SIMULATION MODELS OF HUMAN NEIGHBORHOODS

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GLOSSARY OF ABBREVIATIONS

CA	Cellular Automata Theory and Techniques
CANDE	Burroughs Interactive Conversational Systems Language
CRP	A San Francisco Community Renewal Program Model
DM	A decision-maker
DYNAMO	The Compiler and Systems Language for Systems Dynamics
$\mathbb{E}$	A Vector of Exogenous Variables
F	The F-distributed Random Variable
FD	Feedback Dynamics or Systems Dynamics
FORTRAN	General Purpose Computer Language, FORmula TRANslator
GERT	Graphical Evaluation and Review Techniques
HNM	Human Neighborhood Model
H_o	A Null Hypothesis
H_1	An Alternate Hypothesis
MC	Monte Carlo Theory and Techniques
μ	Mean or average value
NBER	National Bureau of Economics Research
$\bar{p}$	A Vector of Input Parameters
T	Triangular Distribution Function
t	Student-t Distributed Random Variable
U	Uniform Distribution Function
UDM	Urban Dynamics Modle
$\mathbb{W}$	Matrix of Endogenous Variables

GLOSSARY OF HNM VARIABLES

A	Seed Number for Random Number Generator
ADJ	Input Variable used in Distance Calculations
AHV	Average House or Property Value (See HV)
AI	Amenity Index
ALS	Average Length of Stay, or average tenure (See TEN)
AMTMORT	Amount of Mortgage relative to HV
C	Coupling Factor between each Property
D	Socioeconomic Distance between Residents
DIST	Distance between DMEAN and each Resident
DMEAN	The Average Socioeconomic Distance
ES	Economic Status, Normalized Annual Income
HV	House or Property Value
HVMAX	Maximum Property Value
HVMIN	Minimum Property Value
ID	Identification Number for each Resident
IMPF	Property Improvement Factor
LAI	Desired Amenity Index Factor (See AI)
LOC	Grid Location of each Property, Ordered Pair of Integers
LRC	Desired Relative Condition (See RC)
LS	Length of Stay (See TEN)
MONFAC	Money Factor for Interest Rates and Availability
N	Set of Integers [1,64]
NAO	Number of Residents Attracted Away
NB	Number of Buyers

NCM	Number of Causal Movers
NNO	Number of New Occupants, Those who Enter after First Cycle
NOO	Number of Original Occupants
NPA	Number of Properties that Appreciate
NPD	Number of Properties that Depreciate
NRM	Number of Random Movers
NVAC	Number of Vacant Properties
NUMCY	Number of Cycles for each Run
PCCM	Percentage of Causal Movers (See NCM)
PCMT	Percentage of Maximum Tenure
PCNO	Percentage of New Occupants (See NNO)
PCOM	Percentage of Other Movers, or Non-causal
PCVC	Percentage of Vacancies (See NVAC)
RC	Relative Condition of Properties
RESIT	Real Estate Situation or Strategies
SELPR	The Selling Price of a Property
SS	Social Status
TEN	Tenure in Cycles or Years
TF	Resident Awareness Factor
TPNH	Input Variable used to Generate RC
THA,THB,THC,THD	Input Parameters for Property Values
TXA,TXB,TXC,TXD	Input Parameters for Social Status
TYA,TYB,TYC,TYD	Input Parameters for Economic Status
TYPR	Input Variable to control Input and Output Formats
XBAR,XMAX,XMIN	Average, Maximum and Minimum Social Status
YBAR,YMAX,YMIN	Avergae, Maximum and Minimum Economic Status

SUMMARY

Considerable interest has been shown recently in the behavior of large-scale, complex systems. Current emphasis is being placed on the development of simulation models of societary systems. An area of particular interest and practical application has become that of urban problem-solving.

This research concerns the development and analysis of a model of the flow of families into and from a generalized urban neighborhood, and the changes in the variables denoting important social and economic attributes of the residents and residences. A human neighborhood model (HNM) was constructed to represent these processes of change and substantiated in part by available data from racially transitional neighborhoods.

Four separate contributions have been indicated. Firstly, a different synthesis of sociological theories of urban structure and human migration was outlined. From such a description, a mathematical model was then developed incorporating techniques of deterministic Boolean functions, stochastic variable generation, and feedback loop control. Thirdly, an interactive FORTRAN simulation program was designed, implemented and tested for this model. Finally, inferences about desirable ways to control transition in contemporary communities were advanced after a series of investigations.

In these same four areas, the following tentative conclusions have been compiled. However, the degree to which the results can be assessed is plagued by both typical problems of emerging disciplines and inherited modeling difficulties. Nonetheless, the attempt to correlate the struc-

ture and dynamics of human interaction, decision-making and migration presented a novel approach for urban and regional analysis. In the HNM, turnover can be distinguished from transition, where the former indicates the rates of emigration and immigration; whereas, the latter a change in the aggregate character of the community. Dynamic responses of these processes are separately analyzed as a function of certain urban policies.

The ultimate effect of many policy recommendations on urban areas is often obscured since, in many instances, the relationship between turnover and transition may be problematic. From the HNM, turnover appears to be intensified by either uniform zoning assignment or inconsistencies in property tax assessment or the application of public services. Alternatively, turnover seems to be eased by restricting real estate sign use, or liberalizing private fence ordinances.

This model appears relatively insensitive to most choices of variable distributions which characterize the attributes of residents and residences. More important stability features seem to be initial values or conditions and intervariable linkages.

Although this model was developed in an *ad hoc* manner, it proved useful in this study and may be more so in the future. One continuing difficulty is the lack of completely standard formalization for description and analysis. Despite this problem, new directions in modeling and simulation have been noted.

CHAPTER I

INTRODUCTION

Background

This research focuses on questions of neighborhood development and control through the construction and analysis of digital simulation models. As a multi-disciplinary study, it incorporates theories and methods from four emerging disciplines: urban problem-solving; human ecology; computer simulation; and, mathematical modeling methodologies.

Urban Problem-solving

Currently, cities are experiencing severe crises such as increasing crime, pollution, population, costs, physical deterioration, and unemployment [114]. The internal and external forces that cause these complex, coupled and dynamic problems are, in fact, noticeable at the neighborhood level, and often stem from the manner in which communities are formed, developed, and controlled [8]. Frequently, solutions proposed by city planners and various governmental agencies are ineffective or detrimental because the consequences of such actions are difficult to predict.

Human Ecology

Evolving urban sociological theories have prompted research on the nature of human urban environments with particular emphasis on the dual problems of residential mobility and community stability [84]. The movement of people, or migration, reveals a great deal about the style of living [81]. Additional insight into the dynamics of current human migratory activity should contribute to our overall knowledge of contemporary societary systems, or those systems with psychological, sociological, ecological, economic, and demographic dimensions.

Simulation

Many of the methods of analysis used to study the contemporary problems of urban society have not met total acceptance nor success. Therefore, simulation has become a popular alternative in recent years. A review of current literature reveals increasing activity in general urban simulation [16], modeling city-suburban interaction [48], residential propinquity [93], urban growth [42], mobility [100], and migration patterns [54].

Modeling Methodologies

Nonetheless, controversy has surrounded many aspects of the simulation philosophy, its manner of presentation, and the underlying modeling approaches [65]. Critics point out a general absence of theoretical bases, a lack of real data in many cases, and some failures in performance and purpose [130]. Most thoroughly scrutinized has been Forrester's Urban Dynamics Model (UDM) [41].

A basic issue that continues unresolved is the question of how to model social processes. And, attempts are often discouraged by the lack of a taxonomy of previous models and an inability of modelers to adequately evaluate available methods [87,92].

Statement of the Problem

From the previous discussion, some of the enormous difficulties associated with the development of simulation models of human neighborhoods can be recognized. Consequently, it was decided that this research should develop and coordinate four somewhat separate yet major tasks described below.

The first task was the development of a theory or conceptual model of a 'transitional' or 'changing' neighborhood. Such urban areas have been identified by high rates of emigration and immigration, which may be considered as external signs of one form of instability. These activities, it has been claimed, are precipitated by the socioeconomic composition of the community, and perpetuated by the practices of the real estate agencies and lending institutions [98]. It has been further reported that such areas are then more susceptible to physical deterioration and an accompanying social decay [53]. However, renovation can be temporarily characterized by high residential turnover [68]. Thus, this first task would serve to identify the role of:organization in a societary system; aggregate behavioral aspects; individual human information processing; and,decision-making in a migration process.

The second task began with a general study of modeling. Potentially useful techniques were considered for the design and construction of a digital computer simulation model of a typical urban community. This task pointed to a need for a methodology that might combine different approaches in order to represent the time-varying aspects of emigration and immigration. Three methods were ultimately combined. They involved the use of stochastic variables, deterministic transition functions, and feedback loops. Obviously, an important requirement was that the mathematical structure provide the analogues to the real dynamical processes within the constraints imposed by the simulation language and systems programming.

In this case, they were FORTRAN and Burroughs' CANDE, respectively.

Thirdly, an interactive simulation program was designed, written and tested. This program simulated the human neighborhood (HNM) by incorporating within closed-loops both: the micro variables of the components, the individual dwellings and occupants; and, the macro variables of the ensemble, or the neighborhood aggregate. The entire process was interactively controlled from a remote computer terminal. This task also included program debugging, sensitivity analysis, and statistical tests using available real neighborhood data [117,124,125,126,127].

The fourth and last task was the analysis of policy alternatives. Since some urban areas move through growth and equilibrium phases with attendant changes in population and economic activity, there have been various efforts; viz., urban renewal, which attempt to forestall, or reduce, deterioration while encouraging innovation and productive change[19]. Thus, an investigation of these kinds of policies which have been suggested to recurring problems seemed appropriate.

Plan of Presentation

This dissertation is divided into the following chapters. Chapter II provides a survey of the literature related to: qualitative theories of human neighborhoods; urban policies for development and control; current urban simulation models; and, some general comments on systems, models, and simulation.

In Chapter III, a conceptual human neighborhood model is discussed within the framework of general societary modeling. A hybrid modeling method is proposed in Chapter IV where suggestions are made to counter some known modeling deficiencies.

The detailed simulation model is elaborated upon in Chapter V with its assumptions, lists of variables, equation formats, functional interconnections, and flow charts. In Chapter VI, simulated time histories are presented, as are some discussions of the model sensitivities. The experimentation continues in Chapter VII, in which statistical tests indicate the level of validation and verification. In the latter part of this chapter, inferences are drawn from a series of experiments as to some prominent factors that may influence neighborhood stability in a simulated policy exploration.

Chapter VIII concludes with an outline of the results, a review of the conclusions reached, and suggestions for future extensions of this research.

CHAPTER II

LITERATURE SURVEY

This survey is a broad outline of recent work in four areas related to the problem tasks of this research. The first area presented here is that of current sociological theories regarding human neighborhoods. The second describes urban policies for neighborhood development and control such as zoning, taxes, and local ordinances. The third pertains to some other recent simulation studies of urban dynamics. The fourth and final part of this chapter discusses the pertinent methodological issues of systems, models and simulation.

Theories of Human Neighborhoods

The term neighborhood is most often applied to an area with certain physical properties [39]. It may also refer to a set of human activities and relationships [68]. Inasmuch as information and data are yet incomplete on neighborhood formation, many studies have been undertaken [34,90].

Urban sociologists generally distinguish these essential entities: the neighbor, a special human role and relationship; neighboring, a more broadly defined set of activities; and, the neighborhood, a delimited physical area in which neighbors and neighboring may occur [123]. Recently, rapid social and physical change in some areas have upset the traditional relationships causing external disconnection and internal instability [55].

Typically, stable and cohesive neighborhoods have homogeneous populations, historically strong social traditions, and a high degree of social integration [14]. Unstable communities often exhibit inordinate migration levels and are referred to as transitional [107].

In a central work on human migration, Lee [78] outlined a schema for both the volume and characteristics of a stream and counterstream of migrants. Migration factors are partitioned into positive and negative types, equivalent to the traditional "push" and "pull" considerations influencing moving decisions [110].

McAllister [84] viewed the question of prospective residential mobility in terms of the degree of neighborhood integration. By statistically monitoring such variables as tenure and homogeneity, it was possible to show that neighborhoods that were most socially integrated were least likely to exhibit high mobility, and conversely.

Sabagh et al. [112] developed a conceptual framework for the "push-pull" dimensions with both structural and psychosocial components such as: family life cycle; social mobility and aspirations; residential environment; and, local participation. Contrasted to the efforts to formulate demographic models, Wolpert [133] advanced an ecological model in which the major interaction was adaptation. Here, the decision to migrate is equated to a coping mechanism for ecological disharmony. Individuals react to forces of amenity and disamenity levels in a particular living space. Migration is then the mechanism for the adjustment of environmental stress.

Another approach towards an explanation of human migration, borrowed from ethology, involves the notions of space and a territorial mandate.

Influenced by Lorenz [80] and Tinbergen [120], Ardrey [3] and others [56,77] view man as similar to the "territorial animal." Society is defined as a group of unequal beings organized to meet common needs. For societies of territorial animals, the territory is simply a real or an abstract space for which rules dictate certain behavioral patterns.

The principal conclusion is that ethological rules for the territory always evolve in the following manner [3]: competition is mostly for territory; outcomes of the competition favors the proprietors or occupants; proprietary advantage reduces the incidence and severity of the competition; enmity is generally confined to the territory; territorial rights guarantee certain privileges such as breeding; the breeding results in genetic isolation and the retention of identities; and, these identities are strongest through territorial attachments.

These rules are reflected in the work of ethologists as Carpenter [15], paleontologists as Leakey [3], and population geneticists as Fisher [120]. Increasing interest is in characterizing notions of territory in research on personal space [27] and individual distance [75].

Other behavioral relationships have been explored. Frequently studied are migration and xenophobia [63]. Conversely, some studies, such as that by Keller [68], have investigated the intensity of neighboring and its dependence on: the content of neighboring activities; the priority, frequency, level of intimacy, and formality of contact; and, the locality of the residence. In this fashion, it appears that the space and distance concepts can be clearly related to the physical and social contacts.

The importance of these studies of human migration has followed the rise of physical and social mobility [86]. General explanations always include increasing urbanization and industrialization; but, others involve descriptions which differentiate individual and group responses[53]. There have been efforts to determine the effects of the movement of groups on certain individuals, and the effects of individual moves on groups [95]. In both cases, the key question still seems to be: why is migration a human alternative? It always simply appears, as in Wolpert's suggestion, that movement is an option through which the individual expresses a decision, a vote, or a personal choice. Contrasted to the rules for territorial animals, human societies do not openly permit physical struggle and violence. Therefore, competition is transformed from the physical to the social and economic arenas. However, the competition may still be for space, and migration remains a natural behavioral response.

While migration might connote an anti-social act, since the word "social" is a derivation of the Latin "socius" meaning companion, it is an integral part of all societary systems [5]. The process by which an individual adjusts to the rules of the society is known as socialization. Through this process, the individual: satisfies his needs in socially acceptable ways; shares in the attitudes and values of the society; and, reacts to the rules of the society. Thus, a personal response or reaction to those rules might be expressed by moving from, or disassociating himself from, that society.

Societies have both simple and complex rules for conditioning individual behavior. These rules characterize the control in the societary system [60]. The rules are learned by social imitation, or this conditioning to the collective acts of others [59]. And, they are distorted by conflicting motives and status [103]. A social motive or need can be achieved through affiliation, close companionship or attachment; or, through status, the ranking of individuals as perceived by the society. The status rules are a means of determining dominance. When formalized, these rules are often manifested in local ordinances and administrative policies.

Urban Policies for Development and Control

Considered as a collection of neighborhoods, the urban system tends to control itself through an evolving set of written and unwritten rules and policies. Urban policy is usually created for cities or high density areas. Several examples are next discussed.

First, there are the zoning laws which presumably have an economic basis, among others, and are purportedly used to promote economic efficiency and equity [58]. Zoning originated in Germany and Sweden during the Industrial Revolution; whereas, the first zoning law in the U.S. was enacted in New York City as recently as 1916 [21].

The idea of zoning is based on two major assumptions. Firstly, like users of land should be together. Secondly, certain areas are best suited for particular uses [114]. The motivating principle maintains that the ultimate use of the land should be for its "highest and best purpose" [58]. However, the principle does not seem to prevail in its detailed execution [9].

As far as residential property is concerned, the zoning laws affect the neighborhood either at its boundary or within its structrue [108]. Adjacent areas may have some effect, but not as severe as the initial zoning assignment for middle-class communities.

What appears to be the case for a vast majority of residential communities constructed in the U.S. in the past 25 years is that the initial zoning assigns a minimum lot size [9]. This, in effect, describes the density or number of persons per unit area, dictating several ensuing and crucial development processes. From this density figure, the profit, an ever-present incentive mechanism, appears to be maximized for the developer and builder by partitioning a large parcel of terrain into plots of nearly equal size.

This procedure of uniformity standardizes the construction; e.g., a few basic styles of buildings with several slight variations, and, ultimately the cost of each dwelling. Since the land cost is usually a fixed percentage of the final sale price, the zoning assignment actually dictates the range of initial selling prices.

As an example, recent figures [62] indicate that a standard ratio between raw land cost (X) and the final unit sale price (Y): X/Y = 1/20. In other words, the raw land cost is about 5% of the selling price. In 1960, single-family land found for $1000 per unit forced the price of the dwellings into the $20,000 to $25,000 category. By 1974, land values had risen to $4000 to $5000 per acre. With typical average densities of 2.3 units per acre, the raw land cost becomes $2065. By the standard ratio, the final sale price is $40,500. This data is exemplary of certain parts of DeKalb county (Georgia) according to available data [4].

A second control device is the use of taxes. The specific instrument in neighborhoods is the property tax structure. Ideally, taxation appears to be both necessary and desirable for both social and economic reasons [9]. However, it has been noted that taxes can also serve to produce economic decline and to entrap in poverty a segment of the population that could strive for greater self-sufficiency [19]. The great and present danger is that high or misapplied taxation may drive residents away from housing which could upset traditional municipal economic bases[108]. Such a move is obviously self-defeating, since people generate municipal expenditure for schools, fire and police protection, transportation, welfare and others.

In Chapter VII, two alternative tax strategies will be discussed, and the results of the simulation of two different policies analyzed. The first is that of the property tax relief whose aim is to assist fixed income families or those in lower valued housing. This strategy quite often, however, actually produces the plethora of substandard dwellings which contributes strongly to blighted conditions. The second and decidedly opposite strategy is that of a "tax deterrent" which would force the removal of substandard facilities, but creating the difficult problem of simultaneously providing alternative housing.

Finally, a third class of urban policy includes administrative regulations and local ordinances. These consist of building codes, property and building use regulations, local income and sale taxes, welfare, low income housing, and rent control. Other control can be exercised through fence ordinances, real estate codes, and public services. This last item includes refuse collection, street cleaning, park maintenance, and others.

Many established communities have ordinances which limit the size or height, and type by degree of visibility of fences, barriers, or outside walls [111]. One consideration in the explanation of behavior in neighborhoods is that fences tend to extend the abstract personal space, thus reducing the frequency and duration of individual contact.

Although real estate sign ordinances vary widely throughout the country, a universally regulated commodity is information. The agents inform buyers of sellers and vice-versa. The practices, strategies, and general manner in which this information is made available have lately gained public interest. Policies which seek to control real estate activity have focused on real estate signs. The "For Sale" sign has become the singularly most important control feature regulated by local ordinance.

The application of community services perhaps has not heretofore seemed as an appropriate control device. It has lately been regarded as an effective means of implementation of social policy. Recent actions by citizens in several metropolitan counties [121] indicate that there is concern for the following as effective yet subtle control mechanisms: water and sewer services; parks and recreation areas; sanitary services; fire and police protection; and, school policies and facilities.

A final important topic deserves mention here; i.e., the anti-discrimination laws. These Federal laws have repealed local law and custom which segregated urban areas and neighborhoods. In many U.S. cities, residential zoning had dictated black and white communities. Customary practice throughout the world has delineated communities along ethnic, social, or religious organization. While the elimination of discriminatory law and practice is noteworthy, it has fostered more turbulent neighborhood patterns, unethical real estate practices, and attendant community problems [109].

Urban Simulation Models

In his Urban Dynamics [32], J.W. Forrester proposed an Urban Dynamics Model, or UDM, which examines the life cycle of an urban area using the methods of systems dynamics [31]. Subsequent controversy surrounding this particular model concerned: the manner and medium in which it was presented, which was not the usual research or academic channel; and, the admitted lack of advice or scrutiny by a widerange of professionals in urban disciplines [65]. Nonetheless, due to its timing, scope and relevance, the UDM represents a first important attempt to model an urban area. The UDM depicts a social system such as a city or urban area which is composed of three categories of people: managerial-professional, labor and underemployed. The people "flow" to and from areas within the system depending on the relative "attractiveness" of an area to its surrounding environment. Besides the population segment, business and housing are also major components.

In 50 to 250-year life cycles, the UDM version of an urban area "grows, matures, and stagnates" based on a complex, self-regulating system that creates internal pressures that modify economic activity, shifting land use, structures and people. All changes are dominated by construction, aging, and demolition of industry and housing combined with concurrent population movements [2].

Many extensions and suggestions to the UDM have been made [12]. Most notable has been that of Chen [16,17] who recommended incorporating the modifications of urban experts. However, most all agree that the causal structure in the UDM should be retained, because it appears more useful in providing insights to policy decisions than correlational data analyses[2].

A more serious criticism often leveled at the UDM, and other social process models, is that there are implicit values hidden under basic assumptions on which the models are constructed [49]. Different values would not only change the objective functions, but also affect the values of the aggregate variables in the initial structure.

Finally, there appears to be a need to extend the UDM to suburbs, rural areas, and undeveloped areas; and, to incorporate aspects of individual decision-making [43].

There are also urban planning models such as the: Nagoya Model [1]; Detroit NBER Model [64]; Pittsburgh Model [81]; and, San Francisco Model[6]. The earliest notable urban study by computer was the classic Penn-Jersey Transportation Study [57]. Using a novel approach, Orcutt's microanalytical model [99] of a socioeconomic system utilized individual decision-makers. Lowry's model [81] was interesting because of its hierarchy of embedded loops.

The Nagoya (Japan) Model looks at the preference function of each household, the decision-making unit of residential location. Based on the occupation, income, education, etc., a search mechanism is employed using standard utility principles and functions.

The National Bureau of Economic Research (NBER) developed the Detroit prototype urban simulation model drawing heavily on earlier models [67]. The multivariable regression analysis related residential location, property values, commuting behavior, and the selection of development sites.

Lowry attempted to forecast future development in the Pittsburgh area by another utility maximizing model [81]. In an empirical manner, this model simulated the statistical regularities in the geographical distribution of populations. Although it resembles a social physics approach, the model has no time dimension and the only behavioral concept is the minimization of aggregate transportation costs.

The Community Renewal Program (CRP) commissioned Arthur D. Little, Inc., to develop the San Francisco Model. The CRP examined the effects of public policy; e.g., zoning, rent subsidies, mortgage guarantees, etc., by utility principles similar to the Nagoya Model.

Generally representative of most urban planning models, the purposes of the CRP were to: develop alternative, long-range strategies and programs for renewal and redevelopment; serve as an on-going tool for city government, permitting officials a continuing method to test consequences prior to implementation of policies; identify and maintain key statistical indicators to alert the city of the rate and direction of changes affecting it; and, improve the flow of available information.

The original version of the CRP used 30,000 to 35,000 computer instructions, and approximately 15,000 items of data for each run. Although it should have provided predictive answers to many questions about redevelopment in the San Francisco area, the authors conceded that it was not successful for this intended use [6]. The major benefit to date has been the education of city officials and design staff who, after being exposed to the data collected, have become experts on housing conditions in the city.

Typical problems of such planning programs have centered on the models, or lack thereof. The CRP suffers from a glaring model oversight.

There are no feedback loops to incorporate modifications in the behavior of the people of the communities based on changes in policies regarding residential housing. Thus, behavioral variables are considered as inputs to the model whereas some dynamic, adaptive changes are ignored [6]. This is a serious omission. Commonly observed housing patterns in the U.S. support a basic premise of the real estate industry that people do modify their perception of both the availability and physical desirability of housing. And, large numbers of Americans base housing selection on perceptions of the apparent social status of the neighborhood [93].

Additional criticisms of these planning models are that they: are either too large or too small in scale; do not really deal with the crucial issues such as race and poverty; are politically irrelevant; and, are operationally complex and expensive requiring inordinate amounts of data [7,17,130].

A summary of modeling criticisms has been compiled by Ginsberg[44,45], and others [10,17,130,134]. They suggest that most current large-scale urban simulation models: have insufficient substantive or theoretical content; are of little scientific or practical use without causal structure and realistic exogenous variables; need some variability in model values and inputs; yet, show the limits of regression analysis and pure probabilistic mechanisms in the state transition processes.

Systems, Models and Simulation

A clear distinction is sometimes difficult to make among the terms 'system,' 'model,' and 'simulation.' When not otherwise qualified, a system refers to the real world states and relationships of interest.

One meaning of model is a set of abstractions, equations or computational operations, which provide the conceptualization and necessary simplification for analysis. Simulation is a form of model experimentation which allows partial reconstruction of the time-histories of the model for different conditions.

Models of physical systems attempt to relate measureable properties of certain observable phenomena; e.g., electrical, mechanical, hydraulic, and thermal. Models of societary systems must include representations of psychological, sociological, economic, and ecological dimensions. In general, mathematical models of such systems are drawn from assertions of causality. They are sets of time functions which map state variables corresponding to the entities and dimensional representations. Additional terminology and definitions can be found in [87,91,92].

Suffice it to say at this point that a very important simulation decision must be made at the outset. This is the selection of the modeling methodology or technique best suited for the simulation task. This decision may be clouded by the numbers, types and degree of overlap of currently available methods. Neither an exhaustive list nor a detailed discussion will be attempted here. But, several interesting techniques will be mentioned, which are: systems dynamics [32]; eco-systems [92,98], GERT [106]; input-output [79]; and, purely mathematical techniques [22,28].

Forrester's systems or industrial dynamics models utilize many linear and non-linear algebraic, logical and difference equations. Using discrete time representations, behavior patterns of rates, ratios, values and numbers of persons, dollars, and commodities are created and controlled within closed feedback loops. The simulation is performed with a DYNAMO compiler.

Ecologic and eco-systems models also involve difference or differential equations. The structure can be algebraic, graph-theoretic, analog, and again simulated by a DYNAMO-like translation. Although possessing many similarities, these approaches vary greatly in the simulation execution and model interpretation.

GERT or Graphical Evaluation and Review Techniques provides a means to model in a discrete fashion the decision dynamics of selection, costing, scheduling, and termination. Information on activities and events in the nodes and branches are represented by graphical symbols and charts which offer probabilistic, symbolic, and Boolean functions in its structure.

The state models allow a disaggregative approach with a different modeling thrust in the simulation. Models, such as the Leontief Input-Output Model, seem quite useful for regional and national product specification. State values characterize the dollars of each sector which are presented in matrix form. Different levels of activities can be computed from input-output calculations of demands, imports, policies, etc.

Queuing models are useful whenever there are characterizations of demands for processing from a number of sources. Factors considered include the probability distributions underlying arrival and in-process times, the number of waiting lines and processing facilities, and the queue discipline.

Markov, or sequential techniques, are related to the order in which the processing occurs. In this class of techniques, an important measure of effectiveness is the sequence or order of the processes. Again, distinctions between these latter two models may be obscure since they share many similarities while being quite different.

Network analysis (PERT and CPM), linear and dynamic programming, game theory, information and decision theoretic, and other optimization and analytic procedures [66,70,134] are also useful as modeling techniques. However, basic taxonomic problems make it difficult to concretely specify particular applications or to partition these methods into non-overlapping categories.

Further, some promising techniques seem to be embedded within the theory of Cellular Automata (CA), von Neumann's last contribution [128]. While CA appears to possess powerful mathematical tools from which a rich series of results have been generated, it has yet to be applied to many potential problem areas [46]. Nonetheless, its utility lies in the novel and natural ways in which one might model social processes with the possibility of different solutions to persistent modeling problems.

Many of these ideas were suggested in what was commonly referred to as 'social physics.' These classical efforts have been reflected in mathematical sociology and biomathematics, and are evidenced in current work of Dodd [25], Bodington [10], and others [24]. Societal modeling has been done by Windeknecht and D'Angelo [23,131,132], Knuth [71], and Kemeny [70].

The manner in which complex dynamic social processes can best be represented mathematically is neither trivial nor obvious. Modeling difficulties often arise because most mathematical formalisms best accomodate closed, rigidly structured, fixed dimensional processes.

Forrester [33] has observed, conversely, that models of social or complex systems are characterized by: differential equations of high order; multiple positive and negative feedback loops; non-linearities; and, otherwise poorly specifiable expressions. Stability and control may be effected only through influence points, and sometimes with temporary, perverse performance [35]. The responses of such systems to control measures has been frequently observed to be insensitive to parameter changes, and resistant to policy changes exhibiting counteraction to corrective programs with both short and long-term opposition [32].

Therefore, some of the basic questions regarding the structure and dynamics of complex systems remain unresolved. Since adherence to traditional approaches has not always proved satisfactory, the development of new modeling alternatives remains an important area of investigation.

CHAPTER III

CONTEMPORARY HUMAN NEIGHBORHOODS

The first step in the design of a simulation model of a human neighborhood is a suitable description. Such descriptions depend to a large degree on the morphology of definitions and assumptions which reflect the point of view to be presented. And, the description serves as a basis for a more formal, or quantitative, model from which a translation to simulation expressions can be made.

Since our purpose is to study the structure and dynamics of a contemporary community by simulation, some perspective, historical and fundamental, of the urban evolution should be given.

Historical Perspective

One popular view of the contemporary city is that, as an advanced urban form, it emerged quite naturally with civilization. Urban constituents have become known as neighborhoods or communities. However, the term 'neighborhood' should not be considered synonymous with the term 'community.' The former conveys a sense of physical proximity, and the latter a sense of sharing, either space or association.

Cities, although still an evolving form of the human settlement, have exhibited certain constant properties. They are always relatively large in size, dense in population, and limited internally in space. Necessary for their existence are an agricultural surplus, transportation, industry, technology and service support such as water, sewerage, and disease control.

The neighborhood likewise has reflected urban evolutionary change. Developments in transportation, for instance, have permitted an increased separation between work-place and residence. Although differing greatly in culture, most modern urban communities increasingly exhibit anonymous interpersonal relationships, impersonal institutions, and shifting political emphasis. However, the commonalities of contemporary human neighborhoods are broader yet, since it can be argued that the organization can be shown to be a form of the societary system previously described.

Societary System Perspective

Despite the evolutionary aspects, it appears that diachronically human neighborhoods are societary systems that contain, at a minimum: some individuals, space, resources, and procedures for generating _rules_. A set of premises for rule generation is as follows: for survivability, the individuals seek the security of societies against the uncertainty of potential disaster; cooperation and competition is required within the society to gain certain limited resources such as shelter, sustenance, and space; the competition provides a means to establish dominance, or status, thus removing some uncertainty; each individual seeks to protect and upgrade his own status based on the knowledge of the status of others; and, rules are created and modified to regulate the processes of the attainment of status, and the distribution and use of resources.

This fundamental perspective appears not only constant in time, but also independent of the cultural setting. However, the implementation may take many varied forms. In the contemporary U.S. urban environment, the rules are embodied in policy, law, or custom which contributes to the initial structuring of neighborhoods, and in the dynamic control of their ever-changing character.

Neighborhood Evolution

We define two processes which contribute to change in the contemporary neighborhood. The first is the initial structuring; and, the second is the continuing development. In the initial structuring, the density or zoning assignment is usually made concomitantly with a commitment for construction financing. These two decision events dictate the initial real estate activity, and the development costs; which, in turn, determine the initial social and physical characterization of the neighborhood.

Continuing change is derived from rezoning, redevelopment, or changes in local ordinances, real estate practices, and community customs. Such changes are brought about by a human reevaluation, a closed-loop control process. Therefore, the mathematical description of this control involves feedback loops. As the neighborhood evolves, it is controlled by the dynamics of loops that carry information regarding certain levels of aggregate attributes which are perceptible within the neighborhood. As these levels are compared to various thresholds, action is taken locally to regulate the changes in other levels.

Figure 1 illustrates the nature of the control processes in contemporary neighborhoods. The zoning mechanism has been explained in terms of its effect on the structuring of the physical community. The financial policies of lending institutions and the practices of real estate agencies control the socioeconomic character of the community.

Another change mechanism in neighborhoods has been characterized by sociologists as a process of "invasion and succession." In this process, contiguous areas are inhabited successively by different groups of individuals. These involve 'flows' of individuals into and out of a neighborhood such that the neighborhood simultaneously controls and is controlled by these flows.

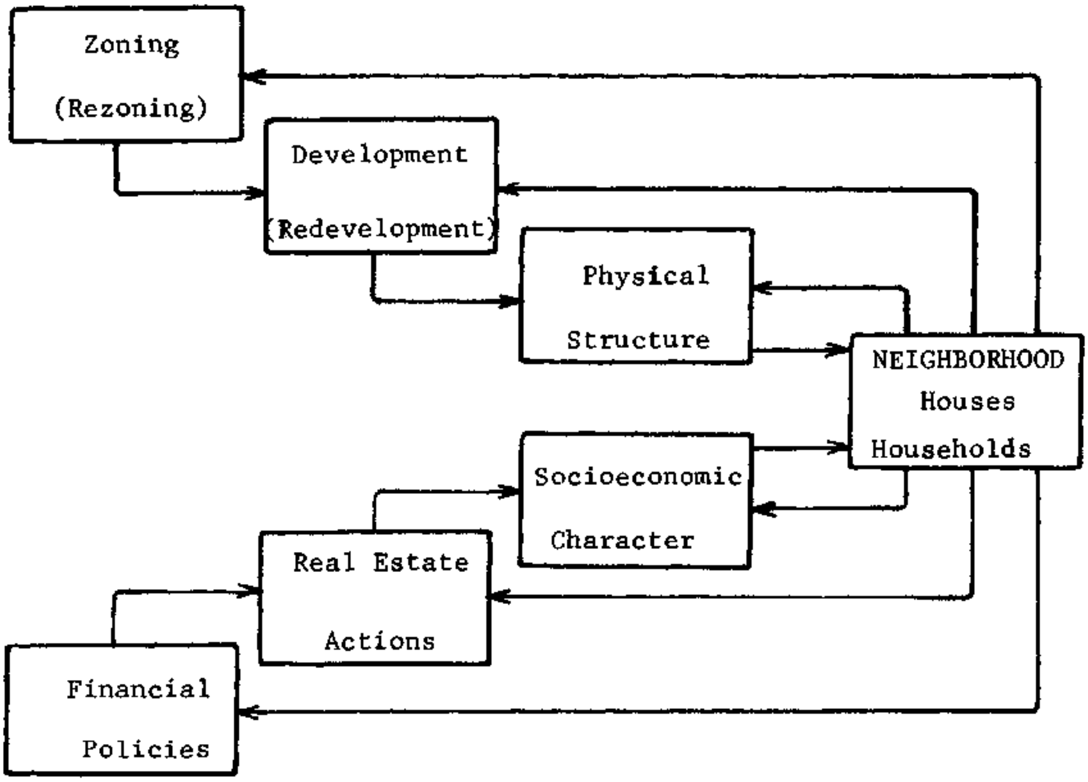


Figure 1. Control Processes in Contemporary Neighborhoods.

A closed-loop version of the above-mentioned process can be seen in Figure 2. Again, we observe that the character of the neighborhood itself determines who enters and leaves; and, the combination of these inflow and outflow processes contributes to the new character of the neighborhood. The latter two processes are commonly called immigration and emigration, and are next discussed in terms of stability of the neighborhood.

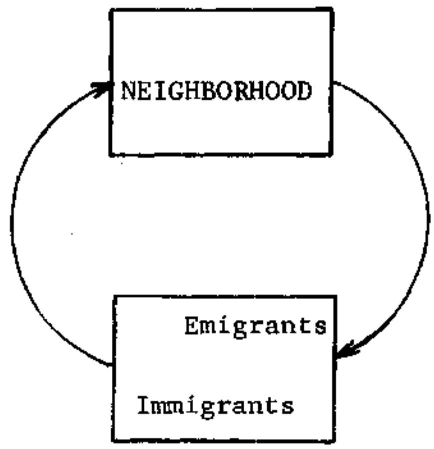


Figure 2. The Neighborhood as a Self-regulating Unit.

Stability and Transition

In this section, we will attempt to answer the following questions. What is meant by a stable neighborhood? What is meant by a transitional neighborhood? What are some of the most common plausible explanations of a transition phenomenon? Finally, from the point of view of research, who is most interested in neighborhood stabilization and transition?

The dictionary defines stability, as it applies in our case, as that property of a system which causes it, when disturbed from a condition of equilibrium or steady state, to develop the necessary actions to restore it to its original condition. With only a slight modification, we then define a stable neighborhood as one which under normal dynamical changes, or the sudden turbulence of high turnover, remains at or returns to the same distributional values of its attributes within a short period of time such as a few years, for example. By contrast, a transitional neighborhood experiences changes for which there is no noticeable return to previous values within a similar period of time.

General systems theorists regard stability of certain organisms as homeostasis, or the property of returning to a normal state [10]. The normal state, it may be contended, is difficult to define; or, in fact, it may be time-varying. Nonetheless, there are some important characteristics of societary systems which resemble homeostasis.

The first observed quality of a stable system is that of group cohesion, or the "psychological glue" that keeps the group together. The more homogeneous the attitudes as expressed in behavioral attributes, then the more cohesive the group structure. However, heterogeneous groups can become quite cohesive if presented with a sufficient external threat.

The second feature is group commitment, or a measure of the willingness of group members to subordinate personal desires for the attainment of group goals; viz., group survival. What is interesting to note is that very demanding groups often endure longer than others. Frequently, this commitment is related to the quantity and quality of the intergroup communications [47].

