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THE ANALYSIS AND DEVELOPMENT OF A SEMI-AUTOMATED BUS UTILIZATION SCHEDULING SYSTEM.

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INVESTIGATION AND RESEARCH FOR AN AUTOMATED, BUS UTILIZATION AND SCHEDULING SYSTEM WAS REPORTED. THE DEVELOPMENT OF THIS SYSTEM WOULD INVOLVE (1) PROGRAM DESIGN AND COMPUTER SELECTION, (2) CODING OF THE SUPERVISOR PROGRAM AND RELATED PROGRAMS, (3) PROGRAM CHECKOUT, (4) DATA CONVERSION, (5) SYSTEM VERIFICATION, AND (6) FINAL DOCUMENTATION, INCLUDING DETAILED PROGRAM DOCUMENTS AND THE USER'S MANUAL PRESENTING SYSTEM CONCEPTS, MACHINE SPECIFICATIONS, AND OPERATIONAL PROCEDURES. A SYSTEM DESIGN AND OPERATIONAL PROGRAM FLOW WAS INCORPORATED IN THE REPORT. THE PROJECT WAS NOT COMPLETED BECAUSE OF INSUFFICIENT TIME. (GC)

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THE ANALYSIS AND DEVELOPMENT OF A SEMI-AUTOMATED BUS UTILIZATION SCHEDULING SYSTEM

Cooperative Research Project No. 6-1192

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I. THE PROBLEM

Public school authorities periodically face the task of establishing new school-bus schedules and of revising them as changes occur in the enrollment and geographic distribution of students. Because of the many variables involved in a transportation problem of this nature, the optimization of bus schedules is very difficult under the present manual methods. And where a reasonable optimization has been effected manually, the tendency is strong, because of these difficulties, to keep to the schedule as changes in the variables occur, resulting in a gradual loss of economy and efficiency. As school enrollments increase and as the geographic complexity of communities increases, the task of bus scheduling becomes increasingly burdensome, and the chances of maintaining a bus schedule in an optimum state become increasingly remote.

The advantage of a computerized bus scheduling system becomes apparent when it is shown that under such a system

a. the number of buses required can be reduced, and

b. individual and total student travel time can be reduced.

II. OBJECTIVES

The following objectives were established for the research conducted.

1. the examination of the requirements and the feasibility of a semi-automatic program for bus scheduling. The user would provide the computer with the specific pick-up points an pick-up point loads, together with data on pick-up point links; the computer would generate optimum paths from these points, and within these optimum paths would optimize time and cost factors in accordance with criteria specified by parameters input by the user. An output would be provided to the user showing the several best solutions for final selection. This entire procedure can be repeated with altered parameters until an acceptable solution is obtained. Final output would be in a form usable by schools, bus companies, and students.
2. to examine extending the application of semi-automatic scheduling program designed for a single destination, i.e., a single school, might be expanded to include multiple-destinations, i.e., all schools within a district. By using a single, integrated schedule, significant savings in time and cost can result.
3. to design and implement a semi-automatic computer program

for bus scheduling called BUSS (Bus Utilization and Scheduling System). This is to be a generalized program which will be adaptable to schools in urban, suburban and rural environments. The program will incorporate the objectives identified in (1) and as many of the objectives identified in (2) as prove feasible.

The accomplishment of the general objectives of this study will entail the following preliminary objectives:

1. Study and selection of mathematical or operations research techniques for third generation computers best suited for the bus routing problem.
2. Study of variables in representative bus scheduling practices and procedures.
3. Survey of suitability of existing computers for a program of this kind. Storage limitations and their effect on the storage requirements for bus scheduling programs for communities of various sizes will be ascertained. Consideration of the feasibility of computer system use costs.
4. Development of criteria by which to evaluate the feasibility and desirability of both semi-automatic and automatic programs.

III. PROCEDURE

The procedures followed for accomplishing the objectives of the project are outlined below:

A. An examination of mathematical and operations research techniques for selection of optimum procedures for the solution of bus scheduling problem was made. Specifically, this activity accomplished:

   1. A survey of established techniques for solving transportation problems with a view of their applicability to the problem. Established linear and non-linear programming techniques and their extensions were applied to the problem using a scratchpad model of an elementary bus schedule as a means of evaluation.

   2. The adaptation of the most promising procedure was made.

   3. An examination of computer processing and storage requirements posed by the procedure selected in (2) followed including an examination of the capabilities of the new generation of computer to satisfy these requirements.

   4. The preparation of a report outlining the mathematical or operations research approach to be used in this project and the reasons for its selection was made with limitations of the method listed.

B. Data Collection and Analysis, was accomplished as follows:

1. The cooperation of a local school district was sought in order to obtain the following information.

   a. data on actual school bus schedules including student loads, routes, pick-up points, number of buses allocated, total student travel time, range of individual student travel times, data necessary to the evaluation of routes (traffic conditions, road conditions, etc.).

   b. information on practices and procedures affecting bus design, such as constraints on student travel time, afternoon return-home bus schedules, bus scheduling during registration days and examination days, actual versus scheduled load fluctuations, etc.

   c. specification on carrier types and capacities.

2. A letter survey of bus scheduling systems from urban, suburban, and rural schools in the nation was accomplished in order to seek to:

   a. isolate special requirements or problems, if any, unique to urban, suburban, and rural schools.

   b. establish probable upper range limits for computer storage requirements.

C. The construction and testing of a mathematical model using the method developed in (A) and the data collected in (B) was made. To facilitate evaluation of the model, the data was taken directly from an existing bus schedule currently in use.

1. one "pass" was made to simulate the operation of a computer. This model attempted to

   a. generate optimum morning bus routes from pre-designated pick-up points.

   b. optimize load and time factors within the generated routes.

   c. output a completed bus schedule giving bus allocations.

D. An evaluation of the model-generated bus schedule was accomplished by direct comparison with the manual bus schedules generated from the same data and currently in use.

1. The following criteria was applied:

   a. has minimization of individual and total student travel time occurred?

   b. has minimization of total bus time occurred?

   c. has minimization of the number of buses and type of carrier occurred?

2. Justification for proceeding with program design and implementation was established. If justification could not be established, project cancellation was to be recommended.

E. The design of Operation Program Requirements for a semi-automatic bus scheduling system were made. This activity included:

1. The selection of a computer and computer configuration for the program.
2. Selection of a suitable programming language.
3. Description of system concepts.
4. Specification of input requirements and design of input formats.
5. Design of program logic for a supervisor program and programs that perform the following functions:
   a. accept preformatted inputs,
   b. generate routes from input data,
   c. allocate type and number of carriers,
   d. assign pick-up times,
   e. optimize bus allocation and time assignments according to parameters set by the user to define the constraints and objective function of the system, and
   f. format outputs of the schedule for use by the school, students, and bus companies.

F. An evaluation of the requirements and feasibility of a fully automatic bus scheduling program completed the project.

IV. RELATED RESEARCH AND FINDINGS

A. INTRODUCTION

The simulation of school bus routing and scheduling by an electronic computer has been relatively undeveloped.[1] The majority of applications of school bus routing, which is described later in this report, is limited to automatic data processing equipment (i.e. non-computer linked machinery such as sorters, printers, collators, etc.). These systems use the prementioned data processing equipment and

1. MAINTENANCE KEY TO EFFICIENTY - The Palatine School District, Cook County, Illinois - School Bus Fleet, June, 1965, pp 11-16.
SCHEDULING WITH AERIAL MAPS SAVES "SHOE LEATHER" - School Bus Transportation, June, 1964, pp 11-13.
OPERATING A SUCCESSFUL SCHOOL TRANSPORTATION SYSTEM - School Bus Transportation, June, 1963, pp 29-31.
SAFE SCHOOL BUS LOADING ZONES DEPEND MAINLY ON LOCATION - School Bus Transportation, August, 1962, pp 18-20.
DATA PROCESSING DISCLOSES NEW ECONOMIES - School Bus Transportation, June, 1962, pp 20-21.
THE MAIN WITH THE PRECIOUS CARGO - A. L. Newell, School Board Journal, February and March, 1964.
ONAWAY, MICHIGAN - School Bus System - F. Hilliker, School Board Journal, December, p. 45.
WATCHOUT FOR SCHOOL BUSES - W. N. McDuffie, Jr., School Board Journal, October, 1960.
PREPARING BUS ROUTES - B. H. BelKnap, School Board Journal, May, 1957, pp 57-58.
SCHOOL BUS ROUTING FOR SAFETY AND EFFICIENTY - W. B. Wolfe, School Bus Transporation, December, 1961, pp 24-26.
PUNCH CARD CONTROL FOR SCHOOL BUS TRANSPORTATION - C. L. Rhein, School Bus Transportation, June 1961, pp 13-15.
AERIAL SURVEYS AID SCHOOL BUS ROUTING - R. S. Knaus, School Bus Transporation, June, 1961, pp 16-20.

school census cards to determine:

1. student eligibility for public transportation and
2. pupil assignment to buses preassigned to an existing route.

The only computer program that has been developed was completed by Dr. Roscoe A. Boyer at the University of Mississippi in 1964.[2] The program has been used successfully[3] during the past two years by the Florida Transportation Department, Board of Public Instruction of Dade County, Florida.

The application of operation research and mathematical techniques to the problem has been virtually non-existent, although there are applications such as network theory, graph theory, linear programming, etc. that appear to apply. The majority of the techniques to solve routing problems that are presently in operation in the transportation field are concerned with the optimization of the cost factor through shortest distance theories.

Therefore, the commercial applications of operational research

2. THE USE OF A COMPUTER TO DESIGN SCHOOL BUS ROUTES - R. A. Boyer, under the Cooperative Research Program of the Office of Education and Welfare, Project Number 1605, 1964.

3. Unpublished letter, The Board of Public Instruction of Dade County, Florida, Florida Transportation Department dated August 17, 1966

techniques in the field of transportation, i.e. truck, rail and sea routing are concerned mainly with the problem of a fully loaded vehicle moving from one destination through a series of points to a final destination whereby cost has been minimized. The distribution of the load remains a constant factor, although in some applications it has been treated as a variable whereby the load is deposited and reused in the system to meet optimization.

B. SURVEY OF EXISTING SYSTEMS

A mail survey[4] and manual search through educational publications was made to determine if any mechanized or semi-mechanized systems were presently in operation. In the mail survey, a letter was sent to every state department of education in the United States. Of the fifty states contacted, thirty-two returned replies as to the existence or non-existence of a system in their state. Of the thirty-two that responded, three states, Florida, Minnesota and Mississippi had districts that were involved with the Boyer program for bus routing while three other states had isolated school districts within their state that developed semi-mechanized systems. These systems used primarily punched card oriented equipment and did not use computers. The systems mainly

1. established the eligibility of pupils for public transportation,
2. assigned area codes to student residencies by division of the school district into zones,
3. prepared bus lists for driver use and bus passes for pupils,
4. assigned buses to predetermined routes and assisted in determining schedules and
5. allowed the preparation of data for related state

4. See Bibliography - Section E

reimbursement.

The semi-mechanized systems that are presently in successful operation are at

1. Mesa Public Schools[5]
   Mesa Elementary School District No. 4
   Mesa High School District
   Mesa, Arizona

2. San Bernadino City Unified School District[6]
   San Bernadino, California

3. Toms River Schools[7]
   Toms River, New Jersey

A study was performed for the Jefferson County Public Schools at Lakewood, Colorado[8] on a manual simulated computer system which involved one school and four or five buses but the conclusions were very indefinite and no further use was made of the study.

