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SIMULATION OF ALTERNATIVE EDUCATIONAL STRATEGIES

With a Case Study of School Provision in the Plan for Milton Keynes

by

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Perhaps one reason surprisingly little study has been made of the relationship between the size and location of school facilities is that traditionally schools have been located simply to satisfy particular catchment needs and have not functioned as part of an open market system. Because of rapid changes in the forces which create educational systems, however—including means of financing, construction methods, philosophies of teaching and learning—the relationship between these different elements within the total urban system will become crucial considerations when locating future schools. It is with the hope of such changes that the research described in this article was undertaken.

One alternative to the present educational system is known as 'the voucher system'. Under this system, a family would have the opportunity of choosing the schools its children would attend. Schools would be financially compensated with a budget allocated on a per child basis.[1] Educational vouchers have been proposed for existing urban situations for a number of reasons including, among others, the unevenness of educational quality across the different sectors of urban communities. Proponents of the voucher system argue that in an open system, with the cost of travel subsidized for all students, children in areas where educational quality is poor and facilities overcrowded would have the opportunity of attending better equipped and less crowded schools of higher educational standards in other sections of their city. Schools which do not meet the needs of their students would presumably stop attracting students and 'go out of business'. Certain schools might serve specialized needs, and a child might attend several schools during the course of a day, and many during the course of an academic year.

The philosophical, psychological and social merits of the voucher system are still being debated by educationalists and politicians and are not the concern of this study. But any future decision to use educational vouchers would significantly affect existing patterns of urban life and would alter our fundamental approach to future community planning. The traditional post-Radburn device (employed in numerous schemes for new towns or new community designs in the US and Great Britain since the 1920s) consisted of placing the primary school at the focal point of a 'neighbourhood'.[2] This neighbourhood was sized so that, in theory, the school age children would approximate the number of school spaces and all children could walk to school. The secondary school, until recent increases in student capacities, determined the size of the community precinct.

This conception of 'building up' a town from distinct elements has been seriously questioned in recent studies.[3] With the adoption of the voucher system, these previously accepted guidelines for building new schools and designing new communities could well be shown inadequate. This study will attempt to investigate what some of those changes are likely to be. It will do so by developing a model to simulate and evaluate alternative educational systems. This model shall focus on key interrelationships between the components of educational facilities and the urban environment. It will provide quantification of an educational component's performance within a proposed physical plan.

Construction of Model

The majority of educational models in use can be readily divided into micro-educational and macro-educational models.[4] Micro-models deal with psycho-sociological aspects of educational systems, the relationships between teachers and students and the psychological aspects of learning.

Macro-models refer to the educational system as a whole or to various parts of it. The data in these models include student flows, numbers of teachers available and amounts of usable teaching space. Some advanced work has also been done for university planning on the inter-relationships between the various urban components and educational facilities.[5] The major concerns of macro-models are:

1. Estimates of the number of teachers and classrooms required to meet projected educational needs.
2. Determination of an equilibrium path in time for the number of students in a system determined by the demand and supply of teachers or classroom space.
3. Estimates of the financial costs required to fulfil an educational plan or to match the resources available.
4. Estimates of the number of educated personnel needed for social development.
5. Evaluation of the suitability of alternative locations for a new facility.

THESIS

This study proposes that the location and size aspects of educational planning can be integrated with the planning of residential densities, transportation systems and open spaces in town developments. It proposes further that objectives for macro-models ought to be formulated in conjunction with the various physical systems so that when the location and size of an educational facility is proposed the response of the total system can be rapidly evaluated.

This article studies the potential relationships between where children live and where they will attend school; further, it attempts to provide a method for determining answers to the following questions which may be added to the list of macro-model concerns:

1. How does *location* of a school facility affect the degree of choice a child has in which school he will attend?
2. How does the *size* of school facilities relate to the level of services a school can provide its students?
3. How does the size of school facility relate to its *accessibility* to a given population?
4. How might *density* and location of population affect the size and location of school facilities?
5. How might location and size of a school facility be affected if it contained activities for the use of the entire community?

HYPOTHESES

The general assumption is that if there are a certain number of children to place in educational facilities, the smaller, more dispersed alternative will increase accessibility

while the larger concentrated facility will offer an increased level of services. On the one hand, therefore, the mini-school is offered as an alternative for reaching more children and creating informal learning environments closer to home.[6] On the other, the educational park, with many students bused from all points of a city is seen as a means of maximizing the use of facilities and of justifying the construction of specialized facilities which could not be supported by fewer students.[7]

If boundaries are drawn around individual schools, as traditionally has been the practice in defining school districts, the assignment of students to a school is the same for one large school as it is for many smaller schools.[8] The solution would be to maximize the use of each school while assuring that a student is not travelling further to that school than he would to another. It is believed that if one large school were to be built, it should be located at the point of highest accessibility to the total polulation. If many smaller schools were to be built (assuming an even distribution of population) a homogeneous distribution of facilities would decrease distances travelled. Alternatively, if a school system were set up so that a family could have the choice of which schools its children would attend, the two major variables would be accessibility to home and quality of education received. Accessibility, while it is a relative measure, is nevertheless quantitative. Quality of education is more variable and means different things to different people. For the purposes of this study, quality of education will mean the measure of extra-educational facilities made available by increasing the numbers of participants at a particular location.[9] By this criterion, 'level of services' is perhaps a more accurate label. It is a function of both the size of the total population and the rate of utilization. The greater the utilization rate and the greater the number participating, the greater the likelihood of an increased level of services.

