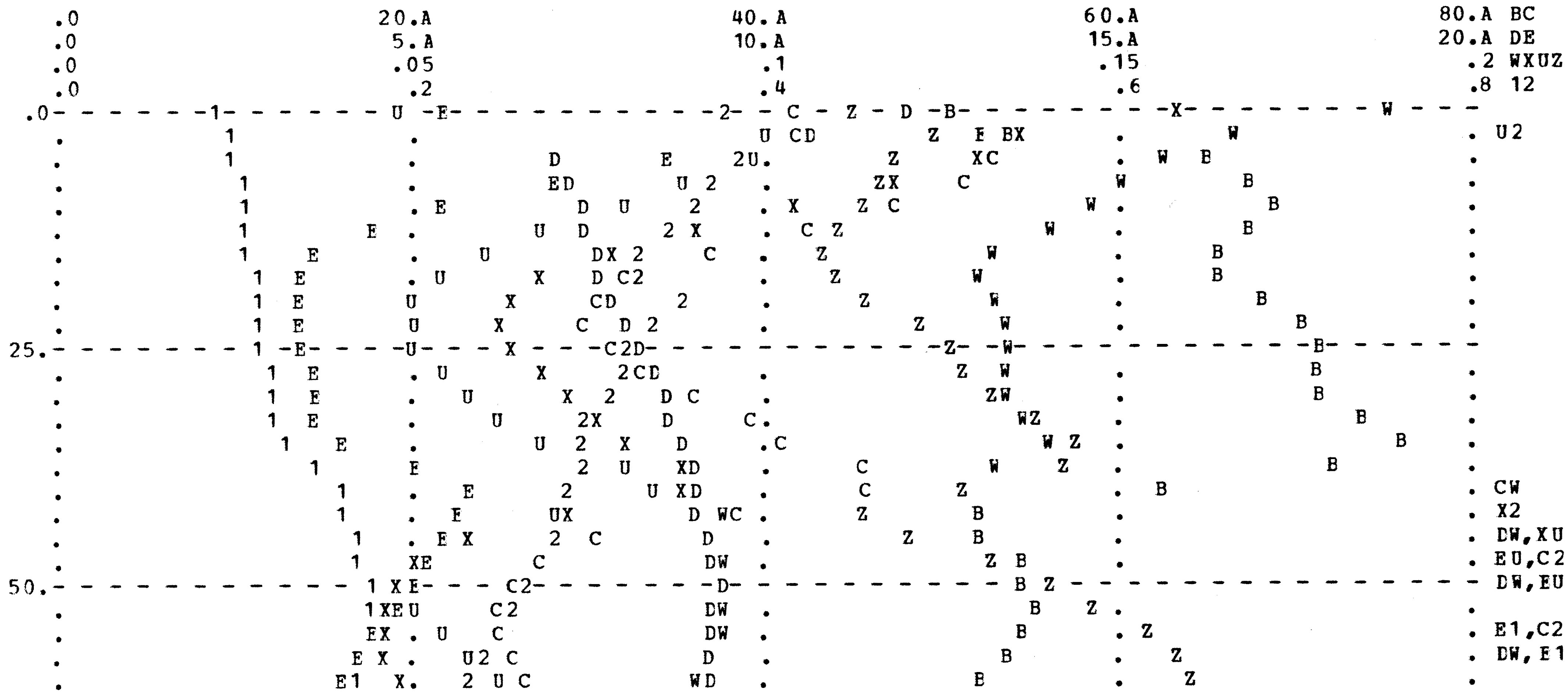


FIGURE A-3 THE FIGURE SHOWS THE LAND FRACTIONS OCCUPIED IN THE CORE CITY AND SUBURBS, THE LAND FRACTIONS WITH ABANDONED LAND IN EACH AREA, THE LAND IN INDUSTRIAL USE,IN THE CORE CITY, THE LAND USED FOR EXPORT INDUSTRY IN THE CORE, THE LAND USED FOR INDUSTRY IN THE SUBURBS, AND THE AVERAGE DENSITY OF EXPORT INDUSTRY EMPLOYMENT IN EACH AREA.

