DOCUMENT RESUME

ED 088 213	88	EA 005 947

AUTHOR	Manji, Ashraf S.
TITLE	Simulation for Educational Facility Planning: Review and Bibliography.
INSTITUTION	Chicago Board of Education, Ill.
SPONS AGENCY	Office of Education (DHEW), Washington, D.C.
BUREAU NO	71-7619
PUB DATE	May 72
GRANT	OEG-5-71-0078(290)
NOTE	66p.; Related documents are EA 005 330, 530, 638, 660-661, and 713; Extended version of paper presented at Metropolitan School Facilities Planning Group Annual Meeting (11th, Milwaukee, Wisconsin, May 4-5, 1972)
EDRS PRICE	MF-$0.75 HC-$3.15
DESCRIPTORS	Bibliographies; City Planning; Community Programs; *Computers; Educational Resources; Enrollment Projections; Housing Needs; *Models; Population Trends; *Resource Allocations; *Simulation; Space Utilization; Universities; Urban Population
IDENTIFIERS	*Computer Simulation; Elementary Secondary Education Act Title III; ESEA Title III; Monte Carlo Technique; Simu School; University Planning

ABSTRACT

This paper provides an overview of selected simulation models pertinent to the problems of educational facility planning. Emphasis is placed on computer simulation models partly because of the greater potential utility of computer simulation models in coming to grips with facility planning problems. The overall objective is to document the state-of-the-art in simulation research as it relates to the planning of educational facilities and to help administrators and planners assess what simulation can and cannot do for them. The use of simulation models for school facilities planning has lagged far behind their use in other fields. This lag is no doubt a consequence of the current state-of-the-art in school facilities planning with its heavy emphasis on check lists and procedural guidelines at the neglect of the model building approach. Consequently, it can reasonably be expected that as the field of educational facility planning becomes more systematic and scientific, the use of simulation models will increase. A selected bibliography of simulation works pertinent to the problems of educational facilities planning is provided in four parts: (1) general works, (2) university planning, (3) school planning, and (4) urban planning. (Author/MLF)

This report was prepared pursuant to a grant from the U.S. Office of Education, Department of Health, Education, and Welfare. However, the opinions expressed herein do not necessarily reflect the position or policy of the U.S. Office of Education, and no official endorsement by the U.S. Office of Education should be inferred.

SIMULATION FOR EDUCATIONAL FACILITY PLANNING: REVIEW AND BIBLIOGRAPHY

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Funded By:
U.S. Office of Education
ESEA Title III, Section 306
Grant OEG-5-71-0078 (290)
Project 71-7619

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May 1972

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FOREWORD

Modern-day educational planners face an extremely difficult task of providing quality education to large masses of urban students in the face of decreased revenues, soaring costs, shifting populations, and changing educational programs. Such a challenge requires that a far greater emphasis be placed on planning for schools than has been the case to date and necessitates the development of improved techniques specially designed for educational planning.

Project Simu-School is intended to provide an action-oriented organizational and functional framework necessary for tackling the problems of modern-day educational planning. It was conceived by a task force of the National Committee on Architecture for Education of the American Institute of Architects, working in conjunction with the Council of Educational Facility Planners. The national project is comprised of a network of component centers located in different parts of the country.

The main objective of the Chicago component is to develop a Center for Urban Educational Planning designed to bring a variety of people--laymen as well as experts--together in a joint effort to plan for new forms of education in their communities. The Center is intended to serve several different functions including research and development, investigation of alternative strategies in actual planning problems, community involvement, and dissemination of project reports.

During the past few years, simulation models have been utilized in a variety of fields. The range of existing work varies substantially, not only in the types of problems tackled, but also in the approaches utilized, the level of sophistication attained and the results obtained. This paper, which was prepared during the first year of Project Simu-School, provides an overview of selected models pertinent to educational facility planning. The work was undertaken as a first step in investigating the feasibility and the utility of developing simulation models for facilities planning. It is being disseminated in the hope that it will be of some use to researchers and planners considering further applications of simulation models.

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SIMULATION FOR EDUCATIONAL FACILITY PLANNING: REVIEW AND BIBLIOGRAPHY*

I. INTRODUCTION

Simulation, in the broadest sense of the word, is a technique which attempts to develop a working analogy, or a model, of a real-world situation and then performs experiments or manipulations on the model. This definition of simulation is extremely broad, however, and may very well include such seemingly unrelated phenomena as war games, business management games, wind tunnel tests of aircraft, simulated lunar landings, simulation of rush-hour traffic at a busy intersection, etc. Consequently, the following more restricted definition of simulation is adopted here because it provides a more appropriate description of the kinds of models dealt with in this paper.

> A simulation of a system or an organism is the operation of a model or simulator which is a representation of the system or organism. The model is amenable to manipulations which would be impossible, too expensive, or impractical to perform on the entity it portrays. The operation of the model can be studied and, from it, properties concerning the behavior of the actual system or its subsystem can be inferred. (Shubik, 1960, p. 909)

There are two different types of simulation models of particular interest to facility planners. The first type consists of *simulation games*, which refers to those simulations in which a given situation is formalized into rules of a game and the play is carried out using strategies and tactics typical of the real world. Most often, it is a role-playing exercise characterized by some form of conflict of interest among players. Generally, the goal for each player is to obtain control over the limited resources available. The overall purpose of such simulations is to depict the behavior pattern characteristic of different roles in specific situations and to identify the kinds of interactions, strategies, and compromises necessary for decision-making.

The second broad class of simulation models, *computer simulations*, consists of those models which attempt to replicate a specific real-world situation. A variety of information describing the situation is provided as input to a computer. Next, functional relationships among variables pertaining to the input information are provided (usually mathematically) together with some predefined and consistent rules for manipulating these variables. Finally, the model is operationalized by programming for solution on an electronic computer.

Computer simulations can be further divided into two groups: deterministic models and probabilistic models. A *deterministic* model is one

*An extended version of a paper presented at the Eleventh Annual Meeting of the Metropolitan School Facilities Planning Group in Milwaukee, Wisconsin, May 4-5, 1972.

which does not allow for chance variation. Each event in the model occurs with complete certainty. A *probabilistic* model, on the other hand, allows for chance variation in the model by incorporating the probability of occurrence of each event. This is most often accomplished by using the "Monte Carlo" techniques in which the values of a given variable are randomly selected from a probability distribution of the variable. Because of random sampling, the outcomes of a Monte Carlo solution generally differ for repeated runs for the same inputs and a large number of iterations are required to produce an "average" or a "typical" solution to the problem

From the preceding discussion, it becomes clear that simulation games are quite different from computer simulations, both in structure as well as objective. In a simulation game, different moves are invented "on the spot" and are constrained only by the rules of the game and the characteristic of each role. In computer simulation, there are no live players and each move is preset and programmed into the model. Recently, some attempts have been made to combine gaming simulations with computer simulations to obtain what are generally referred to as "man-machine simulations" or simply computerized gaming simulations; but these models soon become very complex and cumbersome.

Kibel (1972, pp. 14-15) has summarized the differences between simulation games and computer simulation models in the following words:

1. A computer simulation can perform hundreds of runs (sequences of inputs, moves, and outcomes) in minutes, while a gaming simulation may take hours to produce one run.

2. A computer simulation by virtue of its speed can continually test a situation until a clear pattern of outcomes emerges; a gaming simulation can only be run a few times, and no consistent results may emerge.

3. In a short time interval, various assumptions and hypotheses can be tested with a computer simulation; whereas only one or a few can be tested with a gaming simulation.

4. The creation of a computer simulation requires a clearly stated and well understood "theory" of behavior; the creation of a gaming simulation model requires only a set of behavior characteristics of an institutional framework, and does not require a theory integrating these characteristics into rules of action.

5. In computer simulation, there is little or no action with the model as it performs its programmed stops; in gaming simulation, both the creator of the game and the participating players are actively engaged in a learning process during the actual running of the simulation.

6. Computer simulation tests hypotheses and assumptions for validity and uses empirical data to verify the

results; gaming simulation studies behavior and role interaction, and its success depends less on its results than on the experiences gained while playing the game.

The remainder of this paper is devoted to a review of selected simulation models pertinent to educational facility planning. Emphasis is placed on computer simulation models partly because of the greater potential utility of computer simulation models in coming to grips with facility planning problems, and partly because reviews of the applications of simulation games are already available. The overall objective is to document the state-of-the-art in simulation research as it relates to the planning of educational facilities and to help administrators and planners assess what simulation can and cannot do for them. It was undertaken as a first step in investigating the feasibility and the utility of developing simulation models for facilities planning. The presentation here is not an all-inclusive survey; but, hopefully, it illustrates the kind of work carried out to date. References to several works which are not treated here, but which have substantial relevance for facilities planning, are included in the bibliography.

II. REVIEW OF COMPUTER SIMULATION MODELS

Computer simulation techniques have been applied to a wide variety of problems in a variety of fields. The applications most pertinent to the problems of educational facilities planning come from the fields of urban planning, and, of course, educational planning. As might be expected, such applications differ substantially in their overall objectives, the sophistication of the approaches utilized, the scope of the problems tackled, and the depth of the analyses carried out. Consequently, it is necessary to divide the models reviewed in this section into two broad categories: (A) *special purpose*, small scale models which model a single specific aspect of the planning problem, and (B) *comprehensive* and large scale models which model many facets of the planning problem in a single model or a set of interconnected models. Each category is in turn subdivided into functional categories pertinent to educational facilities planning.

A. *Special Purpose Models*

Computer simulation techniques have been applied to a wide range of problems pertaining to educational facilities planning. They include topics such as enrollment projections, schedules of building construction, simulation of construction costs, evaluation of alternative room layout designs, forecasting space needs, forecasting student course selections and schedules, determination of bussing routes, adjustment of attendance area boundaries, simulation of acoustic characteristics of buildings, impact of alternate resource allocation strategies, etc. Such applications have generally been carried out in a diversity of fields and often have approached the problem from a point of view not directly relevant for school facilities planning. Hence, it is necessary to classify studies reviewed in this section into functional categories pertinent to facility planning. Four categories are identified:

1. Simulation of Space Needs.
2. Simulation of Student Enrollments.
3. Simulation of Population Movements.
4. Simulation of Peripheral Urban Growth.

1. Simulation of Space Needs.

The majority of previous work dealing with the determination of space needs for educational facilities has traditionally been based on simple space-per-student ratios and experienced judgment. Attention has usually been confined to general classrooms of standard size, accommodating a set number of students and of special education rooms. The school schedule is generally forced to accommodate itself to the number and the kinds of rooms available rather than to the educational program desired. Little attention has been paid to designing space patterns according to the activities in which students are engaged. However, recent moves toward individually prescribed instruction (IPI) has required a shift from the rigid pattern of traditional learning spaces.