It is generally agreed that contemporary transition can be inspired externally by urban growth, social and physical mobility; or, internally, by forces associated with the local distribution of attributes. Explanations of this phenomenon involve certain cause-and-effect relationships. Listed below are several proposals and counter-arguments.

The first explanation is that transition parallels normal urban growth. However, the "flight to the suburbs" is inconsistent with a proponderance of data showing movement from suburb to suburb [109]. A second idea is that transition reflects movement up the social ladder; i.e., from poorer to better neighborhoods. However, much movement is lateral between like neighborhoods; or, by individuals who are neither poor nor low on the social ladder. Other moves are into older, well-established areas, where many poor reside, from newer, more expensive suburban areas usually for the purpose of restoring older homes [98].

A third explanation is that movement is mostly outward from the center of an urban area. Again, transition more often appears patchwork, rather than a continuous and progressive movement in any particular direction [84]. A final explanation is that transition is only the turbulence of normal population mobility. However, many stable neighborhoods experience very high turnover, yet remain intransitional [109].

Thus, it can be seen that cause-and-effect mechanisms may not be easily explained. And, an important reason to build models is to test causal relationships for such notions as stability and transition in human neighborhoods.

Hence, the importance of such efforts can be potentially quite significant. Two groups of researchers have expressed an interest in an HNM. The first group are the urban problem-solvers, city planners and urban sociologists. They are preoccupied with problems of migratory disruption and changing community needs. Their concerns are unanticipated population changes both in density and composition, as contrasted to existing plans and projections. Urban sociologists and human ecologists are curious in "invasion and succession," an example of which is racial transition to be discussed next. The second group are the operation researchers, computer scientists, and others who utilize mathematical models. This group should find simulation studies with new modeling approaches interesting and stimulating.

Racial Transition

The dynamics of racial transition accounts for several notable considerations. Firstly, an increasing demand by blacks and other minorities for housing is attributed to both rising population and income level. Thus, need accentuates desire for better dwellings, schools and opportunities [98]. Secondly, through a mechanism of "steering" or screening, real estate agencies direct blacks and whites into different areas [109]. The third consideration is a real estate tactic known as "blockbusting" which amplifies the "invasion and succession" process. This unethical, and often illegal, maneuver plays upon the fears and suspicions of the residents resulting in heightenened anxieties and a disproportionate number of turnovers in a relatively short period of time [37].

A characteristic curve which reflects the progress of racial transition in an Atlanta neighborhood is shown in Figure 3. See Appendix C for additional data. The slope of this curve yields the rate of transition at any particular time; where a steep slope indicates a rapid turnover and a more moderate slope corresponds to a moderate change. This curve also exhibits two other important features. It provides a measure of stability in terms of racial composition; and, a threshold level is identified.

In the first case, the normal annual turnover rate in such communities is approximately 10% where the majority of new occupants in racially transitional areas are black as a result of "steering." Secondly, the noticeable threshold level is, and often observed to be, approximately 35%, a point at which the rate of change increases markedly.

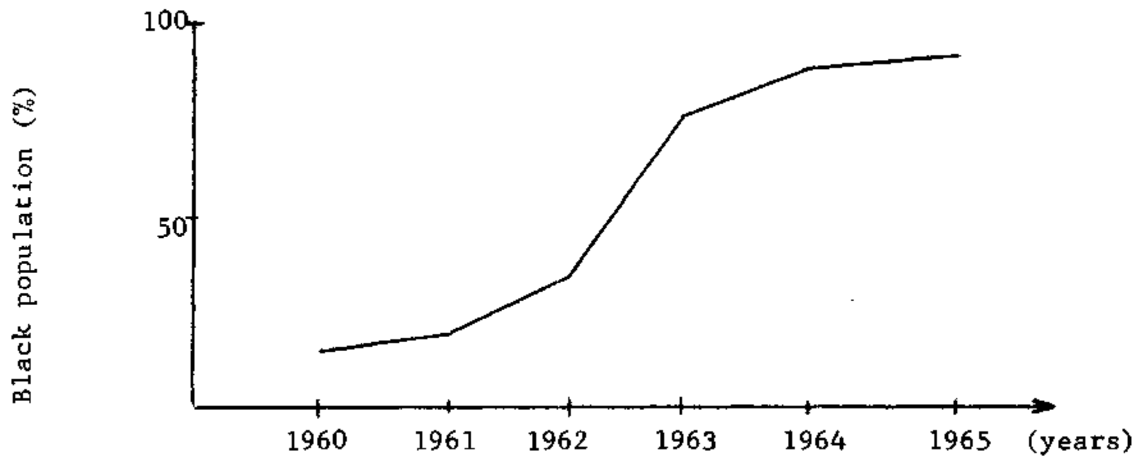


Figure 3. Progress of Racial Transition.

The threshold issue is often linked to the creation of ghettos. Here, the term 'ghetto' implies an urban area in which certain racial or ethnic groups are restricted. A ghetto seems to have, among other attributes, less formal organizational structure, and a number of contagious social pathologies [39]. The forces that maintain ghetto systems are the: prejudices of majorities against minorities; legal and governmental barriers; and, actions by real estate and financial institutions [48].

The home building and sales industries have traditionally maintained that they should never be instrumental in introducing into a neighborhood a character of property or occupancy, members of any race or nationality, or any other individual whose presence will be clearly detrimental to the property values in that neighborhood [99]. Practices, therefore, to assure neighborhood homogeneity and compatibility are proper and justifiable [14].

Some practices become, however, unethical, such as: refusing to show available houses; quoting excessive prices; falsely stating that houses are sold which are not; demanding unfair down payments; and, failing to keep appointments. Concerned citizens groups have reacted to counter such practices. They seek alternatives that would permit: integration without the spread of ghettos; and, stabilization in social, economic, and racial demographics [2,37]. Crucial factors appear to be: the proximity of an established ghetto; the tolerance levels for minorities; the preparation for minority entrance; and, the rate of entry [81].

Stabilization

While the concepts of stability and change are not new, each era encounters them differently. Change is quite disturbing to contemporary communities in two ways. Firstly, the more successful may wish that things remain as they are. The second is that the less fortunate may fear an even further deterioration in their status. Thus, change can be a real threat, and the desire for security quite fundamental [40,112].

We conclude this discussion with a pair of definitions that distinguish throughput and transition. Throughput is defined for our purposes as the measure of migratory activity in terms of numbers of movers in and out of the neighborhood, together with the duration of residency indicators. Transition is the rate of change of property values, school performance, conditions of the parks, or the racial and socioeconomic composition. While the rate of turnover or throughput is important, additional analysis is gained by developing rates of change of certain aggregate neighborhood characteristics.

CHAPTER IV

MODEL METHODOLOGY

General

To model the contemporary neighborhood in a systematic manner, we begin in the following tentative way. Admittedly, the real neighborhood is far more complex than the simple societary system previously described. We must account for: physical features within a delimited area; internal distribution of political and legal powers; mutually supporting economic subsystems; and complicated interrelationships between individuals and groups between and within social orders.

No single standard modeling methodology could possibly suffice for such a specification. However, certain modeling techniques from mathematics, statistics, general systems research, decision theory, and operations research could be combined for a first formulation. Given the nature of the system to be modeled, insights from sociology, economics, psychology, management and political science also would be useful.

Since it is our intention to ultimately specify a simulation model, certain risks must be accepted and the limitations recognized. Since there are few unifying theories, most simulation studies are necessarily *ad hoc*, and highly specific to a particular problem. The strength of simulation, however, lies in its malleability in method, and potential for a high degree of complexity.

A Hybrid Approach

A modeling procedure was therefore proposed and justified as follows. In free market and free migration areas, decisions concerning changes in location of residence, occupation, educational level, social status, standard of living, etc., are made and implemented by individuals, families, or households [56]. Such decisions are based on the specific desires of individuals who, in turn, are influenced by environmental pressures, and constrained by their individual abilities, values, awareness of opportunities, and luck. The degree to which the urban neighborhood as a whole responds depends not only on the availability of skills and resources, but also on the extent to which the participants may be affected by the social rules, laws, and policies.

In order to represent such activities in reasonably accurate detail mathematically, three kinds of relationships are required. Firstly, the manner in which these individual decisions are made suggests that they may be modeled deterministically. Moreover, these decisions are based on individual attributes; viz., desires, skills, resources, and awareness, which are statistically distributed in populations. Finally, the aggregate performance of the neighborhood is affected by closed-loops which express the participants' control processes in feedback structures.

Thus, a technique to incorporate these features was adopted and the structure, dynamics, and control of such a model are next separately discussed. This hybrid approach borrows certain portions of traditional methodologies, and utilizes the resulting configuration for both analysis and interpretation. Three main methods are so used: Cellular Automata(CA), Monte Carlo (MC), and Feedback Dynamics (FD).

From CA, a full working model would include: a predefined cellular neighborhood; a set of transition rules; a specification of states; and special rules for delimitation and transition of cells at or near the boundary. For our purposes, we shall extract these fundamental aspects of CA: the gridlike cellular space; discrete time states for each cell in the grid; transition functions whose arguments are the states of the cells from time t to t+1; and, templates for each cell, considered as a collection of sub-neighborhoods. One template might be, for example, the eight cells orthogonally and diagonally adjacent to one particular cell. The transition functions map the states of the cells in time. Other usual terminology can be found in [46,85,128,129].

MC provides a means of specifying stochastic distributions and generating random variates. Thus, for each cell, it is then possible to specify an array whose elements are random variables. See Appendix D for some additional discussion. However, since most of the techniques are well known, no further elaboration is needed here [52,82].

The notion of feedback control is taken from FD and extended to both individual and aggregate variables because both are available in the model. The goals of a feedback control system are to: reduce the sensitivity to parameters or a process variation; reduce the sensitivity to output disturbances; control the system variances; and, control the transient and steady-state responses. Further discussions can be found in [30,31,32,33, 34,35].

Static Structure

The structure of the model must mirror real physical factors of an area or setting, as well as the psycho-socio-economic attributes of the residents. We shall call a space and time representation of such a model a <u>societal</u> <u>model</u>. Components of such a model correspond to individuals distinguished by their capacity to make decisions.

Each individual is described by certain characteristics. These, in turn, are modeled by an array of variables which can be assembled in a matrix structure. For example, $I_j(v_1,v_2,v_3,\ldots,v_k)$ represents the j^{th} individual with the k attribute variables v_1 through v_k. The individuals are further characterized by a few decision-making algorithms; and, a group of a particular decision type represents a behavioral paradigm. Each decision type is uniquely identified by a particular v_i.

The static model structure is, therefore, an m x n matrix for m individuals and n attributes which shall be called $\mathbb{V}(t)$. Thus,

$$\mathbb{V}(t) = \begin{bmatrix} v_{11} & v_{12} & v_{13} & \cdot & \cdot & \cdot & \cdot & v_{1n} \\ v_{21} & v_{22} & v_{23} & \cdot & \cdot & \cdot & \cdot & v_{2n} \\ v_{31} & v_{32} & v_{33} & \cdot & \cdot & \cdot & \cdot & v_{3n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ v_{m1} & v_{m2} & v_{m3} & \cdot & \cdot & \cdot & \cdot & v_{mn} \end{bmatrix}$$

A relative advantage of such a matrix is the straight-forward manner in which the aggregating, disaggregating, and logical processes can be performed. A second advantage is that the variables are chosen based on the decision algorithms to be modeled. The order and degree of importance of the variables is hypothesized for a particular decision process. They can be initially generated by MC techniques, or inputed separately. The parameters and distributions can be obtained from real data.

Dynamics

The model dynamics can be accomplished in one of three ways, which are always performed in a sequential fashion on the matrix of values, $\mathbb{V}(t)$. For deterministic state transition functions, the expressions are as follows:

$$\mathbb{V}(t+1) = f[\ V(t),\ \mathbb{E}\ ]\ ,$$

where $\mathbb{E}$ is the exogenous variables. For stochastic state transition functions, the symbolism is as follows:

$$\mathbb{V}(t+1) = g[\ V(t), \mathbb{E}, \mathbb{r}\ ]\ ,$$

where $\mathbb{r}$ is a random number. For mixed functions, partially stochastic and deterministic, the latter notation will also be used.

The changes, or dynamic consequences, which can be characterized by this formalism are: the entrance of new individuals into system by the addition of new arrays; behavioral adaptation or changes in the current residents by the transition functions; and, departure of individuals from the system by the deletion of arrays.

The most crucial aspect of this modeling approach may be the development of the distributions of variables for $\mathbb{V}(t_o)$. This is discussed in more detail in succeeding chapters. A major interest will be in the dynamics which the discrete time processes appear capable of accomodating.

Stability and Sensitivity

It was anticipated that some degree of self-regulation could be achieved by the methodology. And, a non-trivial extension to the standard cybernetic notion might be advanced in which control is affected at a different hierarchical level than it is implemented. Further, time lags or delays, or the discontinuities in the model performance could be analyzed by different variables at individual and aggregate level.

Control in the model would be accomplished through a combination of local and global feedback loops. At the local level, actual and potential residents sense attribute changes in their neighbors. In the model, this decision process is carried out by ranging over the values in a particular array. On the basis of several evaluations, decisions are made to move in, move out or change behavioral attributes. Such individual changes are reflected in the aggregate neighborhood attributes.

At the global level, the major control loops allow the levels of particular aggregate output variables to be used in the determination of new input variables. This is accomplished by resetting the values of the parameters for external distributions, not values of individual variables, from which new sets of individual variables are drawn.

The model dynamics with such a structural matrix requires through iteration a large number of local or micro loops which correspond to individual decision processes. The overall effect of these micro loops is then reflected in routine changes of the aggregate or macro variables. Thus, macro variables influence the generation of micro variables, and vice-versa.

Then, the following question arises. How can the stability and sensitivity of such a closed-loop process be contrasted to social equilibrium ? The answer is entirely speculative, one must recognize, since there is little agreement on a definition of social equilibrium. However, it is generally agreed that most social systems maintain some dynamic stability. Yet, the stress on a heuristic utility of the concept such as is done in the physical sciences is not warranted. There, equilibrium represents a convenient assumption of great usefulness in establishing deterministic conditions within a system of interdependent variables. A homeostatic version of equilibrium contends, alternatively, that equilibrium may be an essential property of organic survival, but cannot be considered as a handy starting or reference point [5].

It should be recalled that Homans [59] asserted that equilibrium may not be a state toward which human systems move. In fact, equilibrium may neither be a full accounting of social dynamics, nor even a desirable goal. Instability may be as characteristic of living things as stability. Therefore, the need for a model that exhibits both behaviors is recognized.

This last conclusion places additional emphasis on the normally difficult problem of sensitivity. The usual sensitivity approach is to record the relative changes in an identified variable as a function of changes in some initial value or parameter. A modified *ceteris paribus* technique will be adopted for this model, and is discussed in Chapter VI. A priori, there appear to be at least two stability sensitive features of this model. The first concerns the types and inter-dependence of the distributions from which are generated the matrix of individual variables. The second encompasses the parameters and initial values of the input variables. In either case, the questions of sensitivity and control are inseparable, and the feedback loop control is next discussed.

Feedback Control

FD or feedback dynamics models have a systems structure composed of loops that account for accumulation and flow variables. In the simplest case, as shown in Figure 4 , pressure or force influences the flow based on a comparison of information about the accumulation value relative to a goal.

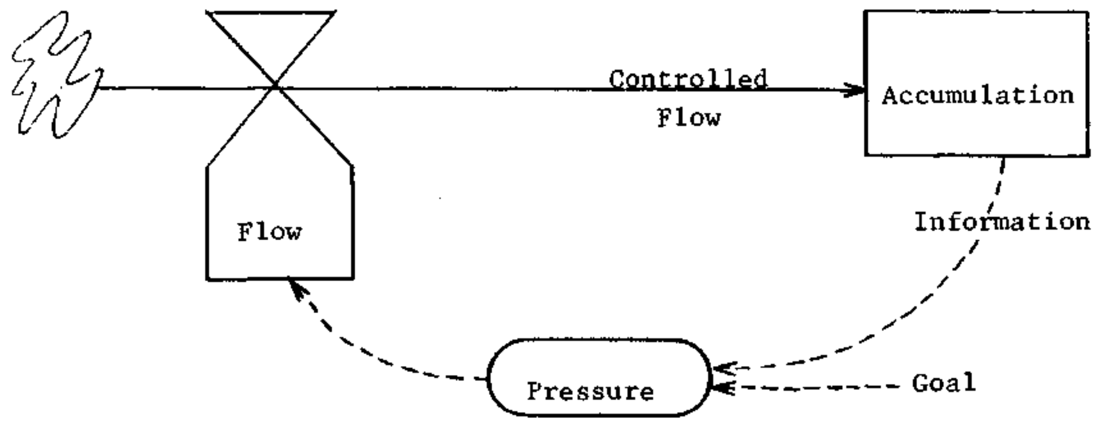


Figure 4. A Simple Feedback Loop.

The notions of flows and accumulations are not restricted in application, as the concept of loops can be seen in many different representations. However, some slight modification may be necessary to use the loop ideas in a model of a human neighborhood. Firstly, the flow will be thought of as a discrete removal and replacement process. Secondly, the structure must deal with both individual units such as families and houses, and their aggregated counterparts. Finally, control loops will be necessary to connect both the micro and macro levels.

While the intent here is not to explore the micro-macro structure in depth, we shall be aware of several important problems when mixing micro and macro variables in a feedback model. Firstly, the modeling emphasis proceeds from a lower to a higher mathematical construction, although the performance of the system is observed in the opposite manner. Secondly, since it is difficult to devise quantitatively defensible models based on currently available data, we shall attempt to represent important components and interaction which allows the most consistent terminology between the model and the real system.

The Hybrid Model

The usual advantage of hybrid models is as follows. Although it must still be evaluated separately on its structure, dynamics and control, a judgment on the overall technique can be made somewhat independently of parametric values and implicit assumptions. Further, the best features of several different methods can be used in the formulation, and certain disadvantages eliminated.

A totally deterministic approach such as from CA proves too simplistic since it omits both control forces, and a certain necessary level of randomness. A purely probabilistic method requires a considerable amount of very accurate data, while possibly excluding causal effects. Lastly, the usual feedback dynamics approach employs aggregate expressions which are sometimes difficult to determine and validate.

Advantages of the hybrid approach are: the speed and flexibility of developing the matix of variables, $\mathbb{V}(t)$; the ease and precision of tracking the transitions by the computer; the rather natural aggregation and control features; and, the potentially powerful verification tests.

Figure 5 illustrates the hybrid model which incorporates stochastic variable generation, discrete state transition processes, and feedback control. The output from each cycle, from t to t+1, can be viewed as a distribution from a class of possible distributions. The input is an array of parameters, and the change processes map the matrix, $\mathbb{V}(t)$, in time.

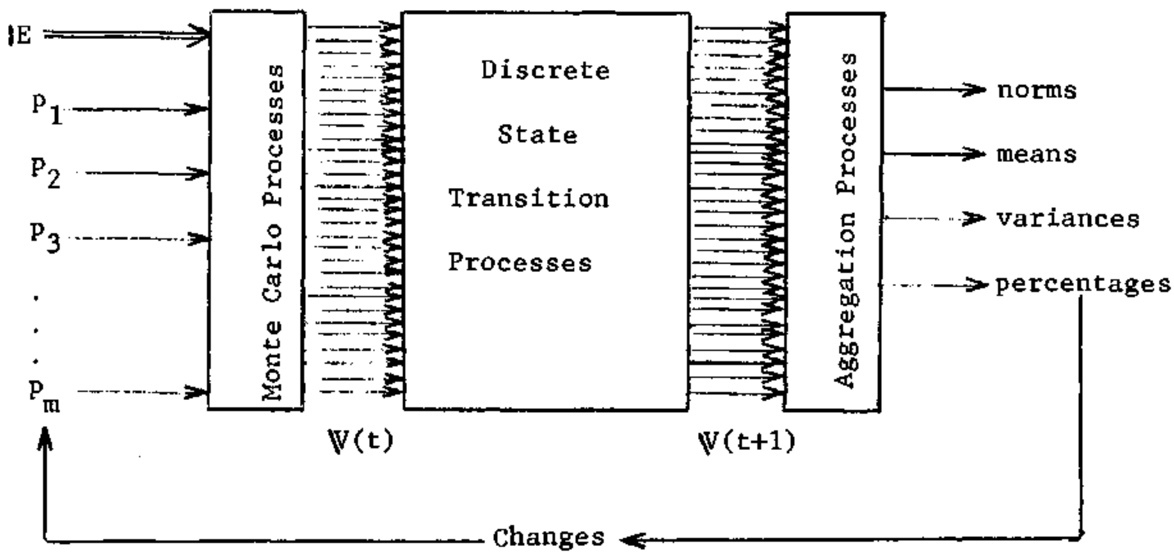


Figure 5. A Hybrid Simulation Model.

The simulation process entails changes in the state description by transition processes assumed to occur at certain discrete instances of time. This is done either by deterministic Boolean expressions, or by random MC functions. The feedback control maps changes in the aggregate variables; e.g., norms, means, and variances, into a new set of parameters for the random variable generation.

CHAPTER V

HUMAN NEIGHBORHOOD MODELS

Introduction

In this chapter, the construction of the simulation program for the human neighborhood model is discussed. Basically, the simulation will allow the manipulation of the variables representing the characteristics of houses and occupants in order that the dynamic results can be interpreted in terms of movement of residents and changes in the residences.

Corresponding to the general societal model framework explained in Chapter IV, the quantitative components of the HNM are next assembled which account for the entrance, change or adaptation, and exit of individual residents in a hypothetical neighborhood setting. The overall aspects of the simulation model are briefly discussed to include the inputs, outputs, states, transition processes, and control loops. Each of these topics then in turn is described in more detail. Finally, a series of flow diagrams yields the final sequencing of simulation events.

The Neighborhood Model

General

To assist in the explanation of the simulation model, an idealized and simplified neighborhood is now presented. This hypothetical neighborhood has resident families living in four street blocks of houses. Each house is already built and situated on a lot. The lots are arranged in a rectangular block of 64 with four streets between rows of houses. The model keeps track of and updates through time various characteristics of the houses and resident families. For the purposes of the analysis, no new houses are built nor old ones torn down; and, multiple family occupancy is not permitted.

The principal functions of the model are to identify families that leave the neighborhood, to generate new residents to replace those that leave, and to update through time the characteristics of the then current houses and residents. There are both individual characteristics of each house and family, and aggregate characteristics of the group of houses and families (neighborhood).

The forces that determine departure, immigration, and change arise from random events, the recognition and evaluation of individual characteristics, and the recognition and evaluation of aggregate neighborhood characteristics. The characteristics of each house that are important include an identification number, the physical condition of the house, the aesthetic attractiveness of the house, the appropriateness of the house by type in the context of the adjacent houses, and the approximate dollar market value of the house.

Each resident family is characterized by an identification number, an annual income or economic status, social status, propensity to improve its respective property, a degree of awareness of differences in characteristics of adjacent residents and residences, and length of residency in years.

The annual moving decision for each resident involves random non-neighborhood factors, comparisons of personal and house characteristics with those of adjacent neighbors, and comparisons of personal characterisitics with the aggregate neighborhood image. Various factors (e.g., company transfer, retirement) not associated with the neighborhood condition result in an average percentage of the residents moving each year. This choice in the model is random.

The resident compares his social and economic status, and the value and type of his house with that of his adjacent neighbors. The number of neighbors with whom he compares himself depends on an individually and randomly selected degree of awareness factor. The greater the differences between the resident and the previously determined adjacent neighbors compared to neighborhood averages, the greater the likelihood of an individual decision to move.

The resident also compares his social and economic status to a measure of the aggregate neighborhood social and economic condition or image. The residents that find themselves significantly above the neighborhood average are more likely to move than the others.

Whenever a resident decides to move, an attempt is made to resell his house. Potential buyers are attracted by sales efforts. The personal and financial characteristics of each potential buyer, and the conditions of the real estate market determine whether a sale is made. Potential immigrants are determined by availability, affordability, and desirability of a given property.

The number of potential buyers is a function of the availability of money for mortgages. In turn, each prospective occupant decides whether or not to buy an available property until one of the following events occurs: the sale is completed; or, the number of buyers for that property is exhausted without a sale effected. Exhausting the supply of buyers for a particular property is equivalent to the situation in which a house remains for sale, either vacant or occupied, for one year.

It goes without saying that the dynamic changes in real neighborhoods occur in a simultaneous fashion. However, in the hypothetical setting, all modifications to individual characteristics or the aggregate image must be accomplished in a sequential fashion. Changes that occur to the characteristics of the remaining residents and to all of the residences are assumed to happen as follows. Adjustments are made only annually to the market value and relative condition of each of the residences, and to the social and economic statuses of the residents.

The dynamic changes to the residences concern the market revaluation of those properties not involved in a sale during the current year. The new property value is a function of the old value, the annual inflation rate, and the improvements made by the occupant. Higher inflation rates and/or increased capital investment by the occupant means a higher market revaluation for the particular residence. And, if the market value increases and substantial improvements are made to the residence, then the individual relative condition factor increases.

There are two primary annual changes to the resident characteristics. The first is an adjustment of the annual income. This is performed on a random basis to selected wage earners, and the amount of increase/decrease is a function of the annual inflation rate. If the inflation rate is above a certain level, the annual wage for a selected wage earner is adjusted by the amount of the difference. The second change to individual characteristics is the enhancement of social status derived by the length of residency. The longer a resident remains in the neighborhood, the higher will be the individual relative social status.

Aggregate Control Features

There are five ways in which the results of the decisions of the individual residents just described and the changes in aggregate neighborhood characteristics affect the characterisitics of the new or incoming residents and the conditions of the residences in the next year.

Firstly, the number of non-random movers influences the degree of sensitivity of remaining occupants as to their moving decision criteria. More simply, a greater number of movers caused by individual decision processes with individual characteristics increases the chances that others will move for the same reason.

The second feature is that the accumulation of newer residents will affect the method in which real estate agents select additional prospective buyers. For example, a salesman is more likely to try to sell a home in an area of a certain socioeconomic composition to a prospective buyer who appears to the salesman to be of like status.

Thirdly, the availability of mortgage loans in a particular area is a function of the rate in which certain movers leave the neighborhood. This group includes the random movers, and, more importantly, the movers due to significantly higher socioeconomic status as was earlier discussed.

The fourth control feature is that the level of vacant properties in the hypothetical neighborhood will influence the willingness of the incoming residents to improve their properties. In other words, the more vacancies that there are lessens the likelihood of maintaininn the residences to any extraordinary degree.

The fifth and final control feature involves the mean residency time ik the neighborhood. The longer that residents remain in the neighborhood, on the average, increases the expectation of potential buyers as to the relative condition of the properties.

Brief Discussion of Simulation Model

The following illustration (Figure 6) identifies the inputs, outputs, state transition and feedback control processes in the simulation of the hypothetical neighborhood.

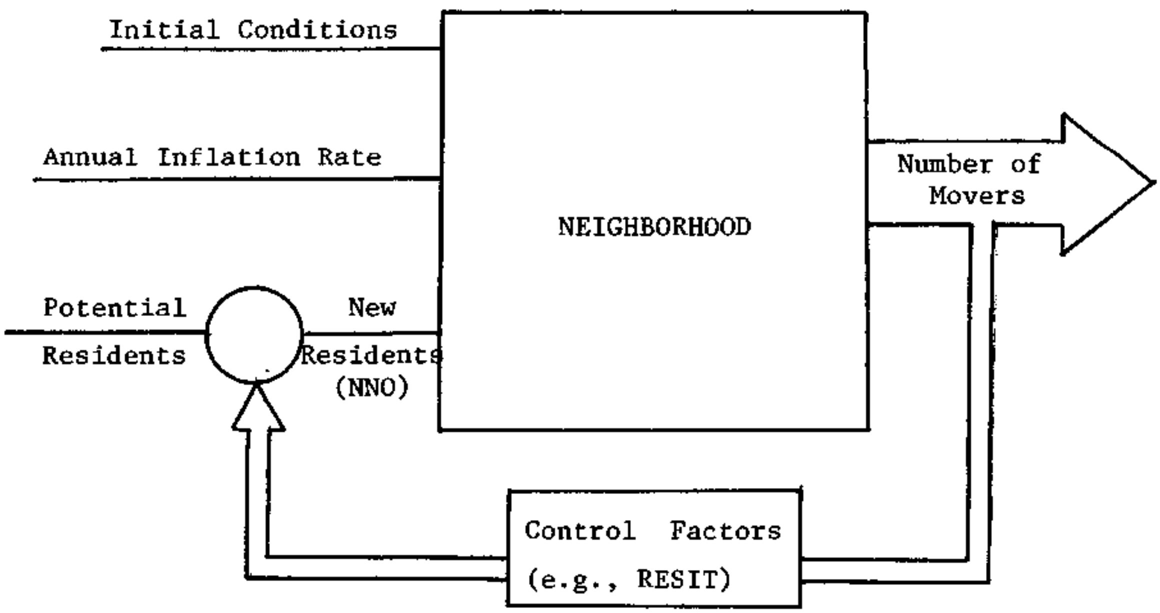


Figure 6. General HNM "Flow" Diagram.

The individual inputs, as will be noticed later, are numerous. For simplicity, they can be grouped into initial conditions, an annual inflation rate, and the local real estate agency control. The outputs are equally extensive. However, information on change is conveyed by the numbers of movers and other dynamic neighborhood statistics. The state transition processes are accomplished in four major steps that comprise a single time advance or cycle. The results of each cycle are then utilized as control factors for the next cycle through several major feedback loops.

Inputs. In the terminology of the hybrid model discussed in Chapter IV, the input array IE has two elements: the annual inflation rate (FLAR) and the flow of new residents (NNO and RESIT). There are several other initial parameters and exogenous variables which are used to produce the initial conditions corresponding to the initial setting of the houses and occupants.

The primary external control input is FLAR. It is involved in recalculating property values, annual incomes, mortgage availability, and the number of buyers for each saleable property. This variable represents an entity which can be considered a direct result of some global state of affairs.

The second class of inputs are derived from the list of variables denoting incoming residents. These inputs partially depend on the present conditions of the neighborhood in terms of both residents and residences. The number of new occupants (NNO) is determined each cycle and serves as one indicator of throughput.

Lastly, the initial conditions for each simulation include a total number of cycles designated by NUMCY. The condition prevalent for the first cycle is the initial state of the model where each state corresponds to the current disposition of the residents and residences. These states will be discussed in greater detail in a later section.

Outputs. The major outputs denote the numbers of movers with the following special distinctions. NCM is the variable which describes the number of causal movers, in the model sense. NRM indicates the number of random movers, and NAO, the number of occupants that are attracted away. The sum of these three variables then yields the total number of movers which is recalculated each cycle.

These three variables mentioned are also important from the point of view of throughput. The relationship is shown in the following expression:

$$\text{NCM} + \text{NRM} + \text{NAO} \quad = \quad \text{Total number of movers/cycle.}$$

Needless to say, there are many other outputs from the model. Only some will be identified here, and all will be discussed in more detail later.

The other important output variables indicate the current degree of socioeconomic dispersion (DMEAN), the average length of residency(ALS), and the average value of the properties (AHV). Stability and sensitivity studies will utilize these outputs and are found in Chapters VI and VII.

States of the Model. The states of the model can be divided into those characterizing residences versus those characterizing the residents. Several endogenous variables are used for these state descriptions, and these variables are either stochastically generated (pseudo-randomly) or deterministically computed (by closed-form algorithm). There are both individual and aggregate computed and generated variables used in a variety of simulation roles.

The variables which characterize the attributes of residents are: an identification number (ID), an economic status (ES), a social status (SS), an awareness factor (TF), a property improvement factor (IMPF), and a length of residency (LS). Denoting the houses are variables for: the location within a grid (LOC), property value (HV), an amenity index (AI), the relative condition (RC), and a coupling factor (C) by type.

Computed individual variables are: the "functional" or socio-economic "distance" between each resident (DIST) and from each to the neighborhood average (D), the amount of money available for a mortgage (AMTMORT), the adjusted selling price (SELPR) and the number of buyers (NB) for each available property.

Further, the states of the model can be changed through time by periodic state transition processes which can occur: each cycle, corresponding to annually; during the cycle, as during the year; and, as needed or intermittently, depending on the values of the variables in the state arrays. In the state transition processes, the following variables are changed in the aforementioned ways. HV, RC, DIST, And D are recomputed each cycle (year). ES and SS are changed during the cycle and perhaps more than once. NB, AMTMORT, and SELPR are always changed as needed. ID and TF are changed only intermittently. Finally, LOC and AI are not changed from their initial values, usually.

<u>State Transition Processes</u>. The state transition processes are divided into four main activities. In each activity, several major algorithms may be performed. Each activity corresponds to a specific real neighborhood event but with modifications required by the idiosyncracies of computer simulation.

In the first activity, the primary annual updating and time advances occur. Here, changes are made to HV, ES, SS, LS, D and DMEAN. These variable changes account for an annual ageing, etc., which is observed in the real neighborhood.

Causal out-migration is accomplished in the second activity. In this activity, decision algorithms involve calculations of LOC, DIST, and differences in C and HV with appropriate orderings of SS and TF. This is analogous to the individual decisions which lead to an expressed moving behavior.

The third activity includes all other moving events. Again, these are of essentially two different types. The first are those random non-neighborhood related moves. The second are those moves precipitated by the reaction of the individual to the neighborhood aggregate.

The fourth and final activity concerns the selection of new occupants or the replacements of residents who have moved or have decided to move. The variables NB, AMTMORT and SELPR are recalculated. New individual values of ES, SS, ID, TF, IMPF and LS are generated.

The detailed explanation of the state transition functions will be given in a later section. However, next to be discussed are the model variables.

Model State Variables

Characterizing the houses are the variables which represent the property values (HV), the relative condition (RC), the amenity index (AI), and the coupling factor (C). The values in HV are the normalized relative market values on a zero-one scale. RC is a collection of integers which shows the level of relative condition of each property to adjacent ones. AI is a collection of integers which indicates an innate amenity index or relative attractiveness of one property to the next. C is a collection of integers which reflects the the degree of similarity of one property to the others by style or type.

The array (THA,THB,THC,THD) comprises the input parameters which are initially used to determine the property values considered in the initial conditions. The four values in the array indicate that a triangular distribution is used for stochastically generating these values. For further explanation, see Appendix D.

The geometry of the subdivision of houses under investigation is provided by two variables, N and LOC. N is the set of integers from 1 to 64. LOC is the set of ordered tuples derived from (1,2,3,4,5,6,7,8) X (1,2,3,4,5,6,7,8). An algorithm in the simulation program maps the values in N to the pairs in LOC.

The variables ID, LS, TF, IMPF, ES, and SS are employed to denote each and every resident. ID is a collection of identification numbers, one for each occupant. LS is a collection of integers which measures the length of residency in cycles (years) for each occupant. TF is a collection of integers which specifies the extent of individual awareness in terms of spatial templates. Each template uniquely describes the specific adjacent neighbors for each occupant. IMPF is a collection of integers which reflects the individual resident's propensity to materially improve the residence or property.

The economic status (ES) is a variable which indicates the normalized relative value of annual income for each household. Admittedly, there is a strong correlation between social and economic status. However, in this model, two separate non-independent values are used. Apparent social status (SS) is a collection of values, on the zero-one scale, which accounts for the individual behavioral social marks. The array (TXA,TXB,TXC,TXD) controls the generation of the individual values in SS, again restricted in the same manner as was HV and its array. Similarly, ES is initially composed by the use of the array (TYA,TYB,TYC,TYD).

Variables Characterizing Residences In this section, the variables RC, AI, C and HV are discussed. Whenever applicable and possible, the justification for the choice is noted.

The relative condition of each residence (a value in the array RC) is initially assigned randomly from a discrete uniform distribution function, such as: $\hat{g}[U(e,f)] = RC$, where e and f are minimum and maximum values. RC is a dynamic collection, and the expressions which change its individual values are shown in a later section.

AI, the amenity index, is determined from an overall neighborhood aesthetic factor (AEFAC). It is assumed that the relative attractiveness of properties and houses is uniformly distributed in small neighborhoods[4].

Hence, an initial specification is: $\hat{f}[U(c,d)] = AI$ where c and d are minimum and maximum values. This variable remains constant during the simulation.

C is the variable which indicates the coupling between properties. It provides a means to monitor the similarities or relative mutual effects between properties. This similarity can be the type or style of house, for example. However, this variable was also used for a certain amount of records-keeping during the simulation consistent with its role in the model. Thus, it could also indicate the relative frequency of "turn-over" or the "reason" of the last sale of a particular property. In the initial conditions, however, it is generated from a set of uniform discrete random variables.

The present value of each house, HV, is a normalized value initially obtained by a triangular distribution function such as: $\hat{h}[T(a,b,c,d)] = HV$ where a, b, and c are the minimum, model and maximum property values, respectively; and, d is the ordinate associated with the value 'b' for a triangular distribution. The distribution and the local neighborhood values were chosen to correspond to Atlanta SMSA 1970 census data [127]. See Appendix C. Successive values in HV are computed as will be explained in the section on microdynamics.

Lastly, the two variables pertaining to the neighborhood geometry were previously identified as N and LOC. A grid on the next page associates the corresponding values in each set. Urbanologists [42,61] have noted that the physical geometry of urban areas in general can be classified as: radial, linear, curvilinear, or gridlike. The last structure was chosen for its convenience and generality.

1 1,1	2 1,2	3 1,3	4 1,4	5 1,5	6 1,6	7 1,7	8 1,8
9 2,1	10 2,2	11 2,3	12 2,4	13 2,5	14 2,6	15 2,7	16 2,8
17 3,1	18 3,2	19 3,3	20 3,4	21 3,5	22 3,6	23 3,7	24 3,8
25 4,1	26 4,2	27 4,3	28 4,4	29 4,5	30 4,6	31 4,7	32 4,8
33 5,1	34 5,2	35 5,3	36 5,4	37 5,5	38 5,6	39 5,7	40 5,8
41 6,1	42 6,2	43 6,3	44 6,4	45 6,5	46 6,6	47 6,7	48 6,8
49 7,1	50 7,2	51 7,3	52 7,4	53 7,5	54 7,6	55 7,7	56 7,8
57 8,1	58 8,2	59 8,3	60 8,4	61 8,5	62 8,6	63 8,7	64 8,8

Figure 7. The HNM Grid Structure.