The only other use of computers outside of Boyer's program for bus routing by educators, is by the State of Ohio which has develcped a computerized bus maintenance file program.[9]

5. Unpublished letter, Mesa Public Schools, Mesa Elementary School District No. 4, Mesa Arizona, dated August 10, 1966

6. PUPIL TRANSPORTATION PROCEDURES IN A MECHANIZED SYSTEM - C. H. Henderson, Journal of Educational Data Processing, Vol. 3, No. 1, Winter 1965-1966, pp. 9-21.

7. TRANSPORTATION BY MEANS OF DATA PROCESSING, Toms River School District, Toms River, New Jersey. Brochure.

8. Unpublished letter, Jefferson County Public Schools, Lakewood, Colorado, dated August 8, 1966

C. BOYER'S COMPUTER PROGRAM

Dr. R. A. Boyer, through the Cooperative Research Program of the Office of Education, developed a computer program at the University of Mississippi in 1964[10] to design school bus routes. The program has been used successfully in the State of Florida. The computer program developed uses a heuristic approach as a solution. It is designed to operate on an IBM 1620 computer with 60,000 characters of storage. The program was coded in IBM's Symbolic Programming System (SPS).

Basically, the program accepts a manually developed route which connects all pick-up points in the system. It sectionalizes and permutes this route until the route has been sectioned into optimal segments based on load capacity and student travel time. The program then outputs the best sectioned routes as the optimal solution. The burden of work that is presently performed manually by the experienced bus scheduler, that of designing what the author calls "suggested routes" has not been relieved.

9. Unpublished letter, State of Ohio, Department of Education, Columbus, Ohio, dated April 28, 1966.

10. Boyer, op. cit.

Though the Boyer program does not exploit the specific capability of the computer, due to the type of computer selected and its peripheral support equipment (tape, drum and disc storage) for simulating a large number of possible route combinations, he has developed a workable model. Boyer in his investigation into a computer solution abandoned the approach that this study has decided is the most feasible[11] and would generate an optimal solution in excess of his present methods. To cite from Boyer's study as to best method "...a combinatorial programming technique which attempted to generate routes and to eliminate poor routes as quickly as possible by the use of time and distance restraints..." This method was thoroughly investigated but a satisfactory program was not written. The use of hand calculations were discarded because the number of possible route generations would be greater than N! As Boyer states "...years would be required to generate and evaluate all the bus routes for even a small school..." Since the IBM 1620 computer that Boyer used was tape oriented and possessed slow processing speeds, the combinatorial programming technique would prove inefficient if not impossible. (See Section E, paragraph 7 for the reasons why combinatorial programming can now be applied.) Boyer did adopt the combinatorial technique as

11. THE USE OF BOYER'S "SEQUENTIAL STEPS" FOR ROUTING SCHOOL BUSES W.A. Thompson, Jr., A. Dissertation Submitted to the University of Mississippi, 1963.

the base for the rationale in his present solution. The review of developments in the field of operations research and their application to school bus routing in this study reveals that Boyer's basic rationale of combinatorial programming is the only solution to school bus routing. His present program lacks system finesse because it is restricted to a small scientific computer with limited external storage devices and internal processing speeds.

D. RELATION OF OPERATIONS RESEARCH TO THE PROBLEM

This section will present an overview of the present progress of mathematical and operations research techniques that appeared to be applicable to the problem of school bus routing and scheduling. The purpose of performing the overview was to determine if any modeling techniques existed that could easily be adapted and programmed. Unfortunately there has been very little progress or to be exact, no work, has been performed at the academic and industrial level that lend itself to adaptation to school bus routing. In fact, each phase of routing for either rail,[12] truck transport, traffic,[13,14,15] sea or air[16] are unique unto themselves due to the inherent variables involved in each problem.

Operations research has been defined as a scientific method

12. DETERMINATION OF THE MAXIMAL STEADY STATE FLOW OF TRAFFIC THROUGH A RAILROAD NETWORK - A. W. Boldyneff, Oprns. Res., Vol. 3, No. 4, November 1955, pp. 443-460.

13. SIMULATION OF A TRAFFIC NETWORK, J. Katz, Communications of the ACM, Vol. 6, No. 8, August 1963, pp. 480-486.

14. APPLICATION OF TRANSPORTATION THEORY TO SCHEDULING A MILITARY TANKER FLEET - M. M. Flood, Journal of Oprns Res., Vol. 2, No. 2, May 1954, pp. 150-162.

15. ORGANIZATION AND OPERATION OF A TAXI FLEET - R. F. Meyer and H. B. Wolfe, Naval Research Logistics Quarterly, June, 1961.

16. MAXIMUM PAYLOADS PER UNIT TIME DELIVERED THROUGH AN AIR NETWORK - G. B. Dantzig and David L. Johnson, Opns. Res., Vol. 12, No. 2, 1964, pp. 230-236.

of providing the users with a quantitive basis for decisions regarding the operations under their control. The general OR and mathematical areas that appear to most readily lend themselves to school bus routing solutions are:

1. Heuristic Modeling
2. Simulation
3. Linear Programming
4. Graph Theory
5. Network Flow Theory
6. Dynamic Programming
7. Combinatorial Programming

Each of the above techniques have been both successfully and unsuccessfully applied to solve the classical problems known as

a. the traveling salesman problem[17, 18, 19, 20, 21, 22]

17. SOLUTION OF LARGE SCALE TRAVELING SALESMAN PROBLEM - G. Dantzig, R. Fulkerson & S. Johnson, Journal of Oprns, Vol. 2, No. 4, November 1954, pp. 393-416.

18. THE TRAVELING SALESMAN PROBLEM - M. Flood, Opns. Res., Vol. 4, No. 1, February 1956, pp. 61-75.

19. GRAPHIC SOLUTION OF THE TRAVEL SALESMAN PROBLEM - Opns Res. Vol. 5, No. 5, 1957, pp. 841-845.

20. INTEGER PROGRAMMING FORMULATION OF TRAVELING SALESMAN PROBLEM C. E. Miller, A. W. Tucker and R. A. Semin, Vo. 7, No. 4, Oct. 1960, pp. 326-329.

21. AN ALGORITHM FOR THE TRAVELING SALESMAN PROBLEM - J. D. Little, K. G. Munty, D. W. Sweeney & C. Karel, Opns. Res., Vol. 10, No. 6, 1963, pp. 927-989.

b. shortest route problem, and [23,24,25,26,27,28,29,30,31,32,33]

c. the transportation problems[34, 35]

22. THE TRAVELING SALESMAN PROBLEM - H. W. Kuhn, Procedures of Sixth Symposium in Applied Mathematics of American Mathematical Society, McGraw-Hill, N.Y.

23. ON THE SHORTEST PATH THROUGH A NUMBER OF POINTS - S. Verblunsky, Procedure of American Mathematical Society II, 6(12/51).

24. ON THE PROBLEM OF SHORTEST PATH BETWEEN POINT I AND II - I. Heller, Bulletin American Mathematical Society, 59, 6 (11/53).

25. ON THE SHORTEST SPANNING SUBTREE OF A GRAPH AND THE TRAVELING SALESMAN PROBLEM - J.B. Kruskal, Jr. - Procedure of American Mathematical Society 7, 1956 pp. 48-50

26. DISCRETE-VARIABLE "EXTREMISM" - G. B. Dantzig, Opns Res., Vol. 5, 1957, pp 266-270.

27. A COMMENT ON THE SHORTEST ROUTE PROBLEM - G. J. Minty, Opns Res., Vol. 5, 1957, pp 724.

28. ON A ROUTING PROBLEM - R. Bellman, Quarterly of Applied Mathematics, Vol. XVI, No. 1, 1958

29. SHORTEST PATH THROUGH A MAZE - E. L. Moore, International Symposium on Switching, Part II, April 1957, The Annals of the Computation Laboratory of Harvard U., Harvard U. Press, 1959.

30. SOLUTIONS OF THE SHORTEST - ROUTE PROBLEM - A REVIEW - M. Pollack & W. Wiebenson, Opns Res., Vol. 8, No. 2, March-April 1960, pp. 224-230

31. THE MAXIMUM CAPACITY ROUTE PROBLEM - T.C. Hu, Opns. Res., Vol. 9, No. 6, 1961, pp. 898-900

32. PATH PROBLEMS - W. W. Hardgrave and G. L. Nemhauser, Opns Res., Vol. 10, No. 5, 1962, pp 647-657.

33. DETERMINING FASTEST ROUTES USING FIXED SCHEDULES - Procedure of AFIPS, 1963, SJCC, Detroit, Michigan, May, 1963, pp. 1-8, Spartan Books, Baltimore, Maryland.

each of which possess a part of the total school bus routing problem.

In the transportation problem the cost of transporting from a variable number of sources to a variable number of destinations is minimized. The most classical solution applying to factory output shipments to warehouse storage. The shortest path problem involves the minimization of time or distance when traversing along a combination or network of routes from an origination point to a destination. Finally, the traveling salesman problem involves the minimization of time or distance through a network whereby all points are entered and the originating point becomes the final point.

Therefore, a computer solution to school bus routing lies in a combination of the above three classical OR problems in that

a. Costs are to be minimized (student travel time) in the transportation problem

b. Time and distance is to be minimized (shortest route problem) and

c. Route combinations are to be optimized (traveling salesman problem).

All three cases can fall into the general category of being distribution problems and are so classified in OR texts.

34. THE METHOD OF REDUCED MATRICES FOR A GENERAL TRANSPORTATION PROBLEM - P. S. Dewey and B. A. Galler, Journal of the ACM, Vol. 4, No. 3, July 1957, pp. 308-313.
35. A HIGH SPEED COMPUTER TECHNIQUE FOR THE TRANSPORTATION PROBLEM - J. B. Dennis, Journal of ACM. April 1958, Vol 5, No. 2, pp 132 - 153

Since a solution to the school bus route problem lies in a combination of the above three, let us look generally at each problem relating it to bus routing.

The closest allied is the traveling salesman problem which is concerned with finding a permutation

$$P = (1 i_2 i_3 i_4 \ldots\ldots i_n)$$

of integers from 1 through n that minimizes the quantity

$$a_{1i_2} + a_{i_2 i_3} + a_{i_3 i_4} + \ldots\ldots a_{i_n 1}$$

Since there are (n-1)! possibilities the problem is to find a minimizing permutation. A segment of the bus routing problem is concerned with permutations as in the traveling salesman case whereby the number of students become a factor in the permutation and the destination becomes a terminal condition (the school) and not the point of origin. The permutation now altered for bus routing becomes

$$P = (a_{i_1} a_{i_2} a_{i_3} \ldots\ldots (a_{i_n}))$$

where the integers range from 1 through n with a restricting control variable placed on the permutation limiting its degree to the $\sum^{n} a$ equal to a constant factor, that being bus capacity and therefore to minimize the quantity (student travel time)

$$a_{i_1} t_{i_{12}} + \sum_{i=1}^{2} a_i t_{i_{23}} + \sum_{i=1}^{3} a_i t_{i_{34}} + \ldots\ldots \sum_{i=1}^{n} a_i t_{i_{ns}}$$

where a = number of students at each point and

t = time or distance factor between points

or in travel time, the minimized quantity is

$$t_{i_{12}} + t_{i_{23}} + t_{i_{34}} + \cdots + t_{i_{ns}}$$

The transportation problem is different from the traveling salesman problem in that the allowable permutations may also be noncyclic. In this problem we find the following conditions:

$$\sum_{i=1}^{m} x_{i_j} = c_j \quad \sum_{j=1}^{n} x_{i_j} = r_i \quad \text{where } x_{i_j} \geq 0$$

and $\sum_{i,j} x_{i_j} d_{i_j}$ = minimum, where m, n, r_i, c_i and d_{i_j} are given positive numbers

with $\sum c_j = \sum r_i = N$ and the quantity d_{i_j} is the known performance rating. The quantity r_i represents the number of carriers initially at an old station i, c_j represents the total number of carriers to be routed to the new station j from all the m old stations. The solution for x_{ij} gives the number of carriers to be moved from old station i to the new station j in the optimal routing.