Since space needs are subject to variables such as student enrollment, activities selected by students, and the activities' pattern of occurrence, all of which are subject to chance variation, computer simulation is a viable approach to the problem.

Banghart et al. (n.d.), working at the Educational Systems and Planning Center of the Florida State University, have developed a simulation model for projecting student module requirements based on activities in which students choose to participate. A student module is defined as the space and resources required to maintain a student in a given activity at a particular time. The simulation model consists of four basic operations:

1. Calculation of probabilities and cumulative distributions of

(a) student selection of activities
(b) number of time modules required per activity type
(c) number of selections per student

2. Development of student course selections and corresponding number of time modules by a random process from distributions (a) and (c) above.

3. Utilization of a heuristic algorithm to generate student modules of each activity type by scheduling each student into one of his selected activities for each time period of the "phase." Phase is the number of school days representing the total pattern of activities occurring within the school.

4. Calculation of the activity type utilization factor UF_i and the overall space utilization factor $\overline{UF}$ using formulas (1) and (2) below:

$$UF_i = \frac{\sum_{k=1}^{K} s_{ik}}{S_i K} \qquad (1)$$

where

UF_i is the utilization factor for student stations in activity type i.

K is the total number of time periods in the phase.

s_{ik} is the total number of student modules of activity type i occupied in the kth time period.

S_i is the maximum number of student modules available in activity type i per time period.

The overall space utilization factor is then calculated as the mean of the activity type utilization factors. Thus,

$$\overline{UF} = \frac{\sum_{i=1}^{N} UF_i}{N} \qquad (2)$$

where

$\overline{UF}$ is the overall space utilization factor.

N is the total number of activity types in the school.

Operations 2, 3 and 4 are repeated over a designated number of iterations to determine the required number of modules for each activity type along with the associated utilization factors. In this way, the decision-maker can choose the configuration representing the "optimal" utilization.

The simulation model was tested using data from the Florida State University High School. Program inputs consist of the items listed in Table 1. The output consists of: (a) the probability distribution of activity requests, (b) the probability distribution of the number of selections per student, (c) the distribution of the number of time periods per activity by activity type, (d) student activity selections generated, (e) utilization of student modules per period by activity type, (f) number of student modules and total square footage required per activity type, and (g) utilization factors by activity type and overall. Table 2 shows a summary output.

TABLE 1

MODEL INPUTS FOR THE
FLORIDA STATE UNIVERSITY HIGH SCHOOL FIELD-TEST

1. Total number of students = 337.
2. Total number of time modules/day = 28.
3. Length of phase = 5 days.
4. Nine activity types defined as follows:

Activity Type	Definition	Sq. Ft./Student Station
1	General class	15.00
2	Art	20.00
3	Home Economics	20.00
4	Shop	30.00
5	Science Lab	30.00
6	Business Education	20.00
7	Music	15.00
8	Gymnasium	100.00
9	Learning Resource	40.00

Source: Based on Banghart *et al.* (n.d.), p. 20

TABLE 2

SUMMARY DATA FOR CONFIGURATION 1 ITERATION 1

ACTIVITY TYPE	STUDENT STATIONS	TOTAL SPACE	UTILIZATION FACTOR
1	203	3045.000	.834
2	31	620.000	.576
3	20	400.000	.519
4	10	300.000	.591
5	48	1440.000	.700
6	19	380.000	.545
7	36	540.000	.667
8	48	4800.000	.685
9	51	2040.000	.642

TOTAL UTILIZATION FACTOR = .640

UTILIZATION FACTOR EXCLUDING LEARNING RESOURCE AREA .640

Source: Banghart et al. (n.d.) p. 25

Banghart et al. (n.d.) have carried out the state-of-the-art in projecting space needs one step beyond the use of fixed space-per-student activity selections. However, the model is largely dependent on being able to calculate probabilities and cumulative distributions of (a) student selection of activities and (b) the number of selections per student. These calculations require that frequency distribution of student activity selection can be provided as an input. It would be interesting to investigate how far in the future past frequency distributions can help to predict future patterns of activity selection. And while the final output of the model does provide a figure for the number of square feet of space required for each activity type, it falls short of providing projected *resource* requirements, an integral part of a student module as defined by the authors. It should also be noted that student enrollment is required as an input to the program. In a subsequent study, Banghart et al. (n.d.,a) have developed a deterministic simulation model consisting of two linked programs. The first program utilizes a modified cohort-survival technique for generating enrollment projections, while the second determines space needs and the associated costs. However, there is no documentation of its use-testing to date. Bregar (1973) has initiated an extension of space projection research for elementary schools by taking into account individualization of activities and the potential for an activity to distract other ongoing activities; however, the work has not been completed at the time of writing this report.

2. Simulation of Student Enrollments

Accurate projections of student enrollments have considerable impact on the quality of educational service provided by a school system. Their significance is obvious in the case of facilities planning where construction decisions based on inaccurate projections can result in a wasteful expenditure of several millions of dollars. Less obvious, but equally important, is their effect on resource allocation, curricular program and learning itself. As a result, most school systems pay--or should pay--considerable attention to the task of projecting student enrollments.

There is a considerable body of literature dealing with methods of making small area population projections. Two recent reviews are provided by Atchley (1970) and Morrison (1971); a review of the methods most frequently used for projecting student enrollments are provided by Jaffe (1969). There is general agreement among these reviewers regarding the types of factors to be considered in making projections; included are birth rates, dropout rates, migration trends, transfers between public and private schools, number of dwelling units, etc. There is also agreement regarding the immense difficulty involved in making *accurate* projections; most writers mention lack of an adequate data base, difficulty in estimating future birth and dropout rates, and, of course, the basic uncertainty accompanying residential mobility, neighborhood change, and external economic conditions. In the light of these problems, a considerable amount of recent research effort has been directed toward developing computer simulation models for projecting student enrollments. Two such models are briefly reviewed in this section.

The first model, designed by Siddiqui and Zaharchuck (1970), is essentially based on two equations:

Population (future) = population (present) + births - deaths + net migration

Enrollments (future) = f[population (future), age composition (future), participation rates (future)]

The model consists of four separate operations:

Operation 1: Project live births for 1966-86, or any 20-year period. Live births in any year depend upon fertility rates and the number of females aged 15-49. Hence, estimates for future live births require: (a) projection of the female population aged 15-49 by single year age groups for every year of the projection period, and (b) projection of age-specific fertility rates by five-year age groups for every year of the projection period. The following procedure is used to estimate:

(a) the female population aged 15-49 by single year:

(i) project live births for the base year and compute the female live births from the results.

(ii) age the female population 1-49 by single-year age groups, and the female live births, to obtain the female population aged 1-49 for the second year of the projection period; then apply a correction for the net migration of females by single-year age groups to obtain the final female population.

(iii) project live births for the second year of the projection period using projected age-specific fertility rates; compute the female live births, and then repeat (ii) above.

If the projected age-specific fertility rates by five-year age groups are not available, then the program computes them using "percentage change in age-specific fertility rate over time" based on data inputs for the expected percentage change in each group and on the year for each age group up to which the change is effective.

Operation 2: Compute enrollment projections based on grade survival, one for each live births estimate. Estimates for future grade-survival rates are deduced by examining trends of past grade-survival rates in conjunction with policy decisions of the educational system. Estimates for either constant or variable grade-survival rates may be used as input to the program.

Operation 3: Make population projections by single-year age groups (ages 1-24) for the period 1967-86, using projected live-births estimates and population by single-year age groups for the base year, 1966. Estimates for either constant or variable life table coefficients are provided as input to the program.

Operation 4: Compute enrollment projections based on "population participation-rate matrix method" using: age/grade distribution, estimates of projected population by single-year age groups, and targets of the participation rates for the various age groups within the educational system. The "population participation-rate matrix method" is based on the assumption that students in a grade vary in age within certain limits, which is a reasonable assumption over the short run. The distribution of students by age and grade is needed as input data.

The data inputs for each operation are listed in Table 3.

The model developed by Siddiqui and Zaharchuk (1970) is fully operational and is in such a form that educational planners and administrators,

TABLE 3

DATA REQUIREMENTS FOR SIDDIQUI AND ZAHARCHUK MODEL

Operation	Data Required
1	Life table for female population aged 1-50, by single-year age groups.
1	Female population aged 1-50, by single-year age groups.
1	Annual net migration of females aged 1-50, by single-year age groups.
1	Age-specific fertility rate.
1	Percentage in age-specific fertility rates for each age group.
1	Year for each age group up to which the change is effective.
2	Live births for previous 6 years.
2	Previous year's actual enrollments.
2	Grade-survival rates.
3	Total population aged 1-24, by single-year age groups.
3	Annual net migration, by single-year age groups, of total population aged 1-24.
3	Life table for total population aged 1-24, by single-year age groups.
4	Age/grade distribution.
4	Participation-rate targets for each age group, starting from age 1.

Source: After Siddiqui and Zaharchuk (1970), p. 236

regardless of their computer experience, can use it easily. It contains many built-in flexibilities and can be used as a labor-saving device to investigate the effect of changing the input parameters.

However, there are some critical limitations. In the first place, the model has a very simple conceptual structure based on a variation of the cohort-survival method which offers little that is new to demography. It is little more than an elaborate computer program with many built-in flexibilities. Secondly, the authors indicate that the model was used by a school district in Canada, but the performance results are not given; hence, the predictive accuracy of the model cannot be determined. Thirdly, the model is rather briefly reported; it is difficult to assess the efficacy of any of the many estimates and projections required as inputs to the program. For example, it is not clear how migration estimates are made. Finally, the model requires extremely detailed data inputs as indicated in Table 1. Generally, these data are not readily available.

Denham (1971) has provided a simulation model for enrollment projection that has two interesting features: first, it uses Monte Carlo technique to incorporate chance variation in the model; second, by providing a figure for the probability associated with each projection figure, it indicates the degree of uncertainty in the projection figures.

Denham's Monte Carlo model is essentially a variation of a basic multivariable method illustrated in Figure 1. The method was modified to require separate "high," "most likely," and "low estimates for each variable affecting school enrollment: births, migrations, retentions, transfers to and from public schools, school dropouts, and deaths. The high and the low estimates represent the limits of the 98 percent confidence interval. Probability distributions were developed from these estimated figures. Then, a Monte Carlo simulation program was used to draw random samples from the probability distributions and combine them according to the multivariable method to generate predicted enrollments and their corresponding probability of occurrence. A sample output is provided in Table 4.

The model was field-tested using actual and projected enrollment data for Brockton, Massachusetts, a city with a 1965 population of 83,499. The results of the field test indicate that the model gives more accurate results compared to the "percentage of survival method" and the non-simulation multivariable method used by the City of Brockton. Unfortunately, an adequate test of predictive accuracy, through a comparison of actual student enrollments in Brockton with the enrollments predicted by the model, was not carried out; hence, it is difficult to assess the predictive validity of the model.