In the 8 X 8 grid of Figure 7, each square contains an element in the set N and an element in the set LOC. For example, the position numbered '45' also has the designation '6,5' in the grid.

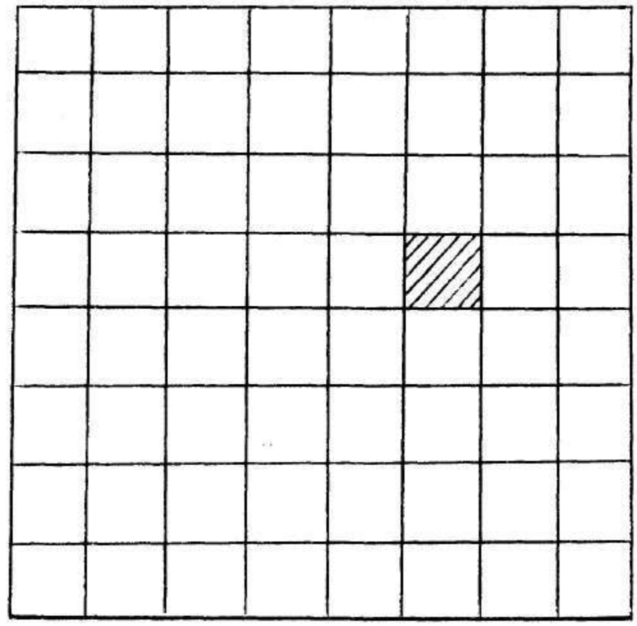
Thus, each grid location can be accessed either sequentially or by spatial proximity, a fact which will be of great importance both for the model and in its simulation.

Variables Characterizing Residents The resident portion of the model contains those variables which are related to households. Again, there may be, perhaps, little agreement as to the definition or method of measure for many of these variables as data are often inconclusive to justify their distributions. It is standard practice, therefore, to assume that many traits, characteristics, and attributes are normally distributed in populations [75]. And, the distribution of wealth and income often conforms to a Pareto-like function [83]. In this case, however, the small group size ($n \leq 64$) renders extremely difficult any strong claims regarding specific distributions. The uniform and triangular distributions proved particularly useful. The variables thus represented and discussed here are: TF, ID, IMPF, ES, SS, and LS.

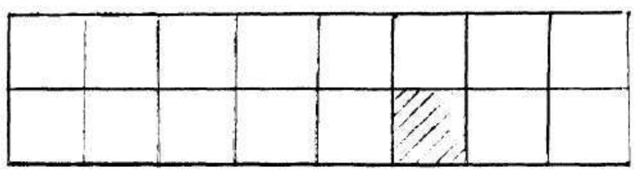
TF, the individual awareness factor, describes the degree to which each occupant and decision-maker senses changes in the neighborhood. The variable denotes a particular template similar to that of the CA model discussed in Chapter IV. In the HNM, it is a specific measure of "distance" from a particular residence and is reflected in the computation of certain functional distances. In a real sense, TF is analogous to the personal space discussed in Chapter II. TF is initially generated from a discrete uniform distribution. And, a different template is associated with each value in the following way.

For integer values, $1 \leq TF \leq 5$, the algorithmically defined spaces or templates are illustrated by several blank grid spaces and one shaded grid location. This indicates that the resident occupying the shaded location is aware of conditions associated with all of the unshaded locations; viz., in the first case (TF=1), the entire neighborhood.

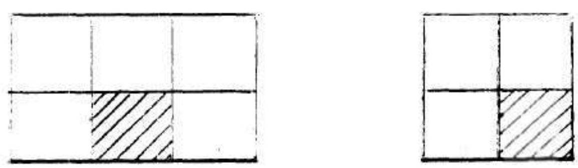
TF = 1



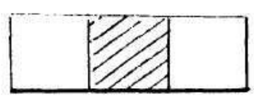
TF = 2



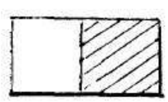
TF = 3



TF = 4



TF = 5



The identification number (ID) is self-explanatory in the sense that it provides a means to identify a collection of individual variables as a single entity; namely, the characteristics of a single resident. This number is initially produced from a uniform distribution of integers from zero to 99999. However, in order to monitor initial occupants, the ID numbers for the initial residents range from 100000 to 199999. And, an individual ID is reset to zero to indicate a vacant house.

The variable IMPF is a measure of the degree of relative propensity on the part of the resident to assist in the capital appreciation of the property. With no clear guidance as to the manner in which this attribute is distributed in populations, this variable was also randomly generated in the model. It also remains invariant during a particular simulation for a given individual.

The economic status (ES) uses normalized values on a zero-one scale from a triangular distribution to reflect annual income. The minimum, modal and maximum values were taken from data in the 1970 census for the Atlanta SMSA [127]. See Appendix C.

Another socioeconomic dimension was created by the use of another variable to represent the social status (SS). The idea of splitting economic and social standing is not novel. It admits a distinction between "wealthy" and "fashionable" as noted in [68,116,122]. These two variables, ES and SS, allow the creation of a socioeconomic space and the development of the concept of functional distance.

The length of stay (LS) or tenure (TEN) is the length of residency of a particular resident in cycles for the simulation corresponding to years in real time. LS is initially randomly generated from a discrete set.

A model control variable, ADJ, was created to provide a means of adjusting the relative distance values and is discussed in the section on computation that follows. In an input role, it serves as a switch which enters in a calculation which can lead to resetting values in TF. Dynamically, ADJ serves to adjust DMEAN based on the performance of PCCM which is discussed in the section on macrodynamics. ADJ assumes real values, and is generally equal to one.

HNM Outputs Several of the output variables that are used to monitor the global behavior of the HNM simulation are expressed as percentages. These variables are the percentage of vacant houses (PCVC), of causal movers (PCCM), of other movers (PCOM), of new occupants (PCNO), and of maximum tenure (PCMT).

PCMT is computed as follows:

$$PCMT = \frac{ALS(t_k)}{ALS(t_o) + k} \cdot 100$$

where $ALS(t_o)$ is the initial average tenure, $ALS(t_k)$ is the average tenure in the k^{th} cycle, and the denominator above indicates the maximum possible value of average tenure for cycle k.

The other percentage outputs are self-explanatory. Additionally, there are several aggregated computed variables which determine minimums, maximums, and average values for many of the variables previously described. There are average: property values (AHV), economic status (YBAR), and social status (XBAR). The minimum values of social and economic status and property values are XMIN, YMIN, and HVMIN, respectively. The maximum values are XMAX, YMAX, and HVMAX, respectively.

NPA is the number of properties that appreciate in a given cycle determined by counting the number of instances: $\Delta HV_i > 0$; and NPD is the number of properties that depreciate , n($\Delta HV_i < 0$). NVAC is the number of vacancies, n($ID_i = 0$). NCM is the number of causal movers; and, NRM is the number of random movers. NOM is the sum of NRM and NAO, the number of movers simply attracted away.

NCM is computed in the following way. If a move occurs by a resident (change in ID) or if a property is vacant (ID=0) and a decision is made to move (TF=0); then, each instance is noted and the total count is recorded as NCM. The number of random movers is selected in the usual stochastic fashion. The movers attracted away are those whose socioeconomic status (both ES and SS) is much higher than the neighborhood average (XBAR,YBAR).

NNO is the number of new occupants. This statistic is determined by counting the number of values in the array ID that are less than 100000. See previous discussion on ID.

The question of which input variables directly affect which output variables is, indeed, difficult. Tantamount to this problem is the proper identification of the several hierarchical levels or tiers of inputs and outputs. The next diagram (See Figure 8) attempts to arrange the inputs and outputs accordingly. The subsequent sections discuss the microdynamics and macrodynamics of the HNM.

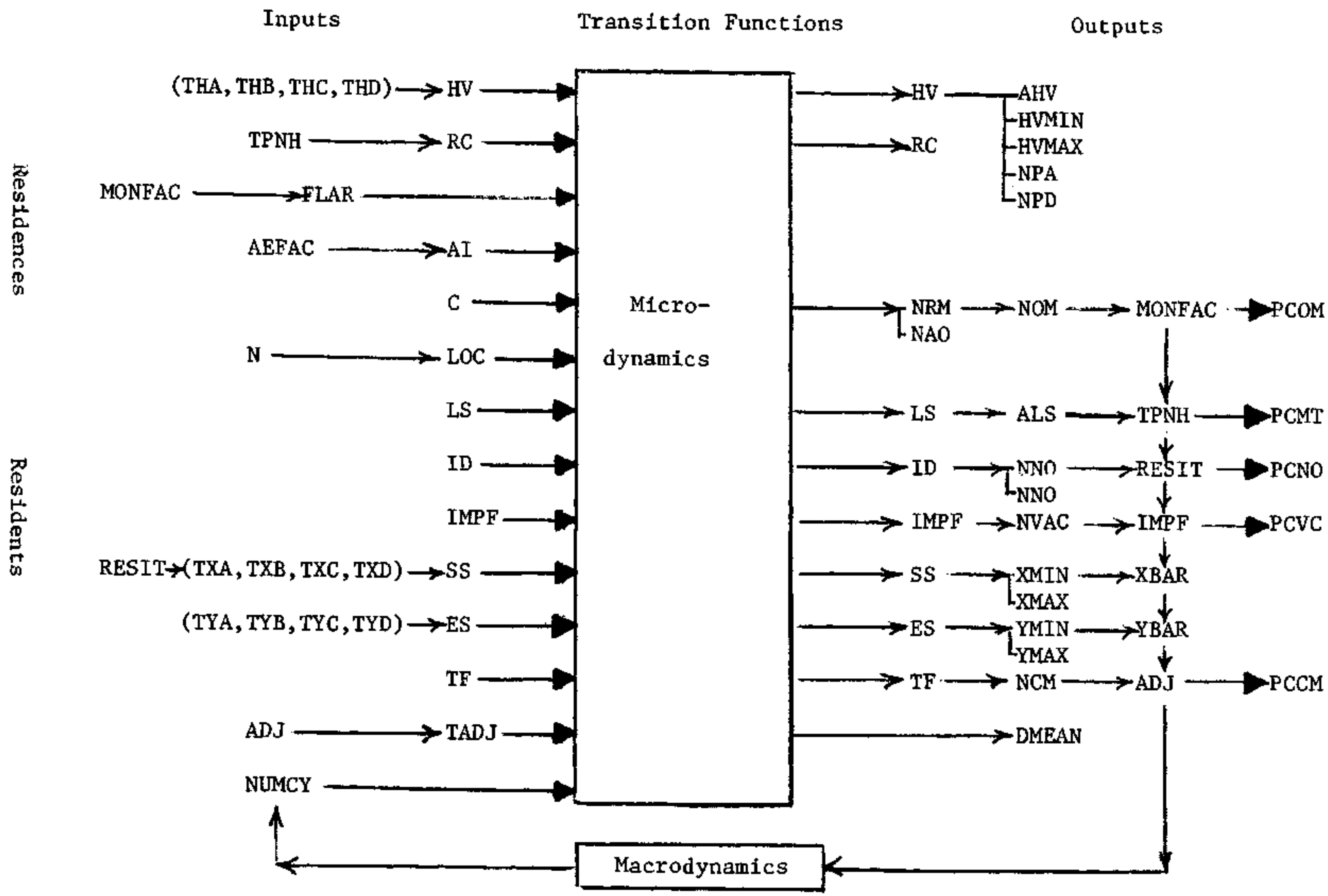


Figure 8 . HNM Input and Output Levels.

The HNM Microdynamics

The HNM accounts for the entrance, change or adaptation, and the exit of individuals. These three processes are reflected in three algorithms in the model which are greatly simplified by the following assumptions.

The exit mechanism operates the causal emigration as follows. The outward movement of families is based on the relative dissimilarity of perceived and displayed marks of socioeconomic status. This difference contrasts the functional distance to the proximity of certain neighbors.

The entrance of individuals or immigration is controlled in the following simplified way. Prospective buyers are generated as a function of the availability of loan money. Each prospective buyer is 'tested' as to his ability to buy and the characteristics he desires with the actual price and condition of an available property.

The change or adaptation processes entail a series of updating equations which correspond to advances in time of certain characteristics of the remaining residents and all of the residences.

Central to each of these algorithms are endogenous variables which are computed from the other individual variables previously introduced. In the following order, each is discussed: DIST, D, XBAR, YBAR, DMEAN, ALS, AMTMORT, SELPR, NB, DC, and DHV.

In order to discuss the computation, it is first necessary to describe a socioeconomic space. This space is created by designating SS and ES as the principal axes. See Figure 9 below.

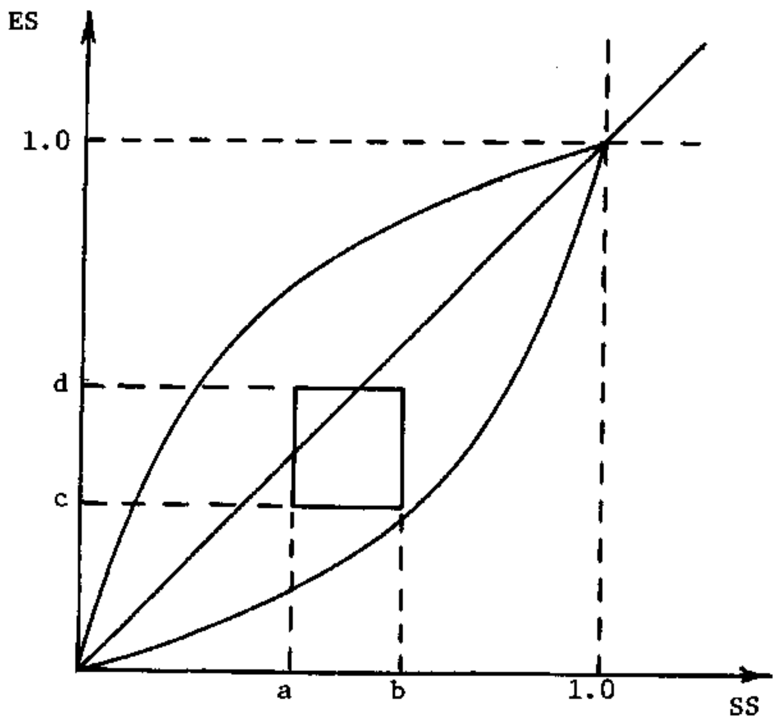


Figure 9. A Socioeconomic Space.

The local limits of a particular neighborhood are shown by the intervals (a,b) and (c,d). The area between the two curved lines indicates the proximate pattern of points in which there is dependence between the two variables, ES and SS. The distance measures can now be defined.

$DIST_{ij}$ is the functional distance between two residents denoted as (SS_i, ES_i) and (SS_j, ES_j), repectively. Then,

$$DIST_{ij} = \sqrt{(SS_j - SS_i)^2 + (ES_j - ES_i)^2} \ .$$

A second variable, D, is computed for each individual to indicate the distance between that individual (SS_i, ES_i) and the neighborhood aggregate (XBAR,YBAR). This variable is also used to compute DMEAN. Thus, we have

$$XBAR = \frac{1}{n} \sum_{i=1}^{n<64} SS_i \quad \text{and} \quad YBAR = \frac{1}{n} \sum_{i=1}^{n<64} ES_i \quad ,$$

and

$$D_i = \sqrt{(XBAR - SS_i)^2 + (YBAR - ES_i)^2} \quad .$$

The average socioeconomic dispersion, DMEAN, is then given by:

$$DMEAN = \frac{1}{n} \sum_{i=1}^{n<64} D_i \quad .$$

The average tenure, ALS, is computed in the same way:

$$ALS = \frac{1}{n} \sum_{i=1}^{n<64} LS_i \quad .$$

AMTMORT, SELPR and NB are three computed variables related to the process of selling houses. At the time of sale, the amount available for a mortgage (AMTMORT), the selling price of the property for sale (SELPR), and the number of potential buyers (NB) are determined in the following way. SELPR is an adjusted value of the current market value (HV) and the inflation rate (FLAR). AMTMORT depends on the annual income of the potential buyer (ES) and the combined effects of inflation and loan availability. Typically,

$$SELPR_i = [\ 1. + 0.02\ (MONFAC)\ ] \cdot HV_i \quad ;$$

and,

$$AMTMORT_j = ES_j \; [\; 1. + FLAR \;] \; [\; 1. + 0.1 \; (MONFAC) \;].$$

Finally, NB is a randomly generated integer which is also adjusted by the availability of money factor (MONFAC).

DC_{ij} is the absolute value of the difference between two values in the C array: $DC_{ij} = |C_i - C_j|$. DHV_{ij} is the absolute value of the difference between the property values at different locations: $DHV_{ij} = |HV_i - HV_j|$.

All of the computation in the HNM microdynamics is subordinate to the central idea that the model dynamics corresponds with the real neighborhood processes of emigration, immigration, and changes through time.

The emigration process is characterized by certain algorithms which are analogous to particular paradigms of individual moving behavior. Moving decisions are based on: physical proximity; socioeconomic distance; and, similarity of properties relative to certain neighbors.

In the immigration process, new occupants are selected by real estate screening; and, a sale is effected by a sufficient level of annual income together with a compatibility of desired and actual condition of the available property.

The dynamic changes are characterized by several equations in the model in which new values in certain arrays are recomputed based on previous values. Emigration and immigration are next illustrated by two examples, and the model equations are discussed subsequently.

The Decision-to-move Algorithm To determine if a particular resident becomes a candidate for migration, a series of decisions are made. Based on the location of the particular occupant, LOC_i, and his awareness factor, TF_i, the other locations in the template are identified, LOC_j. Then, in turn, each location and its respective resident in LOC_j are tested by the following algorithm. If a question can be answered by a 'Yes', the process continues; otherwise, another location in LOC_j is selected until all are completed. At that time, the next potential candidate is selected until all the residents have been tested. The process terminates as TF_i is reset to zero.

The questions are:

1. Is $DIST_{ij} > DMEAN$?;
2. Is $DC_{ij} < ICP$?;
3. Is $DHV_{ij} < HVSPR$?; and,
4. Is $SS_i > SS_j$?

where ICP and HVSPR are assigned or computed parameters in the simulation program.

The following example serves to illustrate this algorithm. Given the data below, the candidacy for migration for resident # 26 is made relative to resident # 30.

	# 26	# 30
LOC	4,2	4,6
TF	2	3
ID	43971	91706
ES	0.3968	0.3243
SS	0.5236	0.4688
HV	0.4944	0.5308
C	1	2

The values that are used for ICP and HVSPR are typical: 2 and 0.075, respectively. Location (4,6) is within the LOC_j of location (4,2) with the TF_{26} value of 2. In fact, all numbered locations 17-32 will be checked, but not used in this example. Further, the computation for some of the variables are not shown here but taken from earlier production runs.

DIST between 26 and 30 is found to approximately 0.009 which is greater than DMEAN, found to be 0.0075, so that the answer to the first question is 'Yes.'

Next, DC between 26 and 30 is obviously 1, which is less than 2, the value of ICP indicated above. Thus, the answer to the second question is also 'Yes.'

The third question question can also be answered affirmatively for the same reason. DHV in this case turns out to be 0.0364 which is less than HVSPR which equals 0.075 .

The fourth and final test is made on the ordering of the respective social statuses. SS_{26} is greater than SS_{30}, as $0.5236 > 0.4688$ attests. Therefore, TF_{26} is changed to zero, and the resident in the location (4,2) has become a candidate for migration. In retrospect, if this had failed, another location in the template would have been selected until candidacy confirmed or all locations failing. All of the residents undergo such a decision-to-move algorithm each year.

<u>The Decision-to-buy Algorithm</u> To determine if an available property is sold, and subsequently occupied by new residents, the following sequence of events occurs. A group of potential buyers, the number, NB, of which was previously discussed, is assembled from a particular socioeconomic segment and individually tested to determine if a sale can be effected. If the following set of questions can be answered affirmatively, then the sale is completed. Otherwise, the next potential buyer is tested until sale or the number of buyers is exhausted. The algorithm operates over all the available properties once each cycle.

The questions are:

1. Is AMTMORT > SELPR X FINFAC ? <u>and</u>,
2. Is LRC < RC ? or,
3. Is LAI < AI ?

where FINFAC is a finance factor expressed as a percent of the selling price (e.g., 95% corresponds to a 5% down payment); and, LRC and LAI are the desired relative condition and aesthetic factor, respectively.

The example below illustrates the above algorithm with the following data.

	Potential Occupant	Available Location
ID, LOC, N	38271	(7,3) or # 51
ES, HV	0.4382	0.5021
LRC, RC	2	3
LAI, AI	3	4

This supposes that there is at least one buyer; and, in this case, there were twelve potential buyers (NB=12) and only one of which has been described. For our purposes, let us assume that: FINFAC=1 which implies no down payment required; LRC=2; and LAI=3. These latter two values are randomly generated integers and functions of the expectations of incoming residents as previously discussed.

AMTMORT is computed to be 0.5364 since FLAR = 0.02 and MONFAC = 2;

whence, $$\text{AMTMORT} = \text{ES}\ [1.+\text{FLAR}]\ [1.+0.1(\text{MONFAC})]$$
$$= (0.4382)\ [1.02]\ [1.2] = 0.5364 \quad ;$$

and SELPR is 0.5222 since

$$\text{SELPR} = [1.+0.02(\text{MONFAC})]\ \text{HV}$$
$$= [1.04]\ (0.5021) = 0.5222 \quad .$$

Therefore, the answer to the first question is 'Yes.' And, the random selection between questions 2 and 3 is immaterial since the answer to both questions is 'Yes.' LRC is less than RC (2<3) and LAI is less than AI (3<4).

Hence, in this example, the sale of property # 51 at location (7,3) is completed to buyer number 38271.

The Updating Algorithms The third and final part of the HNM microdynamics involves the various updating routines which make changes to the endogenous variables from cycle to cycle. These changes reflect the processes of change and adaptation in the real neighborhood that were previously mentioned.

The variables highlighted here are: HV, SS, ES, RC and LS. The first is the change of the property values not involved in sales. The new value of each residence is recomputed from the old value, the inflation rate, and the capital improvements as shown here:

$$HV_i(t+1) = [1.+0.01(3.-IMPF_i)][1.+0.01(MONFAC)]\ HV_i(t).$$

The social status for each resident increases slightly as a function of the specific length of residency as follows:

If	Then
$LS_i \leq 5$	$SS_i(t+1) = SS_i(t)$
$5 < LS_i \leq 10$	$SS_i(t+1) = (1.02)\ SS_i(t)$
$10 < LS_i \leq 15$	$SS_i(t+1) = (1.01)\ SS_i(t)$
$LS_i > 15$	$SS_i(t+1) = 0.01 + SS_i(t)$

where, for example, SS would increase by approximately 1 to 2 % per year between the fifth and fifteenth years.

The changes in annual income (ES) are accomplished by the following routine:

$$ES_i(t+1) = [1. + K]\ \ ES_i(t)$$

where K is chosen by random selection from the set {0.01,0.02,0.03,...}.

The relative condition of each property remains the same unless: $\Delta HV_i > 0$ and $IMPF_i \geq 3$, whereby,

$$RC_i(t+1) = RC_i(t) + 1 \quad .$$

The length of residency of each occupant who remains during each cycle is advanced in the following and obvious fashion:

$$LS_i(t+1) = LS_i(t) + 1 \quad .$$

Other variables which are not recomputed, but which may be replaced are ID, IMPF, and C. The methods whereby these changes are made have already been discussed. The same holds true for TF whose changes were outlined in this section.

The HNM Macrodynamics

The HNM dynamic control is provided by macro-micro linkages in which several main feedback loops connect the different hierarchical levels. See Figures 8 and 10. Initially, certain aggregate or macro-variables influence the parameters of stochastic distribution functions from which are generated the individual or micro-variables. Subsequent micro-changes, as noted in the section on microdynamics, are reflected in statistical processes such as summations and averaging by which the aggregate or macro-variables are modified. Ultimately, with these new output values, the parameters are again changed and new micro-variables are generated as the loop is repeated.

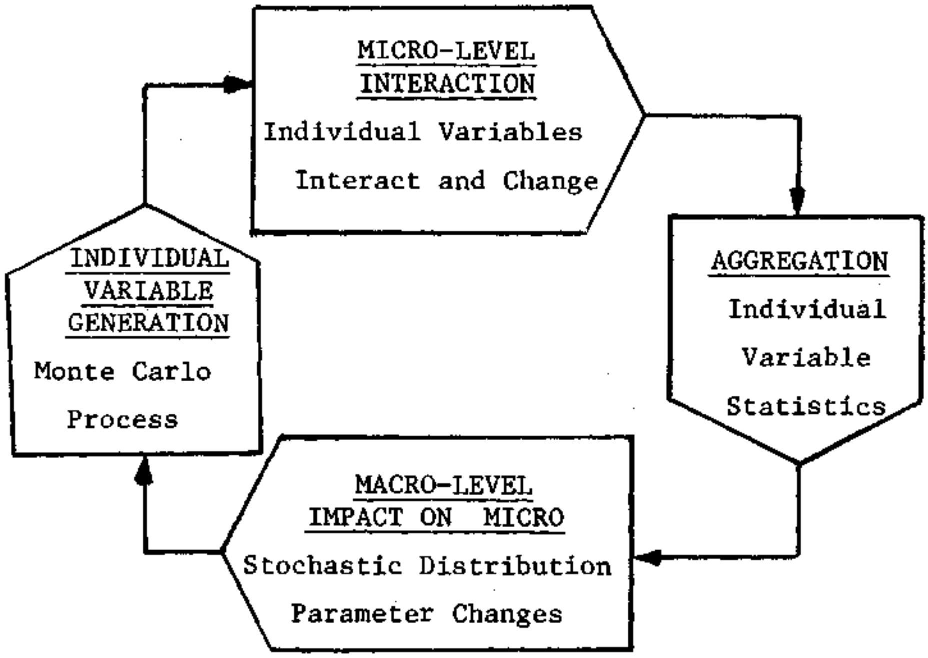


Figure 10. The HNM Macro-control Process

There are five major control loops that can be explained as follows. Firstly, in the hypothetical neighborhood, the level of stability is maintained by the duration of occupancy. In the HNM, changes in average tenure (PCMT) cause adjustments in TPNH which are noticed in the relative conditions of properties (RC). Secondly, the level of vacant dwellings determines the degree of property improvement; or, PCVC affects the parameter of the distribution for IMPF of the new occupants. The third control factor is that the flux of movers affects both the incoming and outgoing rates. This is accounted for in loop three by the level of non-causal movers (PCOM) affecting the availability of money (MONFAC); and, in loop four, the rate of causal movers (PCCM) involves some degree of self-regulation (ADJ). Finally, the real estate screening process is influenced by the level of new occupants, as PCNO is involved in the revaluation of RESIT. Figure 11 below identifies each of these loops.

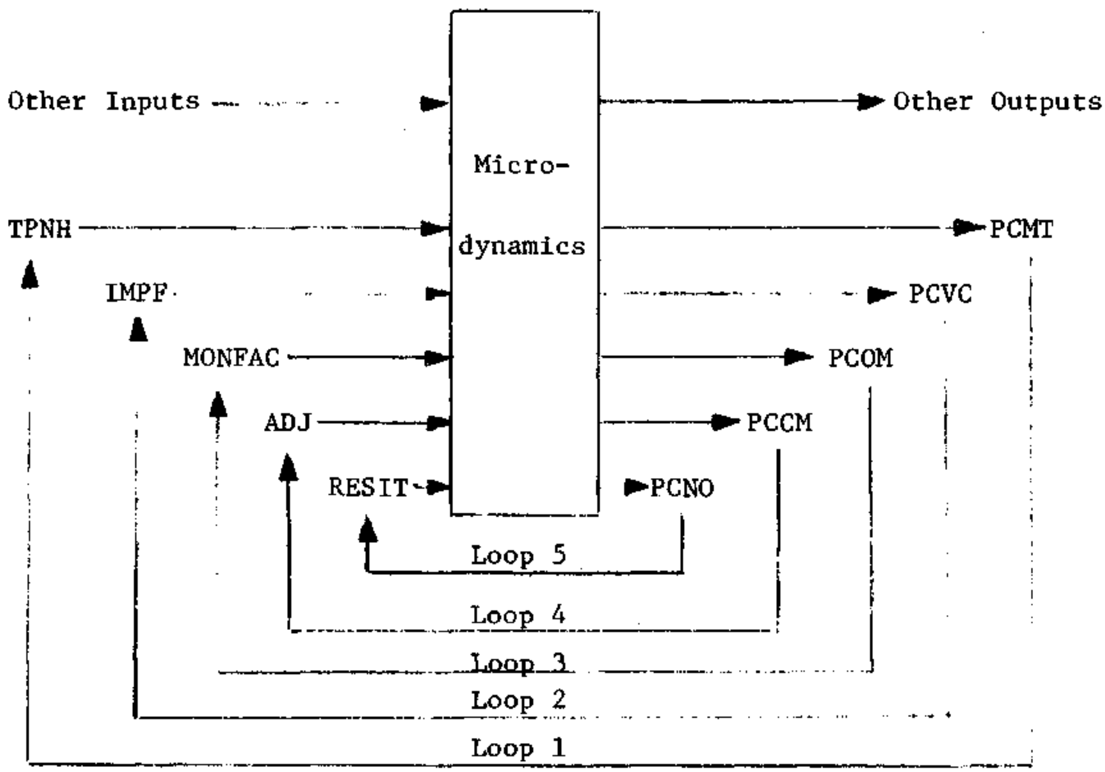


Figure 11. The HNM Macro-control Loops

In Boolean format, the macrodynamic loop expressions are:

If	Then
PCCM>0.12	ADJ(t+1) = AA·ADJ(t)
PCNO>0.35	RESIT(t+1) = AC·RESIT(t)
PCOM>0.10	MONFAC(t+1) = AB·MONFAC(t)
PCVC>0.10	IMPF(t+1) = AD·IMPF(t)
PCMT<0.50	TPNH(t+1) = AE·TPNH(t)

otherwise, in each case, there is no change. And, the constant multipliers, AB through AE, are given by:

AA = {0.95,0.99,1.5,1.75}

AB = {1.1,1.2,1.5,2.0}

AC = {0.975,1.025,1.05,1.1}

AD = {0.95,0.75,0.50,0.25}

AE = {0.95,0.95,0.95,0.95}

in which the choice from each set depends on the total number of cycles (NUMCY) and the particular cycle in process (II). The ratio of II to NUMCY, called CHYR, is computed; and, based on its value, the choice within the ordered sets is made. Typically, this choice is made as follows:

If	Then
$CHYR > 0.75$	Pick value #3
$0.5 < CHYR \leq 0.75$	" " #2
$0.25 < CHYR \leq 0.50$	" " #4
$CHYR \leq 0.25$	" " #1

The macrodynamical processes are next summarized. Analogous to the dynamical control processes in real neighborhoods, the HNM loop structure serves as the object of external control for the simulation. In Figure 12, again as a flow process, the hypothetical neighborhood and the simulation are contrasted to show the the individual/aggregate characteristics and the micro/macro variables.

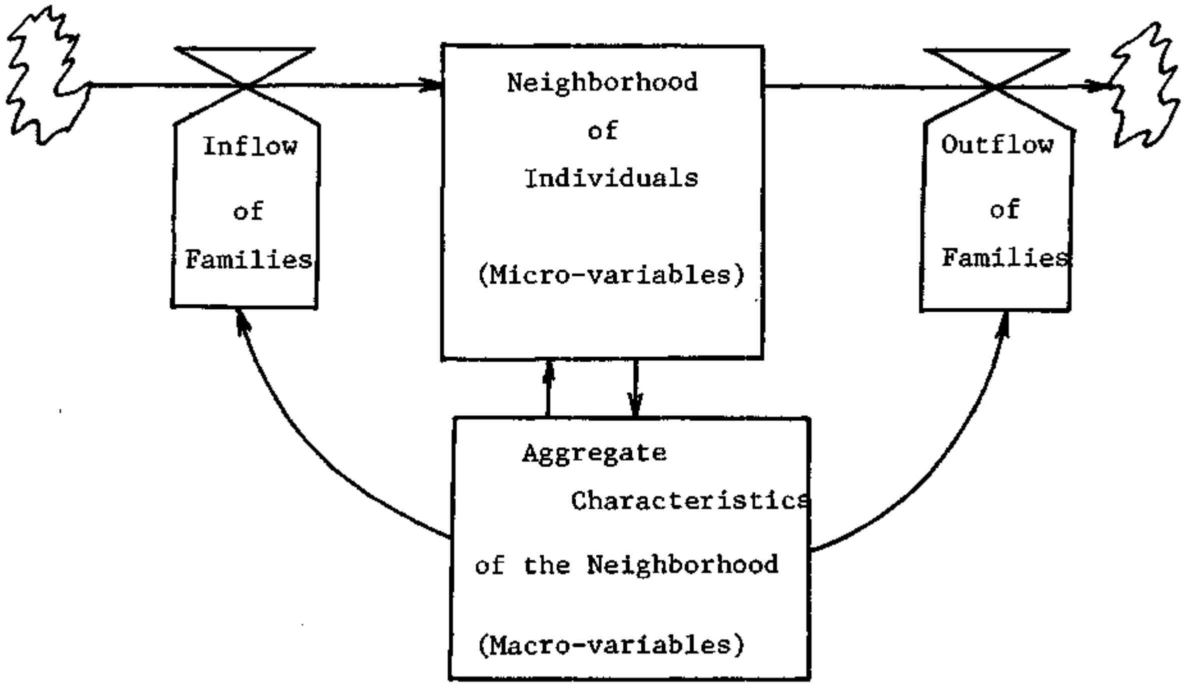


Figure 12. Micro-macro Flow Control.

The HNM Simulation Program

The HNM computer simulation program was written in FORTRAN IV, and can be found in Appendix A. Also contained in the Appendices are the sample outputs of this program, and the plotting routines for the graphical outputs. The program consists of one main routine, two function subroutines, and seven regular subroutines. A brief description is presented on each of these parts of the program using a detailed series of flowcharts.

The flowcharts illustrate the sequence of activities, and identify the major program activities such as inputting parameters, generating variables, calculating successive values of the state variables, computing necessary statistics, and outputting an assortment of data for each cycle.

In the main routine, specific functions assign values, read inputs and generate stochastic variables as well as call the subroutines. The four important subroutines are equivalent to the four major model activities previously described. Three additional subroutines perform input/output operations, variable generation, and certain bookkeeping functions. They are, by name: PRNT, TRIANG, HEAD, and START. The functions RNDY1 and RNDY2 provide the pseudo-random numbers from a discrete uniform distribution (zero-one).

All simulation program runs were made on a Burroughs B-5700 in the Computing Laboratory of the School of Information and Computer Science at the Georgia Institute of Technology. A typical set of instructions is shown in Table 1.

Table 1. Typical Set of Instructions from a Remote Terminal

```
#
RUN
 RUNNING


WHAT TYPE NHOOD - 1,2,3,4, OR 5?
?3
THE AESTHETIC FACTOR - 1,2, OR 3?
?2
HOW ARE THE INITIAL RESIDENTS - BY SOCIAL STATUS?
?.2,.25,.3,20.
BY ECONOMIC STATUS?
?.25,.3,.35,20.
WHAT IS THE SPREAD OF PROPERTY VALUES?
?.15,.2,.25,20.
HOW MANY CYCLES?
?10
NUMBER OF PRINTOUTS PER CYCLE, 0-5?
?1
```

Table 2 provides a typical set of summaries at a remote terminal.

Table 2. Typical Set of Summaries Received at Remote Terminal.

```
MONEY SITUATION - 1,2,3,4, OR 5?
?1
R.E. STRATEGY, 1 - 5 ?
?3
INFL RATE 0.01
NWOC =  18
NVAC =   0
   HVMIN      AHV     HVMAX      NPA      NPD
  0.1516   0.2150   0.2778       29       24
    XMIN     XBAR      XMAX
  0.2124   0.2734   0.3400
    YMIN     YBAR      YMAX    DMEAN
  0.2527   0.3043   0.3529   .03263
ALS =  8.08
NCM =  1
NRM =  4
NAO =  0
```

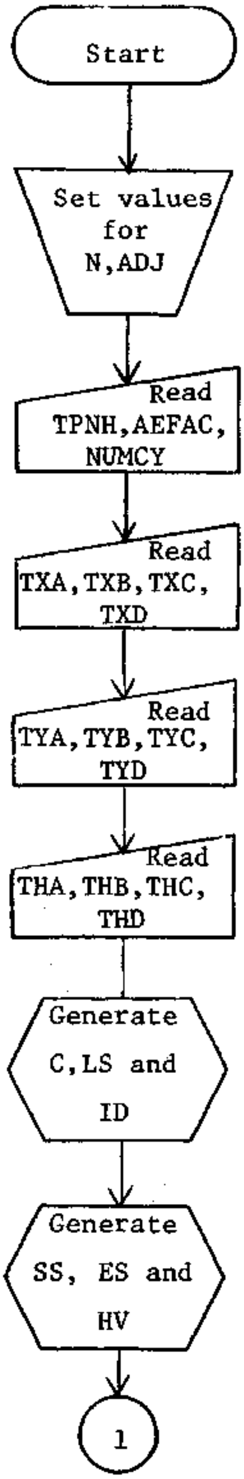
As an example of the summaries that were available on the line printer, Table 3 is shown. This particular run shows oscillations in causal movers (PCCM), and a certain granularity in values (PCOM and PCVC). Also, it is noteworthy that PCMT increased slightly in cycle 14.

Table 3. Typical Summary on the Line Printer.

YEAR END	PCCM	PCOM	PCNO	PCMT	PCVC
...	..	..	..	..	..
8	0.00	1.56	37.50	70.07	0.00
9	4.69	4.69	37.50	71.82	0.00
10	0.00	4.69	42.19	68.92	0.00
11	4.69	1.56	45.31	67.40	1.56
12	0.00	9.38	50.00	64.93	0.00
13	4.69	0.00	56.25	59.54	4.69
14	0.00	7.81	56.25	60.46	0.00
...	..	..	..	..	..