In its application to the school bus routing problem, the carriers now become the school buses and the old stations are altered to be student pick-up points, with the old station becoming the point of origination for all carriers and the school becoming the terminal point.

Thereby, the quantity

r_i = the number of buses at the origination

c_i = the total number of buses needed to be routed to the school

d_{ij} = represents the time/distance between each point and the solution x_{ij} gives the minimum number of buses to be moved from i to j to optimize routing.

In the shortest route problem, a network of points p_1, p_2..... p_n exists with lines between them. From these points a distance/time matrix A can be constructed with elements a_{ij} representing the length of the line between pi and pj. If no line exists, let $a_{ij} = \infty$ and $a_{ij} \neq a_{ji}$ and $a_{ij} \geq 0$.

Therefore the problem is to find a set of elements whereby $\sum_{ij} a_{ij}$ is minimum.

In summary, the school bus routing problem is a combination of three classical operation research problems

a. the traveling salesman problem,

b. the shortest route problem, and

c. the transportation problem.

Basically stated the solution to the school bus routing problem involves the following step -

the permutation of a sequence of points

$P = P_{i_1} P_{i_2} P_{i_3} \cdots\cdots P_{i_n} P_{i_s}$ where i ranges from 1 to s, s being the terminal point (the school) and becomes the final point in the sequence when $\sum_{i=1}^{n}$ a is equal to or less than the capacity of the carrier or bus involved.

Therefore the minimized quantity as expressed in total student travel (i.e., the accumulated individual travel time spent on the bus by each student) as the final solution is

$$a_{p_{i_1}} t_{i_{12}} + \sum_{i=1}^{2} a_{p_i} t_{23} + \sum_{i=1}^{3} a_{p_i} t_{34} + \cdots\cdots + \sum_{i=1}^{n} a_{p_i} t_{i_{ns}}$$

when $\sum_{i=1}^{n} a_{p_i} = C$

where a = number of students at each point p and

t = time/distance factor between points

E. APPLICABILITY OF PRESENT OR TECHNIQUES

With the formulation of the basic model established in Section D, an investigation into the basic OR and mathematical techniques was made resulting in the selection of the following seven OR areas as being applicable to the solution of the bus routing problem:

1. Heuristic Modeling
2. Simulation
3. Linear Programming
4. Graph Theory
5. Network flow theory
6. Dynamic programming
7. Combinatorial programming

Each technique was researched as to the applicability of the model to school bus routing and whether the model could be decomposed to a level whereby it could be programmed (coded) for a computer solution. In addition, the requirements of the merits of each area was established in relation to computer processing, i.e. the characteristics of the computer in regard to core storage, processing speeds, both internal and external and peripheral units that would be available. Other considerations taken into account were complexity of technique and user ability.

The OR technique of combinatorial programming was selected because: 1) applicable to the problem 2) computer programable and 3) this technique takes advantage of the present random access devices and can use a minimum amount of computer storage.

A brief summary of each OR and mathematical technique is presented below:

1. <u>Heuristic Modeling</u>

   In this technique[36], the problem is divided into sub-optimal groups in that a solution is attempted by trial and error with the most satisfactory solution being the best even though it is not optimal.

   This technique was rejected because it is not applicable to the school bus routing problem in that it only considers one route and not the entire grouping of routes. It forced the selected of the best route thereby all following routes resulted in their worst possible condition (i.e. the fourth, fifth, or nth possible route through a set of pick-up points would prove the most feasible when considering the entire routing picture). The solution did not allow a retracing of steps and proceeded to build only in the forward direction.

36. A HEURISTIC APPROACH TO SOLVING TRAVELLING SALESMAN PROBLEMS - R. L. Karg & G. L. Thompson, Management Science, Vol. 10, No. 2, January 1964, pp. 225-248.

In addition, a model if developed would result in a high degree of programming complexity.

2. Simulation

The technique of simulation is used mainly when there is mathematical complexity. It involves the duplication of an environment such that changes could be made to test particular outcomes on either the immediate problem or on its total effect.

Simulation, probably the best of the techniques reviewed because it could be reused from year to year, was rejected because of the amount of computer data involved that would be required to convert each school district into a computer oriented map, the amount of core storage needed and the total amount of system processing time required. In addition, the costs of obtaining the initial data to feed the machine prior to any routing would prove unfeasible at the school district level.

The system design and programming of the simulation technique is complex in that a general system could not be designed. Therefore, each school district would require additional modification to the existing model that was developed. Thus costs would discount its value.

3. Linear Programming

Linear Programming[37] is the most computerized OR technique since its basic approach to a solution parallels computer processing. It is used to determine the allocation of resources among interdependent or competitive ends. Its goal is the maximization, minimization or optimization of available alternatives.

To the layman, linear programming appears to be the optimal solution, but the uncontrollable variable of the combination of number of students, bus capacity and time/distance reduces each solution to producing the optimal route through a network at the expense of all the other necessary routes.

This technique was not used due to its rigidity in not allowing permutations to occur along points in individual routes. Each route is treated independently, thereby as pickup points are used in a route and eliminated from the system, the construction of the best route as to its cost factor would force future route construction into its worse case. The school bus

37. LINEAR PROGRAMMING AND ESTENSIONS, G. B. Dantzig, Princeton University Press, Princeton, N.J., 1963.

routing problem is one of a combination of kth best route groupings while LP would treat each route individually.

In addition, though LP is the most computerized OR techniques, computer programming is difficult and complex and processing times have been long.

4. Graph Theory,[38,39,40,41,42,43,44] a mathematical technique, is basically the analyzation of simple

38. THEORY OF GRAPHS, O. Ore, Providence, R. I. American Mathematical Society Colloquim Publications, Vol. XXXVIII, 1962.

39. A SERIAL TECHNIQUE TO DETERMINE MINIMUM PATHS - D. L. Weimer, Communications of the ACM, Vol. 6, No. 11, November 1963, pp. 664-666.

40. GRAPHS AND THEIR USES - O. Ore, Random Hours, 1963, New Mathematical Library Series #10.

41. THEORY OF GRAPHS AND ITS APPLICATIONS - Proceedings of the Symposium held in Smolenice in June, 1963, Publishing House of the Czechoslovak Academy of Sciences, Prague - Academic Press, New York, 1964.

42. GIT - A HEURISTIC PROGRAM FOR TESTING PAIRS OF DIRECTED LINE GRAPHS FOR ISOMORPHISM - S. H. Unger, Communications of the ACM, Vol. 7, No. 1, January 1964, pp. 26-34.

43. A MECHANICAL ANALYSIS OF THE CYCLIC STRUCTURE OF UNDIRECTED LINEAR GRAPHS - J. T. Welch, Jr., Journal of the ACM, Vol. 13, No. 2, April 1966, pp. 205-210.

44. ANALYSIS OF GRAPHS BY CONNECTIVITY CONSIDERATIONS - C. V. Ramamoorthy, Journal of the ACM, Vol. 13, No. 2, April 1966, pp. 211-222.

geometrical figures consisting of points and lines connecting these points which is different then studying a point in a plane whose coordinates (X, Y) satisfy an equation. Mathematically, graph theory is classified as a branch of topology but is strongly related to algebra and matrix theory.

Graph Theory proves to be most applicable to finding the shortest path. When the variables of students at each point and the capacity of the bus are entered into the problem, the theory breaks down in that it is no longer representative of a true graph. In addition, as explained in the prior techniques, the problem is solved on a route by route basis, thereby the shortest route is determined at the expense of all others.

Graph theory is extremely difficult to apply to computer programming due to its mathematical complexity. The uses of graph theory are still in the developmental stages. In addition, even though algorthms are available for its solution, extremely high running times are necessary for a computer solution.

5. Network Flow Theory

Network flow theory[45,46,47,48,49,50] in reality is an extension of linear programming and is closely related to theories of current distribution in an electrical network. Its special property is that it extreme point solution is integer valued when its constant terms are integers. A network can be considered as connecting two nodes, a source and destination or

45. ON THE MAX-FLOW MIN-CUT THEOREM OF NETWORK - G. B. Dantzig and D. R. Fulkerson, Linear Inequalities and Related Systems, Annals of Mathematics Studies, No. 38, Princeton U. Press, Princeton, N.J. 1956, pp. 215-222.

46. INTEGRAL BOUNDARY POINTS OF CONVEX POLYHEDRA - A. J. Hoffman and J. G. Kruskai, Linear Inequalities and Related Systems, Annals of Mathematics Studies No. 38, Princeton University Press, Princeton, N.J., 1956, pp. 223-246.

47. MAXIMAL FLOW THROUGH A NETWORK - L. R. Ford, Jr., D. R. Fulkerson Canadian Journal of Mathematics, Vol. 8, 1956, pp.394-404.

48. THE MAXIMUM CAPACITY ROUTE THROUGH A NETWORK - M. Pollack, Opns Res., Vol., 8, No. 5, 1960, pp. 773-736.

49. ON NETWORK FLOW FUNCTIONS - L. S. Shapley, Naval Research Logistics Quarterly, June, 1961.

50. FLOWS IN NETWORKS - L. R. Ford, Jr., and D. R. Fulkerson, Princeton University Press, Princeton, New Jersey, 1962, pp. 192.

several intermediate nodes. Each arch of the network is assigned two numbers which represent flow capacity along the arc in each direction. By assuming a steady state condition, the maximal flow from the origination to the destination is found.

When applied to determining optimal bus routes, the problem of solving an undirected network by determining flow values between all pairs of nodes with capacity restraints on paths has not been fully explored in that it will necessitate the solution of all pairs of flow problems. Since network theory and graph theory are closely allied, the problems as stated for graph theory also are applicable to network theory. The main reason fo rejection, is that developmental work in application to computer solution is in the early stages. The problems of multi-terminal maximal flows has not as yet been fully developed (i.e. in school bus routing, the terminal position in the network would not be the school but the node or pickup point at which the capacity of the bus is met and exceeded). Therefore, the bus problem is a multi-terminal problem. Even if the problem of multi-terminal processing is solved, computer programming would be difficult and complex and computer processing time would be lengthy.

6. Dynamic Programming

This technique[51] is most closely allied to the solution of school bus routing by computer. In fact, the final solution used is a merging of both dynamic and combinatorial programming. In dynamic programming, optimization is performed on a set of decisions which are made sequentially at each level of a multi-level problem. From each level a new set of decisions that will lead to a sub-optimal solution is determined. Therefore it becomes necessary to determine the effect of each decision at every level before the final answer can be reached. This technique was not rejected, in the sense that a better technique was discovered and proved to be more applicable to computer programming. Both, dynamic and combinatorial programming, are readily adaptable to computer design and processing.

51. DYNAMIC PROGRAMMING TREATMENT OF THE TRAVELING SALESMAN PROBLEM - R. Bellman, Journal of ACM, Jan. 1962, Vol. 9, No. 1, pp 61-63.

