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An Interactive Graphics System for Resolving Pupil Assignment, Bus Routing, and Resource Allocation Problems in Urban School Systems

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AS IS WELL KNOWN, the problem of providing equality of opportunity for quality education in the public school system is one which confronts school planners today nationwide. In certain cases, it has been found necessary to require that some or all students be transported, by bus, to locations sometimes quite distant from their residences, for purposes of achieving a racial mix at each school which approximates the racial mix in the population as a whole. This aspect of providing equal opportunity of education is but one of the many facets of the problem which confronts the school planner today. We may presume to attempt to list some of the other factors which might affect the planner in his attempt at solution of the problem:

a) Physical Plant Conditions

1. Cost per pupil to provide adequate education at the different schools available for use.
2. Substandard or marginally usable schools.
3. Locations of schools in relation to locations of concentrations of pupils.
4. Educational levels which can be expected to be attainable at each school, versus the cost to achieve that level.

b) Availability of Funds and Budget Restrictions

1. Implications of recent court decisions with respect to the traditional local property-tax method of financing public schools.
2. Local governing bodies' occasional refusal to allocate funds for transportation of pupils.
3. Capital outlays versus operational costs.

c) Allocation of Teachers and Human Resources

d) Reducing Political, Social, and Economic Factors that tend to Reduce Community Cooperation

The problem is obviously a tremendously complex one, and at present it appears to be solvable only by persons having great experience in the field of school administration, and then not always to the satisfaction of all affected parties. Some tools, in the form of computer programs for design and simulation, are available to the decision-maker; however, it is probable that more and better ones are needed. The problem is so large and complex as to be untractable by traditional mathematical methods such as linear programming. However, we feel that just such tools as linear programming may provide the basis for the first phase of a two-phase approach to the problem, in which the second phase is an interactive graphics process.

The decision-maker should have available to him, ideally, a precise model of his system, by which he can evaluate the effects of changes in the parameters of the system and its inputs. If one should consider the school system to be a "black box" into which is fed money, pupils of a given starting educational level, teachers, physical plants, and transportation means, and from which emerges pupils of a higher educational level, then one objective of the planner should be to maximize the output, while minimizing the input, or at least part of the input (money). That is, the designer should attempt to get the most he can for his dollar.

Certain constraints, however, must be satisfied while attempting to maximize the output of this system. One is that it is presumably desirable not only to maximize the total increase in educational level, but also to ensure that this increase be reasonably well distributed among racial and ethnic groups. That is, an "equal educational opportunity" situation is desired. This means that the system should impose no systematic bias, and that a given pupil entering the system at a given educational level, should have equal probability of emerging in one of the higher educational levels. Let us assume, further, that the objective of the system administrator can be reduced to the equivalent objective: "Maximize the number

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of pupils in 'desirable' educational environments, while minimizing dollar expenditure." We must then ask what constitutes a desirable environment. Some answers which might be supplied either by experience or by external sources are:

a) The Physical Plant—does it afford the pupil a pleasant surrounding; is it adequate to the task?

b) Racial Mix of Student Body—may or may not be externally imposed.

c) Teacher Quality and Type.

Also to be considered is the matter of the "efficiency" of each physical plant; that is, the ratio of average educational quality to dollars spent at that site. Certainly, too, the familiar cost of transportation to and from the site, along with the determination of possible alternate sites for each school and the associated construction costs and benefits to be gained from reduction of operating costs and increase of educational efficiency with the newer plants, deserve attention.

AN INTEGER LINEAR PROGRAMMING FORMULATION

If we assume that, somehow, the definition of "educational opportunity" is supplied to the decision-maker, and that the other subjective measures are well-defined, then we may attempt to set up the problems as an integer linear programming model. We note, however, that even a somewhat simplified model is very much too large to be solvable by conventional techniques.

Of course it is true that any mathematical programming model suffers from many major drawbacks. The goal we have stated is entirely subjective; the causal relationship between education and dollars still is yet to be established; and numerous segments of the community have widely disparate ideas on the goals. The social justice to be gained by any change over the current system is vague and difficult to measure. Consequently, the authors feel that a model based solely on the data we have mentioned should only be used to structure the problem data and to be the beginning of a top down design using interactive graphics.

THE INTERACTIVE GRAPHICS APPROACH

Our man-machine design for planning a school system with equal educational opportunity becomes:

1. Man Defines the Problem—recent reports and studies done for the school board assess the merit of the physical plants and the cost of various possible improvements, the merit of various teachers, etc. In addition, a pupil-locator data file has been created. This data, when given to the computer, creates a data base for the interactive system. The school board then defines the goal that they are interested in, for example, minimizing the number of children going to the lowest rated schools. The constraints on this action, such as budget considerations, pupil travel time, court orders, etc., are also defined. The goals and constraints may be modified or changed completely as the study progresses at the discretion of the planner.