The HNM Flowcharts

Main Program



Comments

$N = \{1,2,3,...,64\}$

$ADJ(t=0) \in \{1,2,3,4\}$

$TPNH(t=0) \in \{1,2,3,4,5\}$

$AEFAC \in \{1,2,3\}$

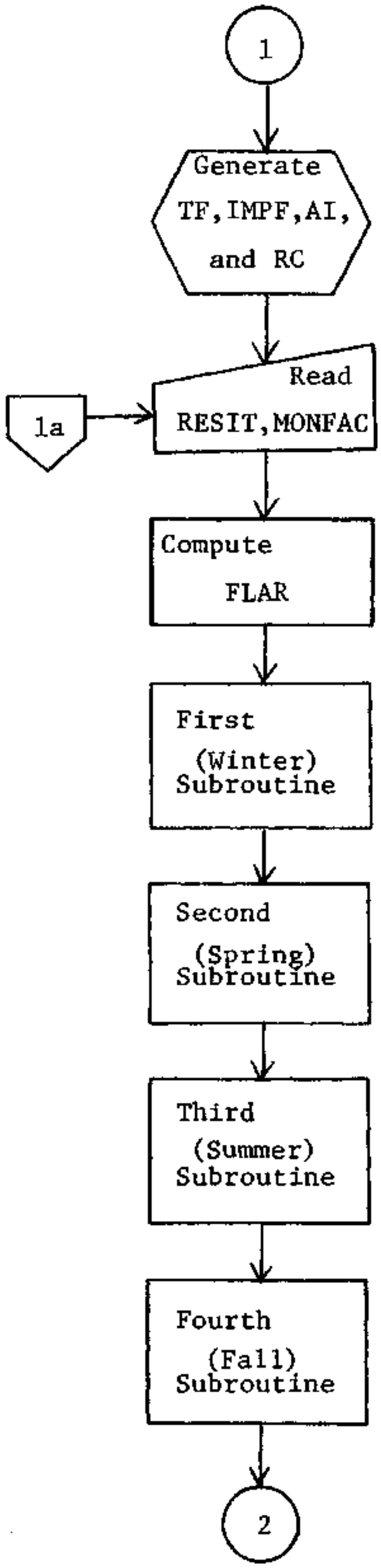
$NUMCY \in \{1,2,3,...\}$

$TXA,TXB,TXC \in [0.0001,0.9999]$
$TXD \in$ Reals

$TYA,TYB,TYC \in [0.0001,0.9999]$
$TYD \in$ Reals

$THA,THB,THC \in [0.0001,0.9999]$
$THD \in$ Reals

$C(t=0) = [C_1,C_2,C_3,...,C_{64}]$ where
$1 \le C_i \le 5$
$LS(t=0) = [LS_1,LS_2,LS_3,...,LS_{64}]$
where $LS_i \in \{0,1,2,3,...\}$
$ID(t=0) = [ID_1,ID_2,ID_3,...,ID_{64}]$
where $10000 \le ID_i \le 199999$
$SS(t=0) = [SS_1,SS_2,SS_3,...,SS_{64}]$
$ES(t=0) = [ES_1,ES_2,ES_3,...,ES_{64}]$
$HV(t=0) = [HV_1,HV_2,HV_3,...,HV_{64}]$
where $SS_i,ES_i,HV_i \in [0.0001,0.9999]$



$TF(t=0) = [TF_1, TF_2, TF_3, \ldots, TF_{64}]$

where $TF_i \in \{1,2,3,4,5\}$

$IMPF(t=0) = [IMPF_1, IMPF_2, \ldots, IMPF_{64}]$

where $IMPF_i \in \{1,2,3,4,5,6\}$

$AI = [AI_1, AI_2, AI_3, \ldots, AI_{64}]$

where $AEFAC \leq AI_i \leq AEFAC+3$

$RC(t=0) = [RC_1, RC_2, RC_3, \ldots, RC_{64}]$

where $TPNH \leq RC_i \leq TPNH+4$

$RESIT(t=0) \in \{1,2,3,4,5\}$

$MONFAC(t=0) \in \{1,2,3,\ldots\}$

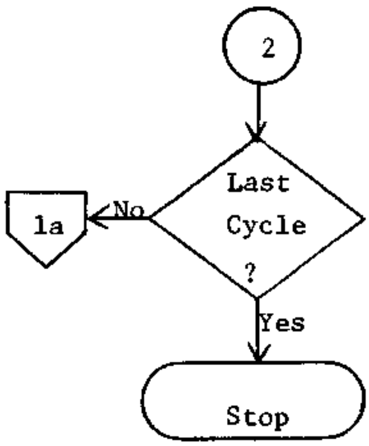
$FLAR = 0.01\ (MONFAC)$

Updating and general time advance

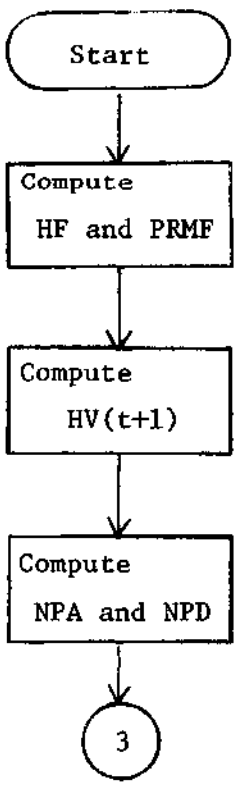
Causal outmigration

Random and non-causal outmigration

Inmigration



First Subroutine



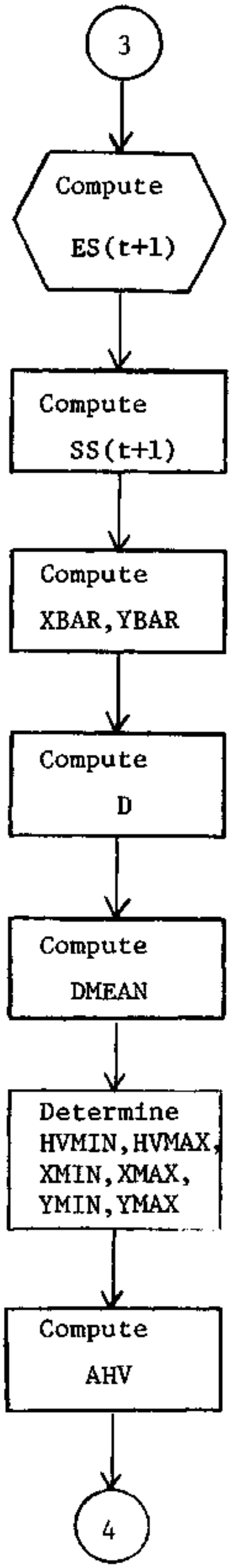
$$HF = 1. + FLAR$$

$$PRMF_i = 1. + 0.01\ (3-IMPF_i)$$

$$HV_i(t+1) = HV(t) \cdot HF \cdot PRMF_i$$

$$NPA = n[HV_i(t+1) > HV_i(t)]$$

$$NPD = n[HV_i(t+1) < HV_i(t)]$$



For some randomly selected ES_i

$ES_i(t+1) = ES_i(t)[1.+FLAR]$

For all values in SS

If: $LS_i \le 5$ Then: $SS_i(t+1)=SS_i(t)$

$5<LS_i \le 10$ $SS_i(t+1)=SS_i(t)[1.02]$

$10<LS_i \le 15$ $SS_i(t+1)=SS_i(t)[1.01]$

$LS_i \ge 15$ $SS_i(t+1)=SS_i(t)+0.01$

XBAR is average of the SS_i

YBAR is average of the ES_i

$D(t) = [D_1,D_2,D_3,\ldots,D_{64}]$

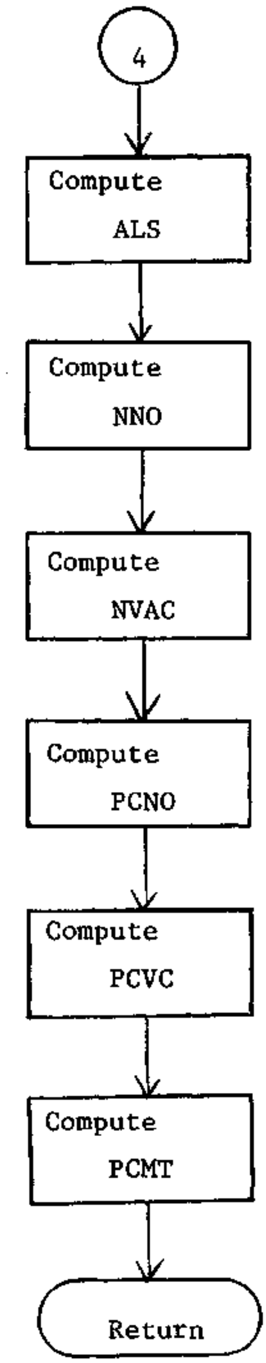
where $D_i = \sqrt{(ES_i-YBAR)^2 + (SS_i-XBAR)^2}$

DMEAN is the average of the D_i

Standard test and branch routines

These values are useful in output analysis

AHV is average of the HV_i



ALS is the average of the LS_i

$$NNO = n[\ ID_i < 10000\ ]$$

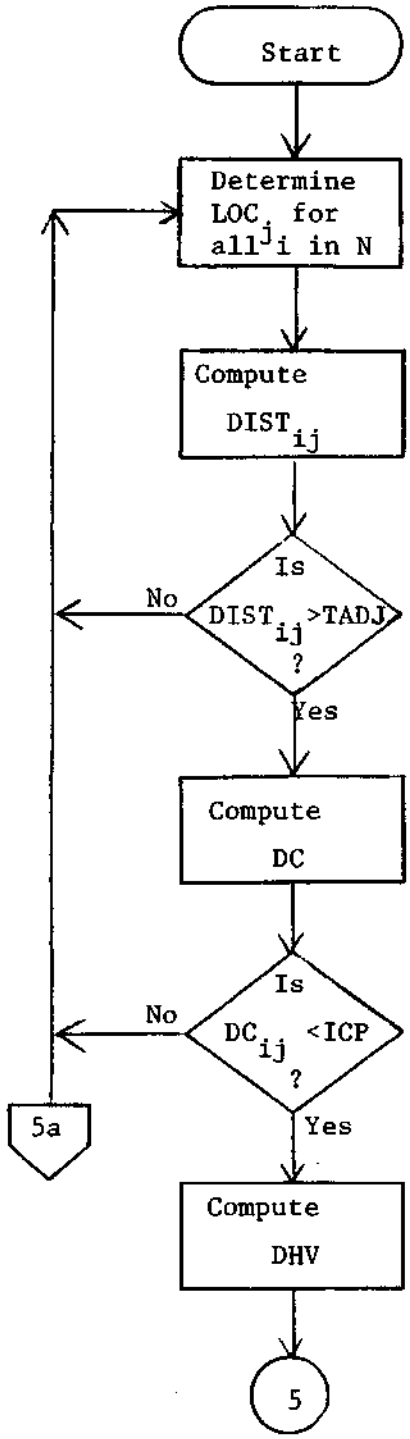
$$NVAC = n[\ ID_i = 0\ ]$$

PCNO is the percent of NNO

PCVC is the percent of NVAC

$$PCMT = \frac{ALS(t_k)}{ALS(t_o) + k} = \frac{ALS(actual)}{ALS(theoretical)}$$

Second Subroutine



Using TF_i, the templates in LOC_j are determined for all residents

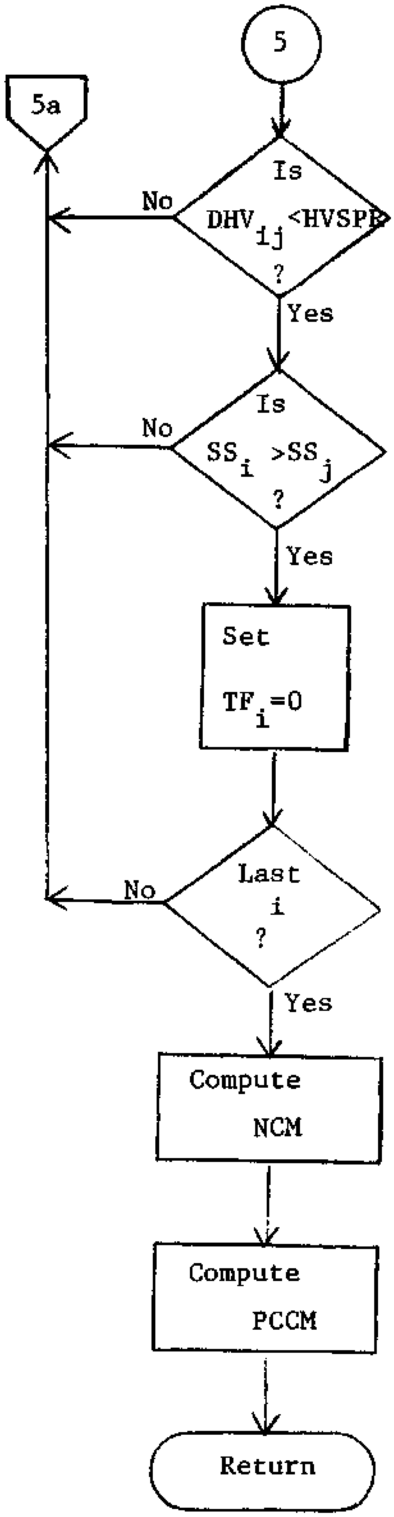
$$DIST_{ij} = \sqrt{(SS_i - SS_j)^2 + (ES_i - ES_j)^2}$$

$$TADJ = DMEAN \cdot ADJ$$

$$DC_{ij} = |C_i - C_j|$$

ICP internally set

$$DHV_{ij} = |HV_i - HV_j|$$



HVSPR internally set

Self-explanatory

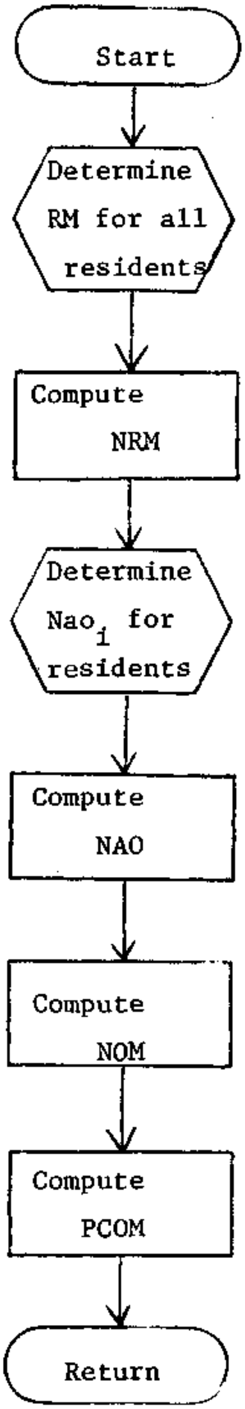
Self-explanatory

Check for all residents

$NCM = n[\ TF_i=0\ ]$

PCCM is the percent of NCM

Third Subroutine



RM is an interval on [0,1] which corresponds to certain percentage of random movers (ID_i=0, C_i=99)

NRM = n[C_i = 99]

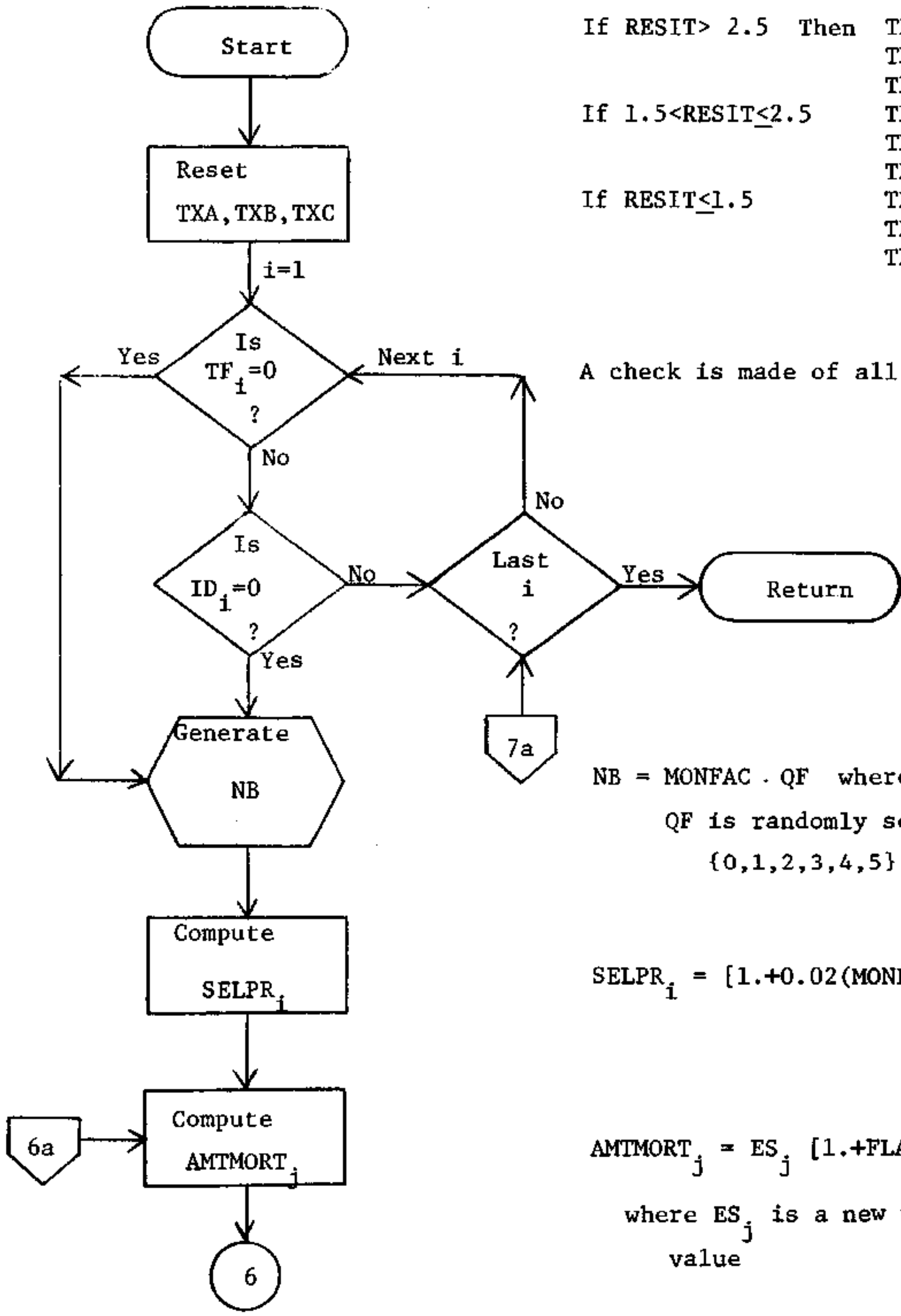
Other movers are selected if
TF_i>1 and ES_i>YBAR and SS_i>XBAR
Whence, ID_i=0 and C_i=75

NAO = n[C_i=75]

NOM = NAO + NRM

PCOM is the percent of NOM

Fourth Subroutine



If RESIT> 2.5 Then $TXA(t+1)=1.01TXA(t)$
$TXB(t+1)=TXB(t)$
$TXC(t+1)=0.99TXC(t)$

If $1.5<RESIT\leq 2.5$ $TXA(t+1)=1.05TXA(t)$
$TXB(t+1)=1.05TXB(t)$
$TXC(t+1)=1.05TXC(t)$

If $RESIT\leq 1.5$ $TXC(t+1)=TXA(t)$
$TXA(t+1)=0.75TXC(t+1)$
$TXB(t+1)=0.5(TXA+TXC)$

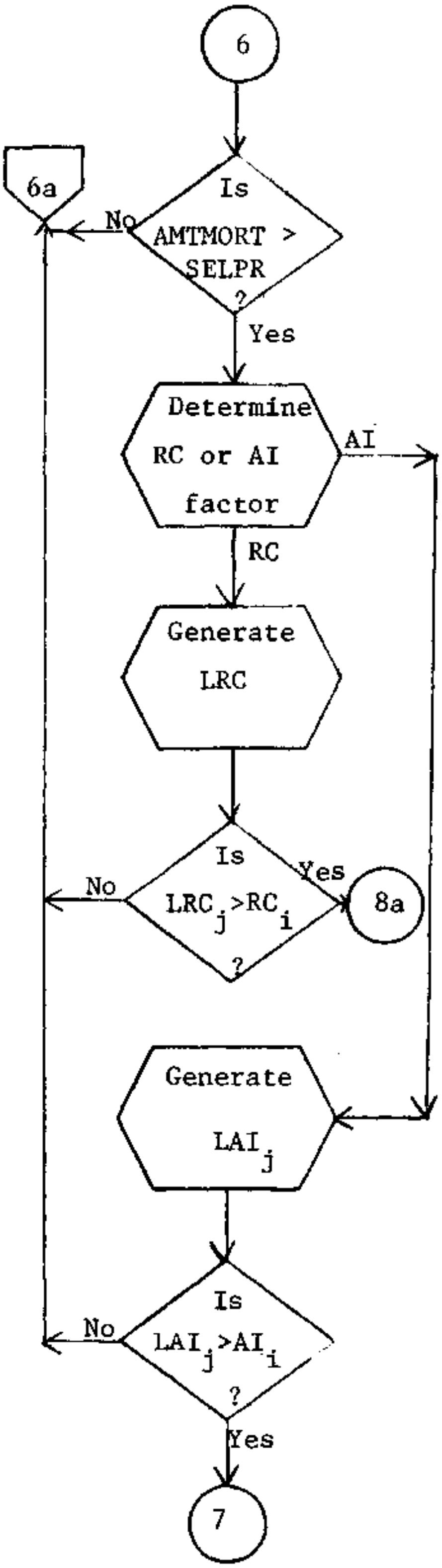
A check is made of all residents

$NB = MONFAC \cdot QF$ where
QF is randomly selected from
{0,1,2,3,4,5}

$$SELPR_i = [1.+0.02(MONFAC)]\ HV_i$$

$$AMTMORT_j = ES_j\ [1.+FLAR]\ [1.+0.01(MONFAC)]$$

where ES_j is a new randomly generated value



Financial test

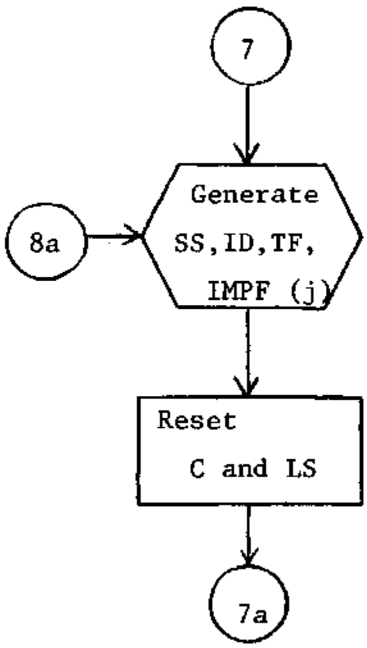
Individual buyer choice

Acceptable relative condition

Test of relative condition

Acceptable aesthetic level

Test of aesthetic factor



Sale is consummated

Same as initial inputs except perhaps for new parameters

To indicate a new occupant, $C_i=0$ and $LS_i=0$

CHAPTER VI

HNM EXPERIMENTS AND SENSITIVITY ANALYSIS

General

To this point, the model-building phase has been concerned with the construction of the HNM and its simulation program. In this chapter and the next, three different phases of effort will be directed towards model experimentation. These phases of experimentation will be designed to answer questions regarding: what the model does and why it does it; the correspondence between model and reality; and, what inferences or conclusions can be drawn from it?

The analysis of the HNM will provide some understanding of the causal relationships in the model. The validation is a comparison of model and real neighborhood examples to determine the accuracy of the model to reality. To explore possible consequences of policy or structural change, some simulations of these processes are also made.

In general, there is no argument as to the uncertainty and difficulty of quantification of social relationships. Thus, great care must be taken to determine the dynamic performance of the model. This involves variation of parameters, and the testing of different distributions and functional relationships to discover the degree and nature of the model behavioral dependence on these factors. Particularly important in this case are the parameters and distributions associated with SS, TF, IMPF, AI, RC, and C. Too, it is often necessary to analyze the individual feedback loops and the impact of change in the computation interval.

tories are the vector of input variables for each simulation. The state trajectories are the outputs or the reference variables. The policy implementation provides correspondences between changes in reality and in the model.

Since these exercises are of three types, the purpose, results and interpretation of each type is provided. The first type contains two experiments: one an example of a typically stable case; and, the other a typical transitional case. The second also has two experiments. The first illustrates the economic effects on transition. The latter experiment attempts to show the general instability effects of an initial setting.

Five additional experiments appear in Chapter VII which indicate some degree of latitude in different urban policy changes.

Experimental Definitions

An *experiment* will be taken to mean a group, one to several, of simulation runs. A *simulation*, simulation run, or run, consists of a set of time trajectories for the reference variables, each 17 cycles in length. One *cycle*, as previously defined, corresponds to one year in real time.

The run length of 17 cycles was chosen in order to overlap two census periods. However, it was felt that at longer run lengths, more prominent effects might be attributable to changing family composition, or life style, etc.

The number of runs, usually between 20 and 60, was chosen because the basic unit size of the census data was the *tract* which contained some three to four thousand persons. Hence, by aggregating the results of approximately 30 runs, there would be some consistency between the size of the experiment sample and the actual size of the particular tract from which data was taken.

The control histories of these various exercises can be divided into initial inputs and input control parameters. The initial inputs include all the input variables except MONFAC and RESIT. Although these two inputs have initial values, they are the only exogenous variables that can be changed during the simulation. Hence, they are the only dynamic control inputs.

As was earlier explained, there are five major output variables which comprise the state trajectories. These variables were plotted, and their graphs studied for possible trends, etc. Only two of these variables, PCNO and PCMT, are shown in each individual experiment discussion.

What cannot be overemphasized is the difficult task of selecting appropriate types of runs to include in each experiment and based on the different values of the inputs. Potentially, there are an extremely large number of runs possible for each experiment type. Even limited to ten inputs where each input can assume only two different values, the total number of possible runs would exceed 1000, since $2^{10} = 1024$. Hence, the simplified approach previously discussed of aggregating like runs was devised.

The first two experiments were designed to establish base-line criteria. Experiment #1 illustrates a stable neighborhood pattern; and, Experiment #2 a transitional pattern. The major differences in inputs are the change in social status of incoming residents, and a mixing which allows

Table 4. Data Set for Experiments 1 and 2.

	Experiments 1	Experiments 2
MONFAC	2 to 4	2 to 4
THA,THB,THC	.15,.2,.25 T	.15,.2,.25 T
TPNH	3	3
RC	3 to 7 U	3 to 7 U
AEFAC	2	2
AI	2 to 5 U	2 to 5 U
C	1 to 5 U	1 to 5 U
LS	4 to 12 U	4 to 12 U
ID	≥ 100000 U	≥ 0 Mixed
IMPF	1 to 6 U	1 to 6 U
RESIT	3	3 to 1
TXA,TXB,TXC	.2,.25,.3 T	.2,.25,.3 T
TYA,TYB,TYC	.25,.3,.35 T	.25,.3,.35 T
TF	1 to 5 U	0 to 5 U
ADJ	1	1
NUMCY (per run)	17	17
NUMBER OF RUNS	1	1

the runs to "begin" with different compositions of "new" residents, but to still to retain the other initial conditions. The last change is a wider distribution of awareness levels (TF) which reinforces the notion that the model neighborhood contains "new" and "old" residents.

Experiment #1. A Stable Case

This experiment is an example of the simulation of a stable neighnorhood. Although many runs of this type were made, this one particular run was selected to indicate both a nominal stable initial setting and resultant pattern.

Description. The neighborhood that is being simulated can be considered middle-class socially (SS) and by annual income (ES). The range of income for this community is $10,000 to $14,000 in 1970 dollars. The properties have a market value (HV) between $24,000 and $30,000 in similar units. The initial average tenure (ALS) is 8.08 years. The relative attractiveness (AI) and condition (RC) of the properties are average. The individual residents are also average in both their propensity to improve their properties (IMPF) and awareness levels (TF). Mortgage financing (MONFAC) is moderately available with reasonable annual interest rates. The real estate agencies (RESIT) are competing fairly for houses to sell with an adequate source of potential buyers who are homogeneous socioeconomically.

The input control variables, MONFAC and RESIT, were not severely altered during the simulation. This particular form of global control seemed to maintain a certain steady turnover and produced the least amount of instability. Thus, the effects of the initial conditions remained in evidence for several cycles, indicating slow and gradual changes in most

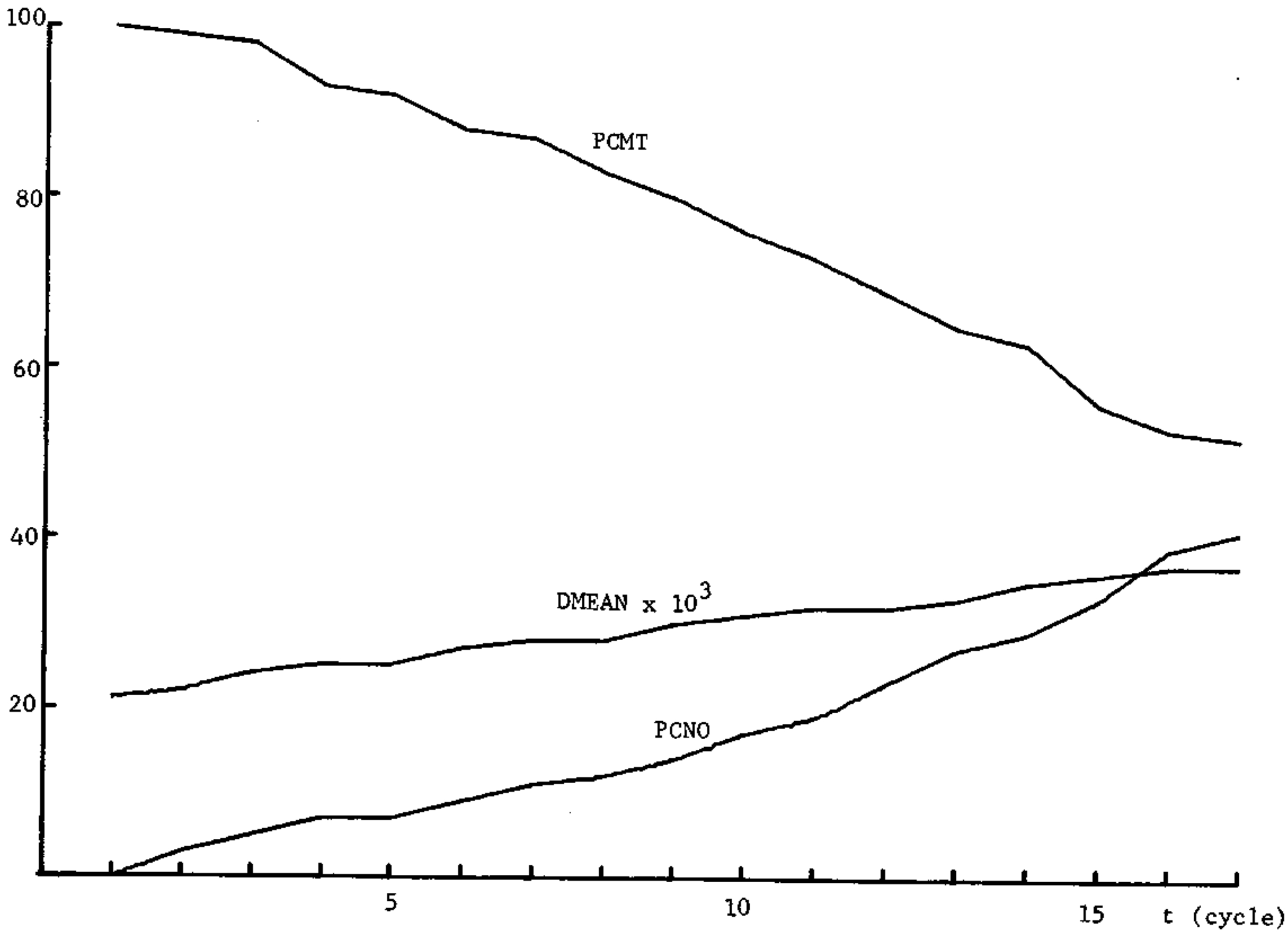


Figure 13. Graphs for Experiment #1.

endogenous variables. The graphs of PCMT and PCNO show the effects of this change. See Figure 13. Fairly low throughput (PCNO ≤50%) and high duration of residency (PCMT≥ 50%) can be observed. This level of turnover is primarily due to the random and other non-causal movers (PCOM) which were recorded to be between 2 and 10 % per cycle. See Appendix B. It is also noteworthy that DMEAN increases somewhat, but its relatively small fluctuations may be attributable to the fact that it is an average value.

Interpretation. For this experiment of a single simulation run, the HNM performance appears to be consistent with data from some real neighborhoods in which change occurred gradually [61,123]. The extent of the changes over a period as long as 17 years may be significant. Most real neighborhoods undergo much cumulative change in this length of time in population composition and movement, and the disposition of residences. This is especially true for the kinds of neighborhoods that are addressed in this study. Characteristic of U.S. middle-class neighborhoods is the manner in which they react to change [54]. In general, Americans are quite mobile. It has been indicated in some reports that 20% move each year, and the majority of these moves are within the same county [117]. Some other estimates of this latter figure have been as high as 80% [118,135].

Experiment #2. A Transitional Case

Using essentially the identical starting conditions as the first experiment, this simulation run is of a transitional neighborhood. The major difference in initial conditions involves the real estate screening process (RESIT), the distribution of new and old residents (ID), and the levels of awareness (TF).

Description. While the initial values of most input variables for this experiment are the same as those of the previous one (Experiment #1), the subsequent changes in the performance are predominantly changes in the social and economic status of the community. This shifting and widening of certain variable distributions, such as SS and ES, are caused by changes in the real estate practices (RESIT) and the heterogeneity in other resident attributes (ID and TF). The implication here is that the real estate agencies are introducing into the neighborhood new residents that are significantly different socioeconomically. Further, the present occupants have become more sensitive to the attributes of these incoming individuals. The combined effect is a decidedly larger emigration rate (PCNO $\geq$ 50% within 10 cycles) and a shorter average residency (PCMT $\leq$ 50% by the 8th cycle). And, the most rapid rate of turnover appears to occur immediately after the new occupant level reaches 35%. See earlier discussion in Chapter III on threshold values. Finally, this experiment experiences a total population turnover.

Interpretation. Contrary to the results of the first experiment, these outputs indicate considerably more turbulent activity. An obvious conclusion is that it is the effect of increased migration. A second implication can be also be drawn. DMEAN increases quite rapidly; and, although it returns to some earlier values, it does not settle near its initial values. From our earlier definition, this condition can therefore be judged to be transitional. A corresponding real neighborhood would show similar signs of instability inasmuch as old occupants would depart, many new residents would arrive, and the aggregate character of the neighborhood would change. From the graphs, one can observe that this instability is practically total by cycle 8 with only mild recovery by cycle 14.

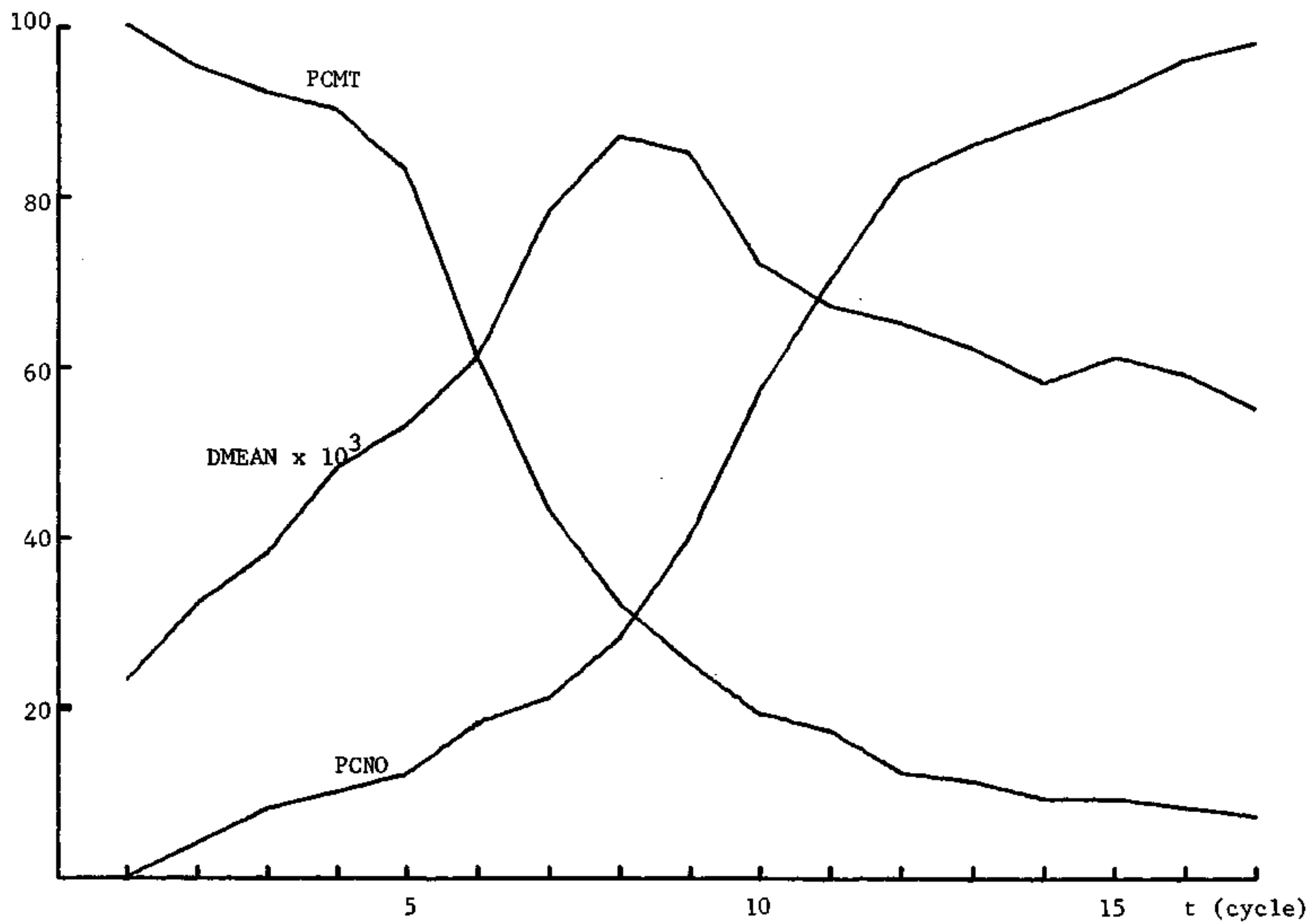


Figure 14. Graphs for Experiment #2.

