A STOCHASTIC MODEL OF RESIDENTIAL MOBILITY AND URBAN STRUCTURE

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ABSTRACT

A stochastic model has been developed to simulate the interrelation between household locational decisions and home-job distribution patterns. The model is designed to study the effects of urban structure on the transportation requirement for work trips. The model also provides an opportunity for studying the stochastic characteristics of urban models in general. Another objective of developing the model is to investigate the significance of individual accessibility preference, availability of residential dwellings, and competition between individuals on the residential location process.

There are three elements in the model. First is the residential mobility. The total number of residential and employment vacancies is derived from a Poisson process. Second, the vacancies are randomly located among specific subareas. Finally, individuals are assigned to vacancies based on an accessibility related probabilistic choice function.

Simulation is carried out in discrete time intervals. The total number of vacancies in job and residence is generated for each interval. Households are classified into three different types: simultaneous job and residence change, job change without change in residence and residence change without job change. The assignment process then matches job and dwelling vacancies to individual households seeking jobs and/or dwellings by a probabilistic accessibility function. The accessibility function, being probabilistic rather than deterministic, allows the model to take into consideration variations in individual behavior and factors other than accessibility. The state of the system is given by the job locations of the residents in geographical spatial units.

Five experiments have been carried out with the model for a rectangular city with two job centers. The job centers are symmetrically located and are of equal size. There are a total of 10,000 households uniformly distributed among 1,000 equal size spatial units. A linear probabilistic choice function of distance is used. The results reported are for different initial household locational patterns and for different rates of vacancies. Steady state conditions, i.e., zero growth in jobs and houses, are assumed. Depending on the rate of changeovers in jobs and homes and the initial state of the system, equilibrium conditions are achieved in anywhere from a few cycles of simulation to 900 cycles.

The model converges to the equilibrium condition asymtotically. The same equilibrium condition is reached independent of the initial state and the rate of household and job changeovers. In addition, if it is assumed that the city is completely vacated and jobs and residences are refilled in a single step, the equilibrium condition is achieved instantaneously. Furthermore, once the model reaches equilibrium, it stays stochastically stable. However, considerable statistical variations remain in the system after equilibrium is reached. The observed stochastic properties of the model will also be presented.

INTRODUCTION

In a society in which households are relatively free in their location decisions, it is likely that urban forms are strongly influenced by the mobility decisions of a vast number of households and the location of primary activities such as employment and shopping centers. The relative location of homes and activity centers, by and large, determines the transportation requirement for work trips and shopping trips which account for 52% (1) of the travel in metropolitan areas. For the purposes of conserving energy and maintaining environmental quality, increasing emphasis has been put on the planning of urban structure as a means of limiting transportation needs.

Analysis of transportation needs is done by using various forms of urban models. In specifying the models, simplifying assumptions are necessary. Senior (2,3) has listed in diagramatic form the various subcomponents of a complete model of disaggregate location decisions. Among the components are a population submodel, a residential mobility model, a housing stock model, and a mechanism for equilibrating supply (housing) with demand (moves) within a given time period. Different simplifications are made for all the urban models in different subcomponents in order to make the problem analytically tractable. The readers are referred to the Senior articles for a review of existing models.

The selection of destination choices is an important element in transportation systems analysis. The modeling of this process is called trip distribution. Trip distribution is usually carried out with three model types: the urban models, the gravity models, and the opportunity models. The key concepts in all models are the attractiveness of the destinations which is usually represented by the size of the activity center and the accessibility which is usually represented by distance, time, or cost of the trip. An introduction of trip distribution is given in Hutchinson (4).

The model described in this paper deals only with the home-work distribution patterns. It differs from previous models in that the decision rule is for individual households through a probability function rather than using a deterministic rule based on average behavior. In addition, the assignments of households to homes and head of household to jobs are made from both the residence ends and the job ends. When dwelling units and jobs are aggregated to large geographical units and deterministic aggregated rules are used as in previous models, equilibrium conditions in the model are obtained through an iterative process. In the model described here, an iterative process is not necessary because equilibrium is reached when all individuals made their decisions. From the point of view of an individual, he can only sense the tightness or ease of the market through his own search experience.

The development of the model is less for the purpose of making predictions than for the purpose of developing a tool for investigating the mathematical properties of urban models. Specifically are the asymtotic, ergodic, and stochastic properties. Assumptions have been made implicitly on these properties in previous models and in planning practices. In addition, the model is developed for the purpose of examining theoretically the general relationship between transportation needs and urban form, the general characteristics of work-trip patterns as a function of city size, and the effect of the number of job centers and their locations on home locations.