In an open system, one large school would eliminate choice. A family would not be able to choose between size and travel distance. Likewise many small schools of equal size and equal facilities would also preclude the opportunity for making a choice. However, if both size and location were independent variables, it is probable that level of services would increase as accessibility to total population increased, and that size would decrease inversely to the distance from the total population.

Density obviously plays a major role both in accessibility and level of services. In large urban areas of high density, more schools are possible in close proximity to each other. If the size of a school were fixed as density increased, the number of schools would have to increase. If distribution and density varied and size of facility were constant, those areas of highest density would have more facilities in closer proximity to one another. It is postulated that if the size of facilities was allowed to vary, those facilities in areas of higher density would furnish a higher level of services; likewise, in order for low density areas to enjoy the same accessibility of facilities as high density areas, more and smaller schools would be necessary. In order for low density areas to enjoy the same level of services as high density areas, fewer facilities would be necessary.

The relations between size and location of educational facilities based on the reciprocal tendencies of concentration and dispersion have been set forth for testing. Part of the concentration philosophy requires that facilities not strictly educational such as public swimming pools or public libraries, be included in the educational complex. These specialist activities are expensive and difficult to duplicate. They would, therefore, have to be accessible to a larger proportion of the population than is normally expected from schools. By combining specialist and non-specialist activities at a central location, one might increase their utilization at the cost of better accessibility of the non-specialist activities to students. If both were combined locally, one would increase local accessibility but possibly at the cost of better facilities.[10] What is needed, then, is some method of measuring the deterrent effects of distance against the attractions of size.

METHODOLOGY

The method used for testing this set of hypotheses is simulation modelling. Simulation modelling provides a means of exploring and illustrating alternative possibilities for the growth and change of the urban environment.[11] One begins by generating a set of alternative plans based on selected urban components and design variables. One then evaluates the performances of the urban components mathematically and finally analyzes the effects of the design variables on the urban components' performances.

Ideally, it would be desirable to simulate interactions through time by developing a dynamic simulation model. However, work in this area is still in its formative stages and results to date appear to be based largely on the hypothesis that the Markov process in continuous time can be used to describe changes in the urban environment over time.[12] The Markov property is based on the premise that 'the specification of the existing value of a variable constitutes the completest description available for that variable, and together with experimentally determined parameters known as transition probabilities, a complete description of a variables' development process for the next time period can be specified'.[13] Lacking the experimental data required to practice dynamic modelling, this study develops a comparative static simulation model using recursive methods. The inter-relationships between design variables and urban components will be described at one point in time only; then through recursive use of the model, change is accounted for by an alteration of values for variables. In this way, continuous monitoring of results is possible and the formal simulation method can be linked directly with periodic design and evaluation.

To analyze the difference between alternative equilibrium states, two conditions are necessary:

1. Those factors that will affect the output within the area under investigation are known or approximated and can be described as an input to the model.
2. The means for translating this information from one point in time to another are known.

The first simply refers to initial data; the second requires both equations of motion and sufficient parameters to calculate rate or frequency of that motion. By combining 'a' and 'b', one should be able to predict results for an alternative.

In physics, equations for motion of matter have been established empirically. These equations have been adapted to urban systems with the result that certain environmental phenomena have been satisfactorily reproduced (simulated). This ability to represent the present has proven to be the best available means for exploring the future. In terms of interactions between individuals and activities (such as jobs or shopping facilities) the equations of motion have been of the form:

$$I_j = \sum_{i=1}^{n} \left(\frac{Ni}{{}_i d_j \, K} \right)$$

where: I_j is the interaction at point j

N_i is the number of individuals at point i

${}_i d_j$ is the distance between points i and j

and K is the coefficient of distance.

This equation forms the basis of potential models. Criticisms of this approach have focused mainly on the often meagre evidence for establishing the value of K. It is often found by regression analysis of large amounts of empirically collected data on movements of people; sometimes it is simply found by continuous iterations until the model represents an existing situation.

Kinetic theorists have sought to circumvent such criticisms of their own approach by describing the rates of change from one state to another as transition probabilities.[14] This rate of change per unit time is related to the difference between inward and outward flows:

$$\frac{dn_i}{dt} = \sum (a_{ji} n_j - a_{ij} n_i)$$

where: n_i is the number of individuals at point i

n_j is the number of individuals at point j

a_{ji} is the probability per unit time of a transition from category j to category i

and a_{ij} is the reverse of a_{ji}

Nevertheless, transition probabilities, like distance coefficients, are based on observation of past behaviour. Without these important observations, neither approach is more valid than the other. However, while the potential model is based only on number of individuals, distance and possibly size of facilities involved in interactions, the probability model could also include causal variables such as age, sex, income, social mobility, etc.

If all students who leave home must enter at least one category of educational facility:

$$a_{ij} = e_i c_j$$

where: e_i is the frequency of movement from i

c_j is the attraction of facility j

At equilibrium, all students have reached a destination. Therefore:

$$\sum (a_j n_j - a_{ij} n_i) = 0$$

and:

$$\sum (e_j c_i n_j - e_i c_j n_i) = 0$$

In a closed system:

$$\sum_j c_j = 1$$

and:

$$\sum_i n_i = n$$

where: n is the total number of students

and: n_i is the number of students at point i.