Table 5. Data Set for Experiments 3 and 4.

	Experiments 3	Experiments 4
MONFAC	3 to 6 (incr)	2 to 4
THA,THB,THC	.15,.2,.25 T	.1 to .3 T
TPNH	2 to 4	2 to 4
RC	2 to 8 U	2 to 8 U
AEFAC	1 to 3	1 to 4
AI	1 to 6 U	1 to 7 U
C	1 to 5 U	1 to 5 U
LS	0 to 15 U	0 to 4 U
ID	Mixed	Mixed
IMPF	1 to 6 U	1 to 6 U
RESIT	3 to 1	3
TXA,TXB,TXC	.2,.25,.3 T	.15 to .3 T
TYA,TYB,TYC	.25,.3,.35 T	.2 to .4 T
TF	0 to 5 U	0 to 5 U
ADJ	.95 to 2.5	1 to 2
NUMCY (per run)	17	17
NUMBER OF RUNS	23	31

Any explanation of transitional patterns, as was earlier discussed, is difficult. Whether racially inspired or not, turnover and change in real communities are masked by a complexity of interrelated factors. A most important control feature, both in terms of the rate and type of change, is the role of the real estate agencies as indicated in several Atlanta studies [99,109]. Moreover, it is often quite difficult to distinguish causal and random movers. Nonetheless, in these first two experiments, aspects of stability and transition in the HNM have been contrasted to those of certain real neighborhoods described in the literature.

Next presented are Experiments 3 and 4 which were designed to show certain variations on the first two experiments. These variations concern the effects of economic restraints and the role of initial settings, respectively.

Experiment #3. Economic Effects on Transition

With the general same initial conditions of Experiment #2, this collection of runs simulates the economic effects on transition. Some variations in the type neighborhood (TPNH), aesthetic factor (AEFAC), and length of residency (ALS) are used. The purpose of this experiment is to analyze the potential consequences of the availability of money, both in terms of the supply and the rates of interest, on a neighborhood change process.

Description. While it may be the case, in general, that overall residential sales are directly proportional to the available money supply, local circumstances and isolated situations may not be discovered in such an obvious manner. In other words, entirely different sales activities may be underway in different parts of one region, where the general sales conditions are known. The resultant effects can be counter-opposing. Thus, this experiment offers the opportunity to study the role of locally "tight" money on a transition process. In this situation, three mutually counterbalancing events can be expected. Firstly, current property who wish to sell may be forced to lower their prices in order to complete or close sales in a minimal amount of time. Secondly, when it becomes sufficiently difficult to close sales and minimum acceptable market values have been reached, further price reductions may not be warranted. Thus, either the residents do not move or properties are disposed of as rentals, etc. Finally, a general economic problem as widespread shortage of loan money may not preclude the possibility of locally available mortgaging.

Interpretation. In these selected runs, the common feature was the initiation of, and continuing potential for, rapid migration and transition processes. This is accomplished by the changing values of RESIT with the results reflected in the values of PCMT and PCNO, particularly by cycle 4. Subsequent input adjustments were made by increasing the values of MONFAC which then caused decreases in the number of buyers (NB), yet with higher rates of increase of property values (HV) and annual income (ES). Thereafter, PCMT leveled off as the experiment continues to show a high duration of residency. However, the high throughput remains as PCNO continues to rise. Stability is realized as DMEAN initially increases but returns to previous initial values. The results simply show that a transition process, once in effect, can be severely diminished by the unavailability of mortgaging financing. Directly coupled to this action can be higher rates of inflation in property values and salaries.

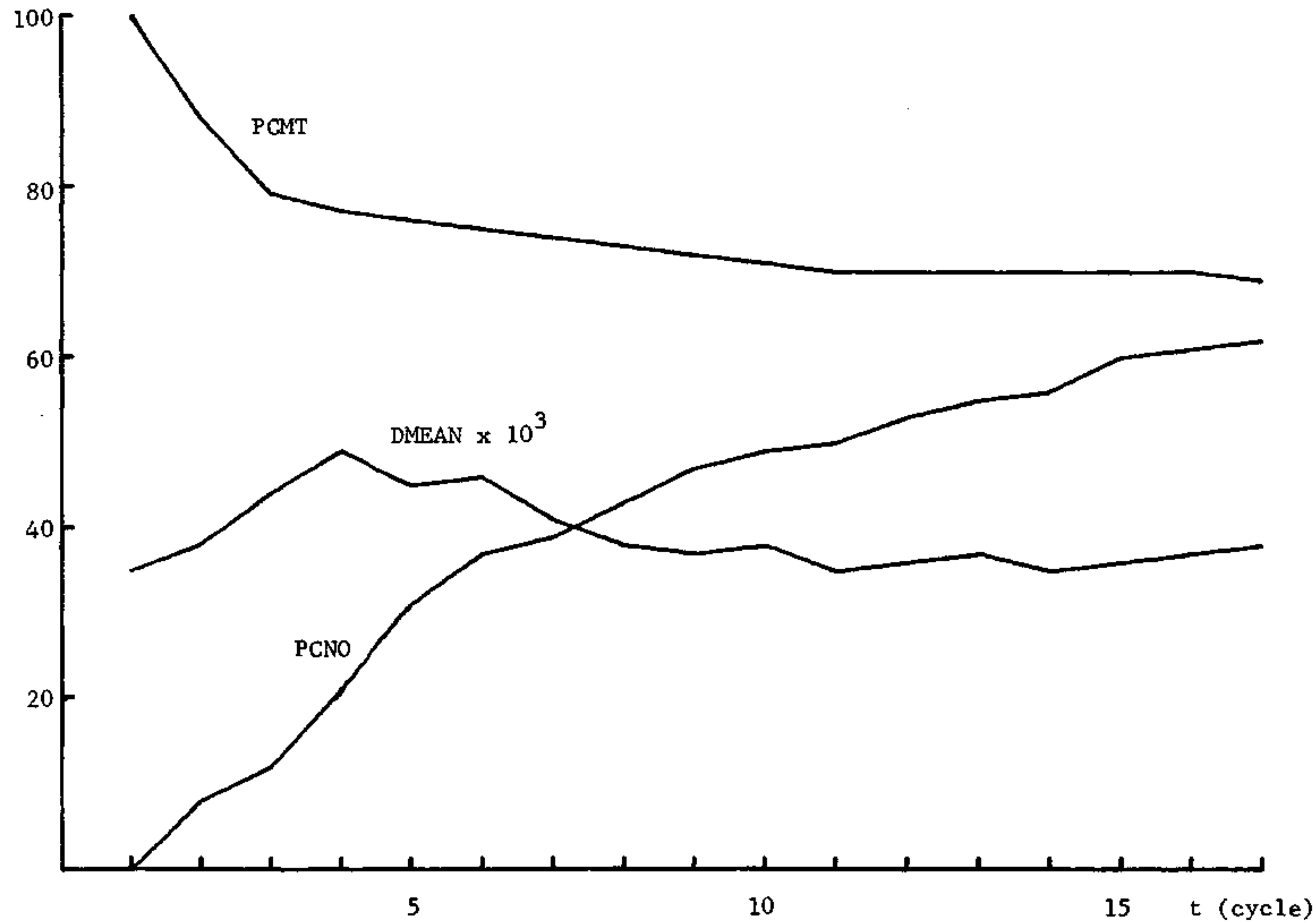


Figure 15. Graphs for Experiment #3.

Thus, one suggested means to control movement or to stabilize certain real neighborhoods has been through the control of the local money supply. However, this method may be neither effective nor desirable. Firstly, a single agency is usually unable to affect the supply. Secondly, if a single agency limits loans in a specific area, the following has occurred of late. This control has become known as "redlining," or the act of drawing a red line around the area. Naturally, the individuals of that area react by removing their money, savings and business, or "greenlining", away from the particular agency. On balance, the effects have become neutralizing [14,20,121].

Experiment #4. Initial Instability

To simulate the effects of initial instability, the runs of this experiment were organized. It illustrates how a community can be initially populated such that either there are no common, distinguishing characteristics of the residents; or, the distribution of attributes is so extreme that migration becomes inevitable. Several well-known and documented cases included the Levittown communities [40] and others [61]. There, and in many other similar unreported circumstances, the original occupants were attracted into these neighborhoods by the relatively lower purchase prices, or other reasons. A short period of time later, there was experienced very high levels of turnover, and, in many cases, transition.

Description. This effect was achieved in the simulation by the wider initial values of the distributions of social and economic status (SS and ES). Also, the "skewing" of these distributions by the opposite choices of mean values in the arrays TXA-TXD and TYA-TYD, respectively,

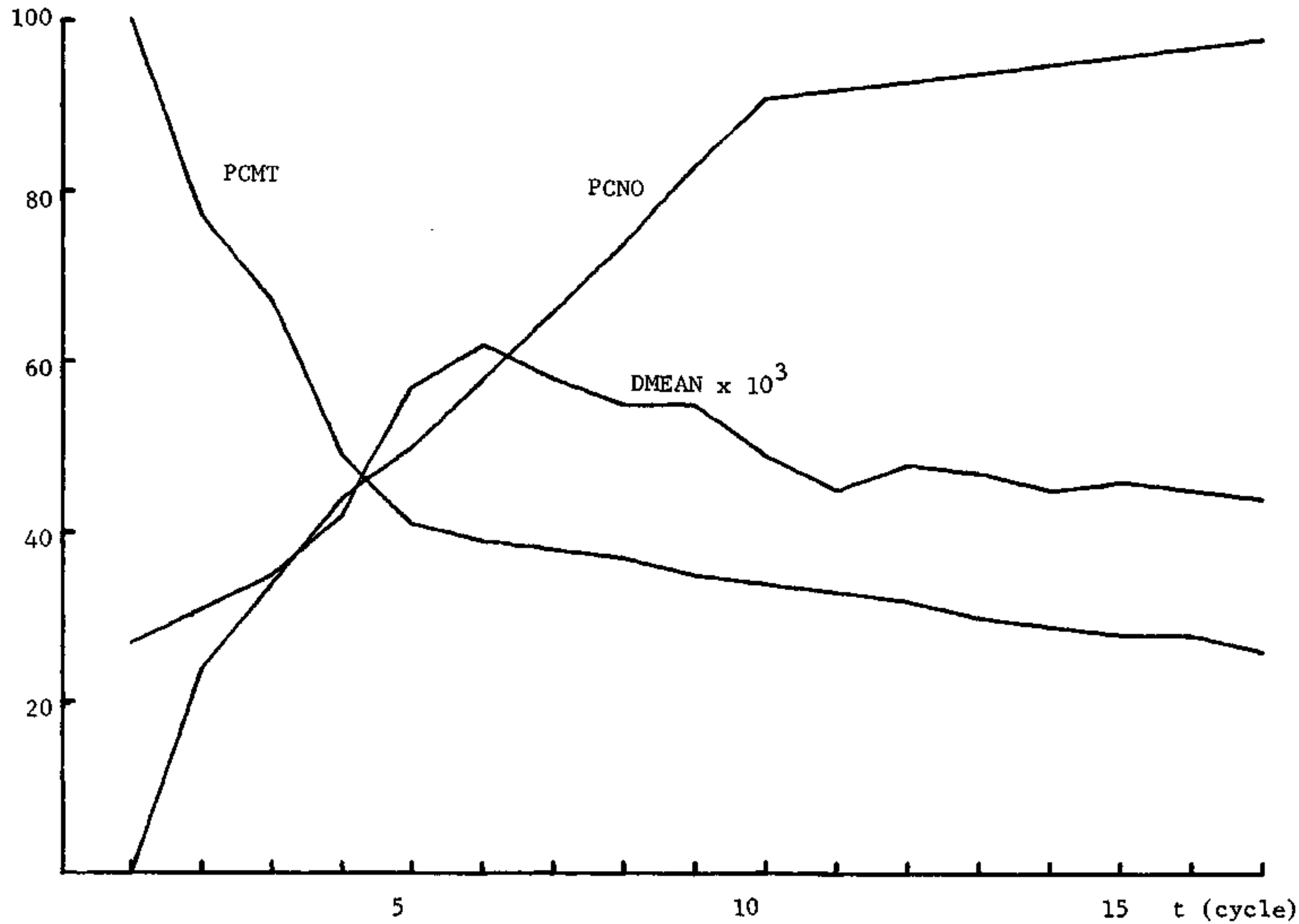


Figure 16. Graphs for Experiment #4.

was also effective. It also was observed that the lower values of HV, or distorting the relationship of arrays TXA-TXD and THA-THD could contribute to an initial instability. This experiment exhibited both high throughput and low duration of residency by cycle 5. DMEAN starts with a higher initial value (0.045) which should be expected, and increases to approximately 0.08 before settling near 0.05, its final value.

Interpretation. This simulation experiment confirms one process that has been documented [39]. It is quite likely for many other real neighborhoods, and certainly for the case of the HNM, that instability can be precipitated by the initial mix of residents. Socioeconomic heterogeneity may be the most severe at that time. However, there are other documented cases of groups with high heterogeneity which remain stable [118]. But, it has also been noted that many of these stable cases became more cohesive only when presented with an external threat [56]. It appears that it was only then possible to develop the internal communications, and the individual commitment necessary for the group stability and maintenance [84].

Now that we have looked at two disparate runs which mark opposite stability performances; and, two other experiments which provide some insight into the variation of initial conditions and exogenous control; let us investigate the sensitivities of the HNM. The following topics are discussed in the next section: sensitivity and performance; sensitivity and tenure; sensitivity and transition; sensitivity and DMEAN; and, a sensitivity summary. The extremely difficult task of separating turnover and transition effects is highlighted. Various case studies have been compiled, and the data for these sensitivity tests is found in Appendix B.

Sensitivity Tests

This series of sensitivity tests were designed and implemented to explore the dynamic consequences of the model assumptions and relationships. These tests were accomplished by recording the relative changes in output variables resulting from variations on initial conditions, parameter values and exogenous control variables. Some limited study included changes to individual variable values, distributions and equation formats. The nature and degree of dependence of the model on these changes is next discussed.

Sensitivity and Performance Curves

Again, the two major performance variables, PCNO and PCMT, were analyzed. Table 6 provides a summary of the observed effects. Collectively, the tabulation is as follows. Firstly, neither the rate of turnover (PCNO) nor the duration of residency (PCMT) were noticeably affected by specific changes to certain distributions such as the mix of new and old occupants (ID), the aesthetic factor (AI), or the relative condition (RC) of properties. This may be attributable to the fact that these variables individually do not enter significantly into either the micro or macro dynamics (See Chapter V). Secondly, when social status (SS), the property improvement factor (IMPF), or coupling between properties (C) were changed, either in range or extent of between 5 and 35 %, the resultant changes in PCNO and PCMT were observed to be less than 10%. Finally, the largest response (10 to 50%) in the performance curves were noted when changes were made in the distribution of levels of awareness (TF) only. This should also be expected, as the important role in the model of TF is obvious in the interconnection of variables in the microdynamics.

Table 6. Sensitivity Ranges for Performance Curves

Changes in	Average Changes during runs in PCNO and PCMT			
	0-5%	5-10%	10-50%	over 50%
Overall operating values of:				
RC	X			
AI	X			
SS		X		
TF			X	
IMPF		X		
C		X		
Type of distribution of:				
RC		X		
AI		X		
SS			X	
IMPF		X		
C	X			
Symmetry between:				
RC-IMPF			X	
SS-TF				X
C-AI			X	

When two are more variables were changed in a contrary manner; viz., distorting the skewness of two related distributions in opposite directions within normal operating ranges, even greater changes were observed. Particular pairs shown in Table 6 are relative condition to improvement factor (RC to IMPF), property coupling to aesthetic factor (C to AI), and social status to awareness factor (SS to TF). From these pairs, it was noted that the last relationship most influenced turnover and tenure.

Sensitivity and Tenure

An interesting sensitivity variable surfaced during the analysis. It was not discussed previously in detail nor expected to be of major concern. However, as an exogenous input, it became useful in determining the importance of certain inferred initial conditions such as the particular stage of family life cycle or the relative age of the community. This variable is the initial set of values for tenure, $LS(t_o)$.

When initial tenure is uniformly generated from a set of non-negative integers, and the distributions shifted for different average values, the HNM performance showed this unusual behavior. For the same rates of turnover, the average residency as seen in PCMT is most seriously affected in the runs with the lowest intial average tenure. See Table 7 .

Three different settings were analyzed for which the initial average tenure, $ALS(t_o)$, was computed to be 2.06 , 8.08 and 14.4 cycles. Four cases are shown which reflect: no turnover (Case I); slight turnover (Case II); average turnover (Case III); and, severe turnover (Case IV). Figure 17 illustrates each of these cases. The average tenure, ALS, is depicted for each case as a function of cycle time in Figure 18. The major conclusion that can be drawn is that simulation runs with lower initial values of tenure, $LS(t_o)$, are more likely to experience shorter duration of residency, PCMT. See Figure 18.

Table 7 . Four Cases of Initial Tenure

$ALS(t_o)$	$PCMT(t_o + 8)$	Case
2.06	100.0	I
8.08	100.0	
14.4	100.0	
2.06	76.0	II
8.08	85.0	
14.4	89.0	
2.06	24.0	III
8.08	51.0	
14.4	64.4	
2.06	14.3	IV
8.08	35.2	
14.4	44.6	

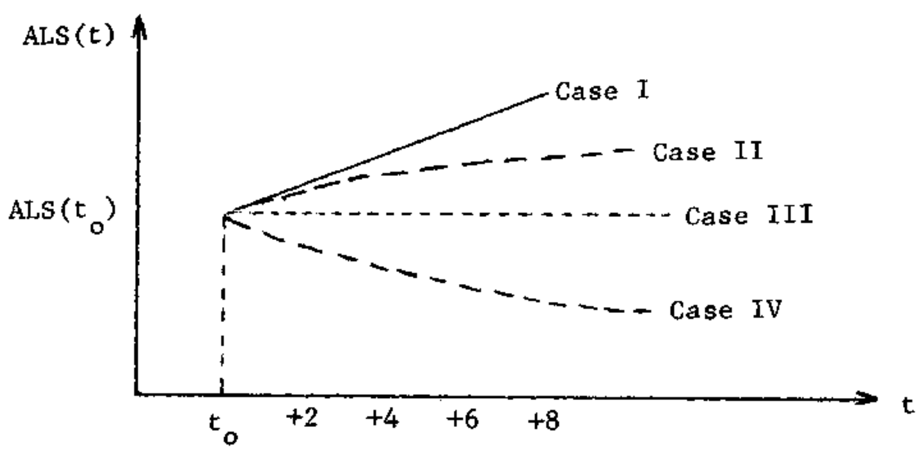


Figure 17. Average Tenure versus Time.

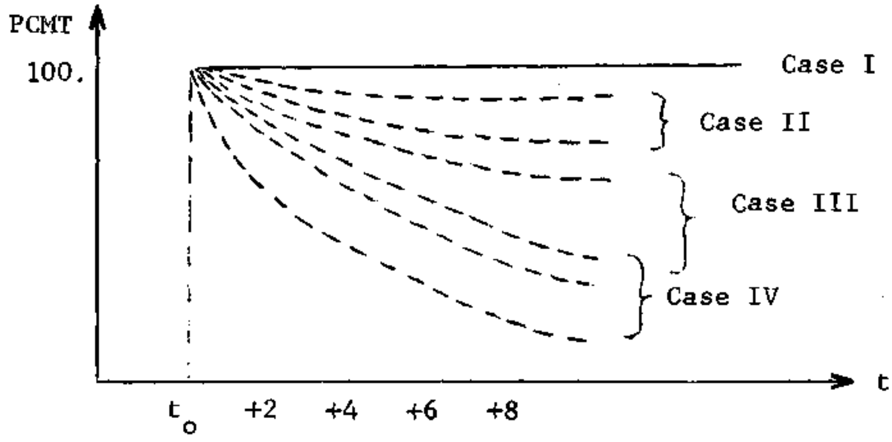


Figure 18. PCMT versus Time.

Sensitivity and Transition

For the majority of simulation runs, the levels of turnover and transition were observed by monitoring the triplet of PCNO, PCMT and PCCM. The last variable, PCCM, is the percent of causal movers. This procedure in retrospect, was unfortunate. The ultimate circumstance was that there was no stability measure clearly identified early in the model design. A subsequent search of both the micro and macro variables produced only marginal evidence for the existence of stable behavior indicators.

Two variables did emerge, nonetheless, which allowed some exploration of the model assumptions and causality. They were average social status (XBAR), and the average socioeconomic dispersion (DMEAN). However, XBAR proved to be a poor measure for several reasons. It remained fairly constant in most runs; its changes were barely perceptible in many cases; and, it could not be related to any other general trends.

DMEAN, on the other hand, appeared to be more oscillatory and could be categorized into several distinct pattern types. But, it was not without drawbacks, the most important of which was the manner in which it was computed. Admittedly, DMEAN is not an exact form of the standard deviation. In fact, the overall mathematical significance of DMEAN has not been determined.

In its present form, however, DMEAN proved useful in the following ways. An increase in its value generally preceded a period of high turnover in the form of either high throughput or shorter residence time or both. This can be inferred to occur in two ways: either individuals of lower socioeconomic status move into the neighborhood; or, part of the neighborhood is undergoing an upgrading which causes the increase in DMEAN. Conversely, a decrease in DMEAN generally left the neighborhood more susceptible to turnover. This instability, if already in progress, becomes dependent on the socioeconomic status of the more recent immigrants.

The evidence for DMEAN as a feasible measure of stability was drawn from approximately 40 runs. In 28 of those runs, there were increases in DMEAN which preceeded high turnover 22 times. In 15 cases in which DMEAN decreased, more immediate stabilization was noted.

Sensitivity and DMEAN

Thus, DMEAN was chosen as a sensitivity measure because of its observed ability to return to original values after being perturbed. If it did not return to a former value, it generally remained a the new level, without much subsequent change. The following cases have been recorded, and are shown in Figures 19 and 20.

For monotonic increases in DMEAN: Case I-a shows a gradual increase; and, Case I-b exhibits a sudden increase, usually occurring later in the run. The latter two cases are: the 'rise and fall' or

Case II-a; and, the 'fall and rise' or Case II-b. For Cases I-a and I-b: $v_i \equiv$ the initial value of DMEAN; $v_b \equiv$ the value at the time of break; $v_m \equiv$ the value at the maximum rate of increase; and, $v_f \equiv$ the final value.

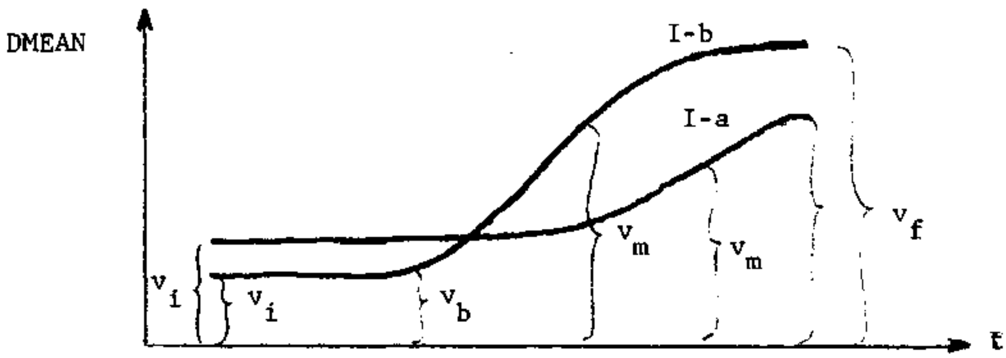


Figure 19. Cases I-a and I-b.

In Cases II-a and II-b, there are additionally: $v_{max} \equiv$ the maximum value; and, $v_{min} \equiv$ the minimum value. An important indicator is the speed of response. The time values to measure this speed are: $t_b \equiv$ the time to break point; $t_m \equiv$ the time to the point of maximum increase; $t_{max} \equiv$ the time to the maximum value; $t_{min} \equiv$ the time to the minimum value; and, $t_p \equiv$ the time between equal levels or inflection points. The graphs have been greatly exaggerated for contrast.

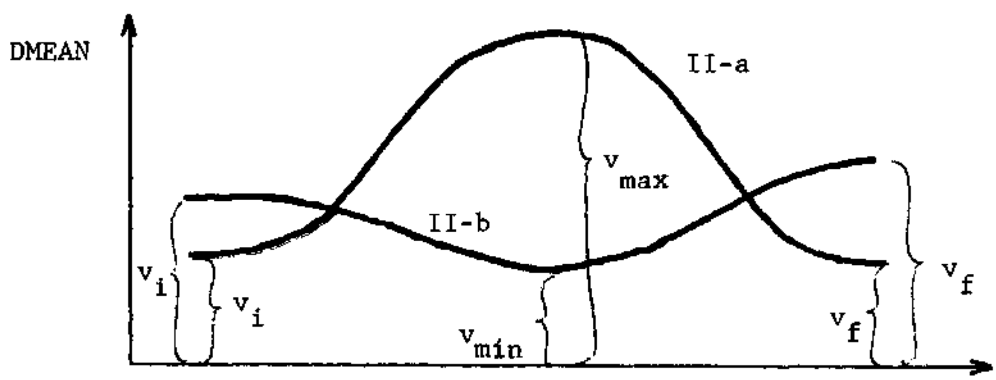


Figure 20. Cases II-a and II-b.

Figure 21 shows one example run for each case. The run number and the case number are shown on each trajectory. For Case I-a, where the runs with $t_m > 8$, the average $t_m = 8.3$, were checked for the average change in DMEAN, it was found that in 11 out of 16 runs, a period of high turnover and low duration of residency (PCNO and PCMT) followed the increase in DMEAN.

Since Case I-b resembles Case I-a in performance, it was suspected that the same parametric values would be involved for certain values of t_b and similar changes in DMEAN. And, such was the results in a majority of runs. See data for runs number 204,207, 203 and 205, in particular. This data is in Appendix B .

In Cases II-a and II-b, an important aspect was the possible discernment of some common feature which might be responsible for the second change of direction of the trajectory of DMEAN. It turned out that there did not appear to be any consistent pattern. However, again, it is suspected that the explanation may well rely on the manner in which DMEAN is computed.

Sensitivity Summary

What can be concluded at this point is that while certain input values and distributions produced few noticeable changes in HNM performance, the initial conditions are in fact the most important collective sensitivity control features. During the simulations, the intervariable relationships caused the greatest average changes in output responses. The variable DMEAN was finally chosen as the main sensitivity parameter, and some examples were shown to indicate its range and activity. A new sensitivity variable, LS, was discovered during this analysis.

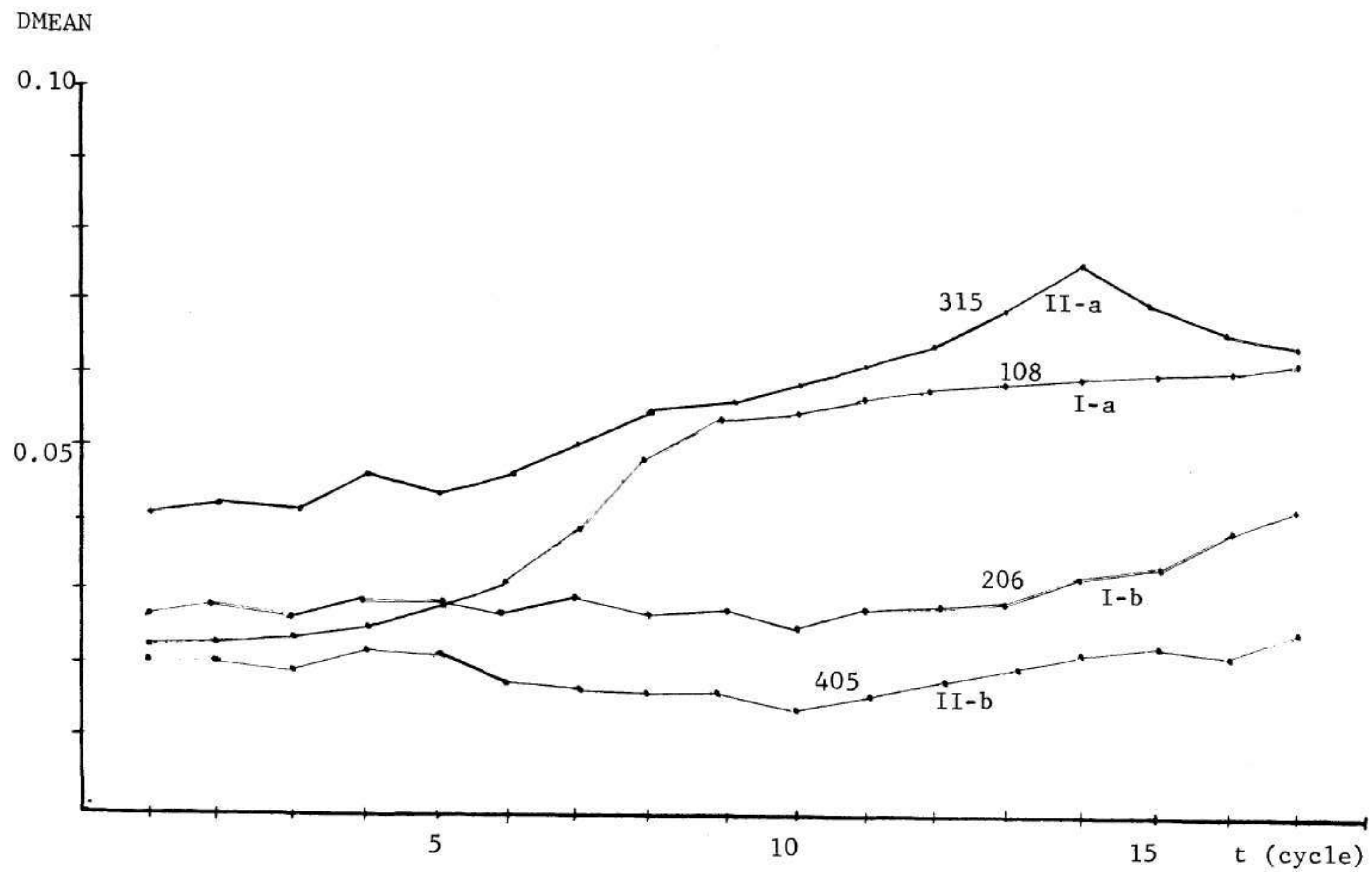


Figure 21. Examples of Four Cases of DMEAN.

Finally, no discussion of sensitivity would be complete without some interpretation of the model performance in terms of the dynamic behavior of the real system. As was previously concluded, the HNM is less sensitive to the choices of certain distributions, but perhaps more to the relationships between distributions. In addition, the starting values of LS are very influential to the performance curves, especially PCMT. From these two observations, it can be inferred that middle-class neighborhoods, or those with greatest variability in the distribution of attributes, are most susceptible to higher rates of turnover [51]. Such urban areas include newer subdivisions or those with average occupancy of less than four years.

As the HNM was not observed to be very sensitive to most choices in the types of distributions, neither did it appear to be dependent on the total number of variables. This may indicate that the processes of turnover and transition are natural at both the aggregate and individual levels. Macro change is inevitable. And, micro decision processes always reduce the complexity of the real situation. In other words, migration is routine; and, individuals select a minimum number of features over which to make these decisions. For further discussions, see [60,69,101,110].

Turnover and transition were previously defined as separate indicators of community dynamics. However, it cannot be assessed whether they are related since our measures of stability and sensitivity are not easily correlated. Some stable neighborhoods have high turnover, and some unstable ones little migration [96,112]. Since the rate of transition depends on measurements of neighborhood attributes, many quite subjective, further extensive research is required.

CHAPTER VII

STATISTICAL TESTS AND POLICY EXPLORATION

The General Validation Problem

The task of validating simulation experiments generally refers to the process of verifying the results of the simulation studies, rather than verifying the simulation model itself. This task has become, according to some [94], the most elusive and difficult of all the unresolved problems associated with computer simulation. There does seem to be, however, widespread agreement on the proposition that model verification is not appreciably different than the verification of any hypothesis, mathematical equation, or computer program [92].

The verification of a model involves a 'proof' that the model is 'true.' However, this implies that there are established criteria for differentiating between models which are 'true' and those which are not; and, a major assumption that this 'proof' is applicable to any given model. A more reasonable approach to the verification task has become the successful reproduction of particular instances of the behavior of the real system. The practical modeler, therefore, endeavors to show in as many ways that are meaningful and relevant that the model is <u>not untrue</u> [97].

Conscientious simulation modeling should provide response vectors which are compatible with a corresponding set of responses of the modeled system in real time [92]. It happens too often, however, that simulation models proceed into controlled experimentation without any real validation attempts [94]. The need to establish model credibility has received much attention recently [87].

Therefore, it seemed appropriate for our purposes to distinguish: model verification, as the act of testing the internal consistency of the model together with the correspondence of its components with their real counterparts; and, model validation, as the tests for external consistency of the model behavioral responses compared with real time histories. Other definitions can be found in [87,91,97].

HNM Testing

Verification

Static and dynamic tests of internal consistency of the HNM were performed during the model design phase. The static analysis involved monitoring the relationships of several endogenous variables; e.g., the number of buyers (NB), the number of appreciating properties (NPA), etc., for range and consistency of values. Dynamical measurements of certain exogenous variables; e.g., the rates of change of vacancies (ID), the average length of residency (ALS), and others, provided checks on the macro-behavior over a period of time.

These verification tests basically attempted to establish the reasonableness of the model. During the tests, model changes entailed continually: reformatting the output; readjusting the length of the runs; resetting appropriate starting and initial conditions; recasting equations; and, experimenting with DM decision policies. A latter facet of the verification was a sensitivity analysis which tested for critical operating conditions of the simulation runs. The DM is a decision-maker.

A crucial issue in the verification was the selection of a computational time interval. A precise definition of one cycle of process time, or a portion thereof, is necessary to draw comparable inferences in real time. Many tests were conducted in which the cycle time corresponded to monthly, quarterly, semiannual and annual real time intervals. While it was found that the model could be redesigned to function with these other time intervals, the optimum conditions resulted when the cycle time coincided with the minimal turnover time for urban properties. Since it is rare that the same property is sold twice (or more often) in a given year, the cycle length corresponding to one year real time was chosen.

Lastly, the issue of the economics of simulation run lengths was not overlooked. Since our primary interest appeared to be in short-term consequences, only the shorter run lengths were considered. In most cases, a simulation run representing 15 to 20 years in real time was completed in less than two minutes of real computer (I/O plus CPU) time.

Validation

The validation of the HNM was conducted by the: justification of some assumptions of other similar projects [26]; advisement by several urbanologists through personal communications [135]; testing hypotheses available in the literature [98,118]; and, fitting performance curves to available data [109].

In the model design phase, some forty potentially useful variables were screened. Here, the separate accounting of physical versus psycho-socioeconomic components proved helpful. The total number of variables finally chosen seemed consistent with similar models [134]. Early in, and throughout the research, assistance was sought and received in the model development, design of the experiments and review of the trends and results. Individuals and groups knowledgeable in simulation and urban affairs were provided with data, papers, oral reports, and results of the various HNM simulations [135]. Critical review was also received during a modeling and simulation conference at which some preliminary details were presented [38].

Subsequent validation tests utilized either hypothesis testing or goodness-of-fit techniques. The real data that was used proved to be difficult to obtain, limited in extent, and awkward to correlate. Many recent studies, such as those in demography, have complained of being similarly hampered by scanty and noisy data [117]. The data sources for these tests were regional reports [4,62,96], comprehensive multi-city studies [76,126], and some Census publications [124,125,127]. One drawback of the Census data was the fact that it was generally collected only at ten-year intervals. Other public data sources, such as County property records, Tax Digests, and Engineers Field Data presented an enormous task of cross-referencing. Private data sources included real estate agency records and price location files of the Multiple Listing Service which were not available , generally.

The HNM Tests

Despite the data handicaps, three hypothesis and one goodness-of-fit tests were performed with reasonably favorable outcomes. These tests show the level of detail and the extent of the precision available in a model of this type. To demonstrate several representative tests, the following are presented.

Hypothesis Test #1

The hypothesis is that rapid turnover, as experienced in racial transition, has an adverse effect on property values. It was not supported in an earlier statistical study [76], nor by this test. In 75 runs observed to be unstable, as defined previously, there were 51 runs in which the average property values increased 36% within 6 cycles. In 67 runs which were not unstable, there were 41 runs in which the average property values increased as rapidly.

Data. In the first group, the number of runs and frequency are: $n_1 = 75$ and $f_1 = 51$, respectively. For the second group, $n_2 = 67$ and $f_2 = 41$. A level of significance, $\alpha = 0.05$ is chosen. And, we define p as the proportion of runs in each group, where $p_i = f_i / n_i$.

