DOCUMENT RESUME

ED 039 641 EA 002 871

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TITLE A Quantitative Approach to the Design of School Bus Routes.
PUB DATE Mar 70
NOTE 23p.; Paper presented at the Annual Meeting of the American Educational Research Association (Minneapolis, Minnesota, March 2-6, 1970)

EDRS PRICE EDRS Price MF-$0.25 HC-$1.25
DESCRIPTORS *Bus Transportation, *Computer Programs, Cost Effectiveness, Decision Making, Educational Planning, Educational Research, *Man Machine Systems, *Mathematical Applications, Safety, Simulation, *Student Transportation

ABSTRACT

A number of factors--including the reorganization of school administrative structures, the availability of new technology, increased competition among groups for limited resources, and changing patterns of communication--suggest an increased need for quantitative analysis in the school district decision-making process. One area of school decision-making that is highly adaptable to quantitative analysis is student transportation. The prevailing manual approach to bus scheduling and routing is time consuming and requires an excessive amount of administrative talent. A more satisfactory method for bus routing that provides optimum service and safety at minimum cost requires man-machine interaction. Under this method, a computer would perform rapidly all the complex mathematical calculations while allowing for administrator intervention when necessary. Additional benefits that would accrue from computer-designed bus routes include simulation capability for planning, and increased management control. For most school districts, quantitative analysis of operations will require basic changes in staffing and data collection procedures. Increased efficiency in subsequent years should more than offset the high initial costs. (JH)

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A QUANTITATIVE APPROACH TO THE DESIGN OF SCHOOL BUS ROUTES

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Paper Presented at Symposium on
Application of Quantitative Techniques
to School District Decision-Making
1970 Annual Meeting, American Educational Research Association
Minneapolis, Minnesota, March 2-6, 1970

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EA 002 871

THE AGE OF AQUARIUS: A NEW ERA IN STUDENT TRANSPORTATION?

The successful introduction of a new technology, mathematical technique, fashion fad, or student riot is strongly dependent upon the simultaneous occurrence of various factors. It seems that we now have the opportunity of incorporating a day-to-day operational use of certain mathematical tools to assist us in the student transportation problem. It is up to us to make sure that this will be so. What are these signs pointing to the possible coming of a new area in student transportation?

First, may I suggest that such a symposium as today's--Quantitative Techniques for School District Decision-Making--will be a common occurrence at future meetings of the AERA and other educational associations.

Second, in various provinces of Canada and states of the U.S.A., there is an ongoing reorganization and amalgamation of boards or school districts of education. For example, in the Province of Ontario, the following pattern has evolved since the end of World War II:

Table 1. Amalgamation of Ontario boards of education

YEAR	NUMBER OF BOARDS	BASIC EDUCATIONAL UNIT
1945	5649	the school board
1946	3767	the school board
1967	1446	the township
1969	125*	the county
1971	???	???

*In addition, there will be fewer than 110 smaller boards to administer school sections and zones in remote areas, on crown lands, and in hospitals and treatment centers.

Previous to 1969, each of the boards in Ontario had been responsible for student transportation in its own area and, since some of the areas overlapped, there was a tendency for services to be duplicated. With the mentioned amalgamation, an ideal opportunity has arisen for the elimination of some of this duplication and the application of more efficient means of bus route planning and design.

Third, the rapidly increasing costs of student transportation have provided a target for the taxpayers' demands for more efficient operation. Nationally, in the United States, $700 million a year is spent transporting 16.5 million students daily; that total is more than three times the number of passengers carried in the same country by the airlines, and the task continues to grow in magnitude.[1]

Fourth, an unusual amount of attention has been paid, through journal articles and school district involvements, to the student transportation problem. For example, the January issue of AEDS Monitor[2] carries a reprint of an article on student transportation that describes New Jersey's pilot program in computer-assisted school bus scheduling. (I shall return to this article later.) In August 1969, the Centre for Continuing Education, York University, Toronto, played host to the Ontario Association of School Business Officials and the School Bus Operators' Association of Ontario, at a Conference on School Transportation.

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1. Association Educational Data Systems (AEDS) Monitor, VIII, 4 (November 1969), 4.

2. Ibid., "School Bus Scheduling," VIII, 6 (January 1970), 11-12. Article reprinted from School Bus Fleet, August/September 1969.

Fifth, enterprising individuals and large consulting firms are turning their attention to the soft sciences: health, education, and welfare. There will be constant pressure on administrators--from these sources, and from the public--to make use of scientific management techniques to assist them in a rational allocation of scarce resources to competing claims.