Finally:
$$n = \frac{\frac{c_i}{e_i}}{\sum \frac{c_i}{e_i}}$$

At equilibrium, the number of students at j is dependent on the number who started out at i, transition probabilities and the competition among locations. Little difference between the form of the probability equation and the potential equation could be distinguished. However, two elements are missing from the potential equation. The first is the ability of a location to reject an individual; the second is the ability of individuals to behave differently from one another during the same time period. For these reasons a probability method has been utilized to translate information on student flows. For each location it is now necessary to do the following:

1. List all activities at each location and describe those groups who would be likely to participate in them.
2. Describe all population points in terms of numbers of students by social and economic mobility and age.
3. Determine a frequency of movement for each student classification.

The most suitable form for storing this information would be in a matrix listing all population points i and destination points j and determining a probability of flow for each group between i and j.

The following categorization can be used in the compilation of a matrix:

Student Categories	*Age*	*Facility Categories*	*Type*
a	1–6	*I*	Infant
b	7–9	*J*	Primary
c	10–12	*K*	Middle
d	13–15	*L*	Secondary
e	16–18	*M*	Further Education
f	18+	*N*	Polytechnic/University.

The point locations of students by number and age group is given by a set of vectors:

$$A_K = [K_1, K_2, \ldots, K_n]$$

Where: A_K is the set of all individuals in age group K

and: K_n is the total number of point locations

The point locations of facilities by number of students acceptable per age group is given by a vector:

$$F = \begin{bmatrix} f_{la}, \ldots, f_{lK} \\ f_{na}, \ldots; f_{nK} \end{bmatrix}$$

Where: f_{la} represents the number of students acceptable at facility location l from age group a

and: f_{nK} represents the number of students acceptable at facility location n from age group K.

The probability that a student from age group K at location i would be attracted to facility n at location j is given by:

$$P_{ij} = \frac{P_i(K) S_j(K)\, d_{ij}^{\beta-\alpha}}{\sum_j S_j(K)^\beta d_{ij}^\alpha}$$

Where:

$P_i(K)$ is the student population at i of age group K

$S_j(K)$ is the number of places available at facility location j for age group K

d_{ij} is the distance between i and j

β is a size factor

α is a distance factor.

The probabilities for age group K at all point locations i moving to facility locations j would be given by:

$$P = \begin{bmatrix} P_{l1}, \ldots, P_{lm} \\ P_{n1}, \ldots\; P_{nm} \end{bmatrix} \qquad P_j = \begin{bmatrix} P_{l1} \\ P_{n1} \end{bmatrix}$$

Therefore:
$$A_K P = \left[\sum_{i=1}^{n} a_i P_{i1}, \sum_{i=1}^{n} a_i P_{i2}, \ldots, \sum_{i=1}^{n} a_i P_{im} \right]$$

and:
$$\sum_{i=1}^{n} a_i P_{im} = N_{im}$$

When: N_{im} is the total number of students from all student locations mixing to facility m.

One can easily view this storage matrix as a mapping of a particular area under study showing those urban components, such as road networks or natural barriers, which would affect transition. Since computer techniques are to be utilized, the above procedure will be adopted. With such techniques it is vital that all information be given in terms of co-ordinate axes. The size of each module or population grouping must reflect a compromise between fineness of detail and the costs and difficulties of computing since the computer allows the simultaneous handling of large amounts of information, but at a high cost.

If one were investigating an existing situation, actual data would be input and matrix distances (or, alternatively, time or cost of travel) between population points n_i and facility location f_j would be measured automatically. These distance/time measurements would serve to limit flow probabilities.

Additional constraints could be added making c_j dependent on capacity:

$$c_j = f(n_j)$$

If a facility were full, a student would have to 'find' an alternative location. The process would carry on until all students had entered a facility. On the other hand, if a proposed situation was being investigated, actual student numbers would not be available. It would be necessary to assume a set of probable numbers on a per household basis. That is, assuming a family size, what is the likelihood of finding a child of a particular age group? Other information on mobility would have to be assumed from data on the types of families that are likely to move in.

The assumption is that the total numbers of trips generated equals the total number of trips accepted and that individuals do not accept intervening opportunities during a transition from one state to another. This is a serious limitation since it precludes testing the potential level of services that a facility might generate if it developed independently of particular age groups. Such would be the case with community related facilities or with schools competing for students. For this reason a derivation of the gravity model which generates level of services information instead of student flows has been employed.

As stated previously, it is believed that to maximize services, facilities must be larger or located nearer to one another to enable greater numbers of individuals to use them; at the same time, to increase accessibility to each facility, facilities would have to be more dispersed. An adaptation of a retail commercial evaluative model has been used to relate the size and distribution of facilities to the residential population.[15] It has been shown that the size of a school or related community facility is determined by the following:[16]

1. The amount of funds available for a facility's construction computed on per capita of population served.
2. The distance between residential points and the locations of these facilities.
3. The number of facilities competing for attenders.