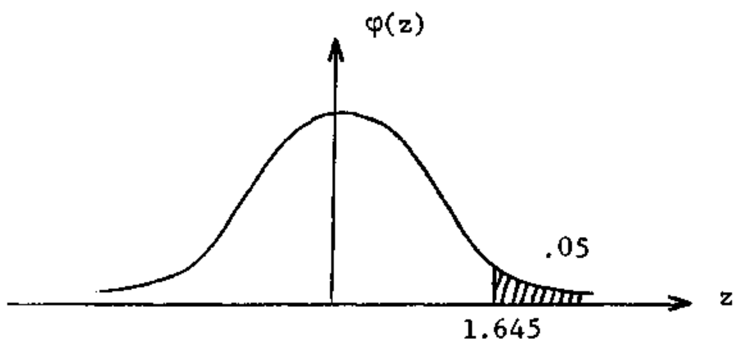
Null Hypothesis. $p_1 \leqq p_2$ or that property values do not increase more rapidly in unstable areas than in areas that are not unstable. This in known as H_o.

Alternate Hypothesis. H_1. $p_1 > p_2$, is that property values increase more rapidly in unstable settings.

Statistic. $Z \approx \{ p_1 - p_2 \} / \{ \sqrt{p \cdot q \cdot (1 / n_1 + 1 / n_2)} \}$ is chosen. Since the best estimate of the parameter p is $(f_1+f_2)/(n_1+n_2)$, and $q = 1 - p$; then, $p = 92 / 142$ or 0.647 and $q = 0.353$.

Criterion. Reject H_o if $Z > z_{.05} = 1.645$.

Figure. The region of rejection is the shaded area to the right of the value 1.645 on the z-axis.



Calculations. $Z = \{ .680 - .612 \} / \{ \sqrt{(.647)(.353)(1/67+1/75)} \}$. Thus, Z = 0.846 which is not greater than 1.645 .

Conclusions. We do not reject H_o at the .05 level.

Interpretation. The proportions of runs from the stable and unstable settings were such that we choose not to reject this hypothesis. Hence, it may be reasonable to assume that the same chances exist for increases in property values in both settings. In fact, other studies have shown that property values tend to increase more rapidly in transitional areas than in other areas [20,51,76,102 103] . See Appendix C. This has been explained by the increased demand for available housing in transitional areas, as was discussed in Chapter III.

Hypothesis Test #2

The hypothesis here is that class tolerance is independent of income level within the middle-class. Or, in other words, upper income groups are less susceptible to transition. However, certain studies, [99] for example, have revealed no propensity on the part of upper income neighborhoods to sustain high rates of turnover, transition, or any downward trend in social status.

Data. Let n and $\bar{c}$ stand for the number of runs and the average number of cycles, respectively; where u ≡ the upper income group and ℓ ≡ the lower income income group, with s ≡ the standard deviation. From Table 8 , we see that: $n_u = n_\ell = 60$; $\bar{c}_u = 6.00$ and $\bar{c}_\ell = 5.83$; and, $s_u = 1.67$ and $s_\ell = 2.86$. Again, we choose $\alpha = .05$.

Ho. The null hypothesis, $\mu_u \geqq \mu_\ell$, is that the upper income group does not experience less turnover. This is based on: the mean number of cycles for the group of runs was the same (PCCM ≧ 20%) for the lower income group ($0.10 \leqq ES \leqq 0.40$) as the upper income group ($0.50 \leqq ES \leqq 0.80$).

Statistic. Since $\bar{c}$ appears to be normally distributed for a large number of runs, $\{ \bar{c}_u - \bar{c}_\ell \} / \{ S \sqrt{1/n_u + 1/n_\ell} \} = t$ can be used; provided it can be shown by an F-test that there are no significant differences in the respective variances, s_u^2 and s_ℓ^2, whereby $S^2 = \frac{1}{2}(s_u^2 + s_\ell^2)$. However, since $s_u^2/s_\ell^2 \geqq F_{.05,59,59}$, or $(2.86)^2 / (1.67)^2 \geqq 1.53$, the variances cannot be pooled. Thus, a psuedo-t Test is used and ν computed.

$$\nu = \left\{ \{ s_u^2/n_u + s_\ell^2/n_\ell \}^2 / \{ (s_u^2/n_u)^2/(n_u+1) + (s_\ell^2/n_\ell)^2/(n_\ell+1) \} - 2 \right\} .$$

Thus, $\nu = .033 / .00034 - 2 = 96.3$; and, $t_\nu = 1.645$.

Criterion. Reject H_o if $t > T_{118,.05} = 1.645$.

Figure. The figure is the same as the one for Hypothesis Test 1.

Calculations. These were performed in the section on the Statistic. And, $t \not> T$ since $1.645 = 1.645$.

Conclusions. We do not reject H_o at this level.

Interpretation. The difference is so slight between the two sets of data that it can be concluded, at this level of significance, that there is little difference in the transitional effects on different income levels with in the middle-class.

Table 8 . Data for Hypothesis Test #2.

	Income Level (ES)	Number of cycles, in ten, in which causal movers in excess of 20% (PCCM)	
Lower	0.100-0.200	Lower ** 2	Upper * 4
	0.200-0.300	4	9
	0.300-0.400	8	8
	0.400-0.500	5	7
Upper	0.500-0.600	6	6
	0.600-0.700	9	5
	0.700-0.800	6	4

Distinction made as follows: * TPNH = 4
** TPNH = 2

Hypothesis Test #3

The hypothesis here is that the expected number of causal movers, for a given set of conditions (see Experiment #2 in Chapter VI as an example), is 23.0 which is a normalized value for conformance with the HNM size of 64. From a set of 20 runs, the average number of causal movers ($\overline{NCM}$) is found to be 25.1 with a standard deviation of 4.6 for similar conditions.

Data. For this number of runs, n = 20, the average is given by: $\overline{NCM}$ = 25.1 ; and, the standard deviation (S) is 4.6 . The level of significance, α, is chosen again at .05 .

Ho. The actual number of movers is 23.0, or $\mu = 23.0$.

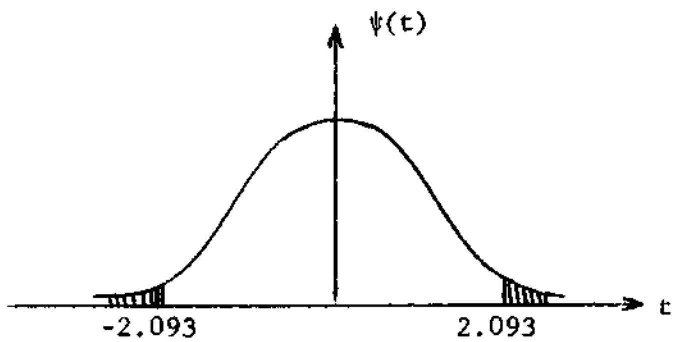
H_1. The actual number of movers, on the average, is not 23.0, or $\mu \neq 23.0$.

Statistic. A normal population is assumed in order to use:

$$t_{n-1} = (\bar{x} - \mu_o) / (S / \sqrt{n}) .$$

Criterion. Reject H_o if $| t | > T_{19,.025} = 2.093$.

Figure. The regions of rejection are shown as shaded areas on the figure.



Calculations. $| t | = | (25.1 - 23.0) / (4.6 \sqrt{20}) | = 2.04 \not> 2.093$

Conclusions. Reserve judgment at this level.

Interpretation. In the 20 runs observed, with the given initial values and the assumed test procedure, there is not sufficient evidence to reject the model average. The implications are that there is reason to believe that the model average and the real data average are quite close.

Goodness-of-fit Test

This test provided an opportunity to compare the HNM performance such as the level of new occupants with data gathered from neighborhoods that experienced racial transition [109]. An assumption is that the number of new occupants in the model sense, seen reflected in PCNO, is equivalent to the new black households in an area undergoing racial transition.

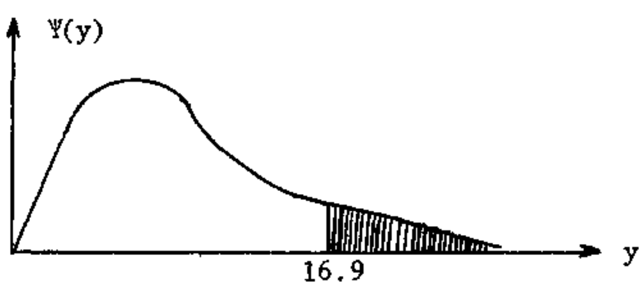
Data. The number of cycles (years) is given by: $n = 10$. The level of significance is again chosen as: $\alpha = .05$. The other data is given in Table 9 .

Ho. The frquencies of new occupants fits PCNO which is adjusted for this test, or $F_1(t) = F_2(t)$.

Statistic. $Y = \sum_{i=1}^{n} (A_i - T_i)^2 / T_i \approx \chi^2_{n-1}$ where $A_i \equiv$ actual number and $T_i \equiv$ theoretical equivalent.

Criterion. If $Y > 16.9$, reject H_o since $P(\chi^2_9 > 16.9) = .05$.

Figure. The shaded area is the region of rejection.



<u>Calculations</u>. $Y = \sum_{i=1}^{10} (A_i - T_i)^2 / T_i = 4.19 \not> 16.9$

<u>Conclusions</u>. Do not reject H_o at this level.

<u>Interpretation</u>. The observed data compares favorably with the expected data. With the given assumptions, this HNM dynamic response appears acceptable with certain real neighborhood behavior.

Table 9 . Data for χ^2 Test

Actual (A_i) Percent Population	Actual (A_i) Projected Units*	Classes Years / Cycles	Theoretical (T_i) PCNO (%)	Theoretical (T_i) Projected Units	$\frac{(A_i-T_i)^2}{T_i}$
8.2	5	1	10.94	7	0.5714
30.5	20	2	23.44	15	1.6667
55.8	36	3	51.56	33	0.2727
62.1	40	4	56.25	36	0.4444
74.9	48	5	67.19	43	0.5814
77.5	50	6	71.88	46	0.3478
82.1	53	7	82.81	53	0.0000
80.8	52	8	84.38	54	0.0741
81.7	52	9	85.94	55	0.1636
83.1	53	10	86.08	55	0.0727
				Sum =	4.1949

* These adjusted values correspond to the HNM size of 64. The actual number of units, during this time period, increased from 1354 to 4966, and the population increased from 5384 to 16675. This data was taken from Census Tract F-78, Adamsville.

HNM Control Experiments

Attention is now directed towards the experimentation with differing analogues to urban policy. The role of the DM will be hypothesized as that of an external controller, whose primary purpose and concern will be the strategy synthesis from alternative policies. A major premise for this view is that a proper selection of policies will optimally allocate human, financial, and physical resources to realize certain objectives.

Two important assumptions must consequently be made. Firstly, there is a high degree of correspondence between the control in the model and in the real system. And, secondly, that the objectives are the same for the DM as the system being controlled implies a mutual betterment by the control.

Such a control approach in socioeconomic settings is obviously useful in, for instance, cost-benefit or worth-performance strategy analysis. And, it appears particularly applicable to neighborhood development and control. However, there are some problems which must be considered in advance. Firstly, it is quite likely that the systems being controlled have some inherent stability, albeit ill-defined. Secondly, we have distinguished perhaps a two-level, multi-goal process.

In Experiments 5 through 9, we consider policy alternatives. The DM may attempt: no change at all with the hope that a given problem corrects itself; policy changes at the macro level such as laws or customs; or, micro level changes which may encourage physical or socioeconomic revitalization. It goes without saying that all three of these options may be well conceived and the expectations are for some degree of revitalization. The first option will not be considered in this study, although it is perhaps observed often in practice. The most likely alternatives spring from the second option. The reason for this conclusion is that this type of policy change is, and has traditionally been, the most accessible to the DM. Option three policies are appealing for altruistic reasons and for their long-term potential. However, there is still no guarantee of success as history has shown. Therefore, the following policy simulations incorporate changing local law, custom and practice to maintain stability and curtail transition.

Experiment #5.

This experiment simulates the effects of initial non-uniform zoning.

Description. As can be seen in the data sets, the only adjustments made in the runs of this experiment are in the values of levels of awareness (TF). Higher values for the parameters of the distributions were chosen without corresponding changes in the values of other related variables. Then, during the progress of certain runs, changes were made in the real estate selection (RESIT) with no noticeable cumulative effects. The average length of residency (ALS) initially drops somewhat as the change in PCMT is -35% in the first five cycles. However, it does not decrease appreciably thereafter. The increase in PCNO appears moderate throughout, as are the increases in DMEAN.

Interpretation. This experiment indicates that the use of non-uniform zoning exhibits marks of providing more tolerable levels of turnover and less change in the socioeconomic indicators. This confirms one notion which attempts to relate stability to population density [73]. Intuitively,

Table 10. Data Set for Experiments 5 and 6.

	Experiments 5	Experiments 6
MONFAC	2 to 4	2 to 4
THA,THB,THC	.15 to .25 T	.15 to .25 T
TPNH	2 to 4	2 to 4
RC	2 to 8 U	2 to 8 U
AEFAC	1 to 3	1 to 3
AI	1 to 6 U	1 to 6 U
C	1 to 5 U	0 to 19 T,U
LS	0 to 15 U	0 to 15 U
ID	Uniform/Mixed	Uniform
IMPF	1 to 6 U	1 to 6 U
RESIT	1 to 5	1 to 5
TXA,TXB,TXC	.2 to .3 T	.2 to .3 T
TYA,TYB,TYC	.25 to .35 T	.25 to .35 T
TF	3 to 5 U	1 to 5 U
ADJ	1 to 2	.95 to 2
NUMCY (per run)	17	17
NUMBER OF RUNS	42	45

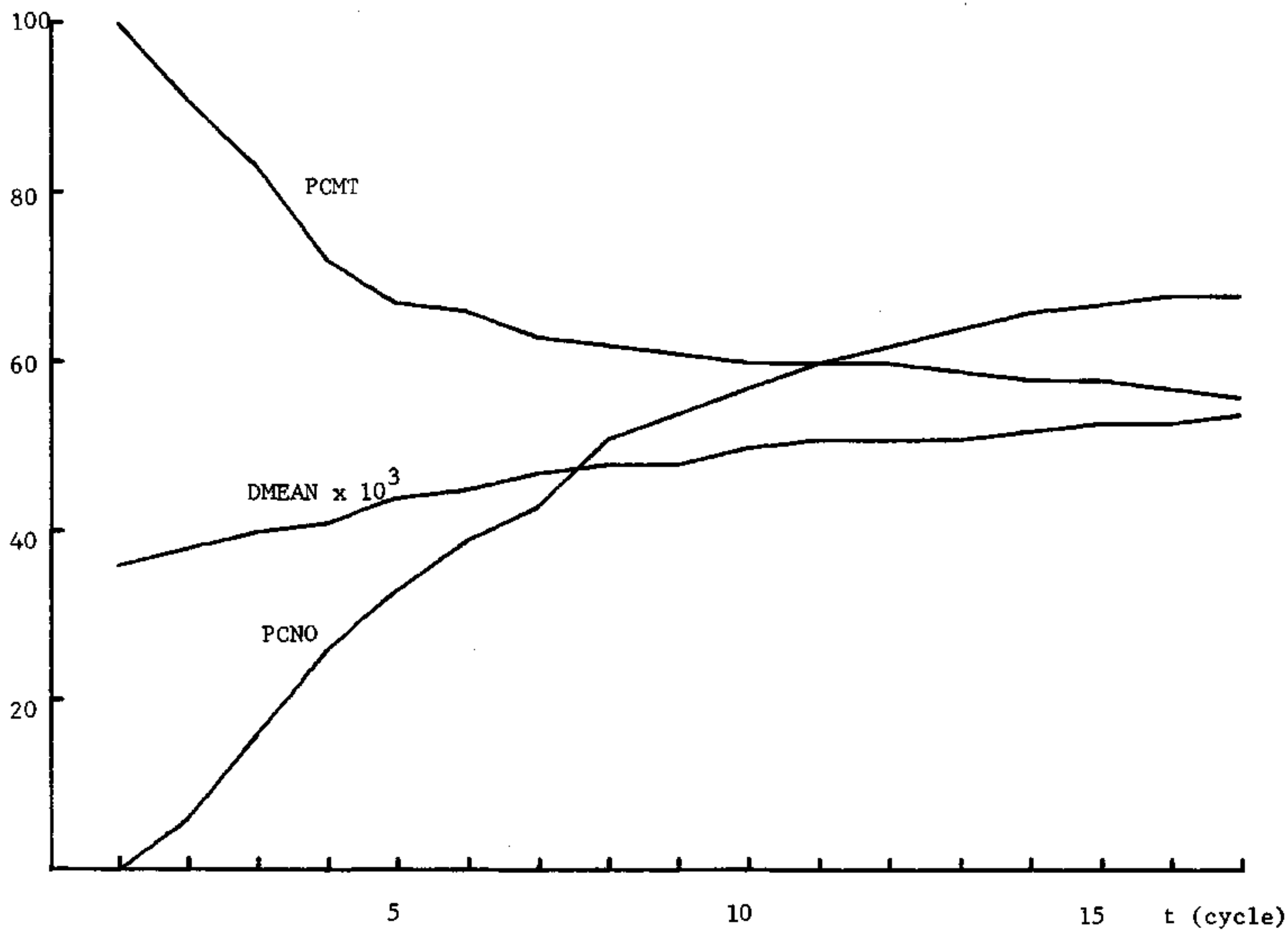


Figure 22. Graphs for Experiment #5.

it would appear that larger and more random lot sizing would slow migration. This effect was accomplished in the model by decreasing the information fields of individual residents. This technique may offer little hope of success in urban areas that are well established as physical structure and geometry may be difficult to change. In that case, other alternatives would be necessary if rezoning is impracticable.

Experiment #6.

In this experiment, an attempt is made to simulate the effects of liberalized fence ordinances, or the elimination of laws which would seriously restrict fence size (height) and type (opacity).

Description. The runs in this experiment were selected based on changes to the property coupling distribution (C). These changes were made both by adjusting only specific values in the total collection, as well as producing new distributions by type and parametric value. Some additional changes were necessary in DC and ICP (See Chapter V). The results were again fairly stable in the sense that changes were gradual and with minimal turmoil.

Interpretation. As was recognized in the discussion on the previous experiment on non-uniform zoning effects, the extension of the individual resident space actually slows the migration and change processes. The simulation feat of "uncoupling" certain residence variables leading to slower responses of output trajectories implies that artificial extensions of the available property by the use of larger fencing may decrease the interaction leading to emigration. These fences or barriers can be of natural material which would not only serve to limit access and visibility, but perhaps noise and other encroachments as well [18,73]. Such items are

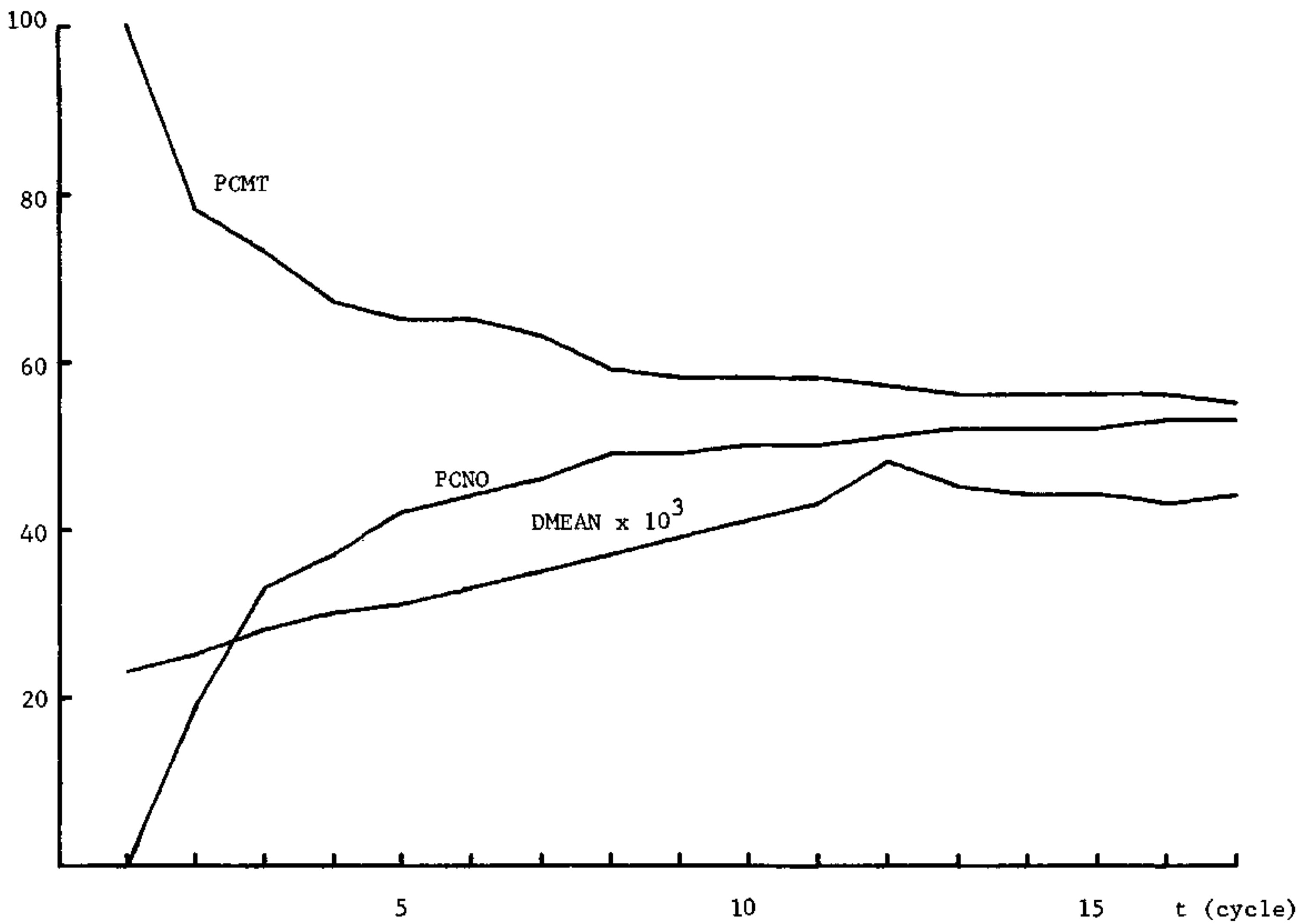


Figure 23. Graphs for Experiment #6.

Table 11. Data Set for Experiments 7 and 8.

	Experiments 7	Experiments 8
MONFAC	2 to 4	2 to 4
THA,THB,THC	.15 to .25 T	.1 to .3 T *
TPNH	3	1 to 5 *
RC	3 to 7 U	3 to 7 U
AEFAC	2	2
AI	2 to 5 U	2 to 5 U
C	1 to 5 U	1 to 5 U
LS	4 to 12 U	0 to 10 U
ID	Assigned/Mixed	Uniform
IMPF	1 to 6 U	1 to 6 U
RESIT	1 to 5	1 to 5
TXA,TXB,TXC	.2 to .3 Assigned	.2 to .3 T
TYA,TYB,TYC	.25 to .35 T	.25 to .35 U
TF	0 to 5 U	0 to 5 U
ADJ	1 to 2	.95 to 2
NUMCY (per run)	17	17
NUMBER OF RUNS	21	48

plentifully evident areas of high population density such as Western Europe and Japan.

Experiment #7.

The effects of restrictive real estate sign ordinances are shown in this simulation experiment. These were, by far, the most difficult runs to produce since the assignment of values of certain arrays had to be individually introduced.

Description. The general procedure used in this experiment was similar to that of previous experiments in that most variable levels are again self-controlling. However, the major difference here is that the real estate screening process is by-passed (RESIT). In other words, the assignment of buyers to available properties was made by manual methods which were either by predetermined selection or randomly. Certain preassignments were also made to the "new" and "old" resident mix. The results were found to be reasonably stable. See Figure 24.

Interpretation. In real neighborhoods, the effect of such actions, as seen in the simulation, may seriously hamper agency sales activities. By restricting advertising signs, the local dissemination of information would be strongly impaired. Neither the extent of this control measure nor its ultimate consequences are known. Unrestricted use of signs has resulted, on occasion, in unethical, and perhaps illegal, activities [107]. The total impact of agencies, and the relative local neighborhood emphasis are also recognized, however [76]. Statutes do exist which limit sign use in many areas, and these rules are often violated [37]. Some slight reduction in transition and blockbusting have been observed by sign control [14].

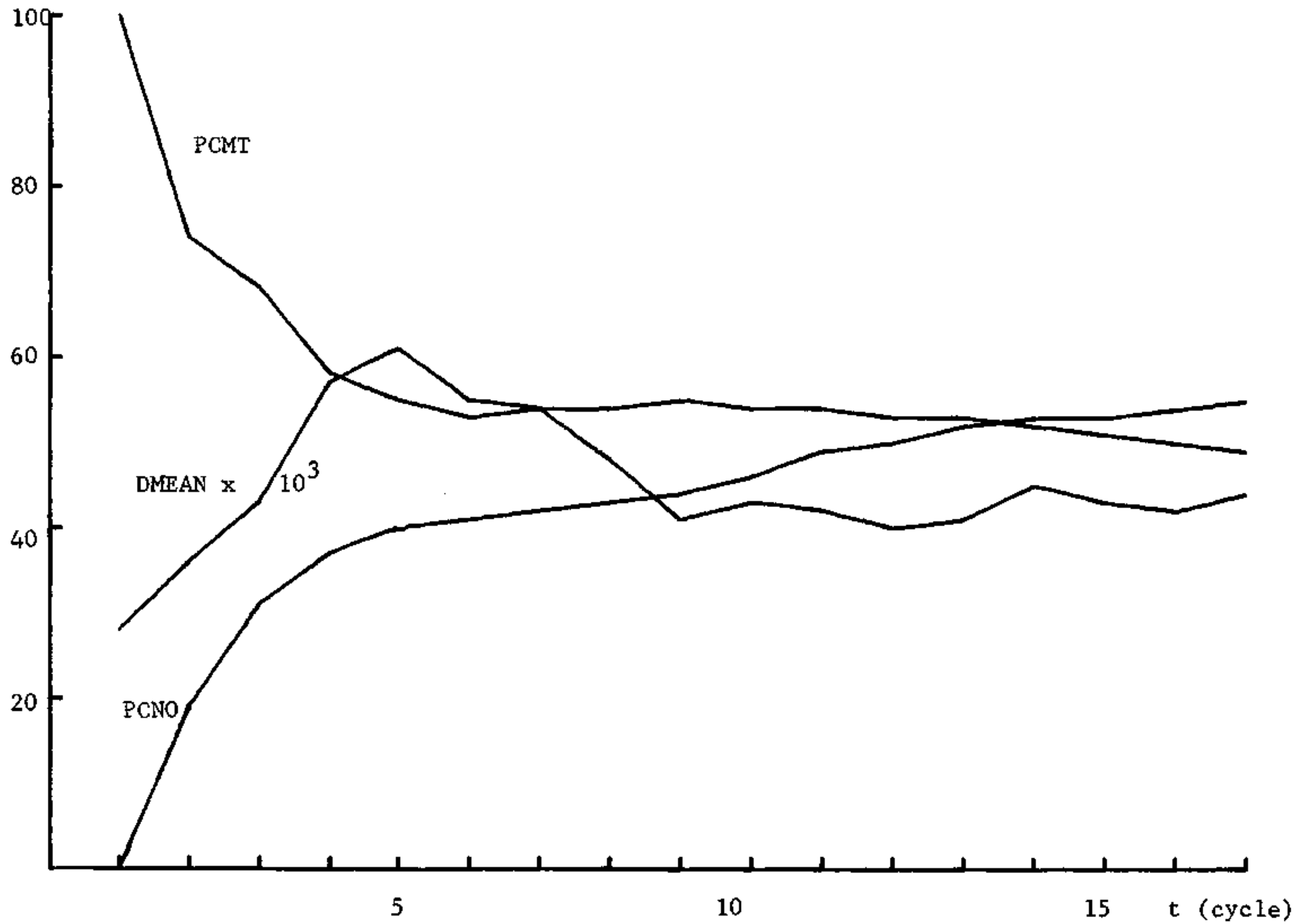


Figure 24. Graphs for Experiment #7.

Experiment #8.

This experiment serves to illustrate two different types of changes in the property tax structure. Two groups of runs were assimilated into this single experiment of both policy effects. The tax alternatives are known as policies of tax relief and tax deterrent, respectively.

Description. These effects were accomplished in the simulation runs in the following ways. The first effect was brought about by initially linking the type of neighborhood (TPNH) to the property values (HV), and then forcing this relationship to be distorted. This was done by limiting the type of change, by direction of change, that could be made to these variables. The second effect was noted by the removal of vacancies (ID_i=0) either by marking in a special way those residences that are vacant, or replacing the residents. The output is turbulent during the first execution phase (1st four cycles) and tends to stabilize during the latter phase (cycles 9 through 12). See Figure 25.

Interpretation. The first effect attempts to simulate a reduction in property tax rate. This policy of tax relief tends to inflate property values relative to their true value, which appears to increase emigration. The results show higher throughput (PCNO) and lower average residency (PCMT). The alternate policy, that of a tax deterrent, simply forces the removal of substandard properties or those houses that are vacant for long periods of time. This action tends to deflate property values which, under certain circumstances, seems to accompany revitalization [9,19]. Thus, the overal effect is that migration is slowed, and some stabilization is realized.

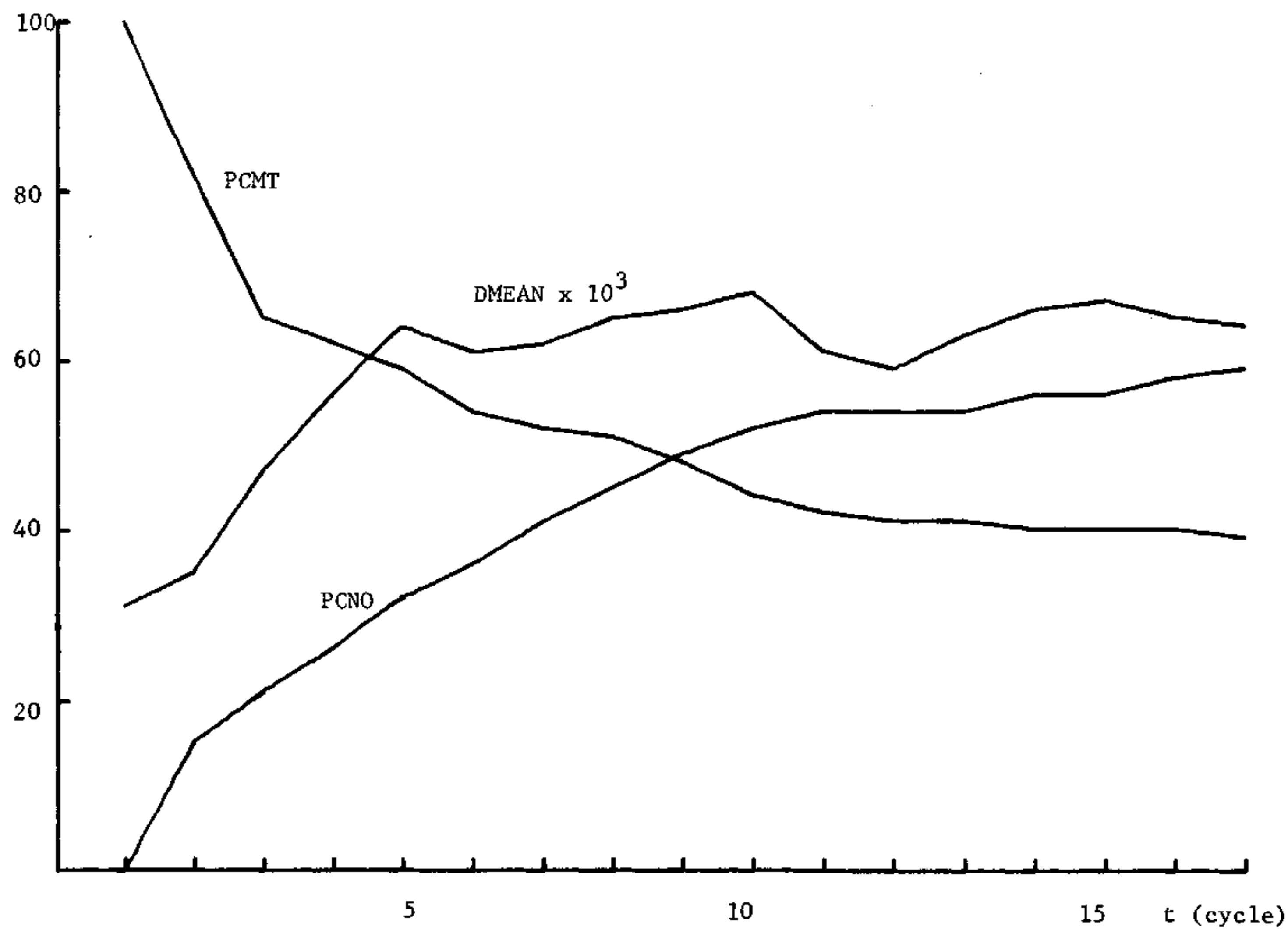


Figure 25. Graphs for Experiment #8.

Table 12. Data Set for Experiment 9.

	Experiment 9
MONFAC	2 to 4
THA,THB,THC	.15 to .25 T
TPNH	2 to 4
RC	1 to 10 U *
AEFAC	1 to 3
AI	1 to 10 U *
C	1 to 5 U
LS	0 to 15 U
ID	Mixed
IMPF	1 to 6 U
RESIT	2 to 5
TXA,TXB,TXC	.2 to .3 T
TYA,TYB,TYC	.25 to .35 T
TF	0 to 5 U
ADJ	1 to 2
NUMCY (per run)	17
NUMBER OF RUNS	38

Experiment #9.

In order to show that certain public and community services are utilized as policy instruments, this ninth and final simulation experiment was designed.

Description. The initial conditions in these simulation runs were characterized by antisymmetric distributions of AI and RC, and by restricting increases in HV. These actions amounted to either situations of unsightly but well maintained, or poorly kept yet naturally appealing, properties. The assumption here is that this relative incongruence has been principally caused by the lack of, or loss of, proper sanitary, safety, or recreational maintenance. A summary of these public services includes refuse collection, road repair, sewerage disposal, and other recreational opportunities such as parks, playgrounds, and gardens, etc.

Interpretation. The more rapid rates of turnover (PCNO) and the oscillation of socioeconomic composition (DMEAN) indicate that transition can actually be exacerbated by untimely physical decay. Conversely, increasing the efforts of community services may, in reality, assist stabilization. Severe increases in the rate of transition have been noted in several real neighborhoods with actual or anticipated loss of services [14]. A consistent theme is that the loss of local control is more detrimental than the actual loss of services [37]. Analogously, the loss of local control of other facilities such as schools, as through the use of busing, appears to cause similar results [96].

Policy Summary

The previous experiments have been presented to show the possible types of simulation exercises. In each, an attempt was made to interpret

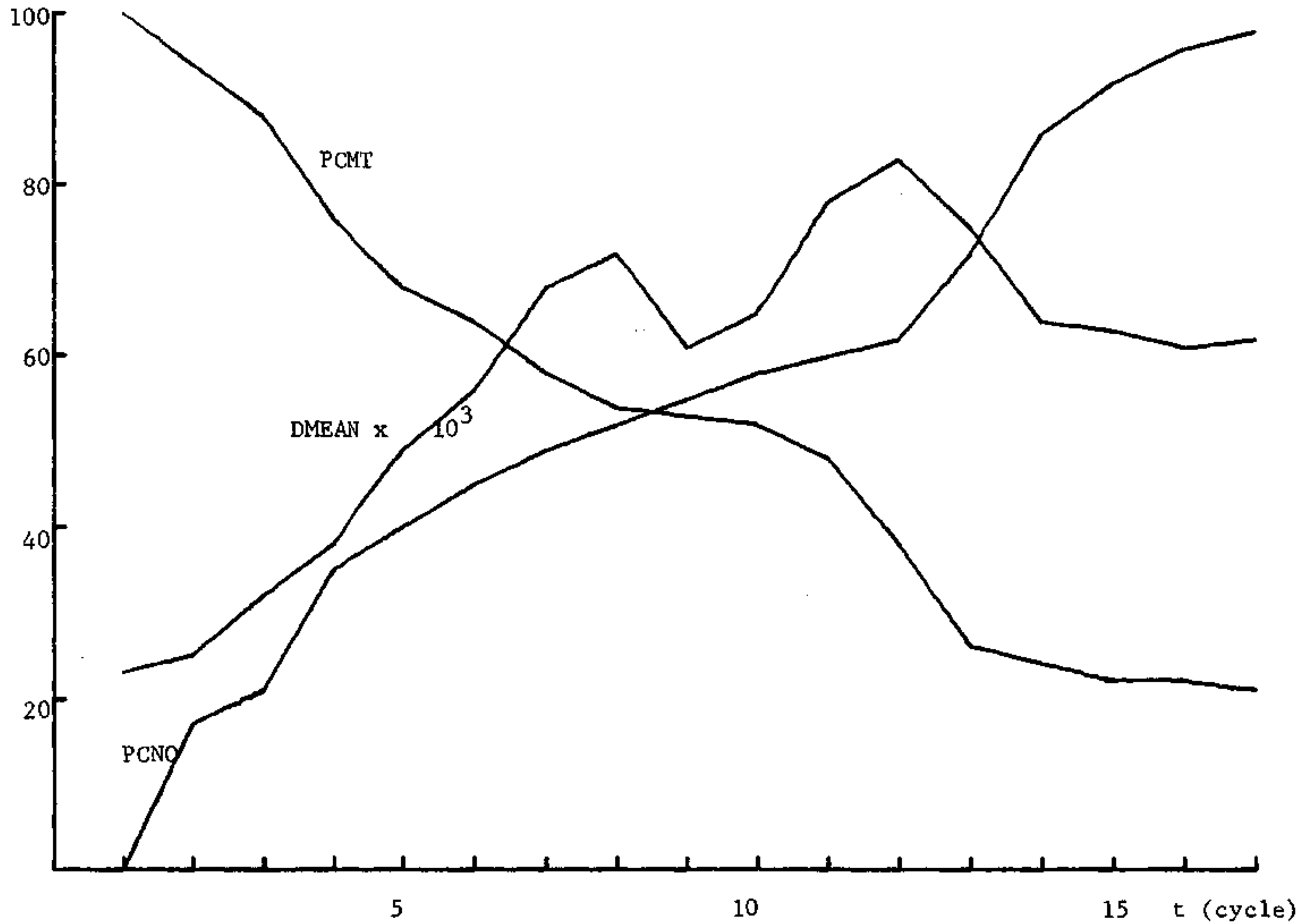


Figure 26. Graphs for Experiment #9.

the results in terms of actual policy changes on structure and dynamics of real urban neighborhoods. In the latter five experiments, changes in the initial conditions of the HNM reflect: non-uniform zoning; unrestrictive fence ordinances; restrictive real estate sign ordinances; consistent property tax assessment; and, effective application of public services.