The stage is set then because of the above factors--namely: changing times and the reorganization of administrative structures; the availability of technology; scarce resources and competing groups; the global village concept of instant communication through media networks (bandwagon effect); and entrepreneurial interests.

So, in fact, while students are singing about the coming of the Age of Aquarius, I hope that administrators will be entering a new era in student transportation.

WHAT IS IT ALL ABOUT? THE GOALS OF STUDENT TRANSPORTATION:

Well, then, what is student transportation all about? What are its objectives? How can we operationalize them? In what manner do we evaluate the services provided and allow for feedback to operate?

Suppose that the following definition be considered:

> The goals of the pupil transportation system are to provide transportation services that conform to State laws and regulations, and local service requirements, in a manner that ensures the maximum safety for school children, as economically as possible.

This definition can be expressed in a tabular version given below:

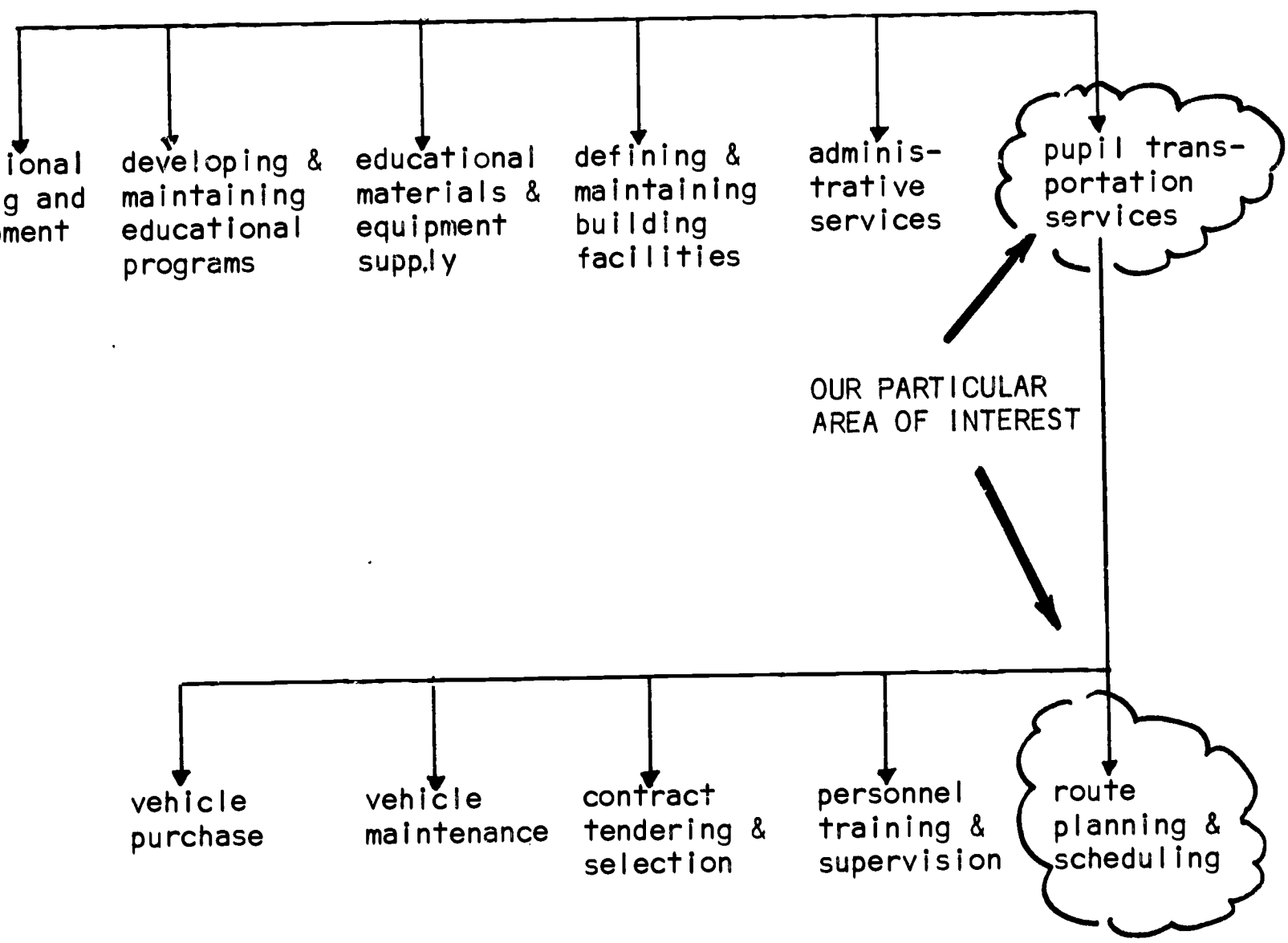
Table 2. Goals of the student transportation system