The revised model would be defined as follows:[17]

$$\frac{C_a}{A_a} = \frac{A_a^{\beta-1}\sum_{i=1}^{n} e_i \frac{l}{{}_i d_a^{\alpha}} + e_a \frac{2}{(q/2)^{\alpha}}}{\sum_{K=1}^{m} A_K^{\beta} \sum_{\substack{i=1\\ i\neq K}}^{n} \frac{l}{{}_i d_K^{\alpha}} + \frac{a^A K^{\beta}}{(q/2)^{\alpha}}}$$

When: C_a is the discounted cost of constructed facility a

A_a is the total area of facility a

e_i are the expenditures available in grid cell i

e_i = children in i multiplied by the expenditures available per child.

β is a size factor (that is, larger facilities would attract more participants; smaller facilities fewer)

α is a distance factor[18]

n is the number of residential points

m is the number of facility points

and: ${}_i d_a$ is the distance from residential point i to facility point a.

The ratio of predicted costs of construction to the area of a facility should indicate the degree of feasibility and efficiency of a proposed plan. If, at first, all facilities were set equal to each other in area, a low ratio for a particular centre might indicate that that centre was not attracting enough people and should be reduced in size. A high ratio might indicate a centre which was successfully attracting attenders and was able to expand with more expensive specialist activities.

By interfacing the gravity model with the probability model the effects of alternative urban configurations in an open market education system can be simulated, with the results in two parts. The first part would assign students on a most probable basis minimizing impediments to travel. The second would evaluate the location of a facility relative to the total population.

Case Study of Milton Keynes

DATA COLLECTION

In order to utilize the method outlined for testing our set of hypotheses, a case study was undertaken. The new town of Milton Keynes, Buckinghamshire, England, was chosen for analysis.[19] The major reason for this choice was the claim of the Consultant who planned Milton Keynes, that it would be a 'city of learning'; the proposed plan would 'enable parents to choose between a number of schools which they feel best suited to the needs of a particular child'. One could simply accept the data offered for the new city and apply it in an hypothetical environment. However, the fact that a goal has been determined (for Milton Keynes choice of educational facilities) similar to the one proposed by proponents of educational vouchers suggests that an evaluation of the Consultant's proposal for the distribution of education and community facilities—and a determination of their implicit goals—might enable other communities in the process of goal formulation to understand the consequences of their potential actions.

Two sets of data were necessary before the educational evaluative model could be employed:

1. The number of school spaces needed. This number depends both on the growth rate of Milton Keynes (that is, the number of new families moving in and the number of children in each family), and the birth rate of the expanding population.
2. The types of school facilities available and the number of children that could be accommodated in each.

As of April 1969, there were approximately 44 250 people living within the designated area. Nearly one half of this number was concentrated in Bletchley and one quarter in Wolverton. The Consultant made predictions on future growth of this population using British Government Actuary's statistics on mortality and fertility. For each five-year period the age/sex/specific survivorship ratios were applied and a general fertility rate for all women aged 15–44 was computed.

Since no growth rate had been specified by the Minister of Housing and Local Government in his designation order for the new city of Milton Keynes, the Consultant had to account for such factors as the capacity of the building industry to meet the housing market demands at different times and the ability of public services and utilities to keep up with the pace of building. Consequently, alternative rates of growth were utilized. One was described as accelerating, which would account for the possibilities of slower initial growth but a faster later pace. The other growth rate reflected a steady growth, such as would occur if all developers and industrialists provided facilities quickly in the initial stages.[20] The accelerating population figures were used in our test study.

Another factor which had to be considered in determining future population figures is the rate of outward migration. In *The Needs of New Communities*, a full chapter describes the problems a family might have in moving to a new town—the problems of settling in—which have led, in the past, to a turn-around rate of nearly four per cent per annum.[21] The Consultant concluded, however, that the population structure would not be significantly affected by outward migration, and that '. . . the net figures on population structure in Milton Keynes can be used to estimate the provision of facilities in the city, particularly those serving age specific needs'.[22]

DATA MANIPULATION

The age/sex distribution data for Milton Keynes provided by the Consultant was broken down into one-year increments for the purpose of this study. Figures were obtained from Great Britain's Department of Education and Science to determine the percentage of total population of each age group.[23] Using these figures and the Consultant's first five-year population projection, the total number of children per age group was calculated in the following manner after Smith and Armytage:[24]

Step 1: Given $n(r, t)$, the number of children in process r at time t, where r may be the number of ten-year-olds, for example.
Step 2: Determine the number of children in $n(r, t)$ who move on to process s at time $(t+1)$

$$n(s, t+1) = \sum_r f(r, s, t) + u(s, t)$$

When the number of children in process s at time $(t+1)$ is equal to the sum of all children who have come from process r at time t plus the new entrants $u(s, t)$ to the system in time period t to $(t+1)$.
Step 3: Determine the proportion of children in process r at time A who move to process s at time $(t+1)$

$$p(n, s, t) = \frac{f(r, s, t)}{n(r, t)}$$

When $p(r, s, t)$ is a probability of movement.

$$\text{Therefore: } \sum_s p(r, s, t) = 1$$

and:

$$n(s, t+1) = \sum_r p(r, s, t)\, n(r, t) + u(s, t)$$

This last formula allows future states of the system to be predicted, provided all past states are known and some rate of new entrants can be determined. This same procedure was followed for five-year increments through 1989 when the total population of Milton Keynes is expected to reach 231 570.