2. The Computer Organizes the Data—a computer model (see appendix) that approximates the true problem is solved and is used to generate an information hierarchy of relationships. These relationships are then displayed on computer-generated overlay maps. These maps illustrate what are the most probable matchings of population cells to schools, based on economic factors such as the costs of transportation, renovation and expansion, geographic and ethnic factors, and other considerations. The maps are crude solutions to the real problem and describe the general character of the final solution.

3. Man Organizes the Data into a Solution—based on the information hierarchy, the planner imposes a solution. Owing to the size and complexity of the problem, the planner generates a gross solution; that is, draws up the school zones, etc., but does not go into complete detail such as routing the school buses.

4. The Computer Generates a Total Solution based on the Heuristic Method—because of the speed of its computation, the computer solution allows for the complete details to be worked out. The computer heuristic is based on the information hierarchy data base. Man compares the computer solution with his own solution and perhaps any others generated by parents' groups, etc., and generates a composite or compromise solution.

5. The Current Solution is Reviewed to Determine how it Compares with the Information Hierarchy—the opinions of educators and other citizens may be drawn upon to criticize the current solution. Regions of the solutions that are not felt to be particularly well handled are interactively examined and improved, based on modification of various heuristics [3, 5, 8]. Solutions that show promise, or other details of interest are stored.

6. The Work is Assessed and an Estimate of the Benefit of Further Study is made—the solutions that result are reviewed for their economic and educational value, and the decision as to whether to continue work or to accept

one of the solutions is made. If it is felt that some benefit can be derived, step 5 is repeated.

The resulting solution contains the following details: a) recommended budgets and allocation of teachers to schools; b) renovation plans and location of temporary classrooms; c) assignment of pupils to schools; d) bus routes for getting pupils to schools; and e) any additional data such as percentages by race at each school, maximum distances that pupils travel on each school bus, etc., which can be generated in standard report form for examination by any authorized individual or group. The benefit of such a powerful tool in answering difficult questions, in addition to developing a real time management system, should not be overlooked.

The current system, a Tektronix 4013 with Graph Pen digitizer terminal and XDS Sigma-7 (130K words and operating under Universal Time Sharing) allows anyone interested in the problem; parents, students, teachers, taxpayers, etc., to participate in its solutions. They can air their ideas and complaints, and the system can be used to evaluate those ideas. Thus the system becomes a moderator for finding compromises that the total community can support. Using it with modern techniques for arriving at group consensus now evolving in the area of management science (DELPHI, etc.) and with some imagination, a powerful tool for creative solution to one of our society's most critical and potentially damaging problems can be developed.

The current problem facing the school boards is the assignment, transportation, and education of the children of metropolitan areas. The best solution to this problem can be found through analysis by an interactive man-machine approach. The following points will illustrate the superiority of man-machine interaction over computer models.

a) The goals of equal educational opportunity, while being partially measured by such quantities as average dollar spent/pupil/race or percentage of a given race in adequate or above adequate facilities, etc.. do not give a complete picture. The subjective views of professional educators, school boards, and the courts are important aspects of the problem, but cannot be brought to bear on the question if only a computer model is used. However, within an interactive model these judgments can be utilized.

b) The interactive total system analysis provides quick and accurate answers to the 'what if' types of questions that arise in the planning stage. Later in the implementation of these plans the system can be used to find rapid solutions to the problems that arise in trying to smooth out random difficulties following the period right after school opens. This cannot be duplicated by piecemeal computer models.

c) Since an interactive total systems model can address itself to the complete problem and not just to one piece of it, the problem of having too many children assigned to one school, or poor utilization of buses, etc., will not occur. Thus, oversights that frequently occur owing to one department failing to communicate its problems to the others are kept to a minimum.

d) The cost of systems development, maintenance, and start-up time would appear to be far smaller than computer models based on previous experience with similar problems.

e) The role of educating the planners to all aspects of the problem is also a key benefit. The ability to draw up and to defend a plan of action is greatly enhanced by this interaction since the planner will have been forced to review many of the questions raised as part of the solution development.

Thus, an interactive program can provide the school board with a powerful planning tool. The judgments of the board provide the final solution based on the use of this tool and, while this may seem to be less objective to some, it provides the human element necessary for so important a decision.

RESULTS

It would be easy to report that on all test problems attempted the system performed satisfactorily, and leave the reader with a high degree of enthusiasm for the method. However, candor bids that we put the interactive graphics approach in a more negative light. A problem-oriented graphics system can fail for a number of reasons:

1. The system is too feeble an approximation of the real world problem.
2. The system, while robust, is too complex, costly, or unreliable for the user and, therefore, not practical for him to learn the new techniques required.
3. The system does its job too well, and causes the human to reject it as a threat to his current job, status, etc.