PAGE 6 RUN - LE

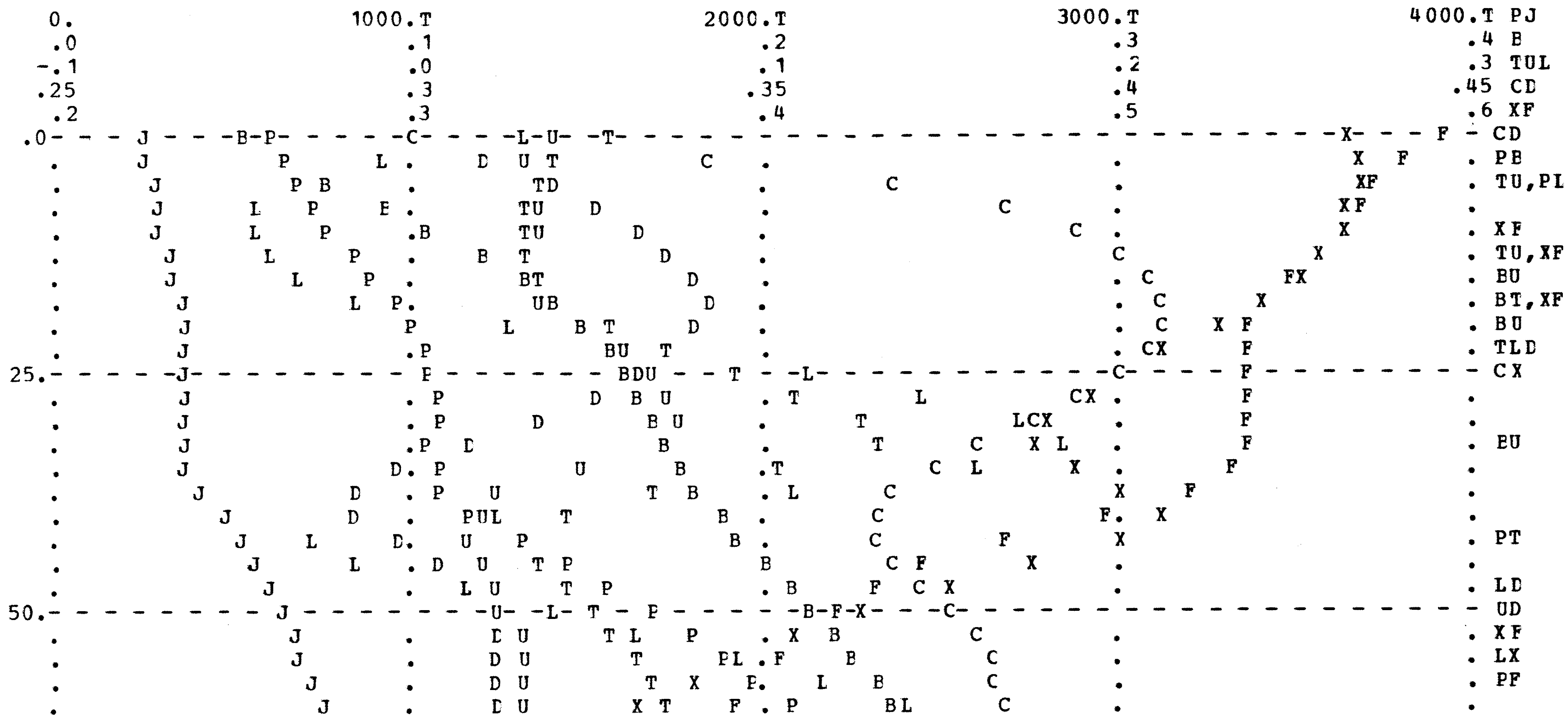
CCBU=B,CCBL=C,CSBU=D,CSBL=E,CCWU=W,CCWI=X,CSWL=U,CSWU=Z,CSAIX=1,CCAIX=2



A-4 THE COMPOSITE ATTRACTIONS FUNCTIONS USED TO ALLOCATE POPULATION AND INDUSTRY. THE FIRST FOUR ARE FOR THE BLACK POPULATION, THE SECOND FOR THE WHITE POPULATION, AND THE LAST TWO ARE FOR EXPORT INDUSTRY.