Experiments based on the model are being planned. Reported here are the details and philosophy of model development, as well as some preliminary results from a small number of limited experiments.

MODEL DEVELOPMENT

The model developed in the study is along the line of a spatial diffusion process. A description of these types of models has already been presented previously by Brown (5). Readers are referred to that monograph for further discussions of the concept. The purpose of developing the model here is to examine some of the general mathematical properties of residential location models that use accessibility as the primary decision rule. Although a spatial diffusion process with distance bias of both the relocation type and the expansion type of diffusion (in Brown's terminology) is simulated, the outputs are simplified by ignoring the details associated with individual moves and concentrating on the macroscopic patterns of home-job locations.

The classical urban models, e.g., the gravity model, are primarily concerned with macro-level behavior. The relationship of individual behavior to the stable macro-pattern is constrained to an a-priori function, such as the gravity equation. In the present model the individual behavior is described as fully as desired. The macro-level pattern emerges as a consequence of a diffusion process of individuals. By varying the individual and macro-system descriptions, then analyzing subsequent patterns, the relations of individuals to macro-system may be explored in detail.

The model to be described, like many urban spatial models, may find an analogy to some physical systems. The analogous systems in this case are those from statistical physics. For example, the behavior of a cylinder of gases separated by a permeable membrane, or a dilute solution of electrolytic materials may be described in statistical physics terminology. In particular, the processes of diffusion of individual molecules in a given container with given initial concentration gradients provides a clear analogy to the behavior of movers in a city to be described. The difference between the present model and physical analogies is fundamental. The concepts are nonetheless similar.

The statistical physics description of human social systems has been used in the field of traffic flow theory (see Prigogine and Herman (6)). The present study is an off-shoot of that pioneering work, extending the concepts of kinetics and statistical mechanics to broader social systems. Although computer simulation is used for convenience, we are basically developing a stochastic model to describe mathematically a complex set of spatial interactions.

Model Assumptions

In order to grasp urban mobility processes in a comprehensible form a discrete-event stochastic simulation model was developed. To minimize well known uncertainties inherent in stochastic computer models, the size of the program was kept to a minimum. (The core of the algorithm is approximately one hundred FORTRAN statements.) A desire to maintain simplicity in the portrayal of a relatively complex event space necessitated specific tradeoff between full detail and output uncertainty. In contrast to previous work simplifying assumptions were considered in light of the integrity of individual processes, rather than details of spatial structure. Our basic motto with regards to assumptions might be: "assume nothing until compelled to do so". The primary criterion for selecting the necessary assumptions has been that of maintaining a level of individual choice consistent with observation and experience. In other words, assumptions regarding individual behavior have been made with all possible cognizance of their implications for individual freedom of choice and operative constraints on that choice. The marked similarity of the urban mobility processes to classical mathematical diffusion processes provides another basis for consideration of the suitability of assumptions. Nonetheless, the assumptions are necessarily judgemental, due to the insufficiency of systematic observational data regarding the individual behavior under question. Our major concern has been to create a model logically consistent with the given assumptions (thus minimizing hidden assumptions). Methodological shortcuts have been conspicuously avoided to provide a logically rigorous framework. Because one aim of the modeling project is to test certain modeling and behavioral assumptions, one needs not be unduly constrained by experience (though mathematical consistency is always required).

Model Reasoning

Individual moving processes, which ultimately account for the spatial form of urban activity patterns, may be significantly more complex than hitherto acknowledged. Without making simplifying assumptions, and relying on personal experience, one may ascertain that the activities classified as changing jobs or moving to a new residential location cannot be easily isolated, temporally, from other activities. The search process might go on for weeks while other activities not related to moving continue unabated. Acknowledging a search process complicates the motion of a moving "decision". In this context the decision to change residential location does not imply actually changing location. The decision does imply the initiation of a search process which may or may not be fruitful. The decision to move is separated temporally from the decision to accept a particular new location by a definite period of search. There appears to be empirical evidence (7) for assuming these two temporally distinct decisions to be governed by the same rules.

Consider the search processes leading to the final decision. The individual's search for employment and housing in urban markets is physically constrained by the availability of housing stock and his ability to locate suitable stock, regardless of his particular preferences. Physical constraints leading to a lack of information mitigate against finding any sort of "global optimum" location. At best a "local" optimum is to be expected, based on limited information digested during the search. Consequently, the final decision must be tempered by new information acquired subsequent to the initial decision to move. There is intuitive evidence to suggest that changing individual urban location status is a relatively complex process. Past efforts at exploring household mobility and urban structure, in the predictive context, have sacrificed process complexity at the expense of retaining a detailed structural description. The present effort shifts that emphasis through retaining the complexity of individual interaction processes at the expense of structure and strict empirical justification. Heuristical reasoning and the demands of mathematical consistency provide the necessary basis for our exploration in individual mobility processes.