A variation on the standard notion of ceteris paribus was applied throughout. The procedure was, firstly, to attempt to model both the nominally stable and unstable settings. Then, by adjusting the HNM structure and relationships, the resulting interactions produced model effects comparable to some of the common real problems. Thirdly, the model was analyzed to provide some understanding of possible causes and effects. Lastly, several revised policies were designed for solving or relieving the problem thus created, or reducing its complexity.

Some implications of these outcomes, several possibly counterintuitive, were identified and discussed. The method by which the HNM was constructed was described in order to enhance the understanding of its role. The first implication is that transition is a natural process. Thus, the phenomenon can only be evaluated by certain relative rates of change. Secondly, catastrophic changes are improbable since they were not observed in the simulations. This suggests that most change occurs gradually without either mass exodus or traumatic events. However, individual acts of protest or violence, for example, cannot be ruled out. A third outcome is the role of thresholds. When particular levels are reached, different types of responses can be observed. Fourthly, middle-class communities may be the most susceptible to transition and change. This implication may be due.

in some part, to the relative uncertainty in status or the recentness of changes in lifestyle for this group.

In terms of the HNM, the only dynamic stabilization control involved the use of exogenous variables MONFAC and RESIT. The inferences recognized here are that, once underway, transition can only be affected by the money supply and the real estate screening. However, it is possible that transition is more easily circumvented than curbed in progress. This idea has been noted previously [122,123]. The experiments further indicated that changes to non-uniform zoning, the allowance of natural barriers and large, opaque fences for privacy, and the encouragement of socioeconomic homogeneity during the initial period of development are useful for the general continuance of stability. Curbing real estate sign excesses, together with applying tax assessments and providing public services consistently, can be effective specifically during a transitional period.

CHAPTER VIII

RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

General

Since research of this type often tends to uncover many serious additional questions, enthusiasm for, and perhaps confidence in, it are consequently diminished [17,44,97]. In no small way, a lack of acceptable standard approaches in both modeling and simulation contributes to this dilemma. Hopefully, this study will not add to the perpetuation of present controversies; but, in its limited way, assist in the progress of those developments which hold the most promise.

Research Results

The results of this research should contribute towards the advancement of four mutually supportive activities. The first result is the development of a uniquely different residential migration model, the HNM, which exhibits both ecologic and demographic features. Structurally simple, the HNM has a potential for dynamic complexity of the interaction of residents and residences.

The survey of alternative techniques in discrete mathematical modeling and interactive computer simulation led to the second result. A hybrid modeling methodology was proposed in which deterministic functions and stochastic variables, specification of hierarchies by mixed macro-micro coupling, and the constraints of feedback control were included. As a by-product of this second result, different directions in modeling were indicated. A more practical role for developing mathematical techniques in modeling large-scale, complex systems was presented.

The third result is the design and testing of an interactive FORTRAN simulation program which provided the means of experimentation of the HNM. Many simulation studies were performed, along with some verification and validation by standard tests of hypotheses, sensitivity, and goodness-of-fit. From the aforementioned studies, inferences were made, the fourth result, as to the stability of contemporary middle-class neighborhoods employing a previously defined set of indicators of stability and transition.

Conclusions

The HNM was constructed whereby an ecological adjustment at the individual level induces demographic changes at a neighborhood level. Further, perceived aggregate attributes play a role in the individual migration decisions. Both the individual component and the collective group behavior are reflected in the model by appropriate choices of micro and macro variables and loops.

Secondarily, the HNM would appear useful in research on group formation and maintenance, and the relative effects of status and dominance, since existing empirical studies [29,47] have devoted minimal attention to differential or time-varying associations. The HNM, however, models fixed physical structure yet with the capability to track flexible group interaction. Further, several other sociometric entities are determined such as physical and functional distance, socioeconomic status, recentness of arrival, and other components of similarity and complementarity. Thus, an approach towards a definition of <u>sociological</u> <u>equili-</u>

brium was made which is more interesting than the standard correlations of acquisition and loss rates.

Implications from the hybrid modeling approach suggest that it may be helpful in modeling organizational structure whether or not the system being modeled is a standard type; viz., ecologic, economic, etc. This would also assist in the production of a much needed taxonomy to discriminate between procedures which allow the modeling of dynamic, multi-level, multi-goal processes. The hybrid approach also appears compatible with flow-analytic models of information and control across hierarchical boundaries characteristic of societary systems.

The HNM clearly confirms for urban problem-solvers that initial physical structuring in contemporary communities is as important as institutional action in redevelopment. Control is exerted through zoning, property taxes, the application of public services, and the enforcement of local ordinances. Dynamic control is effected through the strategies and actions of real estate agencies and the lending institutions.

General inferences from the simulation experiments are as follows. Firstly, some turnover is normally experienced, which may be consistent for the types of neighborhoods studied. Secondly, initial instability may be quite severe especially with random prominent dispersions in attributes. Thirdly, transition is intensified by: an abundance of mortgage money; a severe and obvious socioeconomic heterogeneity; widespread uniformity in zoning assignments; restrictive fence ordinances; certain real estate tactics; liberal sign ordinances; loss of local control; or, counterproductive property taxes.

Throughout the experiments, it was noted that there, in fact, are extremely crucial threshold levels. The model sensitivity and stability appeared to exhibit the common "tipping" mechanism [99,109]. Finally, the results were tested against many recent studies [4,14,37,40,68,76,84, 107,112,133] from which statistical tests, at a 95% level of significance, produced preliminary validation of the model. Several hundred simulation runs were performed, and the graphs of some of the state trajectories were presented.

Discussion

Whereas the purpose of the research was to study the dynamic processes of neighborhood development and control, the synthesis of the simulation model and its subsequent analysis have not only uncovered many deficiencies in the model, but also have produced the following salient features.

Firstly, even though there was no apparent methodology available at the outset of the model design, the hybrid method emerged, nonetheless. Secondly, important issues in descriptive statistics and the dynamic couplings of multi-variable distributions were raised. Thirdly, a vertical and horizontal nature in the relatedness of social groups could be observed in the simulation studies. Fourthly, the fact that many types of confirming tests were performed with the model was very useful.

The deficiencies of the research stem mainly from the fact that the experiments could not be carried in a systematic fashion. The simulations were performed in an *ad hoc* manner, and experimentation with real neighborhoods was ruled out. Lastly, the limited purpose of certain tests impairs any extensive implications of the model at this time.

Although a rather sophisticated simulation artifact, the HNM requires some detailed changes for future use as guidance has been suggested. A number of critical aspects of the mathematical base need further exploration to enhance the credibility and understanding of its dynamics. Much current modeling effort has been concentrated on the development of some symbology and resultant formalisms. For future models, alternative formats, types of expressions, and systematic study are now possible.

In light of the present state-of-the-art of modeling, experiences with the HNM clearly demonstrate the merit and value of models which: exhibit the social context of certain problems; represent open processes with flexible, dynamic yet modularized structures; and, provide user involvement through advanced interactive techniques which incorporate human judgment and creativeness during the simulations.

Recommendations

The most fruitful extensions of this research are now proposed, which include: extending the present version of the HNM; continuing the methodological explorations; adapting other pertinent sociological theories; and, assimilating other current work on urban systems.

The extensions to the present model would attempt to overcome: the exclusion of growth; the problems of granularity; the lack of transportation, crime, or interneighborhood effects. These deficiencies may be handled by expanding the HNM in size, cycle time, and complexity of internal and external loops. Variables needed to be added are indications of familial integration, life style, and density of population.

In the area of modeling methods, a taxonomy of large-scale techniques is sorely needed. Implicit in this need is the requirement for classifying model structure, causality, determinism, and stochasticity. Aggregate/constituent coupling and the inclusion of macro and micro processes appears as other means of examination. New directions in model validation seem to favor a description of the information richness or complexity of the model.

In need of further explication are theories in Human ecology and urban sociology of the concepts of space, population growth, migration, underlying social values, and the relationship of homogeneity of groups to hierarchical control. Future urban studies might include the aspects of: crime and ownership; density and behavior; and, visual and audio encroachments and privacy. The role of technology in the obsolescence and renewal processes is another important topic. Finally, it is recommended that data collection, especially the census, be expanded to include more frequent responses.

Appendix A. Sample HNM Simulation Program

FILE: NHOOD4/ RISSBVE

```
 FILE  5=INPUT,UNIT=REMOTE
 FILE  6=INSTR,UNIT=REMOTE
FILE  7=OUTPT,UNIT=PRINTER
 DIMENSION HV(64),X(64),Y(64),T(64),IMF(64),C(64),LS(64)
 DIMENSION ID(64),AI(64),RC(64),LOC(8,8),O(64),KN(5)
 INTEGER T,RC,AI,C
 COMMON ID,X,Y,T,IMF,HV,AI,RC,O,LOC,C,LS
 COMMON/PARAM/TYPR,ADJ,A,TPNH,AEFAC,MONFAC,RESIT
 COMMON/JUNK/II,N,XBAR,YBAR,DMEAN,AHV,KN,PCOM
 COMMON/STATUS/TXA,TXB,TXC,TXD,TYA,TYB,TYC,TYD
 COMMON/MORE/THA,THC,NUMCY,PCMT,PCNO,PCVC,PCCM
 COMMON/EXTRA/DALS
N=64
 A=1.0
 ADJ=4.0
 WRITE(6,35)
 35 FORMAT("WHAT TYPE NHOOD - 1,2,3,4, OR 5 ?")
 READ(5,/)TPNH
WRITE(6,20)
 20 FORMAT("THE AESTHETIC FACTOR - 1,2, OR 3?")
READ(5,/)AEFAC
WRITE(6,50)
50 FORMAT("HOW ARE INITIAL RESIDENTS - BY SOCIAL STATUS?")
READ(5,/)TXA,TXB,TXC,TXD
WRITE(6,60)
60 FORMAT("BY ECONOMIC STATUS?")
READ(5,/)TYA,TYB,TYC,TYD
WRITE(6,70)
70 FORMAT("WHAT IS THE SPREAD OF PROPERTY VALUES?")
READ(5,/)THA,THB,THC,THD
 WRITE(6,80)
80 FORMAT("HOW MANY CYCLES?")
READ(5,/)NUMCY
 WRITE(6,25)
 25 FORMAT("NUMBER OF PRINTOUTS PER CYCLE, 0-5?")
 READ(5,/)TYPR
K=1
DO 90 I=1,8
DO 90 J=1,8
LOC(I,J)=K
 Z=RNDY1(A)
 A=RNDY2(Z)
 C(K)=IFIX(A*4.+1.)
 LS(K)=IFIX(5.*(2.-A-Z))
K=K+1
90 CONTINUE
DO 100 I=1,N
 A=RNDY2(A)
W=RNDY1(A)
 ID(I)=IFIX(W*100000.)+100000
A=1.-W
100 CONTINUE
DO 110 I=1,N
CALL TRIANG(Z,TXA,TXB,TXC,TXD,A)
X(I)=Z
110 CONTINUE
DO 120 I=1,N
CALL TRIANG(Z,TYA,TYB,TYC,TYD,A)
Y(I)=Z
120 CONTINUE
 DO 185 I=1,N
 A=RNDY2(A)
 Z=RNDY1(A)
 T(I)=IFIX(Z*5.+1.)
 IMF(I)=IFIX(A*5.+1.)
 AI(I)=AEFAC+IFIX(3.*A)
 RC(I)=TPNH+IFIX(4.*Z)
 185 CONTINUE
DO 190 I=1,N
CALL TRIANG(Z,THA,THB,THC,THD,A)
HV(I)=Z
 190 CONTINUE
 CALL HEAD
 CALL PRNT
 DO 1000 II=1,NUMCY
 WRITE(6,30)
 30 FORMAT("MONEY SITUATION - 1,2,3,4, OR 5?")
 READ(5,/)MONFAC
 WRITE(6,40)
 40 FORMAT("R.E. STRATEGY, 1 - 5 ?")
 READ(5,/)RESIT
```

```
IF(TYPR.LT.1.)GO TO 115
CALL PRNT
 115 CALL WINTER
IF(TYPR.LT.2.)GO TO 125
CALL PRNT
 125 CALL SPRING
IF(TYPR.LT.3.)GO TO 135
CALL PRNT
 135 CALL SUMMER
IF(TYPR.LT.4.)GO TO 145
CALL PRNT
 145 CALL FALL
 CALL START
 1000 CONTINUE
STOP
END
FUNCTION RNDY1(A)
MASK=524287
K=61005
FMASK=FLOAT(MASK)
B=A*FMASK
ISET=IFIX(B)
 M=AND(ISET*K,MASK)
 X=FLOAT(M)/FMASK
RNDY1=X
RETURN
END
 FUNCTION RNDY2(A)
 MASK=524287
 K=61005
  FMASK=FLOAT(MASK)
 B=A*FMASK
 ISET=IFIX(B)
 M=AND(ISET*K,MASK)
 X=FLOAT(M)/FMASK
 RNDY2=X
 RETURN
 END
SUBROUTINE TRIANG(V,TA,TB,TC,TD,A)
P=(TD+(TB-TA))/2.
Y=RNDY1(A)
A=1.-Y
IF(Y.GT.P)GO TO 11
V=TA+(TB-TA)*SQRT(Y/P)
GO TO 12
 11 V=TC-(TC-TB)*SQRT((1.-Y)/(1.-P))
 12 RETURN
END
SUBROUTINE PRNT
 DIMENSION HV(64),X(64),Y(64),T(64),IMF(64),C(64),LS(64)
 DIMENSION ID(64),AI(64),RC(64),LOC(6,8),D(64),KN(5)
 INTEGER T,RC,AI,C
 COMMON ID,X,Y,T,IMF,HV,AI,RC,D,LOC,C,LS
 COMMON/PARAM/TYPR,ADJ,A,TPNH,AEFAC,MONFAC,RESIT
 COMMON/JUNK/II,N,XBAR,YBAR,DMEAN,AHV,KN,PCOM
WRITE(7,1020)
 1020 FORMAT(//,7X,"ID",3X,"SOC ST",3X,"ECO ST",3X,"TOLER",
-3X,"INPFC",3X,"LOC",3X,"PR VAL",3X,"AP DEX",3X,"REL CON",
-6X,"DIST",6X,"COUP",3X,"TENURE")
 DO 1030 K=1,N
WRITE(7,1040)ID(K),X(K),Y(K),T(K),IMF(K),K,HV(K),
-AI(K),RC(K),D(K),C(K),LS(K)
 1040 FORMAT(2X,I7,3X,F6.4,3X,F6.4,6X,I2,6X,I2,3X,I3,
-3X,F6.4,7X,I2,8X,I2,4X,F6.4,8X,I3,6X,I3)
 1030 CONTINUE
RETURN
END
 SUBROUTINE FALL
 DIMENSION HV(64),X(64),Y(64),T(64),IMF(64),C(64),LS(64)
DIMENSION ID(64),AI(64),RC(64),LOC(6,8),D(64),KN(5)
INTEGER T,RC,AI,C
 COMMON ID,X,Y,T,IMF,HV,AI,RC,D,LOC,C,LS
COMMON/PARAM/TYPR,ADJ,A,TPNH,AEFAC,MONFAC,RESIT
 COMMON/JUNK/II,N,XBAR,YBAR,DMEAN,AHV,KN,PCOM
 COMMON/STATUS/TXA,TXB,TXC,TXD,TYA,TYB,TYC,TYD
IF(RESIT.GT.2.5)GO TO 1280
IF(RESIT.GT.1.5)GO TO 1260
 TXC=TXA
 TXA=0.75*TXC
 TXB=(TXC+TXA)*0.5
TYD=2./(TXC-TXA)
GO TO 1200
 1260 TXA=1.05*TXA
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 TXB=1.05*TXB
 TXC=1.05*TXC
TXD=2./(TXC-TXA)
GO TO 1200
 1280 TXA=1.01*TXA
 TXC=0.99*TXC
 TXD=2./(TXC-TXA)
 1200 DO 1900 IB=1,N
 IF(ID(IB).LT.1)GO TO 1300
 IF(T(IB).LT.1)GO TO 1300
GO TO 1900
 1300 Q=RNDY1(A)
 A=RNDY2(Q)
NB=MONFAC*IFIX(Q*5.)
JB=1
 1400 A=RNDY1(A)
 A=RNDY2(A)
CALL TRIANG(Z,TYA,TYB,TYC,TYD,A)
AMF=FLOAT(MONFAC)
 Z=Z*(1.+AMF*0.01)
 AMTMORT=Z*(1.+AMF*0.1)
SELPR=(1.+AMF*0.02)*HV(IB)
IF(AMTMORT.LT.SELPR)GO TO 1700
IF(A.GT.0.6666)GO TO 1500
IF(A.LT.0.3333)GO TO 1600
A=RNDY1(A)
 LRC=IPNH+IFIX(4.*A)
 IF(LRC.GT.RC(IB))GO TO 1700
GO TO 1600
 1500 A=RNDY1(A)
 LAI=AEFAC+IFIX(3.*A)
 IF(LAI.GT.AI(IB))GO TO 1700
 1600 Y(IB)=AMTMORT/(1.+AMF*0.1)
CALL TRIANG(Z,TXA,TXB,TXC,TXD,A)
X(IB)=Z
A=RNDY1(A)
ID(IB)=IFIX(A*100000.)
Z=RNDY1(A)
T(IB)=IFIX(A*5.+1.)
IMF(IB)=IFIX(Z*5.+1.)
C(IB)=0
 LS(IB)=0
GO TO 1900
 1700 JB=JB+1
IF(JB.GT.NB)GO TO 1900
GO TO 1400
 1900 CONTINUE
RETURN
END
 SUBROUTINE WINTER
 DIMENSION HV(64),X(64),Y(64),T(64),IMF(64),C(64),LS(64)
DIMENSION ID(64),AI(64),RC(64),LOC(5,5),D(64),KN(5)
INTEGER T,RC,AI,C
 COMMON ID,X,Y,T,IMF,HV,AI,RC,D,LOC,C,LS
COMMON/PARAM/TYPF,ND,A,IPNH,AEFAC,MONFAC,RESTT
 COMMON/JUNK/TI,K,XBAR,YBAR,DMEAN,AHV,KV,PCOM
 COMMON/MORE/THA,THC,NUMCY,PCMT,PCND,PCVC,PCCM
 COMMON/STATUS/TXA,TXB,TXC,TXD,TYA,TYB,TYC,TYD
 COMMON/EXTRA/DALS
 FLAR=0.01*FLOAT(MONFAC)
 WRITE(6,1020)FLAR
 1020 FORMAT("INFL RATE ",F4.2)
DO 1100 IC=1,N
 HV(IC)=HV(IC)*(1.+FLAR)
 1100 CONTINUE
 NPA=0
 NPD=0
DO 1200 IH=1,N
 PRM=3.-FLOAT(IMF(IH))
 PRMF=1.+(PRM*0.01)
 IF(PRMF.GT.1.)NPA=NPA+1
 IF(PRMF.LT.1.)NPD=NPD+1
 HV(IH)=HV(IH)*PRMF
 1200 CONTINUE
A=RNDY1(A)
PR1=A*100000.
A=RNDY1(A)
PR2=A*100000.
DO 1500 IE=1,N
IF(ID(IE).GT.PR1)GO TO 1300
 Y(IE)=Y(IE)*(1.02)
GO TO 1500
 1300 IF(MONFAC.GT.3)DC=0.1
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IF(MONFAC.LT.2)DC=-0.1
IF(ID(IE).GT.PR2)GO TO 1500
Y(IE)=Y(IE)*(1.+DC)
 1500 CONTINUE
DO 1600 IP=1,N
LS(IP)=LS(IP)+1
IF(LS(IP).LT.5)GO TO 1600
X(IP)=X(IP)*1.02
IF(LS(IP).LT.10)GO TO 1600
X(IP)=X(IP)*1.01
IF(LS(IP).LT.15)GO TO 1600
X(IP)=X(IP)+0.01
 1600 CONTINUE
SHV=0.0
SUMX=0.0
SUMY=0.0
 LLS=0
HVMIN=1.0
XMIN=1.0
YMIN=1.0
HVMAX=0.0
XMAX=0.0
YMAX=0.0
DO 1700 I=1,N
IF(HV(I).LT.HVMIN)HVMIN=HV(I)
IF(HV(I).GT.HVMAX)HVMAX=HV(I)
IF(X(I).LT.XMIN)XMIN=X(I)
IF(X(I).GT.XMAX)XMAX=X(I)
IF(Y(I).LT.YMIN)YMIN=Y(I)
IF(Y(I).GT.YMAX)YMAX=Y(I)
SUMX=SUMX+X(I)
SUMY=SUMY+Y(I)
SHV=SHV+HV(I)
 LLS=LLS+LS(I)
 1700 CONTINUE
XBAR=SUMX/N
YBAR=SUMY/N
AHV=SHV/N
 ALS=(FLOAT(LLS))/(FLOAT(N))
 IF(II.EQ.1)DALS=ALS
 PCMT=ALS/DALS
 DALS=DALS+1.
DO 1800 I=1,N
 1800 D(I)=SQRT((XBAR-X(I))**2+(YBAR-Y(I))**2)
ADIST=0.0
DO 1900 I=1,N
 1900 ADIST=ADIST+D(I)
DMEAN=ADIST/N
 NVAC=0
 NWOC=0
 DO 1805 I=1,N
 IF(ID(I).GT.100000)GO TO 1810
 NWOC=NWOC+1
 1810 IF(ID(I).GE.1)GO TO 1805
 NVAC=NVAC+1
 1805 CONTINUE
 PCNO=FLOAT(NWOC)/64.
 PCVC=FLOAT(NVAC)/64.
 WRITE(6,1815)NWOC
 1815 FORMAT("NWOC = ",I3)
 WRITE(6,1820)NVAC
 1820 FORMAT("NVAC = ",I3)
 WRITE(6,1905)
 1905 FORMAT(4X,"HVMIN",6X,"AHV",6X,"HVMAX",6X,"NPA",6X,"NPD")
 WRITE(6,1910)HVMIN,AHV,HVMAX,NPA,NPD
 1910 FORMAT(3X,F6.4,3X,F6.4,3X,F6.4,6X,I3,6X,I3)
 WRITE(6,1915)
 1915 FORMAT(5X,"XMIN",5X,"XBAR",5X,"XMAX")
 WRITE(6,1920)XMIN,XBAR,XMAX
 1920 FORMAT(3X,F6.4,3X,F6.4,3X,F6.4)
 WRITE(6,1925)
 1925 FORMAT(5X,"YMIN",5X,"YBAR",5X,"YMAX",5X,"DMEAN")
 WRITE(6,1930)YMIN,YBAR,YMAX,DMEAN
 1930 FORMAT(3X,F6.4,3X,F6.4,3X,F6.4,3X,F6.5)
 WRITE(6,1935)ALS
 1935 FORMAT("ALS = ",F5.2)
RETURN
END
SUBROUTINE HEAD
COMMON/PARAM/TYPE,ADJ,A,TPNH,AEFAC,MONFAC,RESIT
 COMMON/STATUS/TXA,TXB,TXC,TXD,TYA,TYB,TYC,TYD
 COMMON/MORE/THA,THC,NUMEY,PCMT,PCNO,PCVC,PCCM
WRITE(7,1)
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 1 FORMAT(30X,"NEIGHBORHOOD MODEL 3",/)
 WRITE(7,3)TPNH
 3 FORMAT (30X,"NEIGHBORHOOD TYPE    ",I3)
WRITE(7,4)AEFAC
 4 FORMAT(30X,"AESTHETIC FACTOR    ",I3)
WRITE(7,7)TXA,TYC
 7 FORMAT(30X,"INITIAL SS FROM ",F6.4," TO ",F6.4)
WRITE(7,8)TYA,TYC
 8 FORMAT(30X,"INITIAL ES FROM ",F6.4," TO ",F6.4)
WRITE(7,9)THA,THC
 9 FORMAT(30X,"PROP VALUE SPREAD ",F6.4," TO ",F6.4)
 WRITE(7,11)NUMCY
 11 FORMAT(30X,"NUMBER OF CYCLES    ",I3)
 RETURN
 END
SUBROUTINE SPRING
DIMENSION HV(64),X(64),Y(64),T(64),IMF(64),C(64),LS(64)
DIMENSION ID(64),AI(64),RC(64),LOC(8,8),D(64),KN(5)
INTEGER T,RC,AI,C
COMMON ID,X,Y,T,IMF,HV,AI,RC,D,LOC,C,LS
COMMON/PARAM/TYPF,ADJ,Z,TPNH,AEFAC,MONFAC,RESIT
 COMMON/MORE/THA,THC,NUMCY,PCMT,PTNO,PCVC,PCCM
 COMMON/JUNK/II,N,XBAR,YBAR,DMEAN,AHV,KN,PCOM
 COMMON/STATUS/TXA,TXB,TXC,TXD,TYA,TYB,TYC,TYD
 TADJ=DMEAN*ADJ
 NCM=0
DO 33 I=1,8
DO 33 J=1,8
KK=LOC(I,J)
 IF(T(KK).LT.1)GO TO 33
 IF(T(KK).GT.4)GO TO 33
GO TO (199,299,399,499),T(KK)
 199 KL=1
 KR=64
 GO TO 470
299 IF(KK.LT.49)GO TO 66
KL=49
KR=64
 GO TO 470
66 IF(KK.GT.15)GO TO 77
KL=1
KR=16
 GO TO 470
77 IF(KK.LT.32)GO TO 88
KL=33
KR=46
 GO TO 470
88 KL=17
KR=32
 GO TO 470
399 IF(J.EQ.1.OR.J.EQ.3.OR.J.EQ.5.OR.J.EQ.7)GO TO 666
IF(I-1.EQ.0)GO TO 408
IF(I+1.EQ.9)GO TO 418
 KN(1)=LOC(I-1,J)
 KN(2)=LOC(I-1,J-1)
 KN(3)=LOC(I,J-1)
 KN(4)=LOC(I+1,J-1)
 KN(5)=LOC(I+1,J)
 ND=5
 GO TO 740
 408 KN(1)=LOC(I,J-1)
 KN(2)=LOC(I+1,J-1)
 KN(3)=LOC(I+1,J)
 ND=3
 GO TO 740
 418 KN(1)=LOC(I-1,J)
 KN(2)=LOC(I-1,J-1)
 KN(3)=LOC(I,J-1)
 ND=3
 GO TO 740
656 IF(I-1.EQ.0)GO TO 608
IF(I+1.EQ.9)GO TO 618
 KN(1)=LOC(I-1,J)
 KN(2)=LOC(I-1,J+1)
 KN(3)=LOC(I,J+1)
 KN(4)=LOC(I+1,J+1)
 KN(5)=LOC(I+1,J)
 ND=5
 GO TO 740
 608 KN(1)=LOC(I,J+1)
 KN(2)=LOC(I+1,J+1)
 KN(3)=LOC(I+1,J)
 ND=3
```

```
 GO TO 740
 618 KN(1)=LOC(I-1,J)
 KN(2)=LOC(I-1,J+1)
 KN(3)=LOC(I,J+1)
 ND=3
 GO TO 740
 499 KN(1)=KK-1
 KN(2)=KK+1
 IF(KK.EQ.1)KN(1)=64
 IF(KK.EQ.64)KN(2)=1
 ND=2
 GO TO 740
 470 DO 974  IK=KL,KR
 IF(T(KK).EQ.0)GO TO 974
IF(KK.EQ.IK)GO TO 974
IF(X(KK).LT.X(IK))GO TO 974
 IF(X(KK).LT.XBAR.AND.Y(KK).LT.YBAR)GO TO 974
 IF(C(IK).GT.70)GO TO 947
 ICP=ABS(C(KK)-C(IK))
 IF(ICP.LT.2)GO TO 947
 GO TO 974
 947 DIFHV=ABS(HV(IK)-HV(KK))
 HVSPR=0.075
 IF(HVSPR.LT.DIFHV)GO TO 974
 DIFX=ABS(X(KK)-X(IK))
 DIFY=ABS(Y(KK)-Y(IK))
 TDIF=SQRT(DIFX**2+DIFY**2)
 IF(TDIF.LT.TADJ)GO TO 974
T(KK)=0
 C(KK)=IK+100
 NCM=NCM+1
 974 CONTINUE
 GO TO 33
 740 DO 1074  IK=1,ND
 IF(T(KK).EQ.0)GO TO 1074
KT=KN(IK)
IF(KK.EQ.KT)GO TO 1074
IF(X(KK).LT.X(KT))GO TO 1074
 IF(X(KK).LT.XBAR.AND.Y(KK).LT.YBAR)GO TO 1074
 IF(C(IK).GT.70)GO TO 1047
 ICP=ABS(C(KK)-C(IK))
 IF(ICP.LT.2)GO TO 1047
 GO TO 1074
 1047 DIFHV=ABS(HV(IK)-HV(KK))
 HVSPR=0.075
 IF(HVSPR.LT.DIFHV)GO TO 1074
 DIFX=ABS(X(KK)-X(IK))
 DIFY=ABS(Y(KK)-Y(IK))
 TDIF=SQRT(DIFX**2+DIFY**2)
 IF(TDIF.LT.TADJ)GO TO 1074
 T(KK)=0
 C(KK)=IK+100
 NCM=NCM+1
 1074 CONTINUE
 33 CONTINUE
 WRITE(6,1174)NCM
 1174 FORMAT("NCM = ",I2)
 PCCM=FLOAT(NCM)/64.
 RETURN
 END
SUBROUTINE SUMMER
DIMENSION HV(64),X(64),Y(64),T(64),IMF(64),C(64),LS(64)
DIMENSION ID(64),AI(64),RC(64),LOC(8,8),D(64),KN(5)
INTEGER T,RC,AI,C
COMMON ID,X,Y,T,IMF,HV,AI,RC,D,LOC,C,LS
COMMON/PARAM/TYPR,ADJ,A,IPNH,AECMC,MONFAL,RESIT
 COMMON/JUNK/II,N,XBAR,YBAR,DMEAN,AHV,KN,PCOM
COMMON/STATUS/IXA,IXB,IXC,IXD,IYA,IYB,IYC,IYD
 COMMON/MORE/THA,THC,NUMCY,PCMT,PCND,PCVC,PCCM
U=RNDY1(A)
 A=RNDY2(U)
IF(A.GT.0.5)GO TO 902
IF(U.LT.0.1)U=0.1
 UL=U-.05
UR=U
GO TO 912
 902 IF(U.GT.0.9)U=0.9
UL=U
 UR=U+.05
 NRM=0
 912 DO 922 I=1,N
A=RNDY1(A)
IF(A.GT.UR)GO TO 922
```

```
IF(A.LT.UL)GO TO 922
ID(I)=0
C(I)=99
 NRM=NRM+1
 922 CONTINUE
 WRITE(6,927)NRM
 927 FORMAT("NRM = ",I2)
 NAD=0
DO 932 I=1,N
IF(T(I).GE.1)GO TO 932
IF(X(I).LT.XBAR)GO TO 932
IF(Y(I).LT.YBAR)GO TO 932
 NAD=NAD+1
ID(I)=0
C(I)=75
 932 CONTINUE
 WRITE(6,936)NAD
 936 FORMAT("NAD = ",I2)
 NOM=NAD+NRM
 PCOM=FLOAT(NOM)/64.
RETURN
END
SUBROUTINE START
DIMENSION HV(64),X(64),Y(64),T(64),IMF(64),C(64),LS(64)
DIMENSION ID(64),AI(64),RC(64),LOC(8,8),D(64),KN(5)
INTEGER T,RC,AI,C
COMMON ID,X,Y,T,IMF,HV,AI,RC,D,LOC,C,LS
COMMON/PARAM/TYPR,ADJ,A,TPNH,AEFAC,MONFAC,RESTT
 COMMON/JUNK/II,N,XBAR,YBAR,DMEAN,AHV,KN,PCOM
COMMON/STATUS/TXA,TXB,TXC,TXD,TYA,TYB,TYC,TYD
 COMMON/MORE/THA,THC,NUMCY,PCMT,PCND,PCVC,PCCM
 WRITE(7,19)
 19 FORMAT(//,6X,4HPCCM,6X,4HPCOM,6X,4HPCND,6X,4HPCMT,6X,4HPCVC)
 WRITE(7,2660)PCCM,PCOM,PCND,PCMT,PCVC
 2660FORMAT(/,4X,F6.4,4X,F6.4,4X,F6.4,4X,F6.4,4X,F6.4)
WRITE(7,2600)II
 2600 FORMAT(/,3X,"END OF YEAR",I3)
CHYR=FLOAT(II)/FLOAT(NUMCY)
IF(CHYR.GT.0.75)GO TO 2900
IF(CHYR.GT.0.5)GO TO 2800
IF(CHYR.GT.0.25)GO TO 2700
AA=0.95
AB=2.
AC=1.1
AD=0.5
AE=0.95
GO TO 3000
 2700 AA=0.99
AB=1.5
AC=1.05
AD=0.75
AE=0.95
GO TO 3000
 2800 AA=0.99
AB=1.2
AC=1.025
AD=1.25
AE=0.95
GO TO 3000
 2900 AA=1.5
AB=1.1
AC=0.975
AD=1.5
AE=0.95
 3000 IF(PCCM.GT.0.12)ADJ=AA*ADJ
IF(PCOM.GT.0.1)MONFAC=AB*MONFAC
IF(PCND.GT.0.35)RESIT=AC*RESIT
IF(PCMT.LT.0.5)TPNH=AD*TPNH
IF(PCVC.GT.0.1)AEFAC=AE*AEFAC
RETURN
END
```

Appendix B. Sample HNM Output

NEIGHBORHOOD MODEL 3

NEIGHBORHOOD TYPE 3
AESTHETIC FACTOR 2
INITIAL SS FROM 0.2000 TO 0.3000
INITIAL ES FROM 0.2500 TO 0.3500
PROP VALUE SPREAD 0.1500 TO 0.2500
NUMBER OF CYCLES 10

ID	SOC ST	ECO ST	TOLER	IMPFC	LOC	PR VAL	AN WT	REL CON	DIST	COUP	TENURE
175647	0.2360	0.2962	4	2	1	0.1660	2	6	0.0000	2	4
131441	0.2959	0.2777	5	4	2	0.2178	4	6	0.0000	1	5
119188	0.2597	0.2922	1	5	3	0.2487	4	3	0.0000	4	3
105735	0.2650	0.3007	1	1	4	0.2012	2	3	0.0000	3	3
178525	0.2626	0.3154	2	1	5	0.1830	2	3	0.0000	4	2
193021	0.2513	0.2609	2	2	6	0.2035	2	4	0.0000	1	6
107518	0.2349	0.3153	2	2	7	0.1805	2	4	0.0000	1	3
190139	0.2613	0.2527	1	4	8	0.1931	3	3	0.0000	3	4
102512	0.2294	0.3387	5	1	9	0.2324	2	6	0.0000	4	2
119656	0.2463	0.2684	1	5	10	0.1719	4	3	0.0000	2	5
153273	0.2292	0.2965	4	1	11	0.1897	2	5	0.0000	3	4
156178	0.2459	0.2682	4	4	12	0.2340	4	6	0.0000	3	4
145816	0.2434	0.3321	4	4	13	0.1936	4	5	0.0000	1	7
160064	0.2387	0.2566	5	4	14	0.2019	4	6	0.0000	4	4
102407	0.2411	0.3233	1	5	15	0.2160	4	3	0.0000	3	3
117478	0.2151	0.3354	4	1	16	0.1888	2	2	0.0000	3	2
101551	0.2463	0.2687	3	4	17	0.1503	3	5	0.0000	2	6
194188	0.2270	0.3002	3	3	18	0.1977	3	4	0.0000	4	4
151533	0.2579	0.3269	1	3	19	0.1969	3	3	0.0000	3	4
140389	0.2838	0.3235	1	1	20	0.2160	3	4	0.0000	3	2
149676	0.2449	0.2596	5	1	21	0.2157	3	4	0.0000	1	9
161328	0.2460	0.2992	2	2	22	0.2001	4	4	0.0000	1	9
170619	0.2460	0.3219	4	2	23	0.1804	3	5	0.0000	4	4
194095	0.2795	0.3091	1	4	24	0.2082	3	3	0.0000	2	6
178787	0.2750	0.3147	5	1	25	0.2315	2	6	0.0000	3	7
167339	0.2284	0.2872	3	5	26	0.2273	4	4	0.0000	3	2
157292	0.2409	0.3173	4	3	27	0.1815	3	5	0.0000	1	4
110726	0.2456	0.2628	2	4	28	0.1907	3	4	0.0000	1	4
178888	0.2173	0.2616	3	2	29	0.2015	3	5	0.0000	1	8
120865	0.2481	0.2914	3	4	30	0.2038	3	5	0.0000	3	5
123509	0.2562	0.3186	4	3	31	0.1904	3	5	0.0000	1	9
162624	0.2380	0.2991	4	4	32	0.1826	4	5	0.0000	2	6
119551	0.2372	0.3030	2	4	33	0.2076	3	4	0.0000	3	4
178407	0.2547	0.3008	3	2	34	0.2046	2	4	0.0000	4	2
159277	0.2617	0.2455	5	3	35	0.1868	3	6	0.0000	2	4
191817	0.2504	0.2828	2	5	36	0.1933	4	4	0.0000	4	3
171900	0.2132	0.2084	2	2	37	0.2068	3	1	0.0000	2	4
151495	0.2009	0.3144	4	2	38	0.2328	2	5	0.0000	2	3
164236	0.2318	0.2768	2	4	39	0.1670	4	4	0.0000	3	6
103923	0.2334	0.3139	3	2	40	0.1689	2	4	0.0000	3	3
155424	0.2156	0.3040	5	3	41	0.1829	3	6	0.0000	4	1
149334	0.2876	0.3071	5	5	42	0.2003	4	6	0.0000	1	7
170855	0.2061	0.2075	2	5	43	0.1716	4	4	0.0000	2	5
191713	0.2817	0.3160	3	2	44	0.1961	2	5	0.0000	4	1
142170	0.2845	0.2927	3	3	45	0.1910	3	4	0.0000	4	4
138794	0.2712	0.3268	3	3	46	0.2113	3	4	0.0000	3	3
107259	0.2766	0.2818	1	2	47	0.1838	2	3	0.0000	4	5
102061	0.2265	0.2949	3	1	48	0.2167	2	4	0.0000	4	4
110264	0.2550	0.3333	5	3	49	0.2151	3	6	0.0000	4	2
146750	0.2248	0.2983	2	5	50	0.1983	4	4	0.0000	3	3
101574	0.2546	0.3447	1	2	51	0.2318	2	3	0.0000	2	7
161843	0.2658	0.3023	2	1	52	0.1964	2	3	0.0000	2	5
158442	0.2199	0.3011	3	2	53	0.1978	2	4	0.0000	2	8
162315	0.2402	0.2646	2	3	54	0.1906	3	4	0.0000	2	7
120498	0.2484	0.3002	1	2	55	0.1937	2	3	0.0000	2	7
138293	0.2664	0.3164	2	1	56	0.2149	2	3	0.0000	3	2
160637	0.2460	0.3064	4	2	57	0.1997	2	6	0.0000	1	6
156925	0.2457	0.2987	1	4	58	0.1864	4	6	0.0000	1	6
109492	0.2263	0.3059	4	1	59	0.1838	2	5	0.0000	3	7
141681	0.2147	0.3118	1	4	60	0.1940	4	3	0.0000	1	4
116657	0.2577	0.2963	5	1	61	0.2307	2	4	0.0000	3	4
102941	0.2515	0.3207	4	5	62	0.2039	4	5	0.0000	2	3
170165	0.2577	0.3321	3	4	63	0.2706	3	5	0.0000	3	4
121320	0.2587	0.3193	2	3	64	0.2376	3	4	0.0000	1	7