PAGE 7 RUN - LE

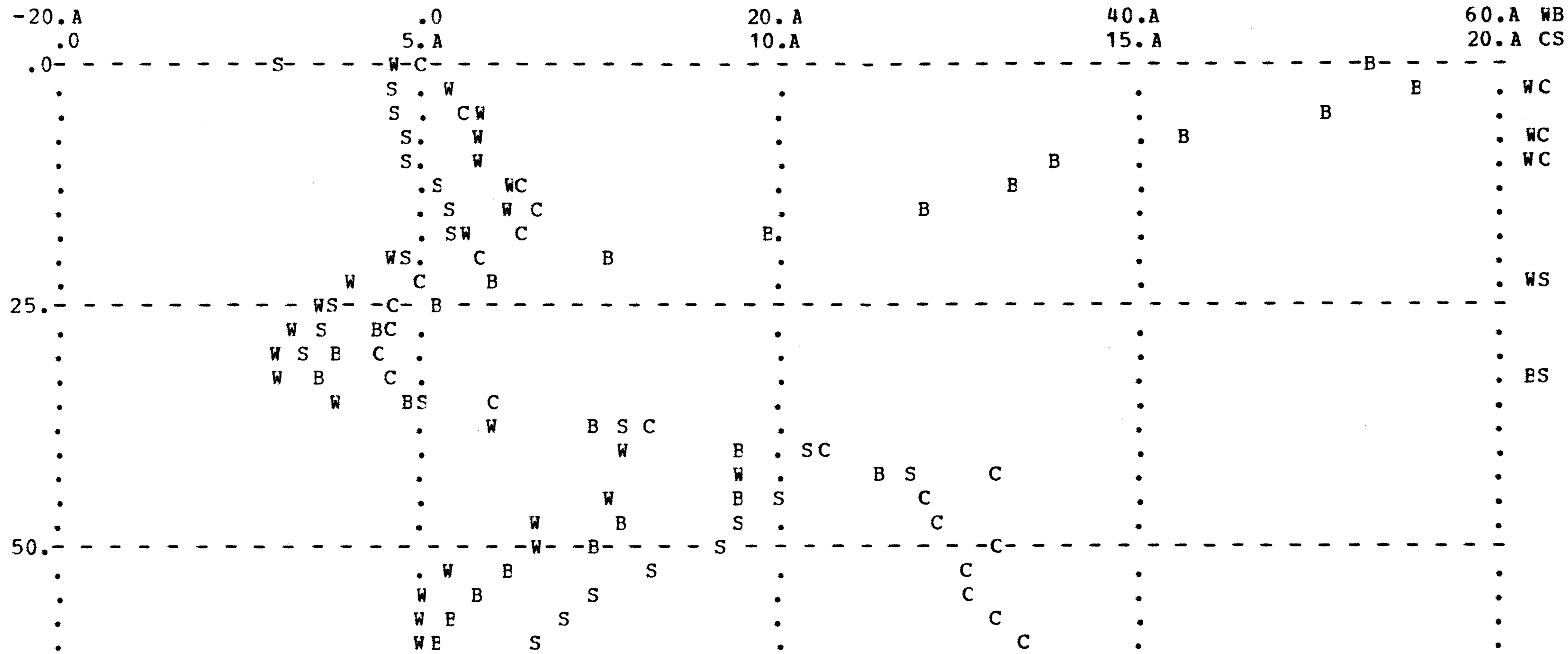
P=P,J=J,PBR=B,UNR=T,UNRU=U,ELRAT=L,CBR=C,CWR=D,EXR=X,FEL=F



A- 5 THE OUTPUTS OF THE GROWTH SUBMODEL----SEE SECTION A OF CHAPTER 8 FOR AN EXPLANATION OF VARIABLES.