Individual Mobility Processes

The inadequacy of deterministic decision models as descriptions of mobility processes has been pointed out. Abandoning the assumption that individuals make instantaneous, all inclusive decisions to modify the job-residence relationship, static notions of urban structure become inoperative, as well. A structural definition becomes incomplete without characterizing relevant individual activities potentially leading to change (i.e., processes). The simple notion that an individual always resides somewhere is modified to distinguish among those "passively" residing and those actively searching for new jobs, residences, or both. These are distinct mutually exclusive individual states of decisions. A-priori, there are no grounds for considering one state "normal" and another temporary. That is, "passively" residing may occur with a given duration and frequency, just as any other state of mobility. That it is observed to be more prevalent may be interpreted as a significant operational difference from other states, rather than a condition of normalcy. For example, the less frequently observed state might be interpreted to be operationally advantageous when only observed at low relative frequencies or duration. For denying the status of normalcy to any particular state, the operative process is kept clearer in mind. This operational point of view is consistent with experience, despite our tendency to view urban relationships in a static frame.

Experience, previous work and casual observation provide the basis for description of the mobility processes in our model. Casual observation of urban spatial relationships points to the marginal stability of individual household locations and job status over time periods commensurable with marked urban change (on the order of months or years). The observed fluidity of urban spatial relationships underlines the continued existence of alternative states of long-term spatial mobility. Further, experience and observation provide ample evidence that an individual's states of long term mobility tend to change periodically, though not necessarily in regular patterns. A random process of the rate of moves is suggested, notably the Poisson process. The individual mobility processes integrated to the macroscopic level provide the scheme for a hypothetical urban structure defined as a Poisson process of spatial-temporal ordering. In contrast to previous static models, the dynamic model to be described does not violate the laws of entropy, wherein order is established without observance of concommitant disorder. Instead, we fully expect that lower level relationships change in a primarily disorderly manner (i.e., randomly altering spatial states). In so designing our model we make an important first step toward discovering principle linkages between unconstrained individual activity and macroscopic urban structure.

THE MODEL

The model developed may be briefly described as a three level stochastic dynamic simulation of long term urban individual mobility processes. Level, in this context, means the degree of aggregation of subsystems. The first level represents individual households in the mobility process. They are categorized as: 1. non-movers, 2. Job changes, 3. residence changes, and 4. combined job-residence changes. The overall simplified urban spatial structure is composed of clusters or cells, each cell being composed of residential units. Two or more of these cells simultaneously represent employment locations. The cellular spatial structure is the second level in our conceptual scheme. The overall closed system structure is the third.

Each cell or cluster is assumed to contain the same number of residences (10 for the cases examined herein). Two or more clusters within the spatially defined set are concentrated job locations containing a given number of job positions. All residences or job positions within a cluster are undifferentiable on the basis of location. The cluster composition is further differentiated by the job status of individuals within the cluster. Two individuals in the same cluster with the same job status cannot be differentiated. They are functionally identical until one changes its status.

In other words, the setting is quite straightforward. First we have individuals looking for jobs and residences, or just remaining at the same job and residence. The job-residence relationship fully specifies the individual's activity pattern as far as the work trip is concerned. The system structure is highly idealized, e.g., a rectangular array with a rectangular grid pattern of access corridors or streets. Distances between cluster centers are assumed to be the shortest grid distance. Furthermore, grid distance is the functional basis of job and residence selection by individuals. The residential blocks are then characterized by the job affiliations of individuals residing in it. The blocks may further be distinguished according to potential availability of housing or jobs. For example, a block may contain houses which have been put up for sale. All individuals looking for a new residence are potential buyers including other present residents of the city who are looking for new accommodations. Finally the whole region (e.g., city) is characterized by the activity or travel patterns of employed individuals. Furthermore, the region, as a whole, may be growing or fully developed and the characteristics of the individuals and cells may be expressed statistically, as averages or totals.