Denham's model is fully operational and all the necessary computer programs are available to any interested user. Incorporation of random variation into the model and provision of probabilities associated with predicted enrollments are two good features of the model; however, this model also has serious shortcomings. First, the model falls short of truly incorporating random variation. The present model requires three estimates for each input variable which are used to develop probability distributions which are then used to introduce random variation into the model. Utilizing some of the input variables themselves as random variables would be conceptually more satisfactory. Second, it is questionable whether probabilities showing the degree of uncertainty

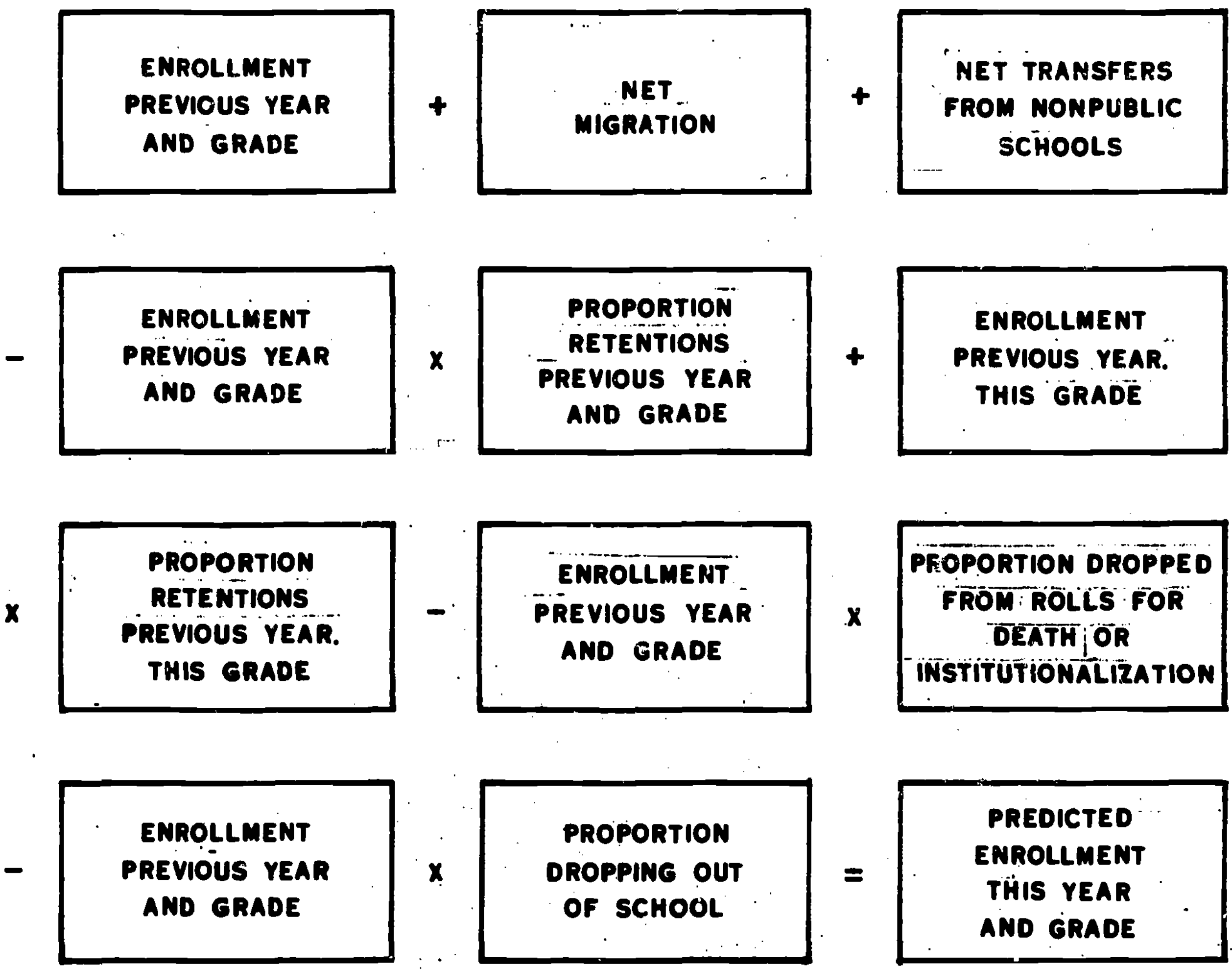


Figure 1

Multivariable Model Used By Denham

Source: Denham (1971), p. 38

TABLE 4

SAMPLE OUTPUT OF THE DENHAM MODEL

PROBABILITY THAT TOTAL ENROLLMENT IN GRADE 2 IN 1975 WILL BE LESS THAN THE SPECIFIED PREDICTED ENROLLMENT

PROBABILITY	PREDICTED ENROLLMENT
.05	1899.
.10	1991.
.20	2042.
.30	2103.
.40	2177.
.50	2234.
.60	2277.
.70	2351.
.80	2384.
.90	2464.
.95	2561.

PROBABILITY THAT TOTAL ENROLLMENT IN GRADE 2 IN 1975 WILL BE GREATER THAN THE SPECIFIED PREDICTED ENROLLMENT

PROBABILITY	PREDICTED ENROLLMENT
.05	2561.
.10	2464.
.20	2384.
.30	2351.
.40	2277.
.50	2234.
.60	2177.
.70	2103.
.80	2042.
.90	1991.
.95	1899.

Source: Denham (1971, p. 99)

would be more useful to planners and administrators than the conventional "optimistic" and "pessimistic" predictions. It is also doubtful whether the average planner and administrator would be able to use such probabilistic input since the bulk of planning is still procedural rather than analytic and quantitative. Third, the accuracy of the model largely depends on the choice of the multivariable model (for which little justification is given) and on the accuracy of the three estimates for each input variable. Developing good estimates for the kinds of input variables used in this model is no easy task. Fourth, and perhaps the most serious shortcoming of this model, little justification is shown for the assumption of either statistical independence of the input variables or the use of beta and normal probability distributions. Further research needs to be carried out on the nature of input variables and their relationships before such assumptions can be made. Finally, the model, which has been use-tested only for Brockton, Massachusetts, has limited geneality. Additional tests are necessary to demonstrate its performance for a diversity of cities.

3. Simulation of Urban Population Movements

Residential mobility is an important characteristic of modern-day urban America. It is estimated that approximately 20 percent of the population of the United States changes residence every year, and that roughly half the people change their place of residence at least once within a five-year period. Thus, intra-urban migration plays an important role in changing the character of urban neighborhoods and is the major cause of changes in demand for educational facilities.

During the past few years, considerable research effort has been directed towards an understanding of the nature of residential mobility and has produced several insights. Excellent reviews of the work to date are provided by Simmons (1968) and Moore (1972). Simmons has ably synthesized much of the work to date in terms of three basic questions relating to intra-urban mobility: "Who moves?", "Why do they move?" and "Where do they move?" "Why people move" is the question of particular interest in this section. Most work dealing with this question has investigated the correlation between a variety of social factors and the propensity to move. Results indicate three factors as important: (1) stage in the life cycle with respect to the growth and decline in family size and the life style; (2) socioeconomic status, defined in terms of income, occupation, and education; and (3) segregation, representing religious, ethnic, or racial change. The last named factor, in particular, can often create dramatic changes in the neighborhood character, hence, it is of special interest to the facility planner. Perhaps the most important example of this is constituted by the "invasion" of white neighborhoods by blacks. With increasing black migration, the composition of a white neighborhood reaches the "tipping-point" (generally around 25 percent black) after which the transition rate increases rapidly until the neighborhood becomes almost entirely black. The consequences of such drastic population shifts for educational facilities are all too familiar to the facility planner. A good case study of changing population and its impact on school enrollments has been documented by deVise (1970).

Morrill (1965) has developed a simulation model of ghetto expansion which could be utilized as a planning tool in predicting urban population shifts. Ghetto expansion is conceptualized as a spatial diffusion process in which Negro migrations gradually spread into a surrounding white area. The model incorporates natural increase of the Negro population; Negro immigration into the ghetto; the nature of resistance to Negro out-migration and its relation to distance; and the population size limits of destination blocks. It is operationalized as follows:

Operation 1: Take into account the natural increase in Negro population for each period at the observed rate.

Operation 2: Assign immigrants into the study area at the "observed mean rate" at the beginning of each period. These are assigned using random numbers in such a way that the probability of an area being chosen is proportional to its present Negro population.

Operation 3: Assign internal migration at a specific rate during each period. This assignment is accomplished as follows:

(a) A movable probability field is superimposed over a potential migrants' block (X in Figure 2). The numbers in each block of the probability field indicate the probabilities of a migrant moving into those blocks from his origin block. The probability field can be moved around so that each potential migrant can in turn become located at X. Such a probability field is derived from empirical observations of migration distances. The one shown in Figure 2 simply represents a higher probability of moving short distances as indicated by three numbers (e.g., 48, 49, 50) in blocks adjoining X; two numbers in the more distant blocks (e.g., 54, 55); and one number (e.g., 98) in the blocks furthest away.

(b) Select random numbers, as many as there are migrants, to choose destination blocks in accordance with the probability field described above. The following rules are used to incorporate differential resistance of different areas:

(i) If a random number indicates a block that already contains Negroes, the move is made immediately.

(ii) If a random number indicates a block with no Negroes, the fact of contact is registered, but no move is made.

(iii) If additional numbers indicate the same block contacted in (ii) in the same or the next period, and from whatever location, then the move is made. (This rule permits a gradual penetration of white areas despite the white resistance.)

Operation 4: Assign any excess population according to the procedures above. Excess population is determined from a limit based on zoning and lot size or the number of families that may live on a block.

Operations 1-4 are then repeated for the next and subsequent time periods.