The next step involved transferring these age groupings data into a format usable in the evaluative education model. This meant defining population as the number of individuals in each age group per dwelling unit. It is known that if an age group represents a given χ percentage of the total population, the probability of finding an individual of that age group by randomly sampling a total population is $\chi(10^{-2})$. To project the number of individuals of an age group per dwelling unit, that age group's probability factor is multiplied by the number of people in that dwelling unit, as in the following example:[25]

1974 Projected Population	=	70 030
Number of children aged 5–9	=	7 240
Age 5–9 as % of population	=	10.3
Probability P_1	=	0.103
Persons/dwelling unit	=	3.11
Age 5–9/dwelling unit $P_2(.103)$ (3.11)	=	.3203

TABLE 1 *Milton Keynes: Probabilities per age group per dwelling unit*

	Year	1974		1979		1984		1989	
	Population	70 030		100 090		162 810		231 570	
	Dwelling Units	22 517		34 197		50 095		67 710	
Age Group		*Number*	%	*Number*	%	*Number*	%	*Number*	%
0–4		6 990	9.9	11 660	10.6	17 650	10.8	24 910	10.7
5–9		7 240	10.3	11 150	10.2	17 100	10.5	24 370	10.5
10–14		6 230	8.8	10 040	9.2	14 820	9.1	21 640	9.3
15–19		4 810	6.8	8 150	7.5	12 570	7.7	17 940	7.7
3–4		3 144	4.5	5 246	5.2			11 209	4.8
5–8		5 769	8.2	8 985	9.0			19 008	8.2
9–12		5 268	7.5	8 246	8.2			17 309	7.5
13–18		6 226	8.9	10 551	10.5			22 426	9.7
		3.11/DU*		3.19/DU		3.25/DU		3.42/DU	
		p_1	p_2	p_1	p_2	p_1	p_2	p_1	p_2
0–4		.099	.307	.106	.338	.108	.351	.107	.365
5–9		.103	.320	.102	.325	.105	.341	.105	.359
10–14		.088	.273	.092	.293	.091	.295	.093	.318
15–19		.068	.211	.074	.236	.077	.250	.077	.263
3–4		.045	.140	.052	.166			.048	.164
5–8		.082	.255	.090	.287			.082	.280
9–12		.075	.233	.082	.262			.075	.257
13–18		.089	.277	.105	.335			.097	.332

* Dwelling unit.

The resulting population of each age group per dwelling unit is shown in Table 1.

TYPES AND SIZES OF FACILITIES

The British Government's official policy behind future educational planning provided sufficient background for studying the types and sizes of facilities.[26] The Buckinghamshire Education Authority, which planned and financed the educational facilities in Milton Keynes, and the Milton Keynes Development Corporation, which will be responsible for building the education and community facilities, supplied information on the types of facilities to be built. It was necessary to express the total area provided by each type of facility as a percentage per individual and finally as a ratio of square metres of space allocated per dwelling unit per each age group. For example, the number obtained for the 13 to 18 age group was five metres of education space per dwelling unit.

An estimate of capital available for construction of facilities was made and expressed as cost per square metre of space per dwelling unit. Again, for the 13–18 age group, this figure was determined to be approximately £51.50 per dwelling unit, based on an approximate expenditure of £500 per full-time equivalent secondary school student.[27]

The last aspect considered in the study was the provision for community-related facilities within Milton Keynes, and their relation to educational facilities. It has been estimated that an expenditure of £5 per resident for an area of .04 square metres is necessary to provide a facility serving a total population of 40 000 which would include a 25-metre swimming pool, a teaching pool, a sports hall, two squash courts, social areas and a gymnasium. To meet this expense, such a facility would have to be built as part of another supporting facility. Isolated community facilities would cost three times as much.[28]

SELECTION OF VALUES FOR VARIABLES

With all known information collected and suitably translated for use in the model it was necessary to select a range of alternative sizes and numbers for education and community facilities. Three basic modules have been selected for the study:[29]

1. Thirty nodes of 1 500 secondary school pupils per node, determined by the educational planners on advice from the Department of Education and Science to be an optimum size for a secondary school.[30]

2. Eighteen nodes serving a population of 15 000 people. The Consultant to Milton Keynes determined this size to be optimum for a community facility catchment area. The Consultant determined that six of these facilities would have services that would not be duplicated elsewhere and would be used by the entire population.

3. Ten nodes of 4 500 secondary school pupils per node, the solution proposed by the Consultant to Milton Keynes and the Buckinghamshire Education Authority.

Ideally, alternative facility distributions would be chosen according to point distribution theory, in a continuum from clustered to homogeneous to random. In this case, the perfectly clustered solution was not considered since results would have been meaningless. The homogeneous distribution, which, it was assumed, would result in the highest accessibility, formed the basic test unit. Each point was positioned so that it would theoretically minimize distance travelled.

The second distribution chosen for study would best be described as 'random-homogeneous'. It was determined by performing a test run with the simulation model to estimate the interaction potential of each location.

$$I_j = \sum_{i=1}^{n} \frac{N_i(K_i)}{{}_id_j^{\alpha}} + \frac{2N_j(Kj)}{(q/2)}$$

Where: I_j is the interaction potential at point j

N_i is the number of residential dwelling units at point i

${}_id_j$ is the distance between residential points i and j

α is a factor for distance

q is the grid size

and: K_i is the probability of finding specific age groups at point i.