In the formulation of the dynamic model each level of the conceptual scheme may be described in terms of spatial and temporal states. Spatial states are the structural conditions at the three levels. These are residence-job relationships and patterns. Temporal states are the unspecified spatial conditions or activities at each of the three levels. A few examples may clarify the terminology. For example, individuals are described by the spatial home-work relationships, in addition to their temporal states of mobility such as looking for a job or remaining at the same residence. A cluster or block is characterized spatially by the job affiliation composition of its residents on the work trip pattern of employees. Temporally they are characterized by the vacancies on availability of housing or jobs. A searching individual is automatically turned away from a block that is in the unavailable state. The region is portrayed in its distribution of spatial activity patterns and temporal availability of new development (i.e., growing and developing). Spatial states are inherent in the structural description of the simulated system at any given moment. Temporal states are inherent in the processing procedures describing the relevant activities of the system. The full system description requires both the description of structural relationships and operational (or processing) rules and conditions.

Processing The Model

Processing rules pattern the temporal states of the system stochastically. In other words, the dynamic pattern of events is constrained by the stochastic processing rules. The meaning of processing constraints may be easily grasped in this context. Consider an unconstrained individual in our hypothetical conceptual setting. He can come into the process in only a few possible ways. He may stay where he is, change residence or job at any time, or make any temporal succession of the four possible mobility states. By constraining this individual we may limit, in some manner, the frequency, duration, and sequence of possible states (e.g., we may assume that housing searches occur infrequently with short duration, and limit such searches procedurally). Due to the constrains, processing rules form the key underlying assumptions of the model.

The system processes may be described in terms of an event space which characterizes the temporal states of the system. "Event", here, has a very specific meaning, being defined as any state transition. In standard modeling terminology an event at the individual level would be called a decision. In this context a decision is understood to be an event, as defined. Several possible events are:

1. the individual initiating a job search process,
2. a residential cluster establishing an available housing unit,
3. the region developing a new housing cluster, and so on.

From the foregoing it is clear that events occur at all three levels. The chain of events from level to level is the essence of the modeled process. The chain itself is determined by the processing rules, while events occur probabilistically according to several assumed probability distributions. The chain of events is summarized below.

The Vacating Process

Many individuals in a region may decide to move during any given time period. The first step in the event chain is the selection of the movers in each mobility state. In other words, we generate many individual transitions from the stationary state to the active moving states, forming a pool of house and job searchers. We impose a cyclic pattern upon the moving process primarily for ease of processing. Other patterns are possible, but less practical from both computational and interpretational standpoints.

Initially, all individuals are working residents characterized by given job and residence locations. Each individual in that state is assumed to have an identical probability (P) of deciding to enter a new mobility state during a given time period. The actual number of individuals deciding to move is assumed to follow a Poisson distribution:

$$P[N(t) = K] = e^{Pt}(Pt)^{K}/K!,$$

where $t = t > t_O$, $N(0) = 0$, and $N(t) = K$ = number of movers since t_O. For a given time period $t_M - t_{M-1} = \Delta t$, an average of $P \times \Delta t$ moving transitions are expected. It follows that if Δt is a unit time period, $t_M - t_{M-1} = 1$, we have

$$P[N(t_M) - N(t_{M-1}) = K] = e^{PN}(PN)^K/K!,$$

the cyclic Poisson distribution. Therefore, the cumulative number of individual transitions may be approximated at the regional level for the unit time period over which P is defined, given that N remains constant. At the regional level, then, the number of moving decisions (K) is specified for $t_M - t_{M-1} = 1$, by generating the Poisson random variable.

The decision-to-move event may lead to any one of the three possible mobility states. Each state is assumed to have the same average duration, and the average frequency of occurrance is assumed to be constant for each state (though not necessarily the same). For any given cycle the sum of the frequencies must equal the total number of individual events. It follows that

$$\sum_s f_s = PN,$$

where f_s is the average frequency of occurrence (events/cycle) of state s. The average proportion of all transitions that lead to state s is given by

$$pr_s = \frac{fs}{PN}.$$

The probability of any individual transition leading to state s is, therefore, pr_s. Transition states may be selected from a multinomial function of pr_s, $s = 1, 2, 3$. After K is specified for the region, the K events are generated individually by selecting the mobility state through a multinomial sampling procedure, then choosing a residence cluster from a uniform random distribution of clusters. As clusters are chosen, the cluster composition is altered to reflect the change. Cluster vacancies are generated and tagged to record the moving state of the resident for future reference. The individual is chosen from that cluster multinomially, based on the distribution of job status within the cluster. For example, if eight individuals are associated with Job A and two with Job B, the probability of choosing an individual from A is 0.8.