GOALS		
	SAFETY	drivers and retraining
		vehicles
		accidents, standards, specifications
	COST	maintenance, replacement, operations
		purchase of supplies
		bus purchase: design of tendering procedure[3]
	SERVICE	policy (with respect to reimbursement formula)
		routing and scheduling
		driver management

3. The factors involved in tendering are: the length of the run, the number of pickup points, the number of pupils, the time of school opening and dismissal, road conditions, availability of drivers, ease of supervision, and the condition of the vehicle.

Alternatively, it may be useful to translate the preceding objectives into the presently popular format of program budgeting. A general example of a possible program (K-13) and activity structure for a county board or school district might be as follows.[4] Each activity in student transportation is further subdivided into subactivities.

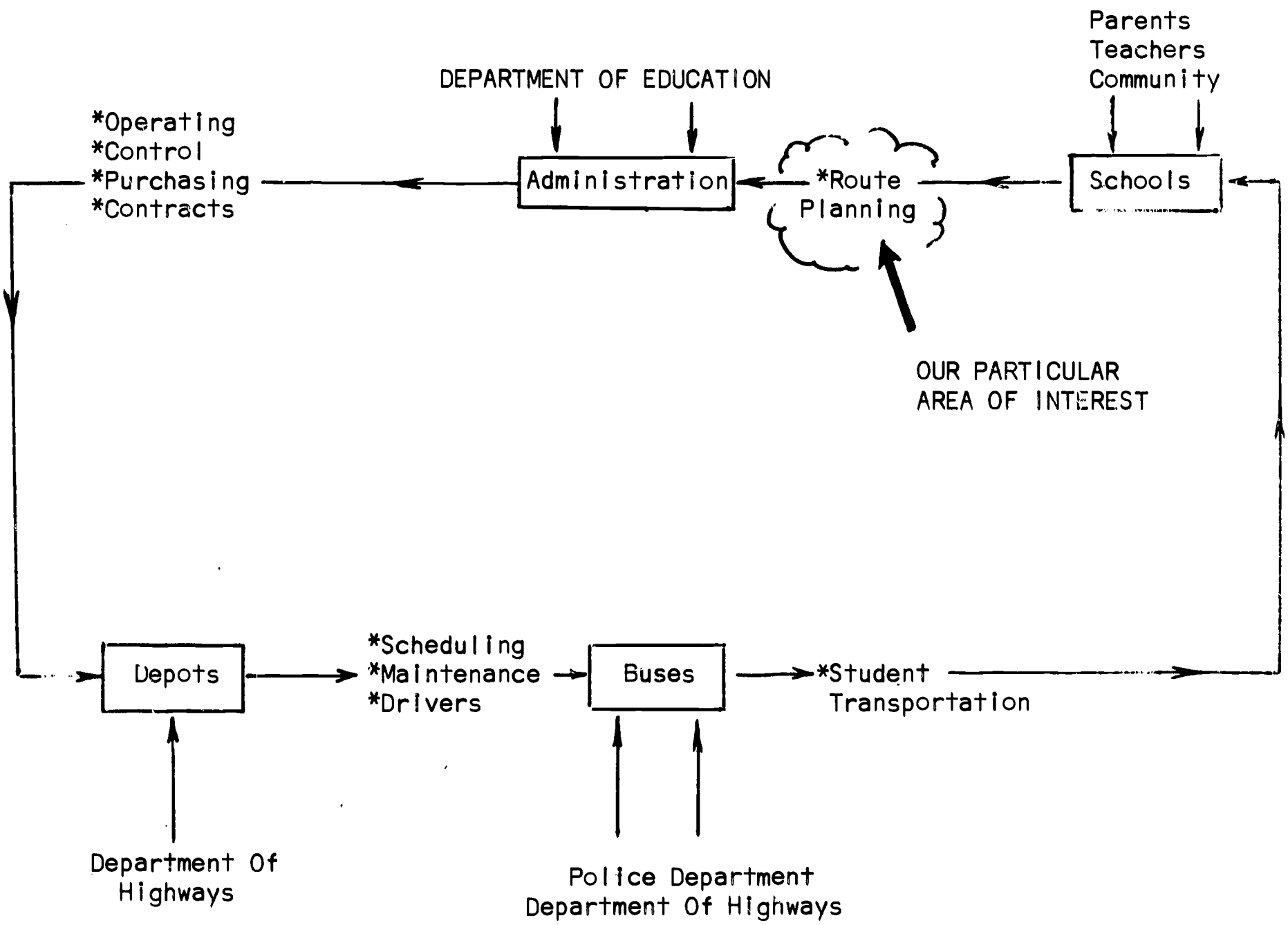
Table 3. Schematic diagram of program budgeting and student transportation