PAGE 8 RUN - LE

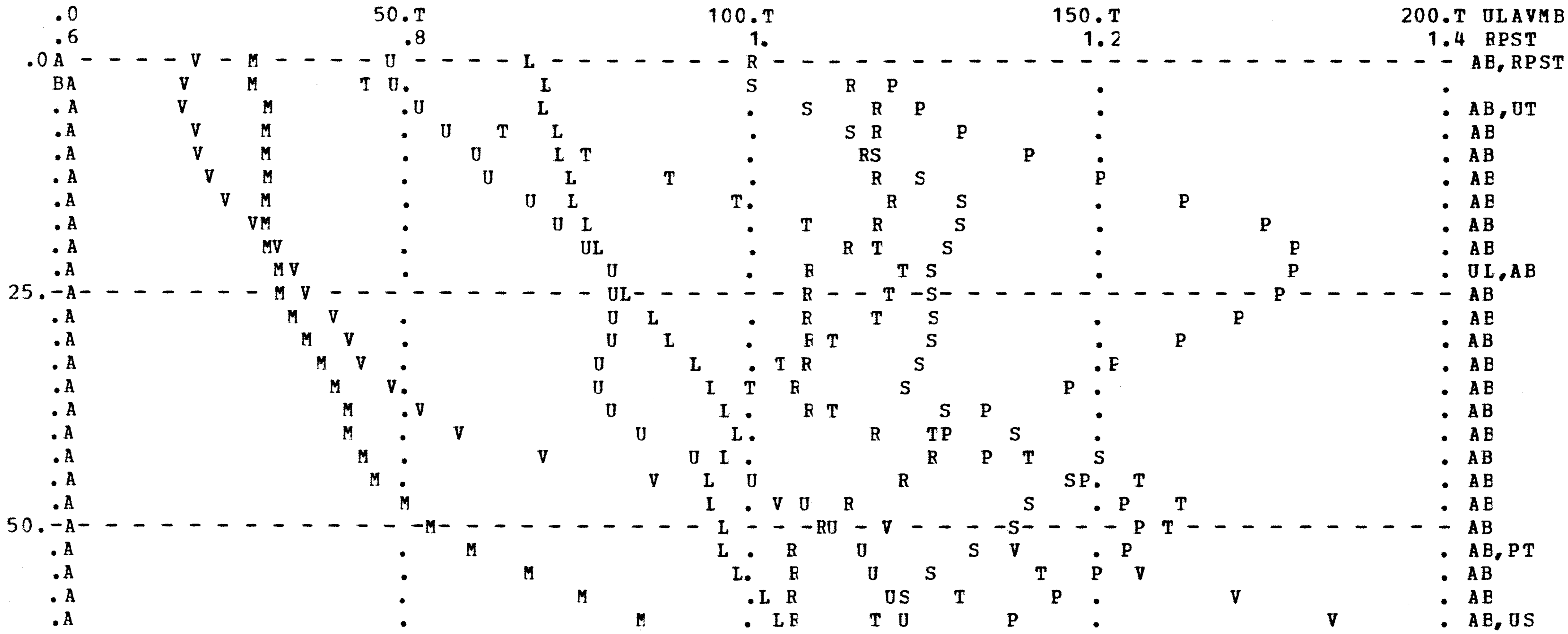
FWMIG=W,FBMIG=B,ULRC=C,ULRS=S



A- 6 THE OUTPUTS OF THE GROWTH SUBMODEL--SEE SECTION A OF CHAPTER 8 FOR AN EXPLANATION OF THE VARIABLES.