When individuals are in an active moving state, they are no longer associated with residence or job locations. The path of the individual is not followed after the transition. The only accounting of individuals is the regional level count of the number of movers in each moving state, and the cluster level record of the moving states of previous residents and employees. A regional level record of moving states is fully specified after all individuals make the transition to the moving states. Consequently, a pool of movers and available housing and job locations has been generated. Locations available for individuals in each moving state form a subset of the total location pool. For example, an individual making a job change will enter the pool and become dissociated with housing, as well. However, when individuals from the pool, in the job change only state, are assigned to a new residence location, it must be from the list of clusters tagged as available. An available cluster would be one originally vacated by an individual changing job only. Therefore, even though individuals are never tagged or specifically identified, the transitions to different temporal states are mathematically consistent at the individual level. The only information lost is the actual paths of individuals between stationary states.

The Assignment Process

The system returns to the beginning of a cycle following the search and selection process. All K individuals in the pool will search from among the available locations. Initially the pool is large, as the first few individuals selecting locations having the greatest choice. Available locations are eliminated one by one as transitions occur. The last few individuals face a limited choice of options. Assignment of the last individual marks the end of the cycle, a complete redistribution of the K movers being the outcome.

The search and selection is carried out by each individual represented in the regional-level record of moving states. Individuals, identified only by state, are selected by multinomially sampling from that record. (The probability of choosing a state is equal to the proportion in that state at a given point in the process.) Individuals are initially assigned either to an available residential location at random, or an available job location, multinomially. Job searchers are assigned residence first; house searchers job first. House and job searchers have one or the other assigned first. The decision is made probabilistically by sampling from a binomial distribution with p specified. The initial location assignment further identifies the moving individual. Only when both job and residence are changed is the location different from the individual's initial location. The selection of a new house or job location, and subsequent transition to a new stationary state, follows the initial house or job assignment. The selection process is the key to system level outputs. The acceptance criterion is the home to work distance. All other variables are subsumed under the random component of the acceptance function. The function is a binomial probability distribution with p, the probability of acceptance, a function of distance (viz. accessibility): $p = p(\text{accessibility})$. Acceptance of locations is determined by sampling the binomial distribution. Job locations may only be sampled once and forced acceptance of the last location is part of the behavioral rule. Residence sampling is restrained to ten locations, but the probability of actually sampling ten is quite small (for the acceptance functions tested, on the order of .001).

At the completion of the assignment phase, the whole system is observed by creating a spatial state array. The spatial patterns are extracted and analyzed statistically. Following observation, new clusters would be added in the regional growth formulation of the model. In the static version the process just outlined is reiterated until stable steady state spatial patterns emerge at the regional level.

RESULTS

Five experiments have been carried out for an idealized rectangular city represented by a 40 x 25 array. There are 1,000 equal size clusters or blocks in the city. Each cluster contains ten residences. Two job centers offer employment to the residents. It is assumed that there would be one employed person per households. The 10,000 jobs are divided equally between the two job centers which are located at cell (10,13) and cell (31,13) with respect to the (x,y) array. The job centers are designated as job centers A and B, respectively.

The simulation is carried out with a linear accessibility function which is shown in Figure 1. The maximum distance from home to work is 42 blocks (rectangular grid distance). The distance from home to work within the same block is assumed to be one block in order to include some travel impedance for these residents. Also assumed is a 3% vacancy of homes and jobs.

The experiments that were carried out simulated the situation of a matured constant-population city. The experiments differ in moving rates and initial conditions. The number of cycles simulated for each experiment also varies depending on the time required for reaching a equilibrium home-job locational distribution. The conditions for each experiment are given in Table I.

The typical model output is depicted in Figure 2, which shows the home distribution of workers at job center A. The job locations A and B are encircled with job center A on the left and job center B on the right. The results shown are from the output of cycle 100 in Experiment 5. Experiment 5 begins with an initial assignment that concentrates all worker residences in the one half of the city nearest to the workplace. After equilibrium conditions have been achieved, only two-thirds of the workers at A have homes in the half of the city containing job center A. The stochastic nature of the results can be seen in the statistical variations of worker densities. Figure 3 shows the distribution of workers and vacant residences as a function of distance in the x direction. There appears to be a linear distribution of households with jobs at A and B as a function of the distance to the job centers for the clusters between the two job centers. For clusters near the edge of the city, the proportion of workers for each job center seems to be relatively independent of the distance in the x direction. A most interesting result from Figure 2 is the high concentration of workers in clusters immediately surrounding the job center and at the fringe of the city nearest to the job center.