4. Damp, H.S., "Programme Budgeting," School Progress 38, 6 (June 1969), 46-48, 50, 52, 57.

The information flow in the administrative structure concerning student transportation, and the outside pressure of the community and its agencies, may be illustrated as follows:

Figure 1. The community and student transportation[5]



5. Modified from "Figure 30: The Transportation System," p.146, of Developing School Systems (Reference 3, Appendix D in this paper).

The purpose of these illustrations is to emphasize how complex the system of student transportation really is, both inside the school (Table 3) and outside it (Figure 1). Because of the existence of so many human activities, and the presence of constraints, it should be kept in mind that the process of route planning and scheduling has few degrees of freedom (hence a small number of "control knobs"), and will likely require a man-machine interactional approach.

STATE OF THE ART: A QUICK OVERVIEW

Generally speaking, most of the routing studies at present are a completely manual operation in which a scale map of the school district is used to outline the actual routes to be established, based on a listing of the school census. This procedure is not only time-consuming but also requires an excessive amount of administrative talent that could better be utilized in other endeavors. Moreover, the best routes are usually prepared by the most experienced schedulers.[6] Furthermore, under the manual approach, routes may become patched to the extent that they no longer satisfy fundamentals of safety, cost, and service. In the case of newly reorganized (and larger) school districts, a manual routing system is incapable of controlling large numbers of vehicles and drivers, while retaining sufficient flexibility.

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6. Newton, Rita, and Thomas, W.H., "Design of School Bus Routes by Digital Computer," Socio-Economic Planning Sciences, III, 1 (June 1969), 75-85.

In my correspondence with one school administrator, I received the following reply:

> . . . A few schools in New York State are experimenting with the use of electronic data equipment in determining school bus routes. There are apparently many factors, such as the existence of dead-end streets, bridges that are impassable for school buses, etc., that present problems present experiments have not been able to resolve.
>
> Electronic data equipment has been used successfully for establishing bus lists of pupils, but this is not to be confused with determining bus routes. . . .

Although the above sentiment reflects the present state of affairs in most places, a few school districts are beginning to test computer-based scheduling techniques--for example, I mentioned the pilot program being pursued in the State of New Jersey. This is an interesting project in which Dr. Orville Parrish, Director of Transportation, has helped organize a series of workshops investigating the adaptability of IBM's Vehicle Scheduling Program for bus routing.[7] I emphasize "adaptability" because the VSP package was originally intended to solve the problem of "distribution of goods." As far as I can determine, the VSP approach and that of the study under discussion, both use the same algorithm, with the exception that the OISE study was addressed specifically to the school bus routing problem. It is unfortunate that in many studies the entire set of procedures--instead of just the "basis," the "soul"--is transferred unchanged to a different environment. I think there is a lot to be said for the "made-to-order" approach versus the "will-alter" one, be it a bus route or a suit of clothes. Another example of the "made-to-order" approach is that