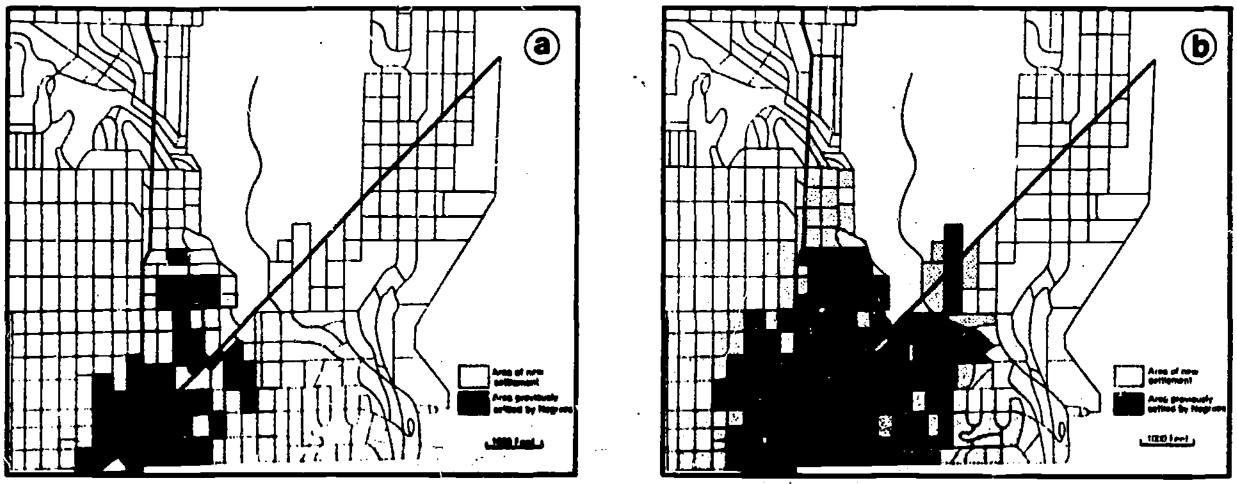
Figure 2

A Typical Probability Field

1	2	3	4	5	6	7	8	9
10	11	12	13	14-15	16	17	18	19
20	21	22	23	24-25	26	27	28	29
30	31	32	33-34	35-37	38-39	40	41	42
43	44-45	46-47	48-50	X	51-53	54-55	56-57	58
59	60	61	62-63	64-66	67-68	69	70	71
72	73	74	75	76-77	78	79	80	81
82	83	84	85	86-87	88	89	90	91
92	93	94	95	96	97	98	99	00

Source: After Morrill (1965)

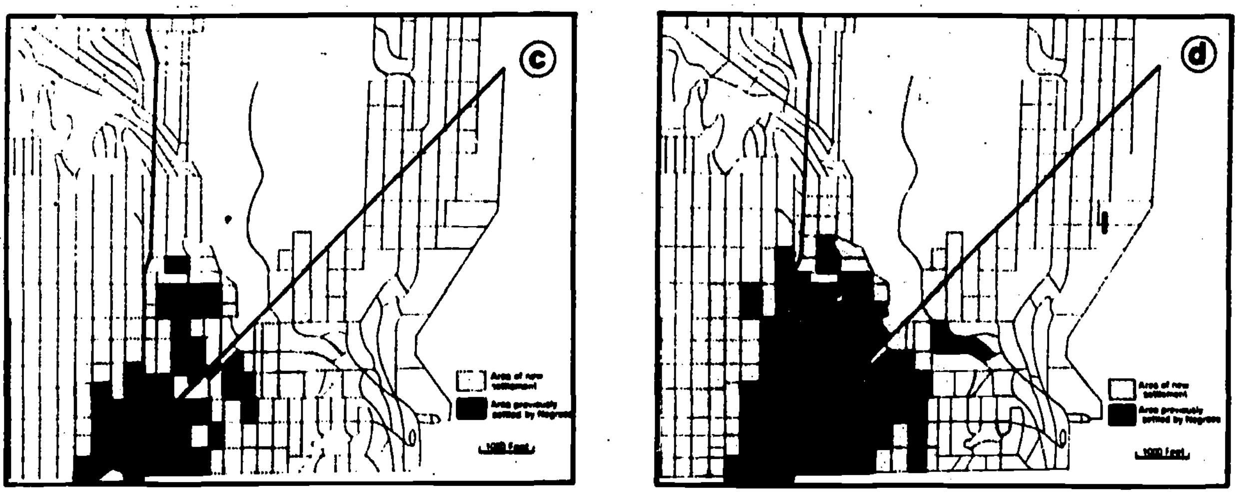
Morrill tested his model by simulating the spread of the Seattle ghetto for ten two-year periods from 1940 through 1960. A comparison of Figures 3a and 3b with Figures 4c and 4d shows a generally close correspondence in the patterns of ghetto expansion. The simulated pattern has the right extent (area), intensity (number of Negro families in blocks), and solidity (provision of white and Negro enclaves). A total



Figures 3a-b

Actual Growth of the Negro Ghetto in Seattle
(a) 1940-50 and (b) 1950-60

Source: Gould (1969) p. 42



Figures 4c-d

Simulated Growth of the Negro Ghetto in Seattle
(c) 1940-50 and (d) 1950-60

Source: Gould (1969) p. 42

of 140 blocks were entered in the simulation compared to 151 for the actual, although block-by-block coincidence was obtained in less than two-thirds of the cases. An investigation of the discrepancies between the simulated and actual patterns revealed that their differences were caused by the model's failure to adequately take into consideration the value of homes and the topography. Some subsequent researchers have extended Morrill's work by incorporating into their models factors pertaining to the demand, supply, and allocation of housing (e.g., Rose [1970]). However, the bulk of the work on simulation of population movements described in this section has not been utilized for planning purposes.

4. Simulation of Peripheral Urban Growth.

The rapid urbanization in the United States need hardly be labored. As the present urban areas expand, they create urgent needs for public facilities and it becomes necessary for the planner to investigate the form and the process of urban growth. In fact, for effective planning, it is desirable that the planner be able to evaluate, ahead of time, how this growth is likely to be distributed under a variety of alternative assumptions with respect to the critical factors governing the process of land development. Chapin and Weiss (1968), working at the Center for Urban and Regional Studies, University of North Carolina (UNC), have developed a simulation model that does just that.

The UNC model is designed to predict the spatial distribution and the timing of conversion of rural or vacant land to residential use. It conceptualizes land development as the result of many private and public actions both in the growth of the urban periphery and in the renewal of the inner city. Some of these actions are "priming" actions that trigger other "secondary" actions which together result in land development. Based on these actions, the UNC model can build a new city from its inception, say at a crossroad, or it can start with a city at some intermediate stage of development and build it further. It is operationalized as follows:

Operation 1: In order to distribute units of new development to the site experiencing growth, the study area is divided into grid cells of a suitable scale (23 acres for a city the size of Greensboro, North Carolina, the study area selected by the authors).

Operation 2: Each cell is assigned an "attractiveness" score on the basis of the following variables:

(a) *Priming* variables, which are the kinds of variables public policy decisions can typically influence:

(i) Accessibility to work areas
(ii) Accessibility to nearest major street
(iii) Accessibility to nearest elementary school

(iv) Availability of sewerage.

(b) *Conditioning* variables, which may be regarded as intrinsic characteristics of the residential site itself:

(i) Marginal land not in urban use
(ii) Assessed value.

These variables were selected after extensive analysis of factors contributing to land developed using stepwise multiple regression techniques showed them to be the most important ones.

Operation 3: Monte Carlo technique is used to allocate households to vacant land. This is accomplished by examining each grid cell, noting its attractiveness and deciding by a correspondingly biased randomizing procedure whether or not the available unit of development goes there.

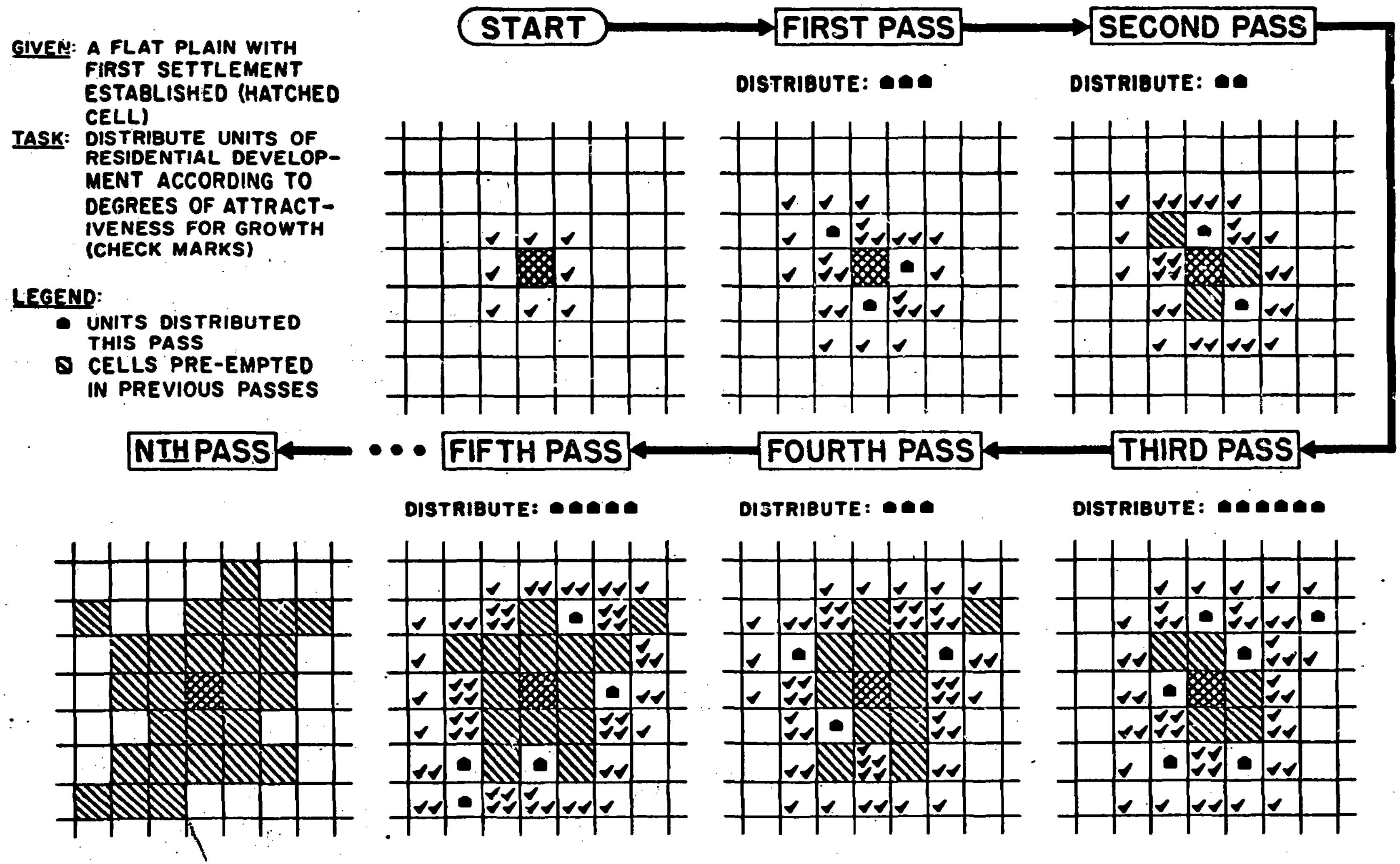
This process is illustrated in Figure 5 which shows a flat plain with a settlement in the middle cell. In a flat plain, without any complications created by hills, lakes, or other similar features, each cell adjoining the developed cell has an equal degree of attractiveness (indicated by a single check mark). During the first pass, three aggregates of households are distributed on a randomized basis. The second frame in Figure 5 reflects the "reassessment" of land as a result of the new development. The "reassessed" attractiveness is based on the predicted effect that priming decisions would have on the next round of growth. Thus, for every cell adjoining the original hatched cell and the three new cells preempted by the new development, an additional unit of attractiveness has been inserted.