7. Combinatorial Programming

As stated in its title combinatorial programming[52,53,54,55,56,57] cuts across the field of operations research in that it absorbs parts of dynamic and linear programming as well as heuristic modeling and simulation. It grasps the time problem of school bus routing in that it is a technique whose main emphasis throughout is on finding the number of ways there are of doing a well defined operation or in school bus routing terms; it is a technique which uses of all the possible routes in a system in combination to determine the grouping which will produce an over-all optimal solution.

52. An Introduction to Combinatorial Analysis, J. Riordan, John Wiley & Sons, Inc., 1958, A Wiley Publication in Mathematical Statistics.

53. PROGRAMMING, COMBINATORIAL APPROACH TO THE TRAVELING SALESMAN PROBLEM - G. B. Dantzig, D. R. Fulkerson, & S. M. Johnson, Opns. Res., Vol. 7, No. 1, January-February 1959, pp. 58-66.

54. SOME COMBINATORIAL PROPERTIES OF CERTAIN TREES WITH APPLICATIONS TO SEARCH AND SORTING - T. H. Hubbard, Journal of ACM, Vol. 9. No. 1, Jan. 1962, pp. 13-28.

55. Combinatorial Mathematics, H. J. Ryser, The Mathematical Association of America, 1963, The Carus Mathematical Monographs, No. 14, distributed by John Wiley and Sons, Inc.

56. PERMUTATIONS BY INTERCHANGES - B. R. Heap, COMPUTATION JOURNAL 6, 3 (October 1963) pp. 293-294.

57. APPLIED COMBINATORIAL MATHEMATICS, E. F. Beckenbach, Editor, John Wiley & Sons, Inc., 1964, University of California Engineering and Physical Sciences Extension Series.

In addition, combinatorial programming is easily adaptable to computer programming since mathematical complexity is reduced. It generates all the possible arrangements of n pick-up points taken c at a time if the sequence is ignored.

Therefore, $C\binom{n}{c} = \frac{n!}{(n-c)!\,c!}$

It can store this data for later analysis and allows retracing of movement through a network. Therefore, it can make use of high capacity random access device to maintain its result and with high speed transmission available it can analyze and form decisions rapidly.

F. ROUTING ALGORITHM

This section presents the sequential steps of a routing algorithm which when applied in a computer program will produce an optimal solution to the school bus routing problem. The routing algorithm as stated below should be used in conjunction with Section B, Chapter V, which describes the approach used for the manual solution. In addition the algorithm should be used in conjunction with the Operation Program Design as shown in Section C, Chapter V.

1. Establish a chain matrix which contains the time/distance factor from each point to each adjacent point. Also included in the matrix, is the t/d factor from each point in the system directly to the school.
2. Determine the farthest point from the school from the matrix. Construct a table in descending t/d factor order keyed by pick-up point.
3. With the farthest point as the starting point, determine a sequence of points that establishes all routes to the school. The number of points in each route is controlled by the maximum allowable bus capacity, i.e. with bus capacity as the controlling variable, calculate student travel time (t/d factor multiplied by the accumulated number of students on the bus.)

4. Compare the calculated route to previously calculated routes to determine if this route is one of n (a variable input to the system based on school size, and pick-up points) optimum routes passing through the point. If the caluclated route is better, insert the route in its proper sequence as an entry in the route construction table in ascending order and eliminate the (n+1) entry. Compute the route index, an alphanumeric quantity which allows for rapid cross referencing in further steps, if the route is selected then assign it to the route. The route index is calculated by assigning the alphabetic designation of the pick point as obtained in Step 3 with its sequence number in regard to optimality. This combination is convertible to a location on disk storage. If the calculated route's controlling total is greater than the nth entry disregard it. Thereby, only optimal routes are saved. Store each calculated route index with its controlling total in ascending order into a pick-up point block (i.e. a block will exist for each pick-up point in the system).

5. Determine if all routes have been calculated for this point. If no, return to Step 3. If yes, proceed to Step 6.

6. Output the fifty maximized routes that have been determined for the selected point for review.

7. Determine if all routes have been generated using each point as a starting point. If no, select next point in t/d factor table and return to Step 3. If yes, proceed to Step 8.

8. Scan every route in each entry of the route table to total the number of occurrences of each pick-up point in the stored routes. Store the calculated route index and its controlling total into its related pick-up point block in ascending order for every point in each route. Thereby, the number of routes through a point is increased and further optimized.

9. Determine if all routes have been scanned and totaled. If no, return to Step 8. If yes, sort the point occurrence table into ascending order and proceed to Step 10.

10. Output the route indices by pick-up point block for manual review.

11. Cycle the point occurrence table. Select the point of minimum occurrence and then select first (ith) route for that point, from the pick-up block. Store the route into the route selection table.
12. Scan the sequence of points in the selected route. Eliminate all routes from the system in which each point occurs. The elimination process is performed on mirror imaged tables, therefore data is never destroyed in the system.
13. Decrement the pick-up point totals in the point occurrence table for each point contained in an eliminated route.
14. Determine if the elimination procedure has created a point that is not included along any existing route. If yes, select next best route, re-image the system and return to step 12. If no, proceed to step 15.
15. If all routes have been analyzed and the condition of a point with no route exists, output all routes containing the operating point as a conflict situation and proceed to step 16.
16. Determine if there are any points remaining in the point occurrence table that do not lie along a route. If yes, return to step 11. If no proceed to step 17.

17. Output all recommended routes as well as conflict situations.

G. MATHEMATICAL ALGORITHM

Let T = a matrix of all time/distance factors from an origination point i to a series of individual points j

$$t_{ij} \neq t_{ji} \qquad i = 1, \ldots\ldots n$$

$$t_{ij} \neq 0 \qquad j = 1, \ldots\ldots n$$

let j = s where s represents the final destination or the school.

$\therefore$ S = is a matrix of time/distance factors from each pick-up point i to the school

$$t_{ij} = t_{is} = s_{is}$$

$$t_{is} \neq t_{si}$$

$$i \neq s$$

$\therefore$ t_{is}^* = farthest point along a route to the final destination (school)

let i = 0 where 0 represents the origination point of all routes

$\therefore$ O = is a matrix of time/distance factors from an organization point to all pick-up points i

$$t_{ij} = t_{oi} = 0_{oi} \qquad 0_{oi} \neq 0_{io}$$

let C = a matrix of the number of students

$\therefore$ c_i = number of students that are at pick-up point ti

$\sum c_i$ = C where i=1,.....n

let P = a matrix of total student travel time

$\therefore$ $p_{ij} = c_i t_{ij}$

where $m_{ij} \neq m_{ji}$

$$\text{and } P = \sum (t_{ij} \sum_{i}^{j} c_i) = \sum p_{ij}$$

let r_a = any route selected from matrix T where a = 1,....,m and is an assigned route number

$$r_a = t_{oi} + t_{ij} + t_{jk} + t_{kl} + \ldots\ldots t_{ns}$$

let p_a = the total student travel time for any route selected from matrix T where a = 1,.....,m and is related to the assigned route number

$$p_a = t_{o_i} c_o + t_{i_j} \sum_{o}^{i} c_i + t_{jk} \sum_{i}^{j} c_j + t_{kl} \sum_{i}^{k} c_k + \ldots t_{ns} \sum_{i}^{n} c_n$$

where $c_o = 0$

$$P_{(optimum)} = \sum p_{a\ (minimum)} = \sum p_{ij}$$

where a = i,....,m

let r_{abi} = the bth best route determined from matrix T where b_i = 1,....q from route number a

∴ p_{abi} is the bth best total student travel time for the ath assigned route number determined from matrix T where b_i = 1,....,q

let ab_i = the assigned route index number

$$M_{opt} = M_{ab_1} \leq M_{ab_2} \leq M_{ab_3} \leq \ldots M_{ab_n}$$

where M is the optimum route combinations

for the system.

H. RECOMMENDED COMPUTER SELECTION

The selection of the combinatorial programming technique to perform school bus routing on a computer requires that the following computer processing requirements are met

1. a large capacity random access storage- this allows the storage of over 200 route blocks (at times well over 10,000 individual routes) from which the optimal route pattern will be selected for n number of buses.
2. high speed input/output transfer rates - as the routes are internally constructed; analyzed and accepted or rejected, they are stored in mirrored image tables and moved from computer storage to peripheral storage areas.
3. rapid internal processing speeds - the number of individual calculations is estimated at well over one million for a ten bus school district as well as an equal number of decisions to select the best combination of points to construct the route necessitate rapid add time (processing speed) and storage cycle time, and
4. computer memory modularity - the great variance of individual school district sizes in relationship to

its population and bus numbers, requires that the users of the system are not restricted in its use due to computer memory size. Therefore, the system should be able to operate on a computer configuration that meets its needs while minimizing costs (i.e. a smaller school of 750 students would require a memory size of approximately 32,000 characters while a school of a population of 2500 students would require a memory size of approximately 131,000 characters.

To meet the above objectives, the computers that were determined to be in the economic range of local school districts, and met the stated criteria were: 1) Honeywell 200, 2) RCA Spectra 70/35, 3) General Electric 415, and 4) IBM 360 Model 30

To satisfy the above four points, and primarily based on the availability (i.e. number of installations throughout the country), the IBM series 360 is recommended as the object computer for the bus routing system. IBM Series 360, is manufactured in a number of models, but it is felt that the range of models for development of the system will be between the model 30 and 40.

Therefore, the initial recommended computer configuration is an IBM 360/30 Processing Unit with decimal arithmetic, floating point arithmetic, 32K to 65K storage capacity having the following peripheral units

1 Line Printer

1 Card read/punch

3 Disk storage drives with a recommended capacity of 7.25 million characters per disk and

2 Magnetic Tape Units

Since the IBM 360 series offers the system advantages of rapid processing time for both compile and test during one run, it is recommended that all programming be performed in the problem oriented computing language, FORTRAN IV. FORTRAN allows the programmer to think in terms of the problem rather than in terms of the computer and reduces the problem of multi-entry processing which is inherent in the solution. In addition, the completed system would be easier to be maintained and upgraded if desired.

V. ANALYSIS OF DATA AND FINDINGS

A. SAMPLE SCHOOL DISTRICT

Ramapo Central School District Number 1 of Rockland County, New York was selected as the local school district to serve as the sample or test school. The school district transports over 5300 students including approximately 640 parochial students. The school board has decided that every child, regardless of the distance from the school is eligible for transportation. In addition, a recent New York State bus regulation requires that all students, both private and public, residing in a school district are eligible for transportation even if the school lies outside of the district's lines.

Ramapo Central School District # 1 consists of seven schools. Approximately 100 students are transferred to parochial and special schools outside of the school district and approximately 640 students are transported to the Sacred Heart Elementary School. Transportation statistics for the district are shown below:

School	# of Students	# of Routes	# of Stops
Airmont Elementary	600	10	104
Cypress Road Elementary	270	5	41
Hillburn Elementary	60	1	6
New Cherry Lane Elementary	600	10	103
Sloatsburg Elementary	310	8	33
Washington Ave. Elementary	270	5	42
Suffern Junior and Senior High School	1590	12	145
Sacred Heart Elementary	640	27	138
Approximate Total	5340	78	612

The transportation of students to non-district oriented schools are treated as special cases with the bus contractors. Bus transportation is made available to district elementary schools between 9:00 AM and 3:25 PM and to the high school between 8:15 AM to 2:55 PM and 4 PM. The school district operates both under shoestring routes, the route starting at a boundary line and proceeding towards the school, and dual routes whereby the schedules of the schools within the district are staggered. Also multiple routing of each bus is made if possible.