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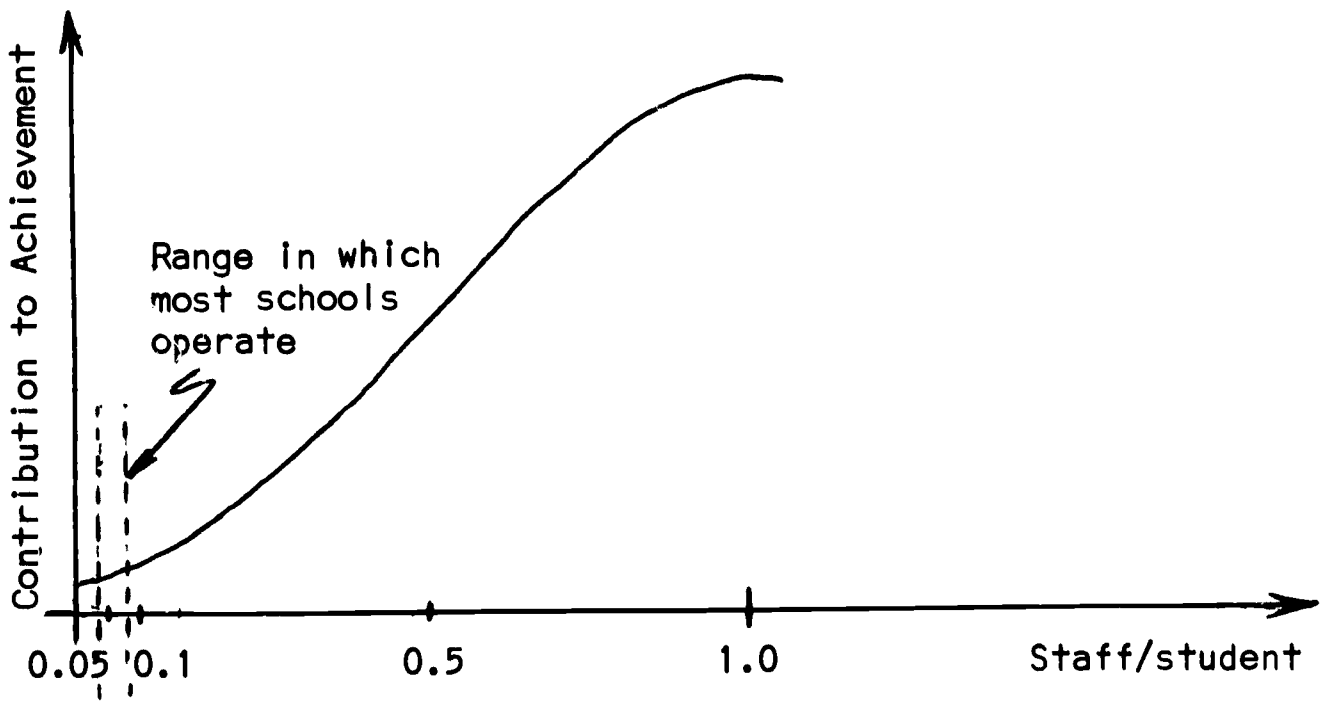
7. See footnote 2.

of Newton and Thomas,[6] who used algorithms to design more efficient bus routes.

What is it about the bus routing problem that makes it an area for continued research? After all, computers have been available for more than a decade, but as yet no complete mathematical solution is available. In my opinion, the student transportation problem is analogous to the "teacher-student ratio" problem that has been around us for a long, long time, and still remains an arena of exciting but dead-end discussions. For those who were unable to attend the historic symposium on "Operations Analysis of Education," sponsored by the National Center for Educational Statistics, Office of Education, Department of Health, Education, and Welfare, and held in Washington, D.C., November 19-22, 1967, I would like to extract a graph from Roger Sisson's paper, entitled, "Can We Model the Educational Process?"[8]

Figure 2. Achievement-staff size relationship



8. Sisson, R.L., "Can We Model the Educational Process?", pp. 109-119 in the Proceedings of the Symposium on Operations Analysis of Education, available as Volume II, Numbers 2/3/4 (Combined Issue) of Socio-Economic Planning Sciences (April 1969), 103-520. Can be purchased from Pergamon Press, Maxwell House, Fairview Park, Elmsford, New York 10523.

Because Roger Sisson is available for questioning*, and because any of you interested in quantitative analysis of educational problems certainly should read the Proceedings, I will not make any comments about this figure except to extract one paragraph:

> . . . The contribution (to achievement) is low as long as the student-staff ratio is, say, 20 or higher. Between 20 and 2-or-3 to 1, there is an increase in achievement; after the ratio reaches 1-to-1, little further contribution can be expected. This certainly reflects one's intuitive feeling about the communication process in a classroom. The more adults working with the students the better, up to the point of diminishing returns. On the other hand, once the number of adults is less than 1 for every 30 children, communication is severely restricted and increase in achievement is low. The problem of finding the exact shape of this curve (i.e., finding the parameters), is extremely difficult, and one we are now attacking. It would be better to have some basic learning theory from which we could derive the parameters for this relationship, but no such theory is yet available. . . .

Now I would like to propose a similar conceptual approach to the design of school bus routes in which the entire range of operations is examined, as in Table 4.

Table 4 sets the upper and lower limits for solutions ("best" and "worst" respectively) to the student transportation problem. Note that the so-called "best" solution (box 6)--of least inconvenience to pupils--may not be desirable operationally and, as yet, is mathematically intractable. In addition, the implementation costs may be prohibitive. On the other hand, box 1--the lowest-level solution--reflects today's general state of affairs.