The second pass is made and the land is "reassessed" again. As the land develops, various priming factors such as new roads and new schools are added at specific locations and, thus, the model takes into account the new attractiveness of the cells affected. The process is repeated until the forecast date is reached. The output indicates the effect of policy inputs on the pattern of land development.

It should be noted that the model depends on four kinds of inputs: (1) a land supply, (2) an attractiveness for development, (3) a set of priming factors, and (4) the total number of residential units to be allocated to the terrain. The efficacy of the model was tested in Greensboro, North Carolina, by a comparison of the actual growth to the allocated growth for the years 1948-60. Table 5 shows that a high degree of predictive accuracy is obtained with over four-fifths of the deviations

Figure 5

A Diagrammatic Representation of the Operation of a Synthetic Model for Forecasting Residential Development



Source: After Chapin and Weiss (1968), p. 380

TABLE 5

DEVIATIONS BETWEEN ASSIGNED GROWTH AND ACTUAL GROWTH, BY CELL, MEDIAN RUN NO. 42

Underallocation			Overallocation		
Deviation	No. of Cells	Percent	Deviation	No. of Cells	Percent
-9	1	0.1	+9	1	0.1
-8	4	0.5	+8	0	0.0
-7	5	0.6	+7	10	1.2
-6	7	0.8	+6	8	1.0
-5	19	2.2	+5	32	3.9
-4	31	3.6	+4	32	3.9
-3	79	9.2	+3	71	8.7
-2	174	20.2	+2	206	25.2
-1	540	62.8	+1	457	55.9

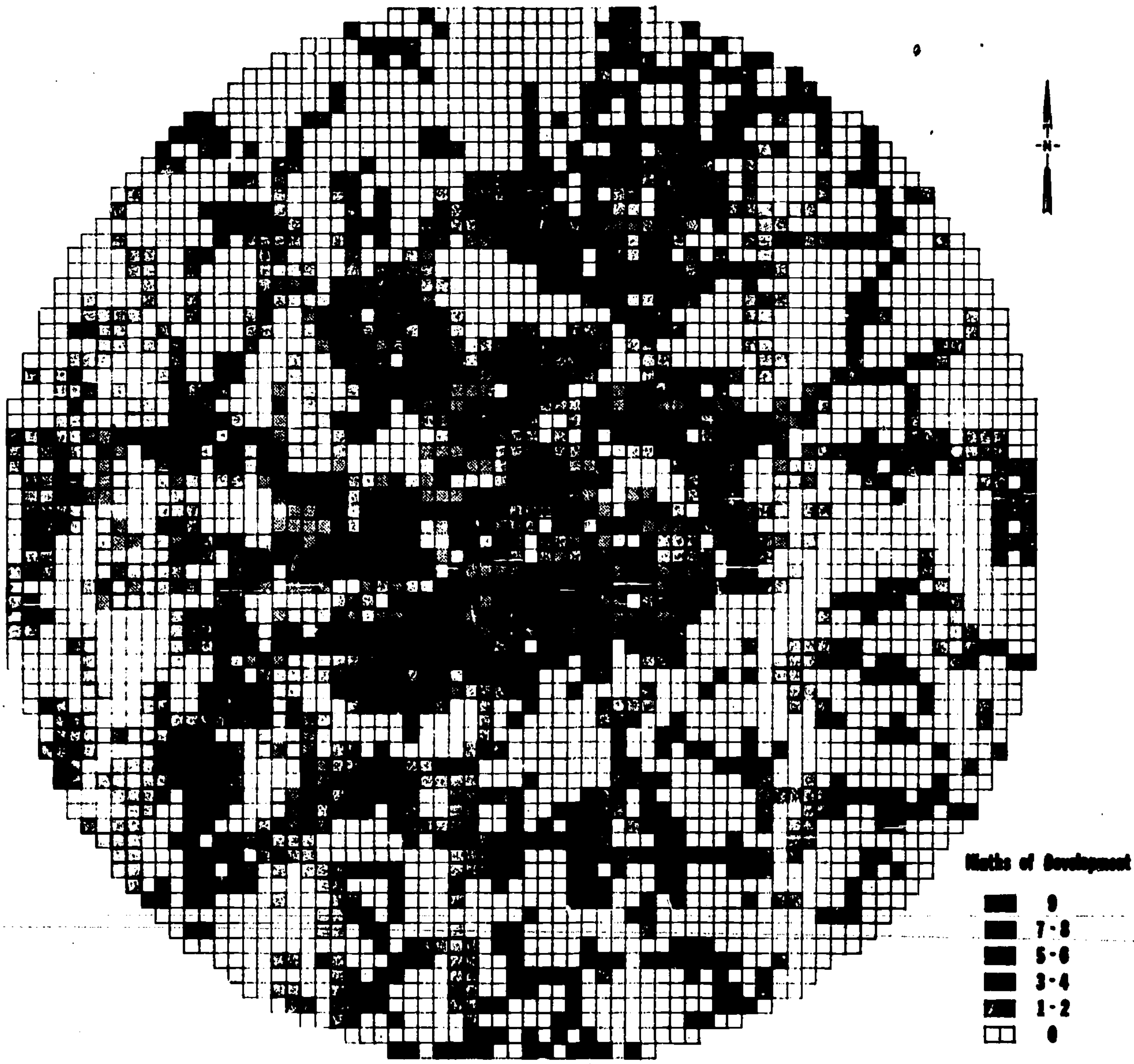
Source: Chapin and Weiss (1968) p. 385

occurring in cells receiving one- or two-ninths of development below or above the absolute growth observed between 1948 and 1960. Figures 6 and 7 provide a visual comparison of the actual development in 1960 with the median outcome of 50 runs of the estimated development in 1960.

The UNC model does not take into account the behavior of land developers involving such factors as speculative overbidding and withholding of choice land from the market. In addition, the model focuses on growth areas and new residential development, leaving out the declining areas and renewal processes so characteristic of urban areas today. However, considerable research is presently underway which will enable both these factors to be incorporated into the next generation of residential allocation models.

In evaluating the UNC model, two important points must be made. First, the model was developed primarily to study the dynamics of residential growth. Thus, the model is oriented towards theoretical and methodological developments. Nevertheless, it is firmly attached to a specific

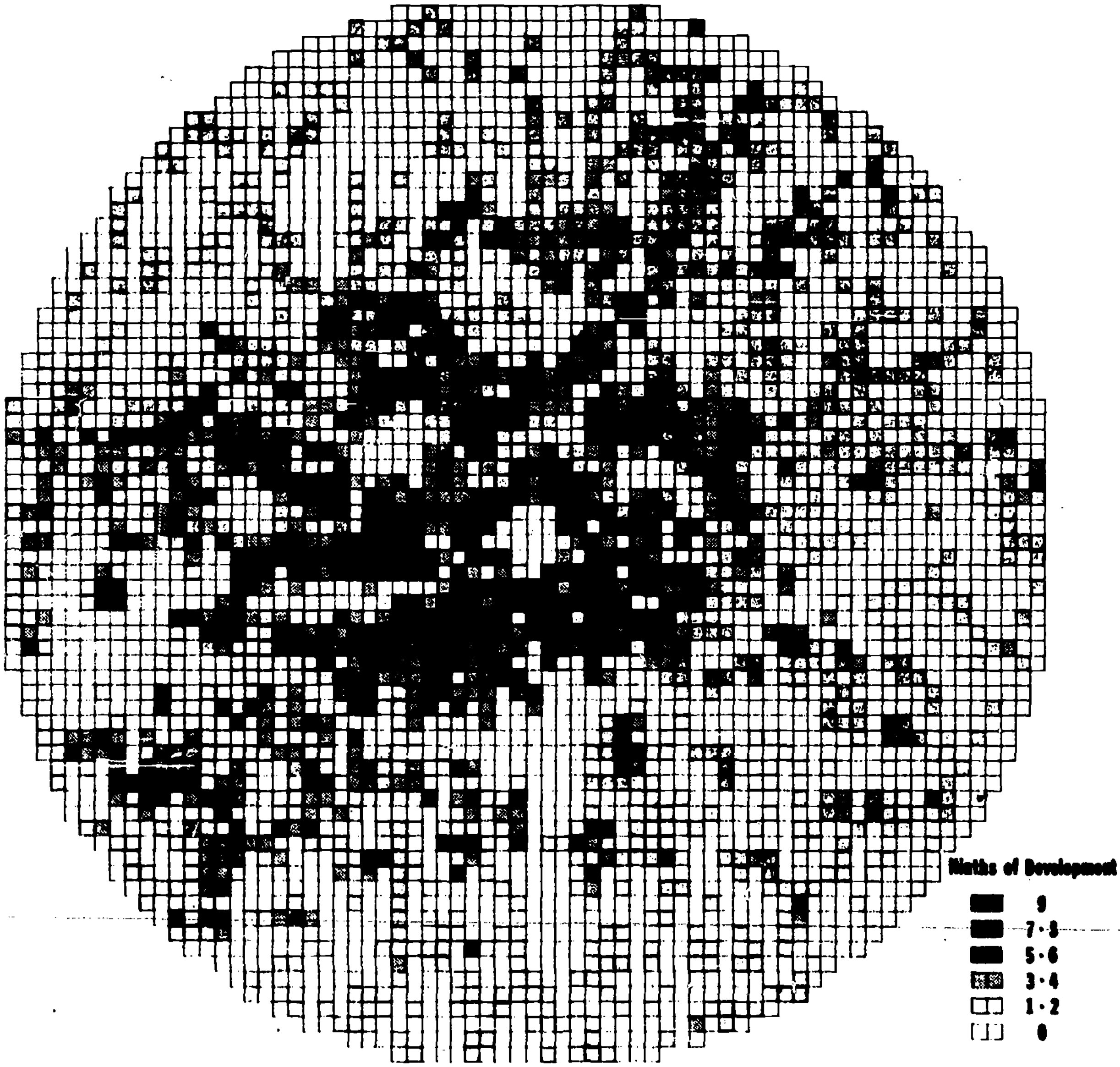
Figure 6



LAND IN RESIDENTIAL USE, GREENSBORO, NORTH CAROLINA, 1960

Source: Chapin and Weiss (1965) p. 28

Figure 7



EXPECTED RESIDENTIAL LAND USE, GREENSBORO, NORTH CAROLINA, 1960
BASED ON USE OF PROBABILISTIC MODEL - MEDIAN OUTCOME OF 50 RUNS

Source: Chapin and Weiss (1965) p. 28

real-world situation, and can be readily used for empirical work. Secondly, the model represents the results of almost a decade of steady work. As such, the research staff has chosen to develop the model through an incremental and evolutionary process rather than proceeding from a grand design or attempting to assemble several loosely related models (Lee, 1968). Their approach has paid off well.