These results were overlaid on each of the homogeneous patterns. The point with the highest interaction potential in closest proximity to the original point became the new location. This second distribution allowed account to be taken of varying densities, natural features or other fixed elements of a plan.

For this study, density and network structure have been kept constant. The Milton Keynes Plan provides for two densities of six and ten dwelling units per acre and a road network comprised of a one-kilometre square grid.

EXPERIMENT DESIGN

An experiment was designed to test the relationships between number of facility locations and facility distributions with respect to a given population. A total of eight alternatives was tested; six of these were used as the basic units of comparison. The remaining two alternatives were the Consultant's ten point proposal and a suggested alternative to this proposal. The relationship between the first six 'test cases' and the last two is the following: after analyzing the consequences for each of the six test cases on the degree to which they would or would not achieve the goal of maximum choice (of accessibility and level of services), the Consultant's proposal will be compared with these findings and alterations suggested to improve performance.

A set of performance measures was selected to exhibit the effects of alternative locations and distributions on accessibility and level of services. The measures were:

1. The number of children attracted to each facility location using network distance;
   (i) Mean value
   (ii) Maximum value.
2. Interaction potential of facility locations with total population;
   (i) Mean value
   (ii) Standard deviation.
3. Distance travelled from residential locations to facility locations;
   (i) Mean value.
4. Expenditures per unit area carried to facilities by population groups;
   (i) Mean value
   (ii) Maximum value.
5. Potential to carry expenditures from residential to facility locations;
   (i) Median value
   (ii) Maximum value.

RESULTS AND CONCLUSIONS

The effects of the two design variables on each of the performance measures are shown on the illustrated graphs (Fig. 1). Conclusions drawn from these graphs substantiate most of the original hypotheses and point at the need for further tests on others.

The original hypotheses stated that the smaller, more dispersed alternative would increase accessibility. A comparison of graphs 1 and 2 shows that as the number of facilities increased, the number of children decreased independent of distribution. In both distributions, distance decreased as the number of facilities increased. It is interesting that an increase from 10 to 18 facilities caused a greater rate of change than an increase from 18 to 30; this suggests that the benefits of shorter travel distances became less significant as smaller, more dispersed facilities are provided.

The second hypothesis stated that a regular homogeneous distribution would increase accessibility in an evenly distributed population. The tested case did not exhibit perfect homogeneity, but graph 2 does indicate that distribution has more effect on accessibility as the number of facilities decreases. With eighteen facilities, there was little difference in mean distance between alternative distributions, while the random-homogeneous distribution actually showed a decrease in mean distance over the homogeneous with thirty facilities. This last result surely indicates a better fit between facilities and densities.

The third hypothesis stated that larger, more concentrated facilities would increase level of services. Graph 3 does show that expenditures per facility increase as the number of centres decreases. The random-homogenous distribution tends to cluster, and the average expenditures are higher for this distribution than for the homogeneous; the

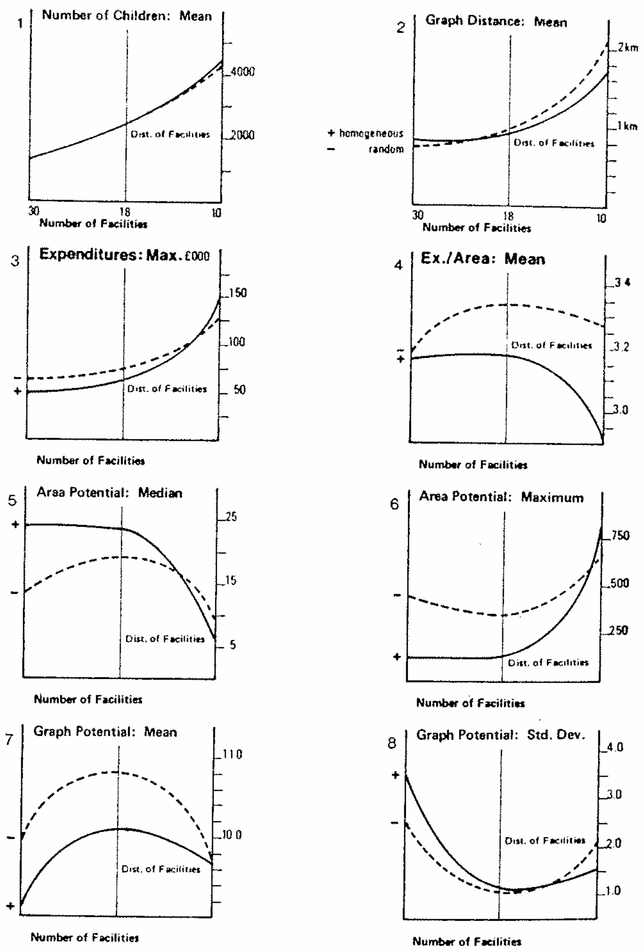


Fig. 1 Graphs showing the effects of the two design variables on each of the performance measures used to exhibit the effects of alternative locations and distributions on accessibility and level of services

third hypothesis is thus substantiated. However, graph 3 also shows that the maximum expenditure values are higher for the homogeneous distribution than for the random-homogeneous using ten facilities. This has been achieved at the expense of other facilities, while the random-homogeneous distribution has maintained relatively high levels of services at most locations.