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*. Roger Sisson is also a panelist in this symposium.

Table 4. Feasible and desirable alternatives in bus routing design

POLICY OPERATIONAL LEVEL OF BUS---→

MATHEMATICAL OPERATIONAL LEVEL OF SOLUTION---→

	A picks up and discharges pupil at specifically designated points	B picks up and discharges pupil at his place of residence
III completely computer-based solution:	5. -operationally, policy is attractive -technically, also attractive but as yet not attained	6. -this would be "ideal" solution, but mathematically still unresolved and operationally probably undesirable.
II computer-and-manual solution ("Man-Machine Interaction"):	3. -combines best features of man and machine -a level school districts should strive for	4. -operationally, policy B may not be practical.
I manual solution:	1. -presently most popular approach -tedious and time-consuming	2. -more buses would be required -may not be feasible -even more time-consuming than 1.

The approach that meets most satisfactorily many contemporary criteria is that in box 3. It attempts to create a man-machine interaction[9] that allows the machine to perform rapidly all the complex mathematical calculations, and the man to intervene when necessary. Intervention may be required when the initial schedule produced is unsatisfactory because of unacceptable bus stop combinations, or when it is clear to a transportation officer that a pair of stops should be switched on the route plan.

The philosophy adopted in the OISE study of a computerized system for school bus routing[10] is that of the man-machine interactional approach, in which the computer's ability to perform high-speed mathematical calculations, and man's intuition and judgment, are maximally brought into play. The system designed not only reduced the manual work required, but also produced routes at least as good[11] as those of the local officials, who had had a great deal of experience in their particular district.

In addition, since the OISE program was designed for board officials who may not have had any data processing experience, the preparation of data for input to the program, and the format of the output from the program, were kept as simple as possible. While the preparation of data must be performed by data processing personnel, boards without such staff of their own can contract this work at minimal cost.

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9. Kemeny, J., "Applying Mathematical Models to the Social Sciences," AEDS Monitor VII, 8 (March 1969), 1-2

10. Reference 1, Appendix D.

11. A "good" set of routes is defined as one that takes all pupils to their destinations, while keeping the total bus fleet mileage to a minimum, and keeping no pupil on a bus longer than an agreed number of minutes.

The overall framework of this program is shown in Table 5. The bus stops, as designated by transportation officials, are located on the map of the school district by means of a grid coordinate system. Such a grid system can also assist school planning departments in the following analyses:[12] (a) the projection of student population; (b) the development of attendance boundaries; (c) and in the very important area of district budget development for teachers, supplies, and the construction of new buildings.

From the input listed, one notes that this approach attempts to provide a feasible schedule that represents a "good balance" between the basic variables of travel time, distance, and the actual number of buses available. From the output listed, it is seen that for each bus route an ordered sequence of bus stops is provided, stops that the driver must cover on the way to and from school each day.

See page 14 for Table 5.

12. Kaimann, R.A., and Marker, R.W., Educational Data Processing--New Dimensions and Prospects (Boston: Houghton Mifflin Company, 1967), especially pp. 225-227.

Table 5. Inputs and outputs of the suggested procedure

INPUT REQUIRED:	THE "PROCESS":	OUTPUT PROVIDED: (for each designed bus route)
student location school location plotting of the bus stops as designated by board officials on a large scale map of the school district involved policy variables: a) maximum time any student is to be required to travel on a bus b) the school starting time number of buses available and their respective capacities human contribution: school district knowledge, intuition a list of parameter variables characteristic of a school district, and of road networks of that area	COMPUTER PROGRAM WRITTEN IN FORTRAN, USING AN ALGORITHM DEVELOPED BY CLARKE & WRIGHT.[13] BASICALLY, THE MATHEMATICAL ALGORITHM MINIMIZES THE DISTANCE TO BE TRAVERSED IN COVERING A NETWORK OF BUS STOPS. BASIC CONCEPT IS THAT THE TWO BUS STOPS THAT PROVIDE THE GREATEST SAVINGS IN DISTANCE SHOULD BE COMBINED INTO THE SAME ROUTE.	the bus capacity the bus stops visited (in the order of pickup) the times of arrival at the bus stops and finally at the school the number of students on the bus the duration of the trip from the first pickup to the school the student-minutes[14] for the trip

(THE SO-CALLED "BLACK BOX")

13. Clarke, G. and Wright, J. W.,"Scheduling of Vehicles from a Central Depot to a Number of Delivery Points," Operations Research, 12 (1964), 568-581

14. "Student-minutes" is the sum of the traveling times of all students on the trip, for each pickup point or bus stop. For example, if there are 5 students at stop XX and they all travel for 20 minutes, the "student-minutes" equals 100.