Chapin and Weiss (1968, p. 386) have provided a succinct statement of the utility of their model in the following words:

> The principal use that can be made of this model in its present stage of development is as an instrument for studying the effects that selected public policy positions can be expected to have on the pattern of residential growth. More particularly, it permits the investigator to study the implications that different alternatives for location and timing in the construction of segments in a thoroughfare network, a sewerage system and a school system, and in the development of employment centers can have for a pattern of urban growth and the associated environmental qualities which go with each alternative. These alternatives may relate to variations in the location choices of one or more of these four priming elements, holding the timing and the locations of the other elements constant. They may relate to timing alternatives, holding location constant; or both timing and location may be allowed to vary, with different timing schemes tested with different location schemes. Further variations can be introduced by modifying density constraints in the areas available for residential development. Obviously the combinations are extensive and quite varied.
>
> This type of application places the emphasis on differential effects of development policies on the broad patterns of growth. If the investigator is more concerned with a forecast and fairly accurate estimates of the distribution of residential growth than with comparative analyses of different policy positions, then we believe the development process will need to be subaggregated to give the accuracy needed. The methodological groundwork for developing the new system of models has been laid in the completed phase of this research.

B. *Comprehensive Models*

It is generally recognized that the planning of educational facilities to date has been largely "procedural" and "check-list" oriented. By far the greatest emphasis has been placed on the architectural design and the construction aspects of the facility itself, at the exclusion of various aspects pertaining to overall educational planning, and, of course, urban planning. Recently, rapid increases in the size of urban areas (hence, of educational systems) and rapid shifts in their social compositions and physical form have made it imperative for the facility planner to develop plans that are well-coordinated with educational and urban planning. In this light, an overview of some selected comprehensive simulation models is included in this section. The models described are divided into the following functional categories:

1. Simulation of Educational Resource Allocation.
2. Simulation of Community Renewal Programs.

1. Simulation of Educational Resource Allocation.

Rising costs of providing urban educational services, coupled with a scarcity of resources, has exerted considerable pressure on educational planners to justify their plans and programs for meeting the ever-increasing expectations of their citizenry. This in turn has resulted in a critical evaluation of the efficiency of the conventional methods of educational resource allocation.

Traditionally, resource allocation in a school district has been carried out without a very careful review of alternatives. Typically, the department heads submit an item-by-item budget for the following year and engage in a collective debate on the merits of each request. Some comparison of alternative requests is made and the final allocation is worked out, generally after each department head has made compromises and concessions. Almost invariably, the original requests are cut by some blanket figure and the department heads are left to modify their plans accordingly. Such a process, in which planning and budgeting are done separately and are brought together only at the time of negotiation for funds, is not conducive to a rigorous comparison of the costs and benefits of alternative plans or to the development of coordinated programs. Furthermore, such a process can rarely be used for long-range planning. A promising alternative to this method exists in Planning, Programming, and Budgeting Systems (PPBS), which attempts to bring planning, programming, and budgeting together by considering educational objectives, program definition, alternative plans, and the corresponding costs. However, before PPBS can effectively be implemented, an evaluation of future outcomes of alternative planning strategies is necessary. As a result, considerable effort has, therefore, been directed towards the development of simulation models to evaluate alternative courses of action.

The bulk of the simulation work on resource allocation has been done at the university level. Table 6 indicates the breadth and the scope of some such work. Perhaps the best known example is the Comprehensive Analytical Model for Planning in the University Sphere (CAMPUS), developed by the Systems Research Group (1971) at the University of Toronto.

The development work that eventually led to the CAMPUS model consisting of a system of simulation models and related information systems and budgeting techniques began in 1964 under the direction of Richard Judy, Professor of Economics and Computer Science, and Jack Levine, a graduate student working for his doctor's degree in systems research. The main objective of the model is to serve as a tool for educational administrators in the development and analysis of alternative long-range plans and annual budgets. As used at the University of Toronto, the model builds up instruction workloads for each department yearly and calculates the resources required to handle the load. It consists of four sections:

(a) Enrollment Formulation
(b) Resource Loading
(c) Space Requirements
(d) Budgetary Calculations

Basically, CAMPUS consists of a set of computational routines which receive the necessary input data, perform selected computations, and produce the resulting output reports (Figure 8). The model is initialized by storing a variety of data pertaining to the institution: its organization structure, cost centers, academic programs, policies on lengths of teaching week and semester, staff pay, space used for a given activity, future trends in enrollment, and academic policy. The calculations carried out by the model can be divided into four main operations (Systems Research Group, 1971a):

Operation 1: Calculation of contact hours, which in turn includes the following calculations:

(a) Calculation of the number of students to be enrolled at each level of each program on the basis of: student transitions, the number of new advanced standing students entering college, the total number of freshmen entering and the percentage distribution of these freshmen into various programs.

(b) Calculation of the number of students to be enrolled in each course at each level of the program on the basis of (a) above.

(c) Determination of the total number of students in each course regardless of the program from which they came.

(d) Calculation of the number of sections required

TABLE 6

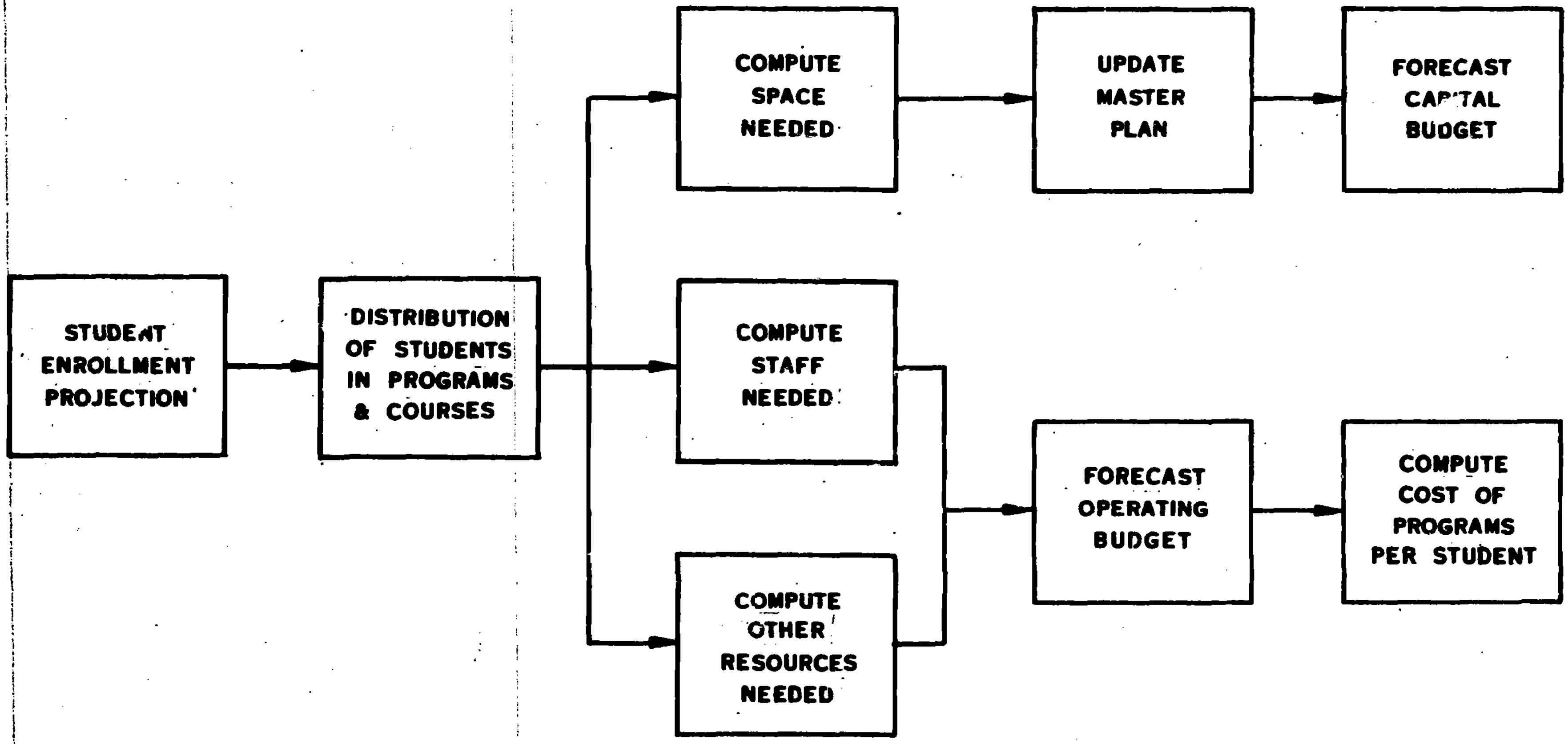
SOME TYPICAL UNIVERSITY PLANNING MODELS

Author(s) Reference	Institution	Overall Objective	Model Components: Resource Allocation	Model Components: Enrollment Projection	Model Components: Facilities	Model Type: Comprehensive	Model Type: Special Purpose
Allen and Daniel (1969)	Rensselaer Polytechnic	Simulation of space requirements		X	X		X
CRS (1968)	-	Simulation of space requirements		X	X		X
Daniel et al.	-	Long-range planning; evaluation of alternatives	X	X		X	
Firmin et al. (1967)	Tulane University	Cost simulation	X	X			X
Keane et al. (1970)	-	Resource allocation; long-range planning	X	X		X	
Koenig et al. (1968)	Michigan State University	Resource allocation	X	X		X	
Mason (n.d.)	University of Rochester	Program planning	X	X	X	X	
Steele (1968)	Miami	Cost simulation		X	X		X
Weathersby (1967)	Berkeley	Cost simulation	X	X	X	X	
Yurkovich et al. (1966)	University of Wisconsin	Space planning			X		X

Figure 8

An Overview of the Campus Model

(Data Flow & Reports Per Simulation Period)



for each course by applying the section size policy specified for each course.

(e) Calculation of the total number of hours per week that a particular course takes.

(f) Calculation of contact hour requirements for specific resources on the basis of the computed number of contact hours per week for a course and the resource requirements of that course as specified by the input.

Operation 2: Conversion of contact hours to resources:

(a) Calculation of the number of teaching staff required by considering the policy dictating the number of hours per week that staff is required to teach and calculation of the total staff contact hours necessary.

(b) Calculation of room requirements on the basis of the length of the teaching week (expressed as the number of hours per week that the physical facilities are available for teaching) and a factor representing the maximum utilization of space to be achieved. Total room requirements are then compared with the room inventory to determine shortages and surpluses.

Operation 3: Calculation of supportive resource requirements using functional relationships between supportive resources and the values calculated in Operations (1) and (2) above. Supportive resources include non-teaching staff, office space, support space (library, cafeteria, etc.), and other resources such as fringe benefits and instructional supplies.