Therefore, under these conditions, where feeder and circular routing are discouraged, each school within the district is treated as a separate entity, having its own related bus stops and bus assignments. The reuse or rerouting of the buses is accomplished on an as needed basis in relation to the completed bus picture for each school.

Since the manual calculations for the solution of the optimum routing picture for the entire district would compound an already enormous computing problem and based on the above reasons, only the Cherry Lane Elementary School was selected to serve as the sample school. The routes as contracted with private bus contractor are shown in Appendix A, for the Cherry Lane School. An additional study of each route was made whereby miscellaneous points were eliminated to reduce the amount of data in the problem but which did not have an effect on the routing picture. The points eliminated, were stops which occurred on a route because of the long distance between points and not at an intersection where a decision was to be made to either proceed ahead or turn left or turn right. This reduction reduced the number of stops or pick-up points from 103 to 85.

At the time the routes were established, the school did not have census data as to the exact number of students at each stop. The routes were manually constructed based on historical data supplied by the school transportation officer. Therefore, a random number sampling was made to establish the number of students at each point based on the established route capacities. A distance factor between adjacent points was calculated from maps provided by the tax assessor's office of the school district and are measurement oriented rather than time oriented. This was necessitated due to the enormity of time that would have been necessary to time clock the distances between each point which is a feature of the system. The final necessary statistic of the system is that 66 seat capacity buses are used and overloads are allowed but discouraged.

B. MANUAL SOLUTION

The manual solution using the Cherry Lane Elementary School as the test vehicle proceeded in the following steps:

1. A two character alphabetic designation was assigned to each pick-up point that had been established by the school's transportation officer. (Table 1).
2. A matrix containing the time/distance factor from each point that established a separate route direction was calculated. (To maintain ease of calculations, the time/distance factors were rounded to the nearest integer values in all cases). (Table 2).
3. The shortest distance from each pick-up point to the school was calculated and tabulated. (Table 1).

POINT DESIG-NATOR	POINT DESCRIPTION	NO. OF STUDENTS AT POINT	DISTANCE TO SCHOOL	ROUTE POSITION ACTUAL	CALCU-LATED
AA	Route 202-Lime Kiln Rd	12	78	01-01	01-01
BA	Route 202-Skyland Rd	8	69	01-02	01-03
CA	Route 202-Grandview Ave	5	66	01-03	01-04
DA	Route 202-Kevin Drive	4	74	01-04	01-05
EA	Route 202-Viola Road	8	66	01-05	01-06
FA	Route 202-Orchard Circle	8	69	01-06	01-07
GA	Route 202-Bayard Lane	2	70	01-07	01-08
HA	Mayer Drive-Victory Drive	12	64	01-08	01-09
IA	Mayer Drive - E. Mayer Drive	12	58	01-09	04-01
JA	Mayer Drive-Montebello Rd	4	50	01-10	05-01
KA	Wilder Rd-Lime Kiln Rd	14	69	02-01	02-01
LA	Wilder Rd-Willow Tree Rd	3	59	02-02	02-02
MA	Willow Tree Rd-Grandview Ave	8	61	02-03	03-01
NA	Grandview Ave-Forshay Rd	19	52	02-04	02-03
OA	Forshay Rd-S. Parker Drive	2	47	02-05	02-04
PA	College Ave-Carlton Road	7	38	02-06	02-06
QA	Carlton Road-Pine Road	4	31	02-07	02-07
RA	Carlton Rd-Arrowhead Lane	6	30	02-08	02-08
SA	Spook Rock Rd-Wesley Chapel Road	8	68	03-01	01-02
TA	Wesley Chapel Rd-Grandview Avenue	3	61	03-02	03-02
UA	Grandview Ave-Spook Rock Rd	5	60	03-03	03-03
VA	Spook Rock Rd-Margaret Ann Lane	13	53	03-04	03-04

TABLE 1

PICK-UP POINT DESCRIPTION

WA	Spook Rock Rd-Rose Hill Rd	6	50	03-05	03-05
XA	Spook Rock Rd-Carlton Road	14	26	03-07	05-05
YA	Spook Rock Rd-Highview Road	2	24	03-08	05-06
ZA	Spook Rock Rd-Pioneer Avenue	9	22	03-09	05-07
AB	Spook Rock Rd-Stemmer Lane	8	20	03-10	05-08
BB	Mile Rd-Montebello Rd	9	42	05-05	05-02
CB	Mile Rd-Nottingham Drive	9	52	05-01	03-09
DB	Viola Rd-Cantebury Lane	16	49	04-02	03-07
EB	Viola Rd-College Road	12	53	04-03	02-05
FB	College Rd-Highview Rd	3	31	04-04	09-02
GB	Viola Rd-Mile Road	4	58	04-01	03-08
HB	Highview Rd-Pine Road	8	29	04-05	09-01
IB	N. Airmont Rd-Pioneer Avenue	8	26	04-06	05-04
JB	N. Airmont Rd-Montebello Rd	4	35	04-07	05-03
KB	E. Meyer Drive-Mile Road	21	49	05-02	04-04
LB	E. Mayer Drive-Sterling Forest Lane	6	55	05-03	04-03
MB	E. Mayer Drive-Robin Hood Lane	24	56	05-04	04-02
NB	Cragmere Road-N. J. State Line	8	53	06-01	06-01
OB	Cragmere Road-Hemion Way	8	43	06-02	06-02
PB	Augur Rd-Fairview Terrace	2	45	06-03	06-03
QB	Augur Rd-S. Airmont Rd	4	38	06-04	06-04

RB	S. Airmont Rd-Majorie Lane	4	40	06-05	06-05
SB	Majorie Lane-Daisy Court	5	37	06-06	06-06
TB	Majorie Lane-Church Road	5	33	06-07	06-07
UB	Smith Hill Road-Church Road	3	29	06-08	08-06
VB	Church Road-Utopian Place	3	33	06-09	08-05
WB	Church Rd-Ackerman Avenue	4	35	06-10	08-04
XB	Church Rd-S. Airmont Rd	6	39	06-11	08-03
YB	Church Rd-S. Airmont Rd	9	36	06-12	08-02
ZB	Edgebrook Lane-Appleblossom Court	3	17	07-01	10-06
AC	Appleblossom Court-Cobblestone Road	23	19	07-02	10-05
BC	Appleblossom Court-Rustic Drive	5	21	07-03	10-04
CC	Rustic Drive-Shuart Road	9	23	07-04	10-03
DC	Shuart Road-Cherry Lane	5	26	07-06	10-01
EC	Cherry Lane-Beaver Hollow Road	3	13	07-07	10-07
FC	Smith Hill Road-Eros Drive	9	24	08-01	08-07
GC	Eros Drive-Kent Road	19	29	08-02	06-08
HC	Eros Drive-Montclair Avenue	2	30	08-03	06-09
IC	Montclair Avenue-Dale Road	3	28	08-04	06-10
JC	Dale Road-Eton Place	9	25	08-05	06-11
KC	Eton Place-Shuart Road	9	23	07-05	10-02
LC	Smith Hill Road-Smith Court	5	14	08-06	08-08
MC	Smith Hill Road-Cherry Lane	9	9	08-07	08-09

NC	Route 59-Highview Avenue	9	16	09-02	05-09
OC	Route 59-New County Road	2	20	09-03	09-03
PC	New County Road-Laura Drive	6	21	09-04	09-04
QC	Laura Drive-Glenmere Court	16	25	09-05	09-05
RC	Laura Drive-Eleanor Place	2	26	09-06	09-06
SC	Laura Drive-Thomsen Drive	18	18	09-07	09-08
TC	New County Road-Murray Drive	6	26	09-08	09-07
UC	Cherry Lane-Phillips Drive	5	9	09-09	04-05
VC	Campbell Road-Cragmere Road	5	38	10-01	07-06
WC	Grandview Avenue-Park Place	13	38	10-03	07-08
XC	Grandview Avenue-VanAlstine Avenue	4	35	10-04	07-09
YC	Campbell Road-Mary Beth Drive	6	39	10-05	08-01
ZC	Mary Beth Drive-S. VanDyke Avenue	3	40	10-06	07-01
AD	S. VanDyke Avenue-Dell Court	8	37	10-07	07-02
BD	S. VanDyke Avenue-E. Haskell Avenue	2	36	10-08	07-03
CD	E. Haskell Avenue-Brookside Drive	9	34	10-09	07-04
DD	Brookside Drive-VanOrden Avenue	8	33	10-10	07-05
ED	Viola Road-Spook Rock Road	5	44	03-06	03-06
FD	Route 59-Stage Street	5	33	09-01	07-10
GD	Campbell Road-Reigate Place	8	38	10-02	07-07

CHAIN MATRIX

ORIGIN POINT	T/D FACTOR TO CONNECTING POINTS
AA	BA 10 KA 11 SA 9
BA	AA 10 CA 10 SA 1 UA 1
CA	BA 10 DA 10 SA 11 UA 9 VA 13
DA	CA 10 EA 8
EA	DA 8 FA 4 GB 8
FA	EA 4 GA 3
GA	FA 3 HA 7
HA	GA 7 IA 6 JA 14
IA	HA 6 JA 8 MB 3
JA	HA 14 IA 8 BB 8
KA	AA 11 LA 10
LA	KA 10 MA 9 NA 7
MA	LA 9 NA 8 OA 13 TA 1
NA	LA 7 MA 8 OA 6
OA	MA 13 NA 6 EB 11
PA	QA 9 EB 16 FB 7
QA	PA 9 RA 1 HB 4
RA	QA 1 XA 5
SA	AA 9 BA 1 CA 11 UA 8 TA 13
TA	MA 1 SA 13 UA 8
UA	BA 13 CA 9 SA 8 TA 8 VA 9
VA	CA 13 UA 7 WA 3
WA	VA 3 DB 10 ED 6
XA	RA 5 YA 2 ED 18
YA	XA 2 ZA 2 HB 5 IB 2
ZA	YA 2 AB 2 IB 4
AB	ZA 2 NC 9 OC 9 UC 10
BB	JA 8 JB 6 KB 8 MB 16
CB	GB 10 KB 2 LB 6
DB	WA 10 GB 9 ED 5
EB	OA 11 PA 16 ED 13
FB	PA 7 HB 6 OC 11
GB	EA 8 CB 10 DB 9
HB	QA 4 YA 5 FB 6
IB	YA 2 ZA 4 JB 11
JB	BB 6 IB 11 YB 19 NC 20 XC 18 DD 16 FD 16
KB	BB 8 CB 2 LB 6
LB	CB 6 KB 6 MB 1
MB	IA 3 BB 16 LB 1
NB	OB 10 GD 21
OB	NB 10 PB 5 QB 11 VC 4 GD 14
PB	OB 5 QB 7