The fourth hypothesis stated that level of services would increase as accessibility to total population increased. Graphs 5 and 6 illustrate the number of facilities, their distribution, and the potential level of services achievable in each alternative. Graphs 7 and 8 display the accessibility values for each alternative. The mean interaction possibility is greatest and the standard deviation lowest for both distributions under the eighteen point alternative, with the random-homogeneous having the more positive results. Graph 6 shows that at 18 points, the potential for a high level of services is greater for the random-homogeneous than for the homogeneous distribution. This was also the case at 30 points. However, at 10 points, mean potentials for interaction are approximately equal for both distributions and standard deviation is less for the homogeneous.

It could be concluded from this that with fewer facilities, a homogeneous distribution

would provide greater accessibility of most centres to an immediate area with the possibility of a few having greater accessibility to the total population. With more centres, the random-homogeneous pattern allows greater interaction of each facility with the total population and places more facilities in better positions to attract larger numbers of participants.

Finally, it can be stated that, in all of the alternatives considered, those facilities in higher density areas exhibit higher levels of services. High levels of services in low density areas could only be achieved by decreasing the total number of facilities. Accessibility in low density areas increases as the number of facilities increases.

RESULTS FOR THE MILTON KEYNES ALTERNATIVE

In most cases, the Consultant's proposed plan compares quite favourably with the homogeneous and random-homogeneous distributions. It has decreased mean distance

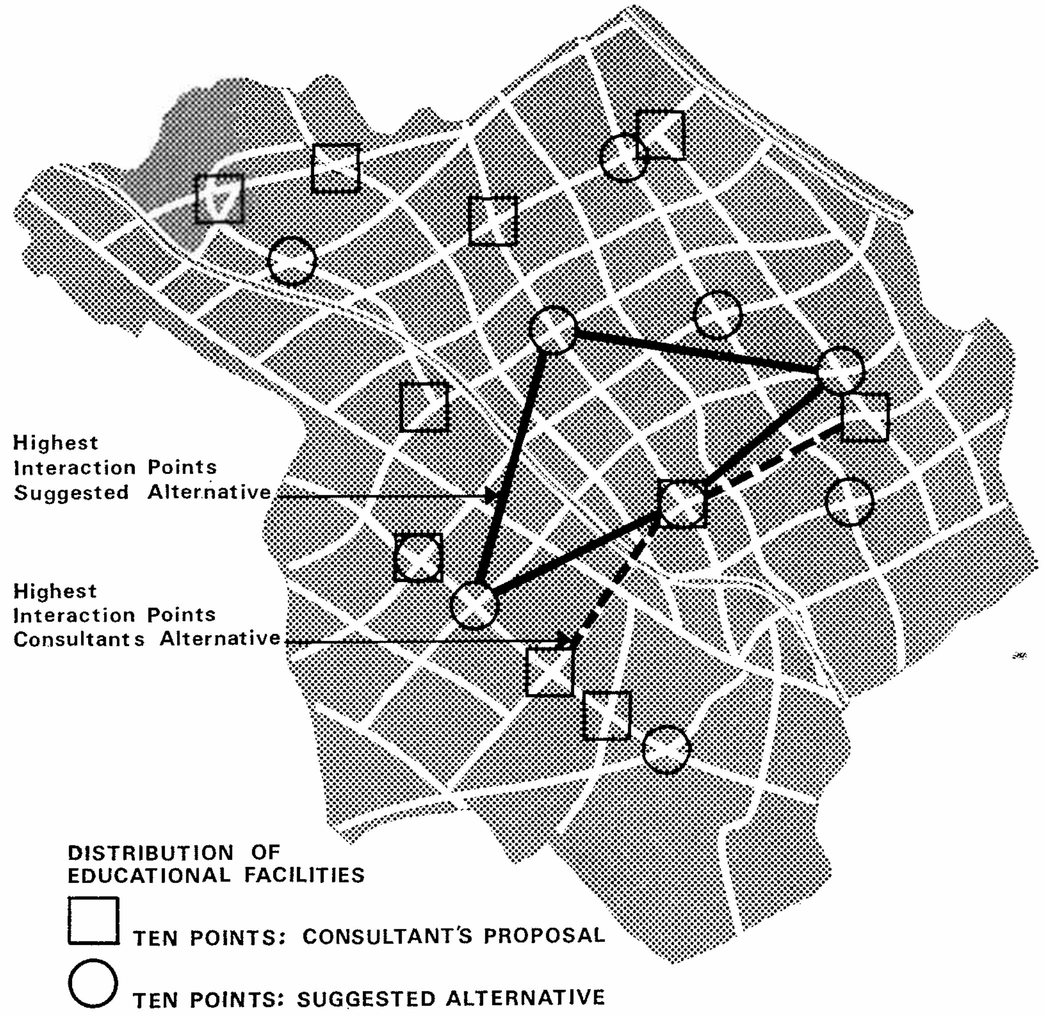
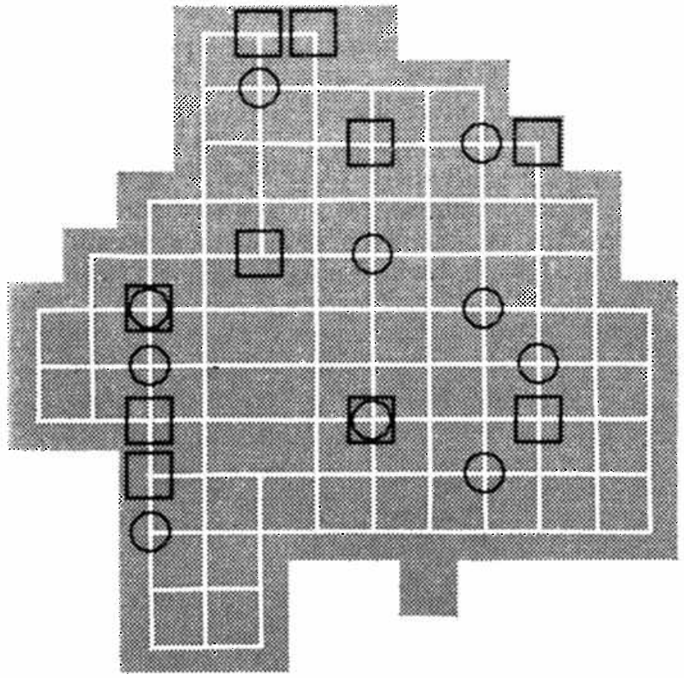