Figure 4 shows the histograms of the number of clusters with N residents whose distance to work is 12 blocks and the distance to work for the other residents in the cluster is 33 blocks. The results shown in the figure are from Experiment 1. Experiment 1 has as its initial condition a uniform distribution of worker households. In Figure 4 the results are shown for cycles 0, 100, 200, 300, and 440. The diffusion characteristics of the distribution function are clearly visible. The process approaches equilibrium rather quickly. After cycle 100, the trend is overwhelmed by the statistical fluctuations.

In Experiment 4, the initial condition is established by using the process rules of the model. This initial condition assumes all houses and jobs are vacant and to be filled in one cycle of simulation. Table II gives the results of the experiment. Tabulated are the frequencies of clusters with N households whose residents work at job center A. The table gives the distributions for cycles 0, 100, 200, 300, and 400. There is considerable stability in these distributions indicating that equilibrium conditions are reached in one step by applying the processing rules of the model on an instant city. In addition, the equilibrium conditions once achieved will be maintained.

The five experiments show preliminarily that the same equilibrium home-job locational distribution is achieved regardless of the moving probability and the initial condition. Although in all five cases the home-job locational distributions approach equilibrium asymtotically, the rate of convergence is influenced by the moving probability and the initial conditions. The experiments further indicate that the equilibrium condition is stable, except for random fluctuations. Furthermore, the results show that there are considerable statistical variations in the home-job locational distribution even though there is a clear expected pattern which may possibly be predicted deterministically.

CONCLUSION

The particular features of the new model are heavily influenced by previous work. The most interesting of these are 1) the model has a dynamic capability, 2) the model allows both "push" and "pull" considerations in the moving decision, 3) the model allows movers to have a fixed job and look for a residence, a fixed residence and look for a job, or simultaneously seek both job and residence, 4) the model allows accessibility to have an affect on moving decisions, and 5) the model has the capability of simulating urban growth.

The dynamic capability allows the testing of hypotheses which compare a static equilibrium state to the final state of a dynamically changing urban area. In particular, it will be possible to determine the effects of the moving rate and the growth rate on the final state of an urban area. In addition, the effects of differing original arrangements of residences with respect to jobs on the final state can be examined.

The model recognizes both push and pull factors by first generating potential movers randomly, then allocating these movers by some accessibility rule. This strategy is consistenx with previous findings that accessibility is more strongly related to the pull factors. It is assumed that nonaccessibility factors are subsumed under the random identification.

A key feature of the model is the individual decision rule, which is assumed to be a function of accessibility and other factors. The accessibility, which is of prime interest, is represented deterministically by some function of distance, while the other factors are represented by a random component. By varying the relative magnitude of the deterministic and random components of the decision rule, it is possible to have a situation where accessibility is of key importance or a situation where it is of little importance. This allows the testing of the consequences of the various views on accessibility.

Finally, the capability of simulating growth is necessary for a dynamic development of urban structure. The growth component can be modeled either randomly or as a combination of a systematic and random process.

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Table I

Experimental Conditions

Experiment	Moving Probability	Initial Assignment	Number of Cycles Simulated
1	.01	Uniform	450
2	.04	Equilibrium	30
3	.005	Concentrated	900
4	.005	Equilibrium	400
5	.04	Concentrated	100

Table II

Number of Clusters with N Residents
Employed at Job Center A

	Cycle				
N	0	100	200	300	400
0	17	14	16	16	16
1	63	52	62	62	52
2	109	118	113	100	107
3	131	136	130	152	139
4	128	128	130	127	129
5	143	152	137	125	159
6	136	137	148	143	130
7	129	116	117	128	136
8	88	91	84	94	82
9	40	46	48	43	38
10	16	10	15	10	12