Operation 4: Calculation of program costs from the results of Operations (1), (2), and (3) above and the necessary cost inputs. Program costs calculated are divided into two groups: course costs, and prorated overhead costs.

CAMPUS can provide a variety of output reports depending on user needs and the level of analysis, a description of sample reports available is contained in Systems Research Group (1971). As is clear from the preceding discussion, the model has a rather simple conceptual structure and does not explicitly take into consideration chance factors. Its power lies in its ability to digest vast amounts of data and to perform a wide range of computations to provide output reports suitable for decision making. Thus, CAMPUS is a large labor-saving device which can be fruitfully used to evaluate alternative courses of action and to carry out long-range planning. The model is adaptable--despite the wide range of data inputs necessary--and has been successfully used in over a dozen colleges and universities, both in Canada and the United States.

Szekely et al. (1968) have developed a simulation model of an entire school system. Designated "S.D. Two," the model is a generalized representation of planning activities in a typical school district under study. The research done at the University of Pennsylvania was financed by the School District of Philadelphia and by the Intermediate Unit Planning Project operated by the Bucks County (Pennsylvania) Board of School Directors.

The model's overall objective is to aid exploration of the consequences of alternative resource allocation policies. The computer program consists of two files and a master program. The first file contains a variety of data for each of the areas into which the school district is divided. It includes demographic and resource data (number of schools by type, number of teachers, etc.) pertaining to each area. The second file contains technical and administrative data (e.g., resources used by the program per student, percentage of students to receive the program by various categories of students, etc.) required to make decisions concerning an educational program. Input policies are defined by specifying the program mix (described in terms of resource requirements) for each year to be simulated and by stating the allocation rules for converting a proposed program mix into an operating program mix. Implementation of a program is specified by designating groups within each area to which a particular program applies. However, all polity inputs are constrained by operating budgets, capital budgets, limitations on the number of teachers and staff available, tenure, and desire for continuity of programs. As the simulation proceeds, it estimates the consequences of various policies in terms of operating expenditures, capital expenditures, programs actually implemented, and changes in student achievement.

The administrator's desires are taken into consideration by assigning a priority of 1, 2, or 3 to a program and by designating preferred areas as "key" areas; for example, poverty areas. Priority 1 programs are given full implementation in all areas; priority 2 programs are fully implemented in all "key" areas; and priority 3 programs are implemented to the extent that resources permit. The basic simulation run is given below:

Operation 1: Application of programs to each area to determine resource needs. If needs exceed the budget available, then a second pass is made to adjust the degree of implementation in accordance with the rules stated in the allocation policy being used.

Operation 2: Projection of space and equipment needs and comparison with the future availability of buildings and equipment now existing, or soon to be completed. On the basis of this comparison, new resources are allocated to different areas in accordance with the policy rules given.

Operation 3: Prediction of student achievement under the operating policy is made and promotion of students carried out. The change in achievement is hypothesized to be a function of "communication resources": staff, materials and space available in school, and the socioeconomic characteristics of the students' home area.

Operation 4: Summarization of yearly operations and updating of files.

This sequence of operations is repeated for each year to be simulated, the output of a given year serving as input to the next (Figure 9).

In evaluating the S.D. Two Model, it should be noted that this is a general model and can be modified to fit any other district. Also noteworthy is the use of student achievement as an indication of the effects of alternative policies, although it does create substantial measurement problems and has necessitated separate research effort directed at more adequate prediction of achievement changes. (The authors claim that the model represents policies and programs in enough detail to facilitate the achievement prediction procedure.) Presumably, the model is still in a developmental stage since there do not appear to be any published accounts of empirical tests. Hence, it is not possible at this time to evaluate the strength of the S.D. Two Model.

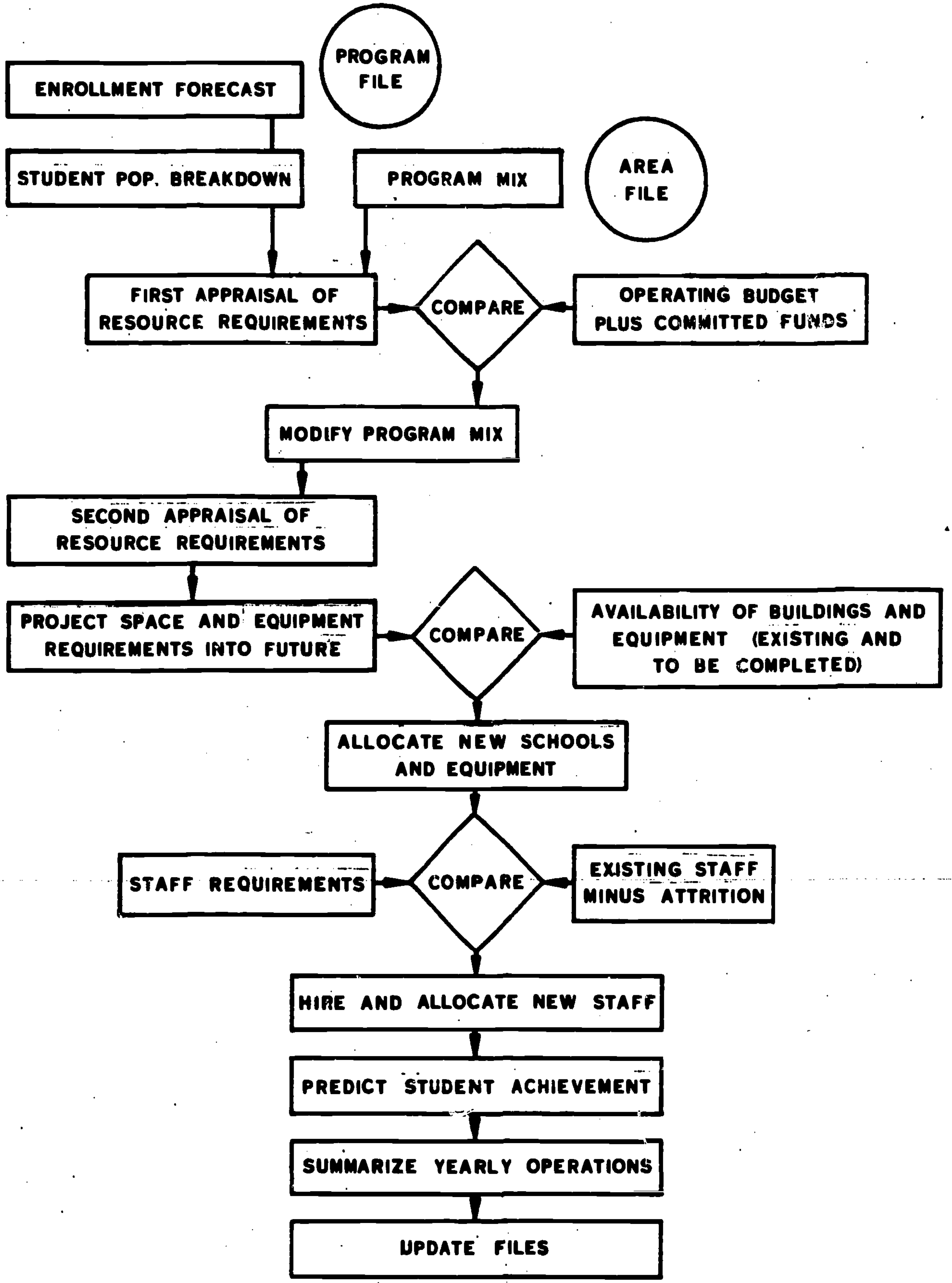
2. Simulation of Community Renewal Programs.

The era of large-scale, comprehensive simulation models for urban planning began in the early sixties. Since then, a great number of models have been developed to tackle a wide range of urban problems, including: the prediction of future growth, location of economic activities, determination of the effect of changing zoning policies, evaluation of the impact of slum clearance, and investigation of changes in the transportation system. Some excellent reviews of these models are given by Lee (1968), Kilbridge et al. (1970), Goldner (1971), Catanese (1972), and Lee (1972). Table 7 indicates the range of models developed to date. The bulk of the more recent work has been directed at the development of simulation models for community renewal programs; hence, the remainder of this section is devoted to a discussion of one such model.

Early Community Renewal Programs (CRP's) were primarily concerned with eradication of the areas of physical blight. In the past, local government agencies have typically attacked their renewal problems on a piecemeal basis, focusing only on a single aspect. Therefore, traditional renewal plans have generally been inadequate (and often divisive) for dealing with the problems of urban development. Through CRP's, however, the scope of urban renewal activities has been made substantially more comprehensive; emphasis is placed on the development of

Figure 9

Flow Chart for S.D. Two Simulation Model



Source: Szekely (1968), p. 235

TABLE 7

SOME TYPICAL URBAN PLANNING SIMULATION MODELS

Author(s) and Approximate Date	Reference	Area	Overall Objective	Model Component			Model Type	
				Land Use	Transportation	Population	Comprehensive	Special Purpose
CATS Group 1960	Irwin (1966)	Chicago	Forecasting transportation demand	X	X	X	X	
Herbert 1960	Irwin (1966)	Philadelphia	Simulation of residential development using linear programming	X			X	
Lowry 1964	Lowry (1964)	Pittsburgh	Simulation of "instant metropolis"	X		X	X	
Rand Corp. 1962	Kain (1962)	Hypothetical	Transportation planning	X	X	X	X	
Seidman 1964	Lamb (1967)	Philadelphia	Allocation of economic activity	X		X	X	
Steger 1964	Steger (1965)	Pittsburgh	Policy testing for urban renewal	X		X	X	
Goldner & Graybeal 1965	Goldner & Graybeal (1965)	San Francisco	Forecasting the effect of plant location on commercial and residential land use (BASS)	X		X	X	
Hill 1965	Hill (1965)	Boston	Forecasting population and employment (EMPIRIC)			X	X	
Lathrop 1965	Lathrop (1965)	Buffalo	Evaluation of alternative policies	X	X	X	X	

TABLE 7

(Continued)

Author(s) and Approximate Date	Reference	Area	Overall Objective	Model Component			Model Type	
				Land Use	Transportation	Population	Comprehensive	Special Purpose
Schlager 1965	Schlager (1965)	S.E. Wisconsin	Land-use plan design	X		X	X	
Graybeal 1966	Graybeal (1966)	Hypothetical	Simulation of residential development	X			X	
Vorhees 1966	Lamb (1967)	State of Connecticut	Forecasting urban growth, shifts in employment and population	X		X	X	
Rose 1970	Rose (1970)	Milwaukee	Expansion of the Negro ghetto			X		X
Yuill 1970	Yuill (1970)	Sample of 11 cities	Forecasting form and shape of urban population growth		X	X		X
NBER Group 1971	Ingram *et al.*	Any (general model)	Evaluating the consequences of alternative public policies	X	X	X	X	

plans and programs for coordinating and integrating diverse sets of renewal activities. These studies generally involve four steps (Steger, 1965): (1) development of alternative plans for urban development, (2) selection of alternative renewal programs as a means of accomplishing the plans, (3) determination of the impacts of each alternative, and (4) selection of the preferred alternative.