PAGE 9 RUN - IE

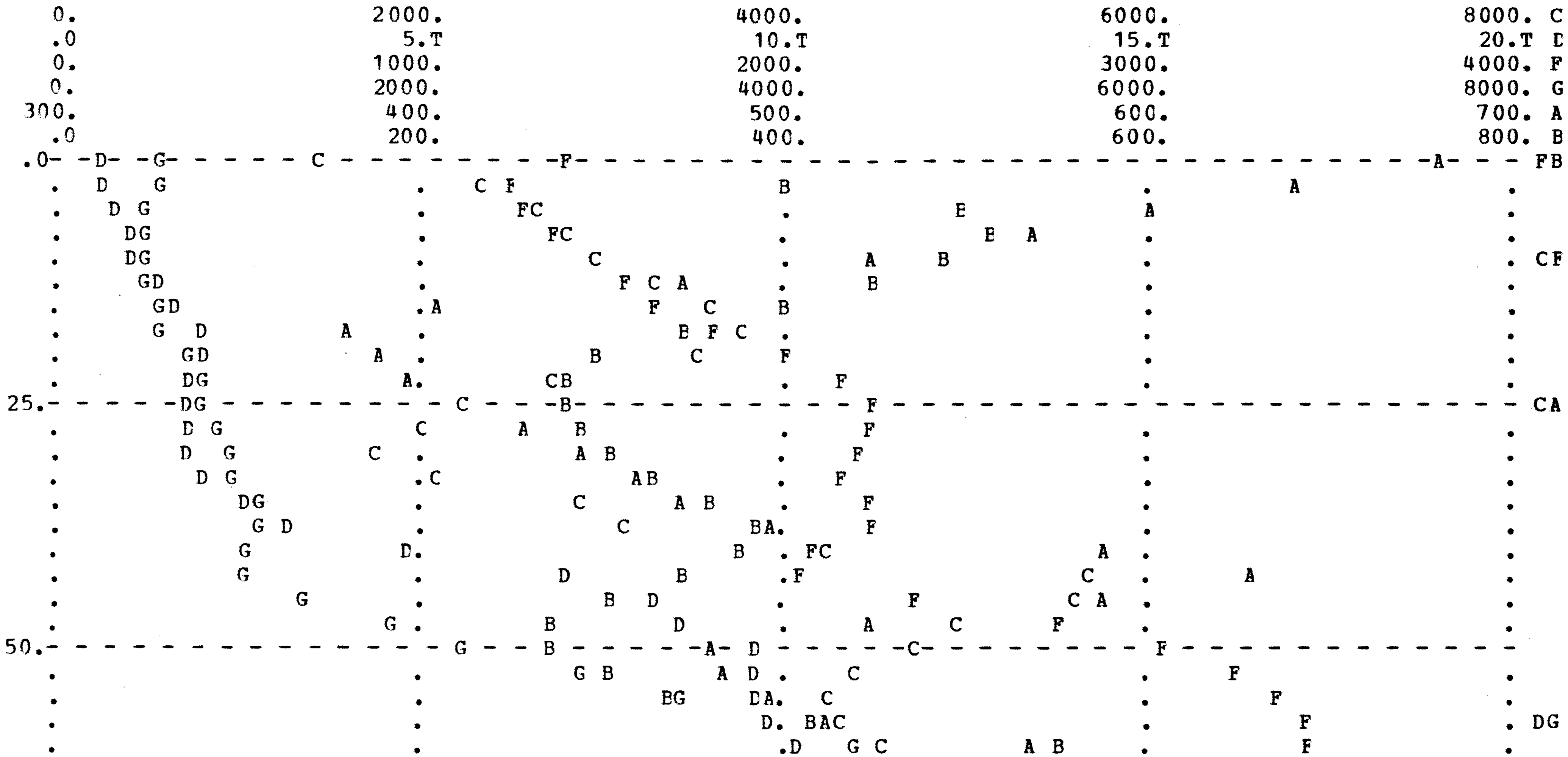
HCU=U, HCL=L, HCA=A, HSU=V, HSL=M, HSA=B, RHCU=R, RHCL=P, RHSU=S, RHSL=T



A- 7 THE OUTPUTS OF THE HOUSING SUBMODEL. THE FIRST THREE VARIABLES ARE THE HOUSING STOCKS IN THE CORE, THE SECOND THREE ARE THE HOUSING STOCKS IN THE SUBURBS, AND THE LAST FOUR ARE THE RATIOS OF HOUSING DEMAND TO SUPPLY IN EACH AREA FOR EACH SKILL LEVEL OF HOUSING STOCK.