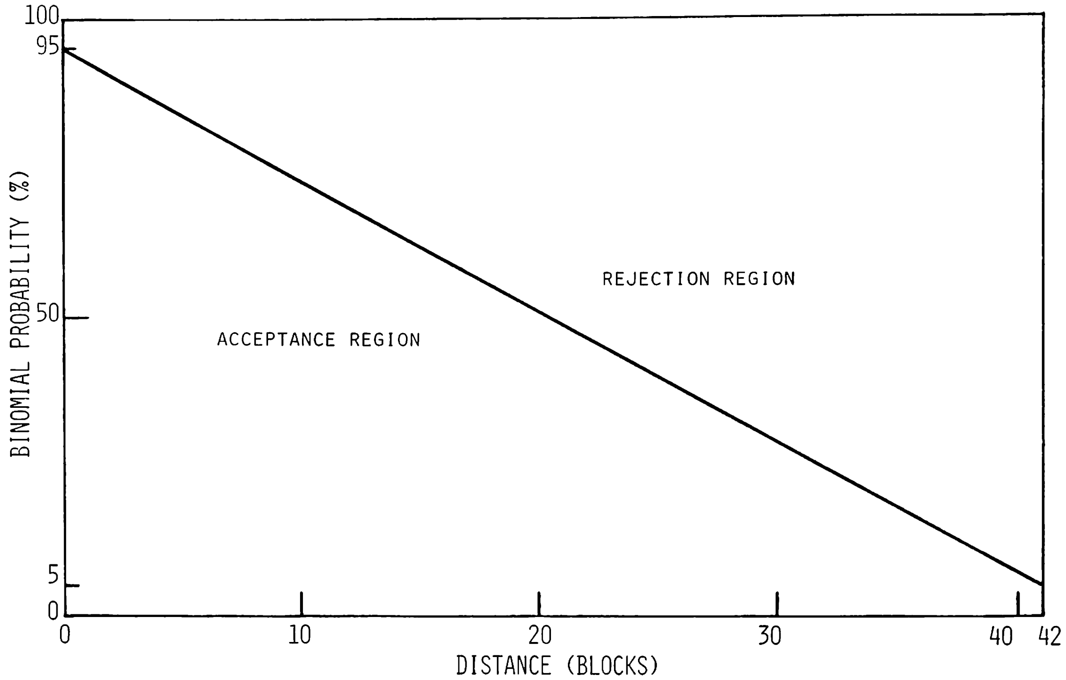

Figure 1. Accessibility function of home-to-work distance preference represented as a binomial probability of accepting or rejecting a vacant residence or job.

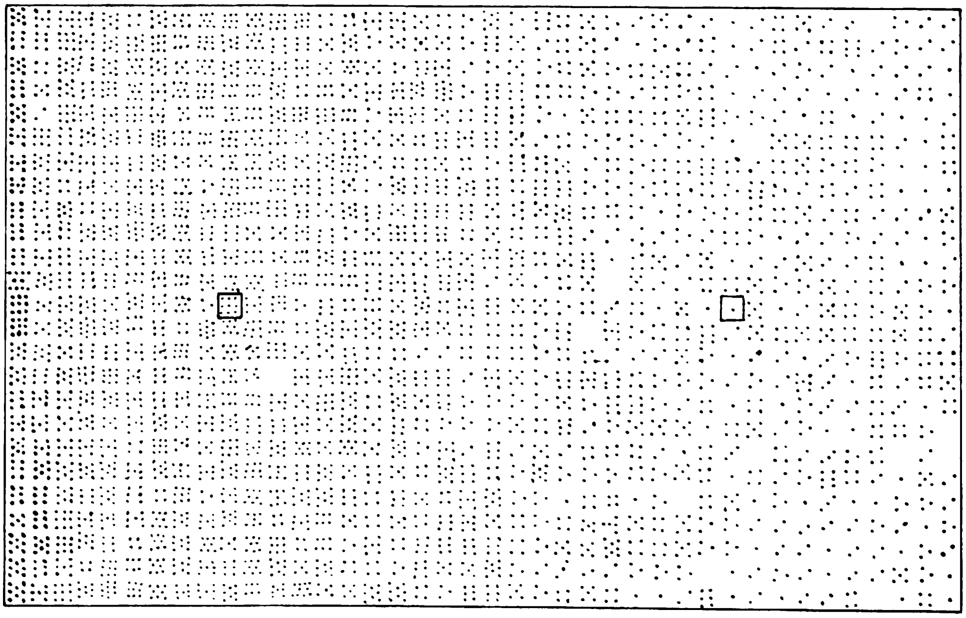

Figure 2. A scatter diagram of the residential locations of persons employed at job center A, which is shown as the encircled block on the left. The results are from cycle 100 of Experiment 5.