SENSITIVITY ANALYSIS AND SIMULATION RUNS

As stated before, the computer-designed set of bus routes is at least comparable to or slightly better than the one manually created by competent transportation officers, with the additional benefit of considerable savings in staff time. But more important, such a program provides various means of simulating and analyzing key questions involved in planning. For example, the model readily demonstrates to the administrator the ways in which changes in the following variables would affect the quality and cost of pupil transportation: (a) the maximum riding time allowed; (b) the minimum distance from their schools that students have to reside in order to qualify for bus service; (c) the staggering of school-opening times; (d) alternative configurations of numbers and capacities of buses in the fleet.

Foreknowledge of the sensitivity of current fleet operations to various changes, and the resulting effect of monitoring change values, can help markedly in school budget planning. To perform such tests by hand would be impractical because of the computation time required, but a computer-based model provides the necessary capability.

CENTRALIZED CONTROL[15]

Lack of control over the costs of existing transportation systems is a matter of concern to educational administrators. One of the main reasons for such lack of control is the practice, prevalent in many boards, of giving commercial bus contractors full charge of all aspects of the operation, including routing. This practice has persisted because boards have not had

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15. Adapted from reference 1, Appendix D.

the means of rapidly checking the economic efficiency of existing bus systems, nor of comparing alternative systems. The computer-based procedure described herein gives boards this capability, if the following recommendations are adopted:

1. The student information (location of home, school attended, grade) is stored on computer tapes at the central offices of the board.
2. The routes are designed (or reviewed) annually by board officials.
3. Where transportation is to be contracted out, a reasonable price is set for each route by the officials of the system, and the routes are then offered to the contractors currently serving the area. If a contractor objects (with evidence) that a suggested route is not feasible or a suggested price is unfair, then arbitration can be made by the transportation committee of the board.
4. If a contractor refuses the "final offer" of the board for a route or for all the routes of an area (depending on the contract offered), then these will be let out to tender.

An alternative to steps (3) and (4) would be to put all routes up to tender annually, or whenever the usual contract period expires, but this procedure may not be practical in all counties.

The information generated by this automatic-routing design system, which allows a large number of alternative routing "packages" to be considered with relative ease, enables a board to arrive at equitable contract prices and a uniform pricing standard. These factors are as much to the advantage of the contractors as to the board.

The introduction of such a procedure for designing bus routes will increase the work load of a board's transportation officials in its first year of operation, since the student data have to be processed in the appropriate form and the input variables have to be calculated. However, the benefits in subsequent years--in efficient routes and reduced manual effort, hence reduced staff time--will more than offset the initial cost.

STAFFING REQUIREMENTS

Since there will be increased need of quantitative analysis of operations at the school district level, and because the concepts of decision-making and planning, especially planning, are gaining greater hold and acceptance in the Western democratic system, it is obvious that provisions will have to be made to staff board of education offices with qualified quantitatively trained personnel. For many of its operations, the board will have to possess immediate access to systems analysts and data-processing personnel. Problems previously solved by consultants will be attacked and resolved by competent in-house staffs. Large school district operations are now making this system of analytical staff viable. One of the activities of the Department of Educational Planning, at The Ontario Institute for Studies in Education, is precisely that: to train qualified planners by means of various programs leading to the M.Ed., M.A., and Ph.D. degrees.

FUTURE DIRECTIONS

In order to provide the proper input, that allows for ready manipulation, educational administrative officers will be pressured to set up (or continue

setting up) so-called data bank systems. Such systems will maintain and update complete records on every pupil in the school system, and be able to point out the pupil's name, etc., and his distance from school--hence whether or not he qualifies for school bus service.

I tend to agree with the statements made by Dr. Orville Parrish when he states that "there is no doubt in my mind that we are only beginning to exploit the computer's potential in school-related activities."

Futuristically speaking, I see no problems in the way of our being able to design electronic large-scale maps of school districts, with bus stops being indicated by miniature bulbs. By using a console terminal directly linked to the control computer, it would be possible to have the designed bus routes shown electronically on the map. Transportation officers would have immediate electronic displays and would be able to modify the routes easily. Each satisfactory route could then be recorded and the driver provided with an actual eight-by-ten-inch route map of his itinerary, along with specific instructions on the back, and even a list of the names of students on his bus.