Fig. 2 Plan of Milton Keynes showing the distribution of educational facilities



DISTRIBUTION OF EDUCATIONAL FACILITIES

□ TEN POINTS: CONSULTANT'S PROPOSAL

○ TEN POINTS: SUGGESTED ALTERNATIVE

Fig. 3 Plan of Milton Keynes translated for the computer model, showing the distribution of educational facilities

from home to school and achieved a more even spread of accessibility. The homogeneous pattern, however, has produced a facility which could potentially develop a higher level of service due to a high value for maximum expenditures. A suggested plan was developed by altering the locations of several facilities. The Consultant's proposal and the suggested alternative are shown in Fig. 2; the computer adaptation is shown in Fig. 3. This new plan provides increased accessibility to facility locations attractive to numerous individuals from the total population: mean graph distance is the lowest for all alternatives and mean expenditures per unit area are highest. This has been achieved at the cost of a wide varieties of facilities since maximum expenditures have decreased as well as graph potential standard deviation, and a more even spread of facilities has resulted.

If the education planners wished to construct facilities of similar size and incorporate into these activities which would be shared by the total community, the suggested alternative would appear to offer a better set of locations to achieve this objective. However, if maximum choice of a variety of facilities is desired at predetermined locations, the size and the activities of particular facilities *should not* be predetermined as a general policy for all locations. If facilities are to function as part of an open system, they must contain those activities appropriate to their interaction with their population group. This study has shown that the appropriate level varies with size and distribution of facilities as well as with size and distribution of population groups.

Conclusions

The study described in this article has investigated the relationships between educational facilities and the urban environment, and has evaluated the performance of an educational component within a proposed physical plan. Computer simulation modelling was employed and the new town of Milton Keynes provided the data base as well as a physical framework for running a test of the model. Milton Keynes also provided a determined education goal and a plan to achieve this goal, thereby permitting an analysis of potential outcomes, an evaluation of these outcomes with reference to the performance of other alternatives and finally a set of recommendations indicating which alternatives might contribute to the achievement of a variety of potential goals.

Since this is an area in which predispositions seem to be lacking, it is also an area in which information and data are meagre. What is needed for further development, if the goal of free choice of education facility is to be pursued, is a wider range of possible alternatives and an in-depth study of the consequences for each alternative on the various sectors in society involving economic and social costs, long and short range societal effects and a study of implicit goals. It would also be necessary to provide research to investigate values for parameters used in the mathematical models presented, especially those on mobility of population groups. This will be especially difficult until an operational case study can be provided for analysis. Further, an investigation should be made of the consequences for a political-administrative unit of attempting to match facility building with fluctuating use.

As stated in the opening section, it has not been the concern of this article to discuss the merits of education facilities functioning in an open market system. However, if such a goal were established by a community, it is imperative that the planner should contribute to the information available to the decision makers. It has been said that 'the heart of the planning process is to encourage the development of programmes that will achieve goals desired'.[31] The model developed has provided a means of simultaneously testing and evaluating both educational and physical plans (programmes) within a physical framework.

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19 The designated area of Milton Keynes is in north Buckinghamshire, approximately 65 kilometres north-west of London. Construction began on the first stages of development in 1971 and by the year 2000 its population is expected to reach 250 000. The chief consultants for the planning and design of Milton Keynes were Llewelyn-Davies, Weeks, Forestier-Walker and Bor.

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30 Size of a facility is determined by an education authority on the basis of optimizing the fit between the number of students, staff and facilities provided. The module of 1 500 has been developed from a number of studies in Great Britain, It is now generally used to size comprehensive schools. In a very cursory test made for this study, costs per square foot versus number of pupils were plotted using information available from a group of newly constructed schools in the US and Great Britain. Very low costs were achieved between 1 200 and 1 600 students. Costs were highest at 900 and 2 500 pupils.

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