The system just described failed in its first attempt to attack a real urban school system problem for reason 3. A solution to the problem at hand, in fact, was not what was desired. As it turned out, the system would have been enthusiastically received if it had failed to find a feasible solution. The threat posed by this system was that it did what the school planners claimed could not be done; it found answers to those problems which the planners did not. Since appeals to higher courts were later made based on the claim that no efficient and safe transportation solution existed, one can understand how an outside solution would not be desirable. Hence, for those who did not support busing, the system was a dangerous threat.

The system posed a threat also to the Transportation Officer who had constantly claimed a need for more funds and buses. The system frequently found reductions of 10-20 per cent in the number of buses needed, and similar reductions in mileage. Suppliers of buses, gasoline, etc., were similarly less than enthusiastic and lobbied against implementation of the system.

The plan recommended as a result of using this interactive graphics system also unmasked the federal government's two-sidedness: on the one hand, the courts were ordering busing; on the other, funds for the planning systems to design feasible busing routes were being withheld, even when requests for funds were made by local community groups such as the Emergency School Assistance Program. Thus, the system has not been as successful as it might have been, and until society decides that it does want true equal educational opportunity, this system will be just another artifact.

It is worthwhile to note, however, that not all of this effort was in vain. The interactive graphics system was modified to solve a large number of distribution problems associated with plant and warehouse location, truck dispatching, bus routing, garbage collection, etc. Results on such problems can produce substantial cost reductions. Since most distribution systems are very inefficient in their allocation of vehicles, a complex interactive graphics program costing thousands of dollars yields an answer saving hundreds of thousands. For instance, a recent study of a newspaper delivery system showed a reduction of 10 per cent in mileage and 40 per cent in the number of vehicles required. That reduction was worth several hundred thousand dollars per year, while the (one-time) cost of the study was under ten thousand dollars. This high benefit ratio was typical of the studies.

The plan outlined can handle a large urban school system involving up to 500 school buses and several hundred thousand school children. Problems of encoding data, etc., are minimal. Due to the interactive features, the transportation network needs only to be roughly approximated.

Safety features, physical limitations of buses, roads, etc., can be edited into the final solution by the Transportation Officer or other qualified person making the review, a task in which his experience and training can be used in an efficient way. Therefore, the Transportation Officer really could have a much more vital and creative role using the interactive graphics approach than in times past. If care is taken to point out that past transportation network performance is not a reflection on the Officer's professionalism, it is our hope that, once the system is presented and worked with, interactive graphics will lead to transportation systems which are efficient in their use of personnel, vehicles, and our diminishing fuel supplies.

CONCLUSIONS

We conclude that the technique of a two-phase approach:

1. locating and identifying an underlying basis for solution; and
2. a man-machine interactive phase,

can be a powerful tool for use by school planners in the solution of the problem of providing equality of educational opportunity in public school systems. The current system is capable of solving a large urban school busing problem.

Extension of the interactive graphics approach to other distribution problems (ones in which a high degree of emotionalism is not present as it is in the school busing situation) has proven successful and financially worthwhile to users. In future work, extensions of the range of constraints which can be accommodated in both phases of the solution process will be attempted, and objective functions other than total cost will be studied.

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APPENDIX

Simplified LP Formulation Actually Used in Solving School Problem.

Assumptions:

a) Teacher problem is already solved.

b) All cost constraints (except for transportation costs) will be satisfied elsewhere.

Goal: Minimize total transportation cost within the system:

$$\text{minimize } z = \sum_i \sum_j d_{ij} (w_{ij} + b_{ij})$$

where d_{ij} = cost of transporting one pupil from stop i to school j.

Constraints:

1. $\sum_i (w_{ij} + b_{ij}) \leqslant c_j$ for each j
2. $\sum_j w_{ij} = W_i$ for each i

   where W_i is the number of type-1 pupils at stop i.
3. $\sum_j b_{ij} = B_i$ for each i

   where B_i is the number of type-2 pupils at stop i.
4. $\sum_i b_{ij} \leqslant \alpha \sum_i (w_{ij} + b_{ij})$ for each j.

   where $0 \leqslant \alpha \leqslant 1$
5. $\sum_i b_{ij} \geqslant \beta \sum_i (w_{ij} + b_{ij})$ for each j

   where $0 \leqslant \alpha \leqslant \beta \leqslant 1$.

Constraint 1 requires each school to accept no more than its capacity c_j.

Constraint 2 requires that all type-1 pupils be assigned.

Constraint 3 requires that all type-2 pupils be assigned.

Constraints 4 and 5 require that the specified ratios of type-1 and type-2 pupils are met.

[NOTE: "type-1" and "type-2" refer to different ethnic or racial groups.]