PAGE 10 RUN - LE

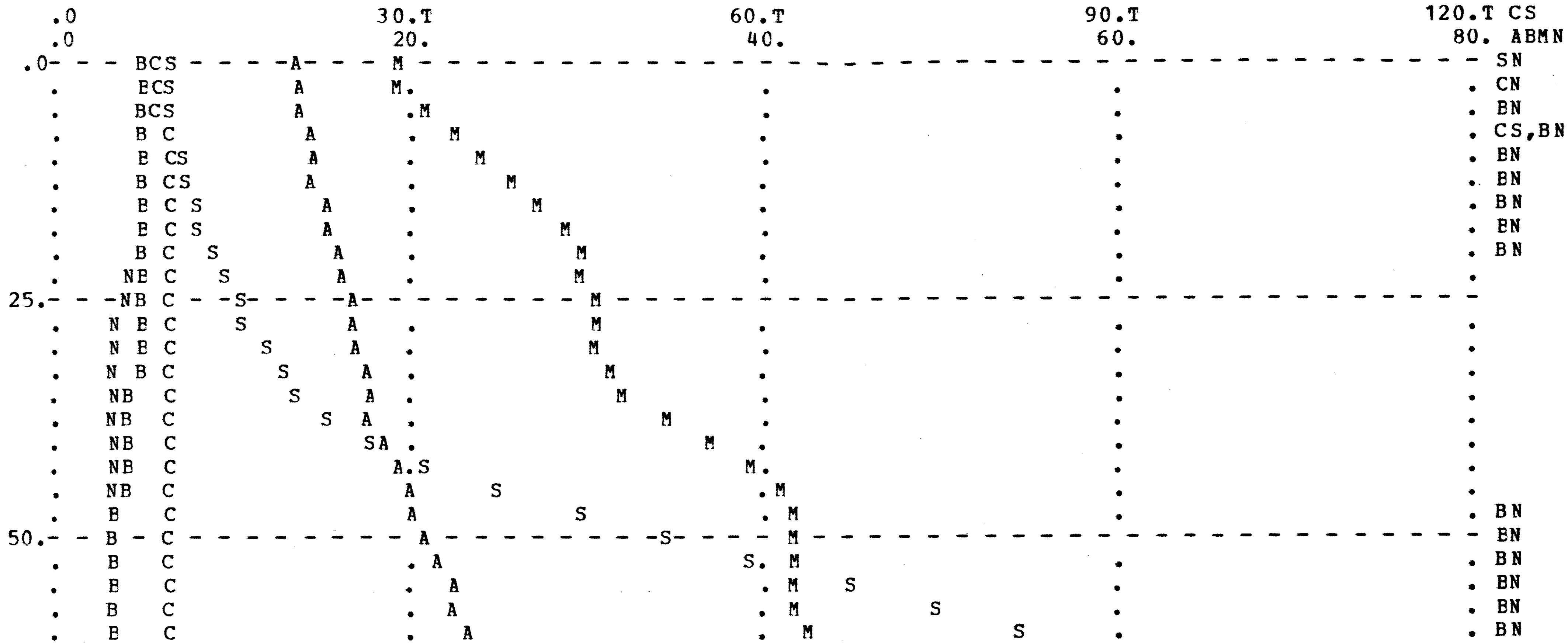
HCUCR=C, HSUCR=D, HCFR=F, HSFR=G, HCAR=A, HSAR=B



A- 8 THE OUTPUTS OF THE HOUSING SUBMODEL (CONT.). THE FØRST TWO VARIABLES ARE RATES OF HOUSING CONSTRUCTION IN THE CORE AND SUBURBS. THE SECOND TWO ARE THE RATES OF FILTERING OF HOUSING IN THE CORE AND SUBURBS. AND THE LAST TWO RATES ARE OF ABANDONMENT OF HOUSING IN THE CORE AND SUBURBS.

PAGE 11 RUN - LE

LHC=C,LHS=S,DAHC=A,DAHS=B,DMHC=M,DMHS=N



A- 9 THE OUTPUTS OF THE HOUSING SUBMODEL (CONT.). THE FIRST TWO VARIABLES ARE THE LAND USED FOR HOUSING IN THE CORE AND SUBURBS, THE SECOND TWO ARE THE AVERAGE DENSITIES OF HOUSING IN THE CORE AND SUBURBS, AND THE LAST TWO ARE THE MARGINAL DENSITIES OF HOUSING IN THE CORE CITY AND SUBURBS.

BIOGRAPHICAL NOTE

James A. Hester, Jr. was born July 20, 1944, in San Juan, Puerto Rico. He received a B.S. (1965) and M.S. (1966) in Aeronautics and Astronautics from M.I.T. During this time he was an Aviation Week Fellow and was elected to Tau Beta Pi and Sigma Gamma Tau national honorary societies. During this period he was an aerospace intern at the NASA Manned Spacecraft Center (Houston, Texas) and research assistant at the M.I.T. Aerophysics Laboratory. Upon graduation he joined the Avco Research Laboratory and became the technical coordinator for part of that laboratory's gas laser development program. Since September 1967, he has been a PhD candidate in the Department of Urban Studies and Planning at M.I.T. His professional experience during this period includes the systems analysis of a proposed expansion of NYC's primary water distribution system; preparation of an economic development and transportation plan for Santa Catalina Island for the Ford Motor Company and participation on the staff of President Nixon's Task force on Transportation. He is currently a Catherine Bauer Wurster Fellow of the M.I.T.-Harvard Joint Center for Urban Studies. His publications include:

1. "Systems Models of Urban Development," Urban Systems Laboratory, M.I.T., November 1969.
2. "A Development Strategy for Santa Cataline Island", Transportation Planning and Research Office, Ford Motor Company, Dearborn, Michigan, November 1968.
3. With de Neufville, Richard, and Stafford, Joseph, "Systems Analysis: The Analysis of New York City's Water Supply System", First International Conference, Design Methods Group, Cambridge, Mass., June, 1968.

Plus several research notes and reports on the analysis of gas lasers.