During the past decade, a number of cities in the United States have tried applying modeling techniques in the preparation of their CRP's. Most notable among these are Pittsburgh and San Francisco. Such models generally incorporate a wide variety of urban activities (land use, transportation, employment, etc.) and the analysis is usually carried out at a rather large areal scale (e.g., one square mile in the Pittsburgh model). Consequently, the level of detail contained in the output is not adequate for facilities planning. However, the overall approach utilized in these models is of considerable interest; hence, a brief review of one such model is presented. The San Francisco model is chosen because it focuses on the residential sector, an item of particular interest in planning school facilities.

The San Francisco simulation model was developed by Arthur D. Little, Inc., under contract with the San Francisco City Planning Commission, with the main objective of identifying and assessing the impact of alternative, long-range strategies for renewal and development of the City and the County of San Francisco. It attempts to replicate the residential market responding to the supply and demand of housing by matching households and dwelling units. Their method involves comparing the preference lists of households with the stock of available housing and assigning houses to those households that offer the highest prices. If the supply and demand are not equal, the housing stock is changed to meet the excess demand or supply within the limitations of the financial feasibility of the change. The change is performed by an "aging" operation (couched in terms of a first-order Markov process) which may cause the construction of additional housing and either rehabilitation or deterioration of a portion of the existing stock. The operation of the market may be altered by introducing public actions, and in this way, the effects of alternative policies and programs can be studied. Financial feasibility is determined by comparing the rent-paying ability of a prospective tenant with both the cost of making the change and the anticipated future yield of changed housing stock. If this comparison indicates that profits can be realized, then the computer adds an appropriate number of new housing units to the inventory of housing stock and computes the new conditions that result: shifts in rent levels, new market values, changes in the taxbase, modifications to the neighborhood amenities, etc. When all effects have been accounted for, new inputs are introduced and the process begins again. An abbreviated flow chart of the operation of the housing market is shown in Figure 10.

Inputs to the model are an inventory of housing stock and certain land-use categories, such as vacant land which may potentially become residential. The housing stock is differentiated as follows:

(a) Housing type

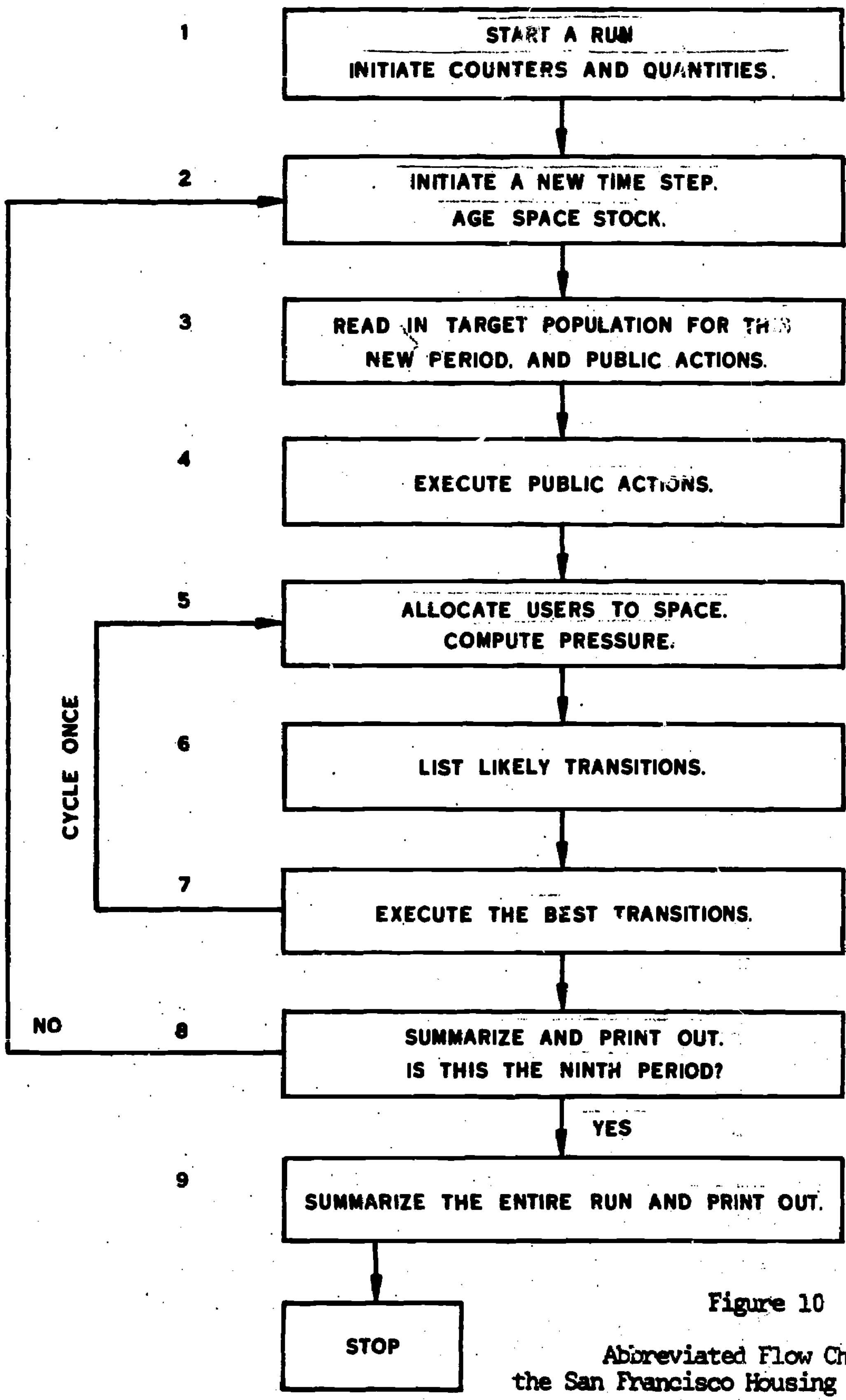


Figure 10

Abbreviated Flow Chart of
the San Francisco Housing Market Model

Source: After Robinson et al. (1965)

- single family, multiple family
- number of rooms per dwelling unit
- owner or renter occupied
- value or rent

(b) Condition
(c) Location

Demand for housing is generated by households which are differentiated on the basis of attributes which include:

(a) Household type
(b) Number of members in household
(c) Income
(d) Race
(e) Occupation
(f) Rent-paying ability

The number of households in each category is predicted exogenously for each iteration of the model. Associated with each household type is a preference list.

Public action can take several forms as indicated in the three general categories below:

(a) Direct operations in the market

- purchase of property by government
- selling of property by government
- maintaining or upgrading government property
- demolition of government property
- site improvements by government
- construction for public or private use
- leasing of property to private sector

(b) Indirect operations on the market

- restriction of private occupancy changes
- tax rate and assessment
- cash subsidies to households
- rent control
- mortgage and loan insurance
- reduction in the cost of financing housing construction

(c) Extra-market decisions

- code enforcement

The model was use-tested using the total quantity of new construction as primary control variable. As Table 8 indicates, the simulated results of new construction compare quite favorably with the actual new construction, but there is a tendency to underestimate single-family dwelling units (Table 9). Tests were also made by introducing a six-year housing code enforcement program proposed for the San Francisco

TABLE 8

NEW CONSTRUCTION
COMPARISON OF INVESTMENT
(Millions of Dollars)

	Actual San Francisco	Simulation Runs
Period 1 (1961-62)	$121.4	$121.7
Period 2 (1963-64)	155.7	156.6

Source: Lee (1968) pp. 5-63

TABLE 9

COMPARISON OF NEW UNITS CONSTRUCTED

	San Francisco Actual				Simulation Runs			
	Single Family	2 - 4	5+	Total	Single Family	2 - 4	5+	Total
Period 1 (1961-62)	1,415	756	5,891	8,062	428	828	6,886	8,142
Period 2 (1963-64)	855	790	8,240	9,885	798	560	7,830	9,188
Total	2,270	1,546	14,131	17,947	1,226	1,388	14,716	17,330

Source: Lee (1968) pp. 5-64

CRP, with a control run without such a public policy. Results revealed that the code enforcement program would affect about 5,000 dwelling units which would be upgraded from substandard to standard. This improvement in quality would be accompanied by an increase in rentals for substandard units, indicating the need for a provision of low-cost housing to accompany the introduction of this particular code enforcement program.

While the above results are generally satisfactory, subsequent tests of the model using a different data set showed that previous agreement on totals had been achieved from large compensating errors in subcategories and that some categories showed errors of well over 100 percent (San Francisco Department of City Planning, 1968). The City estimates that it would take a further sum of $250,000 to get its already operational model ready for potential use. Any further development of the model, therefore, has come to a stop for the time being.

III. CONCLUSION

A review of some selected simulation models pertinent to the problems of planning educational facilities has been presented in the preceding sections. The range of existing work varies substantially, not only in the types of problems tackled, but also in the approaches utilized, the level of sophistication attained, and the results obtained. Yet, while the potential utility of the technique of computer simulation is high, success with its use for planning purposes has been limited. A large number of models have been developed, but many have not been fully operationalized and/or tested. Only a few such models are actually used for planning purposes.

By far the largest number of simulation models have been developed in the field of urban planning, a significant proportion being comprehensive models. These models are rich in their conceptual elegance; however, they have not lived up to the high hopes of their creators and a new generation of urban planners is seriously questioning their utility (e.g., Lee [1972]). As Ingram (1971) points out, the disappointment with urban simulation models results largely from unrealistic expectations about what could be *quickly* learned from such models, a serious underestimation of the difficulties involved in constructing operational models, and the lack of an adequate, long-term financial commitment to their development. Compared to comprehensive models, special purpose models have fared much better. A number of them have been made operational and use-tested with encouraging results.

In the field of educational planning, considerable use has been made of simulation models, although most such models deal with facility aspects only indirectly. Their use has been particularly successful at the university level, for a variety of reasons: the simplicity of the models utilized, the relatively "closed" nature of university systems compared to public school systems, the presence of forward-looking administrators, the availability of technical competence and advanced computing systems, and the existence of an environment that is conducive to research and development.

The use of simulation models for school facilities planning has lagged far behind their use in other fields. This lag is no doubt a consequence of the current state-of-the-art in school facilities planning with its heavy emphasis on check lists and procedural guidelines at the neglect of the model building approach. Consequently, it can reasonably be expected that as the field of educational facility planning becomes more systematic and scientific, the use of simulation models will increase.

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1. General Works
2. University Planning
3. School Planning
4. Urban Planning

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