TABLE 2

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QB OB 11 PB  7 RB  6 VB  5 XB 2
RB QB  6 SB  3 VB 12
SB RB  3 TB  5 UB  8
TB SB  5 UB  4
UB SB  8 TB  4 VB  4 FC  5
VB QB  5 RB 12 UB  4 WB  2 XB  6
WB VB  2 XB  2
XB QB  2 WB  2 VB  6 YB  5
YB JB 19 XB  5 NC 21 XC  2 YC  2 DD 17 FD 17
ZB AC  2 BC  5 CC  6 DC 15 EC 14
AC ZB  2 BC  2 DC 16 EC 15
BC ZB  5 AC [illegible] CC  7
CC ZB  6 BC  7 FC  6 KC  1 LC 10
DC ZB 15 AC 16 EC 13 KC 11
EC ZB 14 AC 15 DC 13 MC  4
FC UB  5 CC  6 GC  5 LC 10
GC FC  5 HC  1 JC  4
HC GC  1 IC  5
IC HC  5 JC  4
JC GC  4 IC  4 KC  1
KC CC  1 DC 11 JC  1
LC CC 10 FC 10 MC  5
MC EC  4 LC  5 SC  9 TC 19 UC 15
NC AB  9 JB 20 YB 21 OC 12 UC  6 XC 19 DD 17 FD 17
OC AB  9 FB 11 NC 12 PC  1 UC 10
PC OC  1 QC  5 TC  5
QC PC  5 RC  4 TC 10
RC QC  4 SC  8 TC  6
SC MC  9 RC  8 TC 14
TC PC  5 QC 10 RC  6 SC 14
UC AB 10 MC 15 NC  6 OC 10
VC OB  4 XC  5 YC  7 CD  4 GD  3
WC XC  2 CD  7 DD  6 FD  6 GD  3
XC JB 18 YB 20 NC 18 VC  5 WC  2 CD  5 DD  3 FD  5 GD  5
YC YB  2 VC  7 ZC  1
ZC YC  1 AD  3
AD ZC  3 BD  1
BD AD  1 CD  2 DD  3
CD VC  4 WC  7 XC  5 BD  2 DD  2 GD  6
DD JB 16 YB 17 NC 17 XC  3 CD  2 FD  5 GD 5
ED WA  6 XA 18 DB  5 EB 13
FD JB 16 YB 17 NC 17 WC  6 XC  5 DD  5
GD NB 21 OB 14 VC  3 WC  3 XC  5 CD  6 DD  5
```

4. By following steps 1 through 7 as outlined in the Routing Algorithm, the Route Construction Table was calculated which shows every route there is possible passing through points AA and KA. (See Appendix B).

It was at this point that a decision was reached to suspend the continuation of manually proving the Routing Algorithm since the length of time to perform the manual calculation was impractical. Point AA was the first point selected, since it was farthest from the school and thus met the conditions as stated in the algorithm. This point took exactly three man days to perform all the calculations and permutations. The second point, KA, was selected at random and based on previous experience, the length of calculation time was reduced to two and one half days. Therefore, continuing at that rate, 2 1/2 days per point, approximately 200 man days (10 man-months) of calculations were needed. Thus, the decision to suspend calculations was reached but to follow through on the data already obtained.

A sample set of calculations for a route is shown in Table 3.

Another decision made at this point was whether a 5, 10 or 15 point model should be constructed. After an analysis

Sequence

		AA	SA	CA	BA	VA	TA	MA	LA	KA	*
1.	Route	AA	SA	CA	BA	VA	TA	MA	LA	KA	*
2.	# of Students at each point	12	8	5	8	5	3	8	3	14	
3.	Cumulative Totals	12	20	25	33	38	41	49	52	66	
4.	Factor between Point		9	11	10	13	8	1	9	10	69
5.	Cumulative Totals		9	20	30	43	51	52	61	71	140
6.	Student Time (Line 3 x Line 4)		108	220	250	429	304	41	441	520	4554
7.	Cumulative Totals			328	578	1007	1311	1352	1793	2313	6867
	For Capacity @ 66										
8.	Bus Capacity @ 65 (7-4)										6728
9.	Bus Capacity @ 64 (8-4)										6729

* School

TABLE 3

SAMPLE SET OF ROUTE CALCULATIONS

based on the failures and successes of small scale models,[58] a negative decision was reached. The decision was predicated on the fact that the main problem with a bus routing system, is the enormous amount of data calculations and manipulations that would be necessary. A five and probably a ten pick-up point model would not generate a feasible solution while a fifteen point pick-up model would increase the number of calculations to make the model impractical. Therefore, since a small model is

a. not representative of the true problem (the volume of data) and

b. would probably produce a "neat and tidy" solution showing feasibility though feasibility on a large scale might not be possible, smallness is not always representative, this course of action was not followed.

5. After the calculation of all routes, in the Route Construction Table, the fifty best routes were selected and ordered by

   a. Travel time/distance factor and

   b. Student time

   (Student time was selected as the controlling variables for all future calculations).

58. Boyer, op. cit.

6. A subset (see Tables 4 and 5) of the Route Construction Table was built showing the top 50 Routes passing through Points AA and KA.

7. From the Route Construction Table, other subset tables (see Tables 6 through 8) for points NA, MA and OA were also begun based on the routes calculated for points AA and KA.

8. Steps 9 and 10 of the Routing Algorithm establish the Point Occurrence Table (see Table 9).

9. It is at this point, that the lack of complete data at each point halts the continuance of the manual solution. Therefore, Steps 11 through 16 of the Routing Algorithm are not manually shown. But, by using a part of the combinatorial technique of point manipulation and shortest route through a network, a final solution was reached through its optimality is not proven. This technique though not relevant to the study was applied to see if a group of routes could be obtained that were better than the existing routes presently in use for the school. As can be seen from Tables 10 and 11, an improvement in the routes can be realized. The table below compares both routes.

POINT AA

	# OF STUDENTS	TOTAL TRAVEL TIME	STUDENT TRAVEL TIME AT BUS CAPACITIES OF 66	65	64
AA SA UA VA WA ED XA YA	65	79	----	3439	3415
BA CA VA WA ED XA YA	65	82	----	3491	3467
SA BA UA CA VA WA ED XA YA	76	98	3610	3584	3558
CA VA WA ED XA YA	65	86	----	3599	3575
BA CA UA VA WA ED XA	67	89	3642	3616	3590
SA TA UA VA WA ED XA	66	90	3805	3779	3753
BA CA UA VA WA ED XA	76	89	3851	3825	3799
CA UA VA WA ED XA	68	89	3874	3848	3822
BA UA VA WA ED XA	71	83	3915	3889	3863
UA CA VA WA ED XA	68	92	3994	3968	3942
VA WA ED XA RA	69	88	4048	4018	3988
BA CA VA WA ED XA	71	86	4048	4022	3996
BA CA VA WA ED XA RA	69	91	4100	4070	4040
UA CA VA WA ED XA	68	98	4106	4080	4054
SA CA VA WA ED XA RA	69	95	4208	4178	4148
UA VA WA ED DB	65	89	----	4250	4201
BA CA SA UA VA WA ED XA	76	99	4272	4246	4220
SA CA UA VA WA ED XA	76	91	4338	4316	4290
TA UA VA WA ED XA	74	92	4372	4346	4320
SA CA VA WA DB ED	65	95	----	4367	4323
BA SA CA VA WA ED XA	71	88	4391	4365	4339
UA TA MA OA EB PA FB OC UC	67	99	4387	4378	4369
SA TA MA OA EB PA QA RA XA	76	104	4427	4401	4375
CA BA UA VA WA ED XA	76	99	4468	4442	4416
TA MA OA EB PA FB HB YA	65	105	----	4446	4422
QA HB	64	105	----	----	4425
CA VA WA ED DB	65	96	----	4511	4462
TA UA VA WA DB ED	68	99	4560	4516	4472
BA CA UA VA WA DB	64	98	----	----	4500
SA BA UA VA WA DB	68	92	4615	4566	4517
CA UA VA WA DB	65	98	----	4567	4518
BA CA DA EA GB DB ED XA	76	104	4584	4558	4532
SA TA UA VA WA ED DB	68	101	4647	4598	4549
MA OA EB PA FB OC NC	66	103	4586	4570	4554
UA CA VA WA ED SA	71	109	4609	4583	4557
BA CA UA VA WA ED DB	69	99	4671	4622	4573
SA CA UA VA WA ED DB	70	99	4690	4641	4592
BA UA VA WA ED DB	73	93	4692	4643	4594

TABLE 4

FIFTY OPTIMUM ROUTES

AA BA CA VA WA DB ED XA	69	106	4680	4654	4628
SA BA UA TA MA NA OA	65	93	----	4677	4630
UA CA VA WA DB	65	101	----	4687	4638
TA MA OA EB PA FB OC AB	65	104	----	4659	4639
CA DA EA GB DB ED XA	76	104	4692	4666	4640
BA CA VA WA DB	68	95	4748	4699	4650
BA UA TA MA OA EB PA FB OC PC	68	102	4701	4680	4659
KA LA MA OA EB PA FB OC UC	68	107	4680	4671	4662
SA UA BA CA VA WA ED XA	76	106	4744	4718	4692
SA UA TA MA OA FB ED XA	69	107	4738	4712	4686
SA UA CA VA WA ED DB	70	102	4810	4761	4712
BA UA SA CA VA WA ED XA	76	68	4764	4738	4712

POINT KA

	# OF STUDENTS	TOTAL TRAVEL TIME	STUDENT TRAVEL TIME AT BUS CAPACITIES OF 66	65	64
KA LA MA OA EB PA QA HB YA ZA	69	99	3383	3863	3843
ED XA YA ZA	71	100	3910	3888	3866
TA UA VA WA ED XA	73	88	3965	3939	3913
NA OA EB PA FB OC UC	67	83	3966	3957	3948
MA OA EB PA FB OC NC UC	65	94	----	3957	3948
NA OA EB PA FB HB YA ZA	68	101	4010	3988	3966
MA OA EB PA FB OC AB UC	64	105	----	----	3995
QA RA XA	70	100	4049	4023	3997
ED XA YA IB	70	103	4108	4083	4058