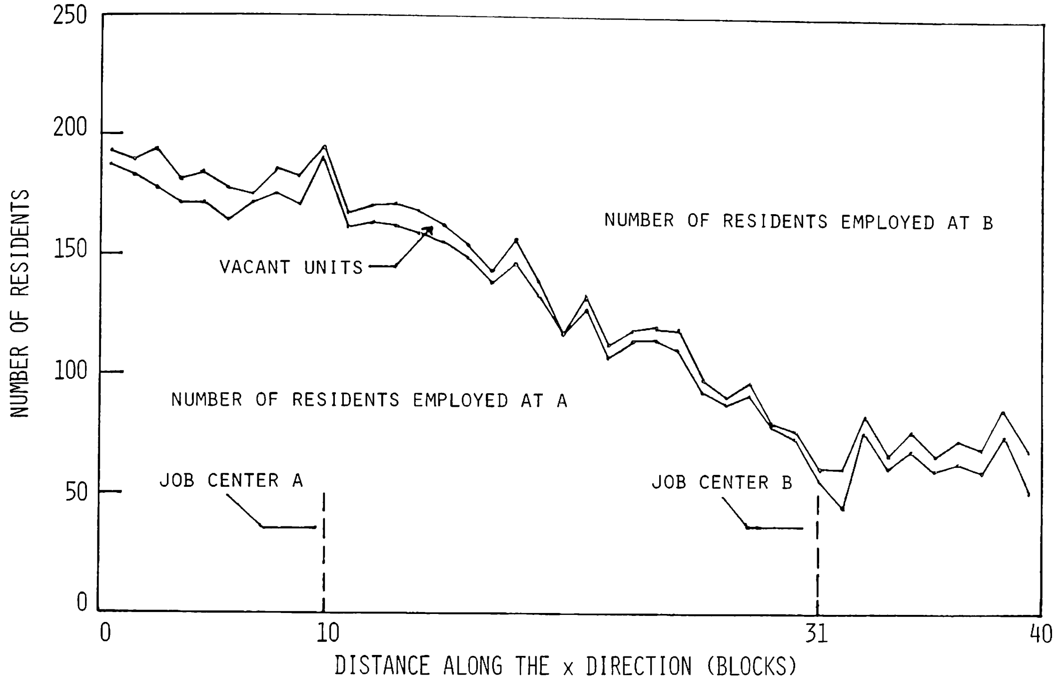

Figure 3. Distribution of residents employed at the two job centers in clusters along the y direction. The results are from cycle 100 of Experiment 5.

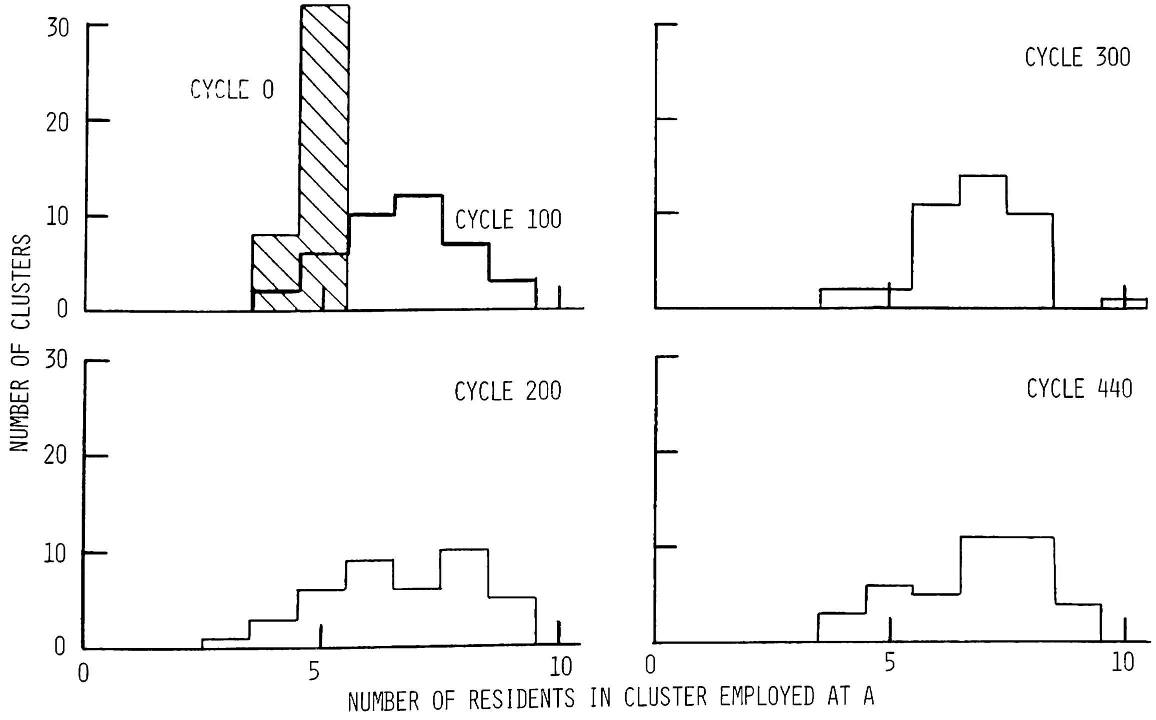

Figure 4. Histograms showing the number of clusters with various number of residents employed at A for different cycles of simulation. The results are from Experiment 4.