ACKNOWLEDGEMENTS

I gratefully acknowledge the financial assistance for this project provided by the National Research Council, Ottawa, under Grant No. A5301 (1968/69). I would like to express my appreciation for the cooperation provided by officials of the Waterloo County Board of Education during the course of this work. My thanks also go to Michael Norman, who ably programmed the Clarke-Wright algorithm and went on to study additional elements of the routing problem,[16] and to Bryan Elwood for discussing the student transportation problem[17] in general.

16. Norman, M.J., "Contributions to School Transportation Problems," unpublished M.A.Sc. thesis, Department of Industrial Engineering, University of Toronto, October 1969.

17. See reference 2, Appendix D.

APPENDIX A:

DATA: PROVINCE OF ONTARIO

STATISTICS

Pupil Transportation 1967-68

Board Supplying Transportation	Daily Number of Routes	Pupils	Miles	Total
Elementary Boards	7,251	289,040	247,594	$ 23,406,796
Secondary Boards	2,779	125,176	131,596	13,061,590
Grand Total	10,030	414,216	379,190	36,468,386

	Boards		
	Elementary	Secondary	Total
Routes of Board-owned Vehicles	1,116	209	1,325
Routes of other Vehicles	6,135	2,570	8,705
Total, Number of Routes	7,251	2,779	10,030
Pupils Transported on Board-owned Vehicles	39,883	4,722	44,605
Pupils Transported on other Vehicles	249,157	120,454	369,611
Total, Number of Pupils Transported	289,040	125,176	414,216
Destination of Pupils: Secondary Schools	11,091	125,176	136,267
Destination of Pupils: Elementary Schools	277,949	-	277,949
Total, Number of Pupils Transported	289,040	125,176	414,216
Distance from home to school			
Under 2 miles	55,301	5,087	60,388
2 - 3 miles	100,178	29,681	129,859
4 - 5 miles	59,205	21,151	80,356
6 - 8 miles	43,761	24,892	68,653
9 -11 miles	14,715	17,019	31,734
12 -24 miles	12,540	24,894	37,434
25 -34 miles	1,863	1,871	3,734
35 -44 miles	872	389	1,261
45 miles and over	605	192	797
Total, Number of Pupils Transported	289,040	125,176	414,216

Source: "Report of the Minister of Education" 1968

APPENDIX B:

WATERLOO COUNTY BOARD OF EDUCATION:

In the year 1969/70, about 8,900 pupils will travel on regular bus routes each day; 130 sixty-seat buses, each traveling 10,000 route miles annually, will be required to meet this demand. The total expected cost of providing these services (including extracurricular activities) will be in the neighborhood of $900,000.

The approach described in this paper, for planning school bus routes, was fully tested in Waterloo. Routes designed (using 1968/69 and 1969/70 student data) compared favorably[18] with those prepared by local officials. The cost of running the program on an IBM Model 360/65 computer--to design routes for one high school and a group of elementary schools, involving a total of 1,265 students--was less than five dollars.

APPENDIX C:

OHIO DEPARTMENT OF EDUCATION:

The school bus fleet in the State of Ohio totals approximately 13,000 buses. These buses are used to transport well over a million students daily at a yearly operating cost in excess of forty million dollars.

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18. See reference 1, Appendix D.

APPENDIX D:

The following reports are published by and can be purchased from

Publications Sales
The Ontario Institute for Studies in Education
252 Bloor Street West
TORONTO 181, Ontario
Canada

1. Tracz, G.S., & Norman, M.J. A Computerized System for School Bus Routing. 1970. Pp. 29. ($1.50)

2. Elwood, B.C. Student Transportation: A Comparison of Alternative Methods for Providing Service. 1970. ($2.00)

   In general, a student transportation service can be provided in one of four ways: (a) Board owned and operated; (b) private contractor operated; (c) public transportation; (d) some combination of the preceding three. A procedure for selecting and comparing viable alternative methods has been developed and implemented in a county school board system. The report describes this procedure, along with worked examples that illustrate its application.

3. Greenfield, T.B., House, J.H., Hickcox, E.S., & Buchanan, B.H. Developing School Systems: Planning, Organization, and Personnel. 1969. ($3.50)

   A manual for the guidance of trustees, administrators, and teachers in the organization and function of large school districts. The authors recognize that large school systems can improve the quality of education only if they deal successfully with a number of organizational problems that arise quickly and grow disproportionately as system size increases. This handbook outlines the means of setting objectives, and relates them to planning and development; organization; personnel; finance; data processing; plant management; plant planning and development; transportation management; purchasing and stores; and external relations. Checklists and guidelines are included.