NA OA EB PA FB OC PC	68	86	4200	4179	4158
MA OA EB PA FB HB YA IB	67	104	4208	4183	4158
QA HB YA IB	68	104	4213	4188	4163
NA OA EB PA QA RA	67	90	4247	4217	4187
ED XA	69	91	4249	4223	4197
MA OA EB PA QA HB YA XA	74	105	4279	4253	4227
AA SA UA VA WA ED XA	79	98	4287	4261	4235
LA MA OA EB PA FB OC UC NC	65	109	----	4286	4270
NA OA EB PA FB HB	68	92	4366	4337	4308
QA HB	69	92	4366	4337	4308
FB OC UC MC	65	111	----	4335	4326
PC QC	73	108	4386	4361	4336
MA OA EB PA FB HB QA RA	67	107	4424	4394	4364
QA HB FB OC UC	68	108	4396	4387	4378
FB OC AB NC	68	111	4446	4430	4414
AA BA UA VA WA ED XA	77	94	4483	4457	4431
LA MA OA EB ED XA RA	66	109	4494	4464	4434
PA FB OC AB ZA	68	110	4529	4507	4485
ED XA YA HB	70	110	4558	4529	4500
AA BA SA UA VA WA	66	90	4601	4551	4501
LA NA OA EB PA FB OC NC	71	96	4542	4526	4510
AA SA TA MA NA	64	94	----	----	4555
BA CA VA WA ED XA	77	97	4609	4583	4557
LA MA TA UA VA WA ED DB	68	97	4665	4616	4567
OA EB PA QA HB FB OC NC	69	111	4621	4600	4579
NA OA EB PA FB OC AB	70	93	4630	4610	4590
MA TA SA UA VA WA ED	65	92	----	4639	4595
UA VA WA ED DB	73	98	4742	4653	4604
CA VA WA ED XA	78	93	4660	4634	4608
NA OA EB PA	65	98	----	4661	4623
AA SA CA VA WA ED XA	77	96	4683	4657	4631
BA UA VA WA	66	94	4755	4705	4655

TABLE 5

KA LA MA OA EB PA FB OC PC TC RC	65	115	----	4744	4718
AA SA UA TA MA NA	69	97	4846	4794	4742
LA MA OA EB PA FB OC UC AB	64	117	----	----	4750
NA MA TA UA VA	65	94	----	4811	4758
AA SA BA CA VA WA	66	97	4863	4813	4763
LA MA OA EB PA FB OC PC TC SC	81	115	4806	4788	4770
AA BA CA UA VA WA ED	68	100	4876	4832	4788
SA CA UA VA WA ED	68	100	4882	4838	4794
BA SA TA MA NA	67	96	4903	4851	4799

POINT NA

	# OF STUDENTS	TOTAL TRAVEL TIME	STUDENT TRAVEL TIME AT BUS CAPACITIES OF 66	65	64
KA LA NA OA EB PA FB OC UC	67	83	3966	3957	3948
HB YA ZA	68	101	4010	3988	3966
OC PC	68	86	4200	4179	4158
QA RA	67	90	4247	4217	4187
ED XA	69	91	4249	4223	4197
PA FB HB	68	92	4366	4337	4308
QA HB	69	92	4366	4337	4308
FB OC UC MC	65	111	----	4335	4326
PC QC	73	108	4386	4361	4336
NC	71	96	4542	4526	4510
AB	70	93	4630	4610	4590
MA NA OA EB PA	65	98	----	4661	4623
AA SA BA UA TA MA NA OA	65	93	----	4677	4630
BA SA UA TA MA LA NA	66	96	4821	4769	4717
KA AA SA UA TA MA NA	69	97	4846	4794	4742
LA NA MA TA UA VA	65	94	----	4811	4758
AA BA SA TA MA NA	67	96	4903	4851	4799

TABLE 6

POINT MA

	# OF STUDENTS	TOTAL TRAVEL TIME	STUDENT TRAVEL TIME AT BUS CAPACITIES OF 66	65	64
KA LA MA OA EB PA QA HB YA ZA	69	99	3383	3863	3843
ED XA YA ZA	71	100	3910	3888	3866
TA UA VA WA ED XA	73	88	3965	3939	3913
QA EB PA FB OC NC UC	65	94	----	3957	3948
AB UC	64	105	----	----	3995
QA RA XA	70	100	4049	4023	3997
ED XA YA IB	70	103	4108	4083	4058
PA FB HB YA IB	67	104	4208	4183	4158
QA HB YA IB	68	104	4213	4188	4163
XA	74	105	4279	4253	4227
FB OC UC NC	65	109	----	4286	4270
HB QA RA	67	107	4424	4394	4364
AA BA UA TA MA OA EB PA FB OC UC	67	99	4387	4378	4369
SA TA MA OA EB PA QA RA XA	76	104	4427	4401	4375
KA LA MA OA EB PA QA HB FB OC UC	68	108	4396	4387	4378
FB OC AB NC	68	111	4446	4430	4414
AA SA TA MA OA EB PA FB HB YA	65	105	----	4446	4422
QA HB	64	105	----	----	4425
KA LA MA OA EB ED XA RA	66	109	4494	4464	4434
PA FB OC AB ZA	68	110	4529	4507	4485
ED XA VA HB	70	110	4558	4529	4500
AA SA TA MA OA EB PA FB OC NC	66	103	4586	4570	4554
KA AA TA MA NA	64	94	----	----	4555
LA MA TA UA VA WA ED DB	68	97	4665	4616	4567
OA EB PA QA HB FB OC NC	69	111	4621	4600	4579
TA SA UA VA WA ED	65	92	----	4639	4595
UA VA WA ED DB	73	98	4742	4653	4604
CA VA WA ED XA	78	93	4660	4634	4608
NA OA EB PA	65	98	----	4661	4623
AA SA BA UA TA MA NA OA	65	93	----	4677	4630
TA MA OA EB PA FB OC AB	65	104	----	4659	4639
BA UA TA MA OA EB PA FB OC PC	68	102	4701	4680	4659
KA LA MA OA EB PA FB OC UC	68	107	4680	4671	4662
BA SA UA TA MA LA NA	66	96	4821	4769	4717
KA LA MA OA EB PA FB OC PC TC RC	65	115	----	4744	4718
AA SA UA TA MA NA	69	97	4846	4794	4642
LA MA OA EB PA FB OC UC AB	64	117	----	----	4750
NA MA TA UA VA	65	94	----	4811	4758
MA OA EB PA FB OC PC TC SC	81	115	4806	4788	4770
AA BA SA TA MA NA	67	96	4903	4851	4799

TABLE 7

POINT OA

	# OF STUDENTS	TOTAL TRAVEL TIME	STUDENT TRAVEL TIME AT BUS CAPACITIES OF 66	65	64
KA LA MA OA EB PA QA HB YA ZA	69	99	3383	3863	3843
ED XA YA ZA	71	100	3910	3888	3866
NA OA EB PA FB OC UC	67	83	3966	3957	3948
MA OA EB PA FB OC NC UC	65	94	----	3957	3948
NA OA EB PA FB HB YA ZA	68	101	4010	3988	3966
MA OA EB PA FB OC AB UC	64	105	----	----	3995
QA RA XA	70	100	4049	4023	3997
ED XA VA IB	70	103	4108	4083	4058
NA OA EB PA FB OC PC	68	86	4200	4179	4158
MA OA EB PA FB HB YA IB	67	104	4208	4183	4158
QA HB YA IB	68	104	4213	4188	4163
NA OA EB PA QA RA	67	90	4247	4217	4187
ED XA	69	91	4249	4223	4197
MA OA EB PA QA HB YA XA	74	105	4279	4253	4227
FB OC UC NC	65	109	----	4286	4270
NA OA EB PA FB HB	68	92	4366	4337	4308
QA HB	69	92	4366	4337	4308
FB OC UC MC	65	111	----	4335	4326
PC QC	73	108	4386	4361	4336
MA OA EB PA FB HB QA RA	67	107	4424	4394	4364
AA BA UA TA MA OA EB PA FB OC UC	67	99	4387	4378	4369
SA TA MA OA EB PA QA RA XA	76	104	4427	4401	4375
KA LA MA OA EB PA QA HB FB OC UC	68	108	4396	4387	4378
FB OC AB NC	68	111	4446	4430	4414
AA SA TA MA OA EB PA FB HB YA	65	105	----	4446	4422
QA HB	64	105	----	----	4425
KA LA MA OA EB ED XA RA	66	109	4494	4464	4434
PA FB OC AB ZA	68	110	4529	4507	4485
ED XA YA HB	70	110	4558	4529	4500
NA OA EB PA FB OC NC	71	96	4542	4526	4510
AA SA TA MA OA EB PA FB OC NC	66	103	4586	4570	4554
KA LA MA OA EB PA QA HB FB OC NC	69	111	4621	4600	4579
NA OA EB PA FB OC AB	70	93	4630	4610	4590
MA NA OA EB PA	65	98	----	4661	4623
AA SA UA TA MA NA OA	65	93	----	4677	4630
TA MA OA EB PA FB OC AB	65	104	----	4659	4639
BA UA TA MA OA EB PA FB OC PC	68	102	4701	4680	4659
KA LA MA OA EB PA FB OC UC	68	107	4680	4671	4662
KA LA MA OA EB PA FB OC PC TC RC	65	115	----	4744	4718
UC AB	64	117	----	----	4750
PC TC SC	81	115	4806	4788	4770

TABLE 8

POINT OCCURRENCE TOTALS

STARTING POINT

POINT	AA	KA	TOTAL
AA	--	11	
BA	26	7	
CA	30	6	
DA	2		
EA	2		
FA			
GA			
HA			
IA			
JA			
KA	1	--	
LA	2	38	
MA	10	33	
NA	2	15	
OA	9	32	
PA	8	27	
QA	2	9	
RA	4	4	
SA	39	10	
TA	14	9	
UA	32	13	
VA	38	15	
WA	38	14	
XA	27	13	
YA	4	7	
ZA		4	
AB	1	5	
BB			
CB			
DB	17	2	
EB	8	32	
FB	6	20	
GB	2		
HB	2	11	
IB		3	
JB			
KB			
LB			
MB			
NB			
OB			
PB			
QB			

POINT	AA	KA	TOTAL
RB			
SB			
TB			
UB			
VB			
WB			
XB			
YB			
ZB			
AC			
BC			
CC			
DC			
EC			
FC			
GC			
HC			
IC			
JC			
KC			
LC			
MC		1	
NC	1	4	
OC	5	16	
PC	1	5	
QC		1	
RC		1	
SC		1	
TC		2	
UC	2	7	
VC			
WC			
XC			
YC			
ZC			
AD			
BD			
CD			
DD			
ED	35	15	
FD			
GD			
	370	393	

TABLE 9

ACTUAL ROUTES

BUS NUMBER	ROUTE SEQUENCE												# OF PUPILS	TIME	STUDENT TIME
	1	2	3	4	5	6	7	8	9	10					
1	AA	BA	CA	DA	EA	FA	GA	HA	IA	JA			75	132	7022
2	KA	LA	MA	NA	OA	PA	QA	RA					63	100	4423
3	SA	TA	UA	VA	WA	ED	XA	YA	ZA	AB			73	81	3131
4	GB	DB	EB	FB	HB	IB	JB						55	109	4129
5	CB	KB	LB	MB	BB								69	67	4092
6	NB	OB	PB	QB	RB	SB	TB	UB	VB	WB	XB	YB	61	89	3583
7	ZB	AC	BC	CC	KC	DC	EC						57	49	2297
8	FC	GC	HC	IC	JC	LC	MC						56	41	1598
9	FD	NC	OC	PD	QC	RC	SC	TC	UC				69	86	3308
10	VC	GD	WC	XC	YC	ZC	AD	BD	CD	DD			66	72	3058
										TOTALS			644	826	36641

TABLE 10

CALCULATED ROUTES

BUS NUMBER	ROUTE SEQUENCE 1 2 3 4 5 6 7 8 9	# OF PUPILS	TIME	STUDENT TIME
1	AA SA BA CA DA EA FA GA HA	67	116	6028
2	KA LA NA OA EB PA QA RA	67	90	4277
3	MA TA UA VA WA ED DB GB CB	69	101	5397
4	IA MB LB KB UC	68	59	3456
5	JA BB JB IB XA YA ZA AB NC	67	60	2201
6	NB OB PB QB RB SB TB GC HC IC JC	69	85	3464
7	ZC AD BD CD DD VC GD WC XC FD	65	60	3066
8	YC YB XB WB VB UB FC LC MC	54	44	1557
9	HB FB OC PC QC RC TC SC	61	65	2539
10	DC KC CC BC AC ZB EC	57	51	1885
	TOTALS	644	731	33870

TABLE 11

	Actual Route	Calculated Route	Percent Reduction from Actual
Time/Distance Factor	826	731	11.5
Student Time	36641	33870	7.6
Bus Capacity Range	55-75	54-69	
Time/Distance Range	41-132	44-116	
Student Time Range	1598-7022	1557-6028	