PCCM	PCOM	PCNO	PCMT	PCVC
0.0000	0.0469	0.0000	1.0000	0.0000

END OF YEAR 1

ID	SOC ST	ECO ST	TOLER	IMPFL	LOC	PR VAL	AN DEX	REL CON	DIST	COUP	TENURE
175647	0.2436	0.2962	4	2	1	0.1997	2	6	0.0119	2	5
131481	0.3019	0.2777	5	4	2	0.2178	4	6	0.0536	1	6
119188	0.2597	0.2922	1	5	3	0.2457	4	3	0.0112	1	4
18396	0.2422	0.3079	1	4	4	0.2072	2	3	0.0111	0	0
178525	0.2426	0.3154	2	1	5	0.1893	2	3	0.0176	4	3
193071	0.2589	0.2609	2	2	6	0.2076	2	4	0.0413	1	10
107518	0.2149	0.3153	2	2	7	0.1841	3	4	0.0234	1	4
190139	0.2461	0.2927	1	2	8	0.1970	3	3	0.0121	3	5
162512	0.2294	0.3187	5	1	9	0.2398	2	6	0.0493	4	3
119658	0.2716	0.2684	1	5	10	0.1702	4	3	0.0378	2	6
153273	0.2738	0.2965	4	1	11	0.1955	2	5	0.0209	3	5
156176	0.2712	0.2882	4	4	12	0.2340	4	4	0.0220	3	5
195816	0.2687	0.3321	4	4	13	0.1936	4	5	0.0336	1	8
188069	0.2435	0.2566	5	4	14	0.2018	4	4	0.0465	4	5
162407	0.2411	0.3233	1	5	15	0.2138	4	3	0.0250	3	4
117428	0.2131	0.3359	3	1	16	0.1985	3	5	0.0318	1	7
181561	0.2737	0.2687	3	4	17	0.1503	3	5	0.0366	2	7
194188	0.2425	0.3002	3	3	18	0.1997	3	4	0.0285	4	5
171533	0.2431	0.3269	1	3	19	0.1968	3	3	0.0266	3	5
140385	0.2434	0.3235	1	1	20	0.2225	2	4	0.0364	3	3
199675	0.2730	0.2936	5	3	21	0.2178	3	6	0.0191	1	10
181328	0.2740	0.2992	2	5	22	0.1981	4	4	0.0206	1	10
170419	0.2488	0.3719	4	2	23	0.1844	3	5	0.0207	4	5
194095	0.2451	0.3091	1	4	24	0.2087	3	5	0.0319	2	7
178787	0.2605	0.3147	1	1	25	0.2384	2	6	0.0255	3	8
182339	0.2284	0.2672	3	5	26	0.2250	4	4	0.0295	3	3
157292	0.2457	0.3173	4	3	27	0.1833	3	5	0.0175	1	5
110728	0.2709	0.2628	2	4	28	0.1907	3	4	0.0426	1	5
178986	0.2216	0.2610	4	2	29	0.2055	3	5	0.0572	1	9
120985	0.2433	0.2514	3	4	30	0.2037	3	5	0.0140	3	6
123509	0.2440	0.3188	4	3	31	0.1923	3	5	0.0196	1	10
152628	0.2427	0.2991	4	4	32	0.1825	4	5	0.0118	1	7
119551	0.2420	0.3030	2	4	33	0.2075	3	4	0.0121	1	5
178402	0.2547	0.3008	3	2	34	0.2087	2	4	0.0012	4	3
159277	0.2469	0.2855	5	3	35	0.1825	3	6	0.0208	2	5
191517	0.2504	0.2826	5	5	36	0.1914	4	4	0.0194	4	4
12949	0.2589	0.2594	1	5	37	0.2178	3	3	0.0390	0	0
151495	0.2809	0.3148	1	4	38	0.2371	2	5	0.0181	3	4
164236	0.2364	0.2768	2	4	39	0.1669	4	4	0.0307	3	7
103923	0.2334	0.3139	3	2	40	0.1723	2	4	0.0239	3	8
155824	0.2156	0.3040	3	3	41	0.1848	3	6	0.0380	4	2
139336	0.2933	0.3071	5	5	42	0.1983	4	6	0.0397	1	8
170555	0.2103	0.2875	5	5	43	0.1849	4	4	0.0461	2	6
191713	0.2817	0.3160	3	4	44	0.2000	2	5	0.0160	4	2
142170	0.2494	0.2927	3	3	45	0.1929	3	4	0.0103	4	5
138794	0.2712	0.3266	2	3	46	0.2134	3	4	0.0303	3	4
107259	0.2821	0.2818	1	4	47	0.1875	2	3	0.0345	4	6
102061	0.2310	0.2949	1	1	48	0.2253	2	4	0.0260	4	5
110266	0.2550	0.3333	5	5	49	0.2172	3	6	0.0314	4	3
196750	0.2248	0.2983	2	5	50	0.1962	4	4	0.0295	3	4
101574	0.2597	0.3447	1	4	51	0.2365	2	3	0.0432	2	8
101843	0.2711	0.3023	3	1	52	0.2024	2	3	0.0170	3	6
155442	0.2743	0.3011	3	2	53	0.2018	2	4	0.0298	2	5
162312	0.2654	0.2646	2	4	54	0.1925	3	4	0.0390	2	8
120488	0.2738	0.3002	1	4	55	0.1976	2	3	0.0196	2	8
138293	0.2464	0.3154	2	1	56	0.2714	2	3	0.0191	3	3
160437	0.2714	0.3064	4	4	57	0.2037	2	6	0.0179	1	7
156925	0.2710	0.2987	1	4	58	0.1878	4	3	0.0173	3	7
109492	0.2308	0.3059	4	1	59	0.1493	2	5	0.0235	1	8
131881	0.2190	0.3118	1	4	60	0.1940	4	3	0.0364	3	5
116657	0.2577	0.2963	5	1	61	0.2377	2	6	0.0067	2	4
18396	0.2083	0.3058	1	1	62	0.2018	4	5	0.0190	0	0
170165	0.2629	0.3321	1	4	63	0.2205	3	5	0.0315	3	5
121320	0.2638	0.3193	2	3	64	0.2400	3	4	0.0200	1	8

PCCM	PCOM	PCNO	PCMT	PCVC
0.0000	0.0156	0.0469	0.9665	0.0000

END OF YEAR 2

ID	SOC ST	ECO ST	TOLER	INPFC	LOC	PR VAL	AN WEX	REL CON	DIST	COUP	TENURE
175647	0.2685	0.2982	4	4	1	0.1938	2	6	0.0101	2	6
131481	0.3079	0.2777	5	4	2	0.2177	4	6	0.0548	1	7
119188	0.2469	0.2922	1	5	3	0.2432	4	5	0.0109	4	5
18386	0.2022	0.2771	1	3	4	0.2093	2	3	0.0277	0	1
178525	0.2026	0.3154	2	1	5	0.1951	2	3	0.0218	4	4
193021	0.2457	0.2609	2	2	6	0.2118	2	4	0.0401	1	11
107518	0.2396	0.3153	2	2	7	0.1878	2	4	0.0236	3	5
190139	0.2510	0.2927	1	2	8	0.2010	3	3	0.0099	3	6
162512	0.2794	0.3387	5	1	9	0.2466	2	6	0.0481	4	4
119654	0.2770	0.2684	1	5	10	0.1484	4	3	0.0369	2	7
153273	0.2385	0.2965	4	4	11	0.2018	2	5	0.0197	3	6
156175	0.2766	0.2842	4	4	12	0.2339	4	6	0.0222	3	6
145615	0.2781	0.3321	4	4	13	0.1938	4	5	0.0360	1	9
165064	0.2483	0.2566	5	4	14	0.2019	4	6	0.0444	4	6
162407	0.2459	0.3233	1	5	15	0.2118	4	3	0.0282	3	5
137828	0.2151	0.3358	4	1	16	0.2003	2	5	0.0555	3	8
181561	0.2792	0.2687	3	4	17	0.1503	3	5	0.0378	2	8
194188	0.2482	0.3002	3	3	18	0.2017	3	4	0.0303	4	6
151533	0.2453	0.3269	1	3	19	0.2008	3	3	0.0289	3	6
140388	0.2534	0.3235	3	1	20	0.2293	2	4	0.0347	3	4
199676	0.2812	0.2996	5	3	21	0.2200	3	6	0.0233	1	11
181378	0.2423	0.2992	2	5	22	0.1961	4	4	0.0245	1	11
170419	0.2538	0.3219	4	2	23	0.1861	3	5	0.0223	4	6
194095	0.2908	0.3091	1	4	24	0.2042	3	3	0.0342	2	8
178787	0.2862	0.3187	3	1	25	0.2456	2	6	0.0319	3	9
162339	0.2284	0.2672	3	5	26	0.2227	4	4	0.0321	3	4
157292	0.2506	0.3173	4	4	27	0.1851	3	5	0.0188	1	6
110728	0.2763	0.2628	2	4	28	0.1907	3	4	0.0415	3	6
178986	0.2283	0.2610	4	2	29	0.2097	3	5	0.0489	1	10
120885	0.2485	0.2914	3	4	30	0.2037	3	5	0.0137	3	7
123509	0.2719	0.3188	4	3	31	0.1943	3	5	0.0235	1	11
162624	0.2876	0.2991	4	4	32	0.1825	4	5	0.0183	2	6
119551	0.2468	0.3030	2	4	33	0.2075	3	4	0.0115	3	6
178402	0.2547	0.3008	3	2	34	0.2129	2	4	0.0033	4	4
129277	0.2722	0.2855	5	3	35	0.1444	3	6	0.0204	2	8
191817	0.2554	0.2828	2	5	36	0.1894	4	4	0.0173	4	5
12949	0.2589	0.2335	1	2	37	0.2171	3	3	0.0665	0	1
151495	0.2858	0.3144	4	4	38	0.2418	2	5	0.0188	2	5
164236	0.2411	0.2768	2	4	39	0.1669	4	4	0.0286	3	8
103923	0.2381	0.3139	3	4	40	0.1758	2	4	0.0242	3	5
135424	0.2156	0.3046	5	3	41	0.1864	3	6	0.0426	4	3
139338	0.2992	0.3071	5	5	42	0.1963	4	6	0.0420	1	9
170855	0.2145	0.2875	2	5	43	0.1687	4	4	0.0452	2	7
191713	0.2417	0.3160	3	2	44	0.2041	2	5	0.0184	4	3
142170	0.2544	0.2927	3	3	45	0.1948	3	4	0.0080	4	6
138798	0.2767	0.3268	2	3	46	0.2155	3	4	0.0328	3	5
107259	0.2477	0.2818	1	2	47	0.1917	2	3	0.0349	4	7
102051	0.2356	0.2949	3	1	48	0.2321	3	4	0.0228	4	6
110264	0.2550	0.3333	5	1	49	0.2164	3	6	0.0335	4	4
146750	0.2293	0.2983	5	5	50	0.1942	4	4	0.0286	3	5
101574	0.2549	0.3447	2	2	51	0.2412	2	3	0.0453	2	9
181843	0.2765	0.3023	2	1	52	0.2085	2	3	0.0158	3	7
34086	0.2827	0.3415	2	4	53	0.2059	2	4	0.0291	0	0
182317	0.2707	0.2646	2	3	54	0.1944	3	4	0.0378	2	9
120988	0.2793	0.3002	1	2	55	0.2016	2	3	0.0214	2	9
138293	0.2460	0.3154	2	1	56	0.2281	2	3	0.0188	3	4
160437	0.2768	0.3064	4	2	57	0.2078	2	6	0.0200	1	8
156925	0.2764	0.2987	1	4	58	0.1868	4	3	0.0188	1	8
109452	0.2155	0.3059	4	1	59	0.1950	2	5	0.0232	1	9
131891	0.2234	0.3116	1	4	60	0.1940	4	3	0.0364	3	6
116657	0.2629	0.2963	3	1	61	0.2448	2	6	0.0062	2	5
18346	0.2083	0.2752	1	1	62	0.2079	4	5	0.0554	0	1
170165	0.2681	0.3321	3	4	63	0.2203	3	5	0.0338	3	6
121320	0.2691	0.3193	2	3	64	0.2424	3	4	0.0224	1	9

PCCN	PCDN	FCNO	PCNT	PCVE
0.0000	0.1094	0.0625	0.9585	0.0000

END OF YEAR 3

ID	SOC ST	ECO ST	TOLER	INPFC	LOC	PR VAL	AN UEX	REL CON	DIST	COUP	TENURE
175647	0.2985	0.2562	4	2	1	0.2018	2	0	0.0085	2	8
131441	0.3203	0.2777	5	4	2	0.2177	4	6	0.0605	1	9
119186	0.2756	0.2922	1	5	3	0.2303	4	3	0.0144	4	7
18386	0.2422	0.2883	1	3	4	0.2135	2	3	0.0264	0	3
170525	0.2520	0.3154	2	1	5	0.2070	2	3	0.0185	4	6
193021	0.2831	0.2609	2	2	6	0.2204	2	4	0.0440	1	13
107518	0.2893	0.3153	2	2	7	0.1954	2	4	0.0206	1	7
190139	0.2812	0.2927	1	2	8	0.2081	3	3	0.0096	3	8
162512	0.2386	0.3307	5	1	9	0.2618	2	6	0.0453	4	6
71006	0.2621	0.2920	4	4	10	0.1867	4	3	0.0245	0	1
153273	0.2081	0.2945	4	1	11	0.2137	2	5	0.0175	3	8
126175	0.2878	0.2882	4	4	12	0.2339	4	6	0.0267	3	8
145016	0.2909	0.3321	4	4	13	0.1935	4	5	0.0399	1	11
160064	0.2584	0.2566	5	4	14	0.2018	4	6	0.0457	4	8
162407	0.2559	0.3233	1	5	15	0.2073	4	6	0.0232	3	7
117426	0.2238	0.3354	4	1	16	0.2126	2	5	0.0530	3	6
40891	0.2514	0.3344	3	5	17	0.1487	3	5	0.0352	0	1
194188	0.2978	0.3002	3	3	18	0.2057	3	4	0.0350	4	8
131533	0.2792	0.3269	1	3	19	0.2049	3	3	0.0289	3	8
140388	0.2948	0.3235	3	1	20	0.2433	2	4	0.0370	3	6
199676	0.2984	0.2996	5	3	21	0.2244	3	6	0.0337	1	13
13135	0.2499	0.2787	1	2	22	0.1921	4	4	0.0349	0	0
170419	0.2661	0.3219	4	2	23	0.1957	3	5	0.0201	4	8
194095	0.3056	0.3091	1	4	24	0.2042	3	3	0.0414	2	10
178787	0.3037	0.3147	5	3	25	0.2807	2	6	0.0409	3	11
162339	0.2372	0.2672	3	3	26	0.2182	4	4	0.0309	3	6
157292	0.2807	0.3173	4	3	27	0.1488	3	5	0.0160	1	8
110726	0.2875	0.2826	2	4	28	0.1906	3	4	0.0451	1	8
178566	0.2023	0.2610	4	2	29	0.2167	3	5	0.0467	1	12
77571	0.2703	0.2963	4	5	30	0.2037	3	5	0.0179	0	0
123509	0.2826	0.3186	4	3	31	0.1982	3	5	0.0292	1	13
182624	0.2402	0.2491	4	4	32	0.1825	4	5	0.0054	2	10
119551	0.2588	0.3030	2	4	33	0.2075	3	4	0.0082	3	8
178402	0.2450	0.3608	3	5	34	0.2215	2	4	0.0010	4	6
159277	0.2832	0.2855	5	3	35	0.1481	3	6	0.0246	2	8
191817	0.2457	0.2828	2	5	36	0.1856	4	4	0.0190	4	7
12949	0.2589	0.2459	1	2	37	0.2259	3	3	0.0593	0	3
97840	0.2500	0.2808	5	2	38	0.2516	2	5	0.0155	0	0
108236	0.2534	0.2768	2	4	39	0.1669	4	4	0.0275	3	10
103923	0.2477	0.3139	3	2	40	0.1829	2	4	0.0210	3	7
135624	0.2199	0.3086	5	3	41	0.1908	3	6	0.0431	4	5
139334	0.3176	0.3671	5	3	42	0.1923	4	6	0.0530	1	11
170855	0.2231	0.2675	2	5	43	0.1647	4	6	0.0441	2	9
191713	0.2869	0.3160	3	2	44	0.2123	2	5	0.0143	4	5
16267	0.2502	0.3392	1	3	45	0.1967	3	4	0.0401	0	1
138794	0.2878	0.3260	2	3	46	0.2199	3	4	0.0340	3	7
107259	0.2994	0.2618	1	2	47	0.1990	2	3	0.0399	4	9
102061	0.2452	0.2949	1	1	48	0.2463	2	4	0.0209	4	8
110260	0.2453	0.3333	5	3	49	0.2238	3	6	0.0315	4	6
146750	0.2386	0.2963	2	5	50	0.1903	4	4	0.0265	3	7
101578	0.2811	0.3987	1	4	51	0.2510	2	3	0.0459	3	11
181643	0.2877	0.3023	5	1	52	0.2213	2	3	0.0226	3	9
91383	0.2400	0.3182	5	4	53	0.2142	5	4	0.0579	0	0
27740	0.2609	0.2740	2	2	54	0.1964	3	4	0.0435	0	0
94650	0.2839	0.3169	5	2	55	0.2007	2	3	0.0243	0	1
138293	0.2772	0.3164	2	1	56	0.2470	2	3	0.0191	3	6
160637	0.2909	0.3064	4	2	57	0.2162	2	6	0.0264	1	10
86218	0.2715	0.2687	5	4	58	0.1887	4	3	0.0546	0	1
109492	0.2899	0.3059	4	1	59	0.2070	2	5	0.0155	1	11
131881	0.2324	0.3718	1	4	60	0.1939	4	3	0.0339	3	8
91275	0.2313	0.2551	3	2	61	0.2573	2	6	0.0576	0	1
18346	0.2063	0.2863	1	1	62	0.2206	4	5	0.0587	0	3
170165	0.2789	0.3321	3	4	63	0.2205	3	5	0.0334	3	8
0	0.2365	0.2727	5	3	64	0.2472	3	4	0.0407	99	1

PCCM	PCOM	PCND	PCNT	PCVC
0.0313	0.0625	0.2344	0.0016	0.0156

END OF YEAR 5

Table 13. Experimental Data

Experiment Number: 1

NUMCY	PCCM	PCOM	PCMT	PCNO	DMEAN
1	2.	3.	100.	0.	0.021
2	6.	0.	99.	3.	0.022
3	5.	5.	98.	5.	0.024
4	2.	8.	93.	7.	0.025
5	0.	3.	92.	7.	0.025
6	2.	5.	88.	9.	0.027
7	0.	3.	87.	11.	0.028
8	0.	5.	83.	12.	0.028
9	0.	5.	80.	14.	0.030
10	0.	3.	76.	17.	0.031
11	0.	5.	73.	19.	0.032
12	0.	2.	69.	23.	0.032
13	2.	5.	65.	27.	0.033
14	0.	3.	63.	29.	0.035
15	0.	6.	56.	33.	0.036
16	0.	3.	53.	39.	0.037
17	0.	5.	52.	41.	0.037

Experiment Number: 2

NUMCY	PCCM	PCOM	PCMT	PCNO	DMEAN
1	3.	5.	100.	0.	0.023
2	0.	6.	95.	4.	0.032
3	5.	3.	92.	8.	0.038
4	6.	2.	90.	10.	0.048
5	9.	0.	83.	12.	0.053
6	13.	6.	61.	18.	0.061
7	19.	8.	43.	21.	0.078
8	23.	5.	32.	28.	0.087
9	19.	9.	25.	40.	0.085
10	22.	5.	19.	57.	0.072
11	14.	8.	17.	70.	0.067
12	11.	9.	12.	82.	0.065
13	9.	5.	11.	86.	0.062
14	9.	6.	9.	89.	0.058
15	11.	8.	9.	92.	0.061
16	8.	5.	8.	96.	0.059
17	11.	3.	7.	98.	0.055

Table 13. Experimental Data

Experiment Number: 3

NUMCY	PCCM	PCOM	PCMT	PCNO	DMEAN
1	6.	3.	100.	0.	0.035
2	9.	6.	88.	8.	0.038
3	6.	3.	79.	12.	0.044
4	5.	5.	77.	21.	0.049
5	6.	3.	76.	31.	0.045
6	9.	6.	75.	37.	0.046
7	11.	5.	74.	39.	0.041
8	8.	3.	73.	43.	0.038
9	6.	3.	72.	47.	0.037
10	5.	3.	71.	49.	0.038
11	5.	3.	70.	50.	0.035
12	6.	2.	70.	53.	0.036
13	5.	2.	70.	55.	0.037
14	5.	2.	70.	56.	0.035
15	5.	2.	70.	60.	0.036
16	3.	2.	70.	61.	0.037
17	2.	3.	69.	62.	0.038

Experiment Number: 4

NUMCY	PCCM	PCOM	PCMT	PCNO	DMEAN
1	13.	5.	100.	0.	0.027
2	16.	3.	77.	24.	0.031
3	14.	6.	67.	34.	0.035
4	19.	9.	49.	44.	0.042
5	13.	3.	41.	50.	0.057
6	9.	2.	39.	58.	0.062
7	6.	3.	38.	66.	0.058
8	3.	2.	37.	74.	0.055
9	5.	5.	35.	83.	0.049
10	2.	3.	34.	91.	0.045
11	3.	5.	33.	92.	0.048
12	2.	6.	32.	93.	0.047
13	0.	5.	30.	94.	0.044
14	2.	6.	29.	95.	0.045
15	0.	5.	28.	96.	0.046
16	2.	3.	28.	97.	0.045
17	0.	2.	26.	98.	0.044

Table 13. Experimental Data

Experiment Number: 5

NUMCY	PCCM	PCOM	PCMT	PCNO	DMEAN
1	0.	5.	100.	0.	0.036
2	8.	3.	91.	6.	0.038
3	5.	8.	83.	16.	0.040
4	6.	6.	72.	26.	0.041
5	6.	5.	67.	33.	0.044
6	9.	8.	66.	39.	0.045
7	8.	6.	63.	43.	0.047
8	6.	8.	62.	51.	0.048
9	8.	6.	61.	54.	0.048
10	3.	2.	60.	57.	0.050
11	3.	3.	60.	60.	0.051
12	3.	3.	60.	62.	0.051
13	5.	2.	59.	64.	0.051
14	3.	3.	58.	66.	0.052
15	0.	2.	58.	67.	0.053
16	2.	2.	57.	68.	0.053
17	0.	2.	56.	68.	0.054

Experiment Number: 6

NUMCY	PCCM	PCOM	PCMT	PCNO	DMEAN
1	6.	3.	100.	0.	0.023
2	11.	6.	78.	19.	0.025
3	8.	5.	73.	33.	0.028
4	8.	5.	67.	37.	0.030
5	5.	3.	65.	42.	0.031
6	3.	6.	65.	44.	0.033
7	2.	5.	63.	46.	0.035
8	2.	3.	59.	49.	0.037
9	2.	6.	58.	49.	0.039
10	0.	5.	58.	50.	0.041
11	2.	5.	58.	50.	0.043
12	3.	6.	57.	51.	0.048
13	2.	5.	56.	52.	0.045
14	0.	6.	56.	52.	0.044
15	0.	5.	56.	52.	0.044
16	2.	6.	56.	53.	0.043
17	0.	3.	55.	53.	0.044

Table 13. Experimental Data

Experiment Number: 7

NUMCY	PCCM	PCOM	PCMT	PCNO	DMEAN
1	6.	9.	100.	0.	0.028
2	13.	5.	74.	19.	0.036
3	11.	6.	68.	31.	0.043
4	9.	5.	58.	37.	0.057
5	8.	5.	55.	40.	0.061
6	9.	6.	53.	41.	0.055
7	6.	3.	54.	42.	0.054
8	8.	3.	54.	43.	0.048
9	5.	3.	55.	44.	0.041
10	5.	3.	54.	46.	0.043
11	5.	3.	54.	49.	0.042
12	6.	5.	53.	50.	0.040
13	3.	2.	53.	52.	0.041
14	3.	2.	52.	53.	0.045
15	2.	3.	51.	53.	0.043
16	2.	0.	50.	54.	0.042
17	2.	0.	49.	55.	0.044

Experiment Number: 8

NUMCY	PCCM	PCOM	PCMT	PCNO	DMEAN
1	8.	3.	100.	0.	0.031
2	11.	5.	82.	15.	0.035
3	13.	3.	65.	21.	0.047
4	9.	5.	62.	26.	0.056
5	8.	3.	59.	32.	0.064
6	9.	6.	54.	36.	0.061
7	6.	3.	52.	41.	0.062
8	5.	5.	51.	45.	0.065
9	8.	3.	48.	49.	0.066
10	6.	2.	44.	52.	0.068
11	5.	3.	42.	54.	0.061
12	6.	2.	41.	54.	0.059
13	5.	3.	41.	54.	0.063
14	5.	5.	40.	56.	0.066
15	5.	5.	40.	56.	0.067
16	6.	3.	40.	58.	0.065
17	5.	5.	39.	59.	0.064

Table 13. Experimental Data

Experiment Number : 9

NUMCY	PCCM	PCOM	PCMT	PCNO	DMEAN
1	5.	5.	100.	0.	0.023
2	6.	3.	94.	17.	0.025
3	5.	2.	88.	21.	0.032
4	6.	5.	76.	35.	0.038
5	9.	5.	68.	40.	0.049
6	11.	6.	64.	45.	0.056
7	11.	6.	58.	49.	0.068
8	3.	8.	54.	52.	0.072
9	6.	8.	53.	55.	0.061
10	9.	13.	52.	58.	0.065
11	14.	17.	48.	60.	0.078
12	16.	11.	38.	62.	0.083
13	13.	6.	26.	72.	0.075
14	9.	5.	24.	86.	0.064
15	8.	5.	22.	92.	0.063
16	6.	3.	22.	96.	0.061
17	6.	5.	21.	98.	0.062

Table 14. Sensitivity Data

Case	Run No.	v_i	v_{max}	v_{min}	v_f	t_m	t_b	t_n	t_ℓ	t_p	t_1	t_2	Δv
I-a	101	.023			.051	5							.028
	102	.036			.067	9							.031
	103	.041			.064	8							.023
	104	.032			.052	12							.020
	105	.028			.048	6							.020
	106	.036			.043	7							.007
	107	.027			.045	11							.018
	108	.023			.066	8							.039
	109	.023			.039	8							.016
	110	.036			.049	9							.013
	111	.036			.055	10							.019
	112	.036			.081	8							.045
	113	.023			.062	7							.039
	114	.041			.073	13							.032
	115	.036			.054	5							.018
	116	.036			.051	7							.015
I-b	201	.021			.078		7						.057
	202	.023			.053		11						.030
	203	.036			.048		15						.012
	204	.036			.061		12						.025
	205	.041			.058		16						.017
	206	.027			.043		13						.016
	207	.041			.062		12						.021
	208	.028			.058		10						.030
	209	.036			.051		5						.015
	210	.023			.062		11						.039
	211	.032			.073		8						.041
II-a	301	.044	.087		.066			15		6	11	17	
	302	.028	.041		.032			6		4	4	8	
	303	.041	.052		.046			5		4	3	7	
	304	.036	.069		.048			8		7	5	12	
	305	.023	.058		.051			14		6	11	17	
	306	.036	.083		.067			12		5	10	15	

Table 14. Sensitivity Data

Case	Run No.	v_i	v_{max}	v_{min}	v_f	t_m	t_b	t_n	t_g	t_p	t_1	t_2	Δv
II-a	307	.036	.059		.049			14		7	9	16	
	308	.032	.075		.062			15		6	11	17	
	309	.027	.066		.051			10		7	5	12	
	310	.021	.070		.065			10		5	8	13	
	311	.023	.079		.058			13		7	9	16	
	312	.036	.047		.045			13		6	10	16	
	313	.036	.087		.057			11		8	7	15	
	314	.041	.073		.062			15		6	11	17	
	315	.041	.076		.065			14		5	12	17	
	316	.023	.055		.041			14		7	9	16	
	317	.027	.067		.043			9		6	5	11	
	318	.021	.081		.067			11		6	8	14	
II-b	401	.037		.025	.053				5	4	3	7	
	402	.048		.031	.051				13	5	11	16	
	403	.041		.035	.048				10	3	9	12	
	404	.023		.019	.062				4	3	3	6	
	405	.021		.015	.025				10	6	6	12	
	406	.023		.018	.048				8	5	5	10	

Appendix C. Real Neighborhood Data

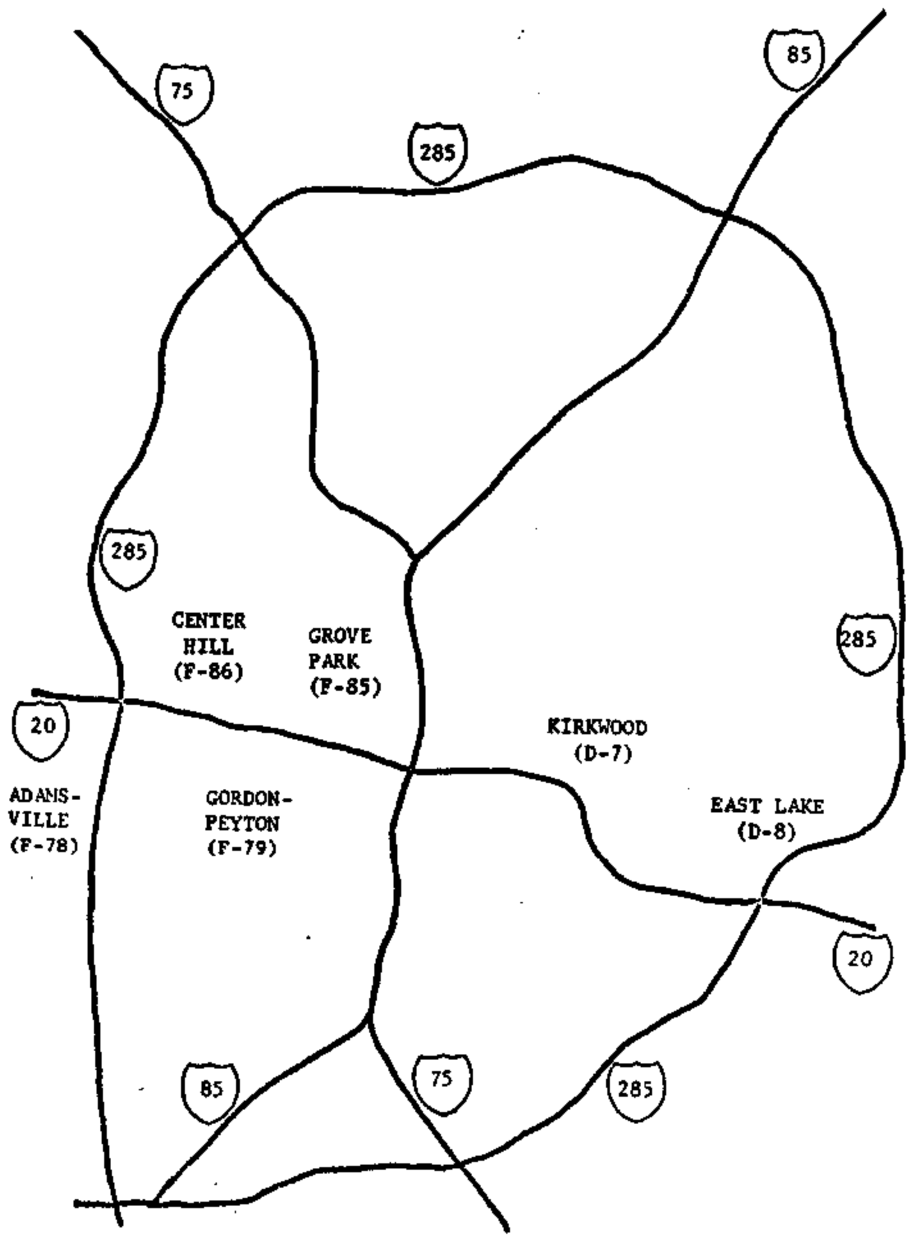

Figure 27. Atlanta Neighborhood Census Tract Locations

Table 15. Racially Transitional Data By Census Tract

	F-78		F-86		D-8		F-85		D-7	
	Units	Pop.	Units	Pop.	Units	Pop.	Units	Pop.	Units	Pop.
1960	10.9	8.2	4.9	4.1	0.1	0.1	0.1	0.1	0.0	0.0
1961	25.2	30.5	5.5	7.3	0.1	0.1	0.1	0.1	0.0	0.0
1962	51.2	55.8	5.8	7.4	0.1	0.1	0.1	0.1	0.0	0.0
1963	58.2	62.1	8.4	8.9	0.1	0.1	3.1	3.4	9.0	13.0
1964	72.9	74.9	26.7	33.0	0.1	0.1	17.4	18.7	19.5	25.8
1965	75.9	77.5	71.8	77.1	37.4	42.5	68.3	70.0	68.5	75.1
1966	82.2	82.1	82.5	85.5	49.8	57.5	97.5	97.5	86.5	89.9
1967	80.5	80.8	92.1	93.6	62.9	66.2	100.0	100.0	98.4	98.0
1968	83.5	81.7	92.5	93.5	64.9	67.2	100.0	100.0	98.5	98.4
1969	83.0	83.1	93.5	94.3	82.0	83.9	100.0	100.0	98.5	98.5

Table 16. Data for ADAMSVILLE Neighborhood

(Census Tract F-78)

YEAR	DWELLING UNITS			POPULATION		
	Black	White	% Black	Black	White	% Black
1960	147	1211	10.9	340	5044	8.2
1961	395	1191	25.2	1941	4452	30.5
1962	1036	973	51.2	4566	3622	55.8
1963	1369	983	58.2	5989	3609	62.1
1964	1977	752	72.9	8040	2740	74.9
1965	2534	800	75.9	9846	2837	77.5
1966	3078	776	82.2	12054	2674	82.1
1967	3318	826	80.5	11711	2853	80.8
1968	3795	847	83.5	13147	2899	81.7
1969	4104	862	83.0	13804	2871	83.1

Appendix D. Monte Carlo Random Variable Generation

The usual Monte Carlo random variable generation produces random 'variates' through a specific inverse function with a pseudo-random number generator [11,71,82,119]. The random number generator generally utilizes a congruential method which dictates the number cycle by the word size of the particular machine. This technique is initiated by the selection of four nonnegative numbers: x_o, the seed or starting value; a, the multiplier; c, the increment; and, m, the modulus. The random numbers are then:

$$x_{n+1} = a \cdot x_n + c \pmod{m} ,$$

with these stipulations on the values of m:

$$m > c \ , \ m > a, \text{ and } \ m = 2^b - 1 \ ,$$

where b is the word length in bits. The value of 'a' determines the period, where the maximal period is of length m.

The HNM enjoyed two modifications to the standard Monte Carlo procedure. Firstly, an additional measure of randomness was gained by the use of two independent random number sequences [82]. Secondly, many of the random variables were from a triangular stochastic distribution which was developed as follows.

The density function for the distribution was taken to be:

$$f(x) = (D/(B-A)) \cdot x \qquad \text{for } \ A < x \leq \ B$$

$$\text{or} \quad f(x) = -(H'/K)\,x + H'\,((C-A)/(C-B)) \quad \text{for} \quad B < x \le C.$$

It can then be shown that the inverse function for the random variables is as follows:

$$x = A + (B-A)\cdot r/P \quad \text{for} \quad 0 \le r \le P$$

and,

$$x = C - (C-B)\ \sqrt{(1-r)/(1-P)} \quad \text{for} \quad 1. \ge r > P.$$

P = F(B) and r is the pseudo-random variable from {0,1}.

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