TABLE 12

ROUTE COMPARISON

The calculated routes shown in the solution are not the optimum grouping, therefore the reduction percentage, would prove to be even greater than that shown above.

The true value of optimum bus routing can be seen from the table below when multiple bus routing is applied in a school district. If multiplicity was in effect, the number of buses necessary to transport all students to the Cherry Lane School could be reduced by one if BUSS was used.

ACTUAL

ROUTE NUMBER	# OF STUDENTS	T/D FACTOR	STUDENT TIME	BUS NUMBER
01	75	132	7022	1
02	63	100	4423	3
03	73	81	3131	4
04	55	109	4129	2
05	69	67	4092	8
06	61	89	3583	5
07	57	49	2297	8
08	56	41	1598	7
09	69	86	3308	6
10	66	72	3058	7

CALCULATED

# OF STUDENTS	T/D FACTOR	STUDENT TIME	BUS NUMBER
67	116	6028	1
67	90	4277	3
69	101	5397	2
68	59	3456	5
67	60	2201	5
69	85	3464	4
65	60	3066	6
54	44	1557	6
61	65	2539	7
57	51	1885	7

TABLE 13

BUS REDUCTION

Under the actual condition, eight buses would be needed, while the results of BUSS would reduce the number of buses to seven.

C. OPERATIONAL PROGRAM DESIGN

The programming system will be designed to operate on either an IBM series 360 model 30 or 40 computing system. The entire system will be coded in FORTRAN (See Chapter IV, Section F).

This section contains the Operational Program design which

1) shows the system flow, i.e. the movement of data between core storage and peripheral devices through the four programs of the system,
2) presents detailed descriptions as to the card formats, internal work areas, system files and output listings, and
3) details through an operational program flow diagram the porgram logic separated into the update option and generate option.

1. System Flow

The system is comprised of four programs:

a. Supervisor Program which is responsible for checking the legality of all system inputs and converting the raw data that is input into system files. The program will determine the option requested, update or generate, and monitor the respective programs in the requested option.

b. Route Construction Program is the first program to operate in the generate option. The program reads the converted inputs from tape and constructs the fifty optimum routes passing through each pick-up point. The routes are stored in point blocks on disc and are output for review.

c. Route Selection Program is the final program to operate in the generate program. The program analyzes the constructed routes and selects the combination of routes that passes through every pick-up point which will minimize total travel time. The selected routes are stored on disc and are output for review.

d. Update Program is the only program to operate in the update option. The program is responsible for making any corrections to the selected routes that have been input. In addition, the program will order the data into formats desired for use by the school, students and bus companies. The program will also schedule pick-up times and allocate the buses by capacity and type.

SYSTEM FLOW

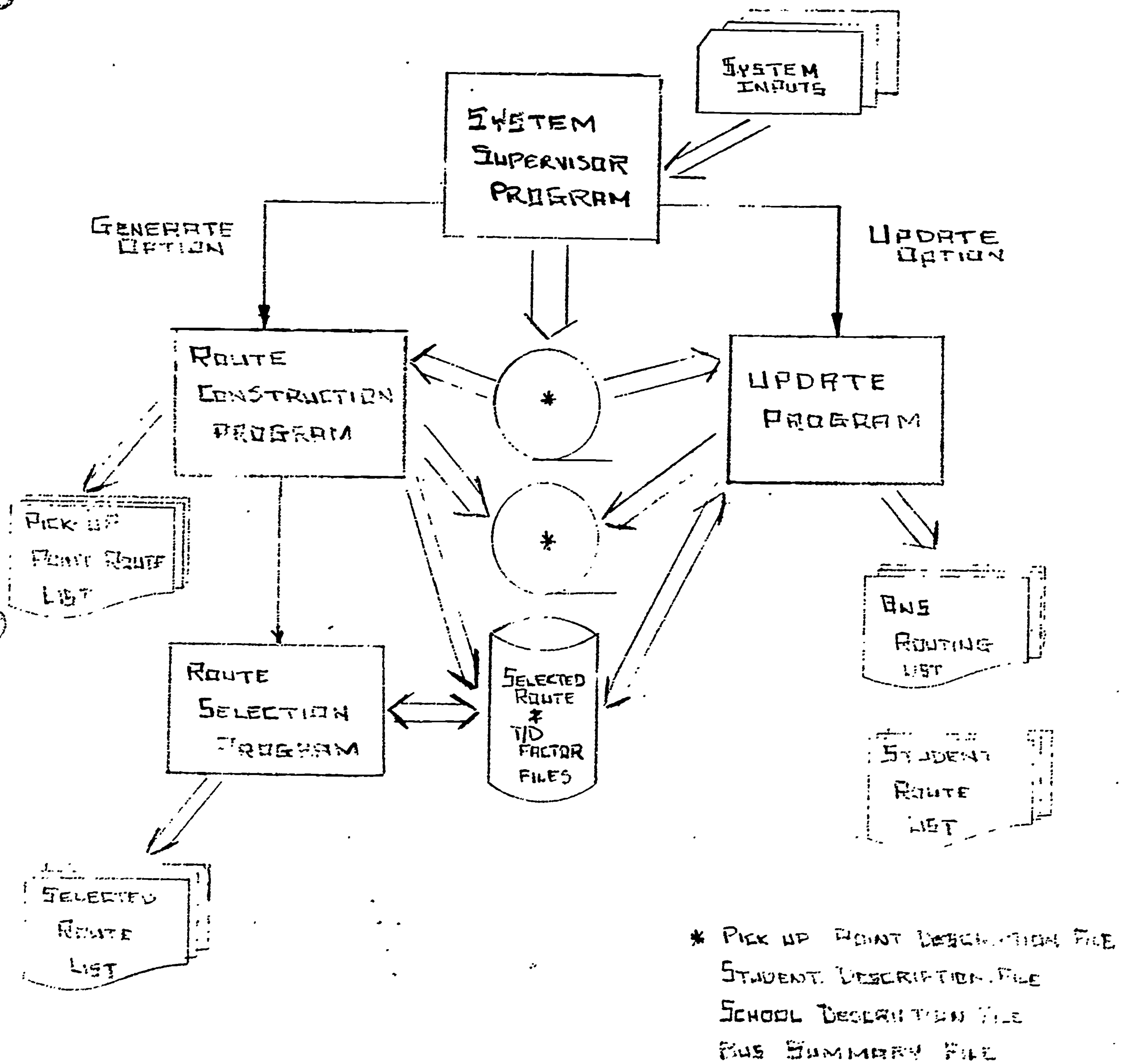


FIGURE 1

2. System Inputs

The inputs to the system, are on punched cards which are stored on magnetic tape units and disc. The required data consists of the following:

a. Distance and Pick-up Card - contains the distance factor from a local point to every adjacent point. In addition, descriptive information of the point such as number of students to be picked up and street address are on the card.

b. Student Control Card - contains information for use by the supervisor program if the format of the student name and address cards to follow does not meet system requirements (i.e. the user can input previously preformatted name and address cards by describing column locations and lengths without having to repunch for BUSS).

c. Student Address - Name Card - contains the student's name, address, grade and pick-up point assignment.

d. School Control Card - contains the school's name and address.

e. Bus Control Card - contains description of the buses in the system as to capacity, number, and loading.

f. Route Modification Card - allow the transportation officer to modify a constructed route.

g. Option Card - is used by the supervisor program to determine the mode of operation and general header information.

h. Variable Output Card - allows for variable formats when output listings are desired.

3. System Files

a. Time/Distance Factor File - is a matrix of the time/distance between adjacent points and the number of students at each point.

b. Pick-up Point Description File - is composed of descriptive information of each pick-up point.

c. Student Description File - contains a student's name, address, grade and school.

d. Bus Summary File - contains descriptive data of the buses as to capacity, number, etc.

e. Selected Route File - describes the optimum routes with information relating the sequence of pick-up points and the accumulated number of students, travel time and student time at each point.

4. System Outputs

a. Bus Route Listing - describes the route grouping that has been selected as optimum.

b. Student Route Listing - details each route by listing the students at each pick-up point along the route.

c. Variable Output Listings - can be obtained keyed on a user selected parameter.

FINAL

BUS ROUTE LISTING

FOR

RAMAPO SCHOOL DISTRICT NO. 1

BUS NUMBER STOP NUMBER	DRIVER NAME AND ADDRESS STOP ADDRESS	PHONE # OF STUDENTS	ARRIVAL TIME
0001	Hunt, R. 1622 Kings Court	914-263-0814	
	Masonite Garage		0715
1	Spook Rock Road-Wesley Chapel Road	8	0732
2	Spook Rock Road-Margaret Ann Lane	12	0746
3	Spook Rock Road-Rose Hill Road	4	0758
4	Spook Rock Road-Highview Road	16	0810
5	Spook Rock Road-Pioneer Avenue	10	0815
6	Spook Rock Road-Stemmer Lane	16	0821
	Suffern High School		0828
0002	Bressoud, E. 1201 Shea Drive	914-263-1121	
1	Route 202-Wilder Road	2	0815
2	Route 202-Lime Kiln Road	8	0830
3	Route 202-Skyland Road	24	0837
4	Route 202-Grand Avenue	16	0845
5	Route 202-Kevin Drive	10	0851
	Airmont Elementary School		0857

by District
by School
by Driver

FIGURE 2

FINAL

STUDENT ROUTE LISTING

FOR

CHERRY LANE ELEMENTARY SCHOOL

BUS NUMBER 0012, E. D. Slaughter, Driver

BUS STOP ADDRESS STUDENT NO.	STUDENT NAME - ADDRESS		Stop No.	TIME GRADE
Mile Road -	Montebello Road		1	07:48
00412	Hepler, W.	1027 Montebello Rd.		11
00513	McGraw, T.	1013 Montebello Rd.		10
00783	Friend, R.	2233 Mile Road		8
Mile Road -	Nottingham Drive		2	07:55
00303	Shaw, R.	1260 Mile Road		12
00361	Fischer, J.	1282 Mile Road		12
00422	Gardner, R.	131 Chasm Court		11
00981	Ribant, D.	1414 Evergreen Pl.		6
Mile Road -	Viola Road		3	08:00
00312	Hamilton, R.	868 Mile Road		12
00392	Terry, R.	101 Hopewell Junc.		12
00626	Selma, D.	862 Mile Road		10
00848	Rusteck, S.	1108 Viola Road		7
Viola Road -	Cantebury Lane		4	08:20
00422	Arrigo, G.	623 Viola Road		11
00436	Bearnarth, L.	121 Maple Drive		11
00537	Richardson, G.	101 Oak Street		10
00916	Sutherland, D.	597 Viola Road		7
00920	Eilers, D.	103 Oak Street		7
Cherry Lane School			LAST	08:28

SUPPLEMENTARY PRINTOUTS - BUS PASSES

FIGURE 3

WORK LISTINGS

1. BY ORIGIN (PICK-UP ROUTE LISTING)

ORIGIN POINT	MAIN STOPS WITH CUMULATED STUDENTS, TIME						STUDENT TIME AT CAPACITY 66	65	64
AA	10 8	BA 22 16	CA 32 22	DA 50 31	EA 66 38		1811	1800	1789
				KA 49 38	FA 66 42		1873	1861	1849
	10 10	CA 24 12	DA 40 21	EA 56 28	FA 73 32		1874	1862	1850

2. BY SHORTEST ROUTE FACTOR

POINT - AA

ROUTE NUMBER	ROUTE	# OF STUDENTS	TOTAL TIME	STUDENT TIME AT CAPACITY 66	65	64
AA01	AA BA CA DA EA	64	28	1811	1800	1789
DA01	AA FA DA HA BA	71	32	'873	1861	1849

3. SELECTED ROUTE LISTING

ROUTE NUMBER	ROUTE WITH CUMULATED STUDENTS, TIME					STUDENT TIME AT CAPACITY 66	65	64
LA01	AA 22 16	CA 32 22	LA 50 31	EA 68 38		1811	1800	1789
DA02	KA 10 10	FA 24 12	DA 40 21	JA 56 28	GA 66 32	1873	1861	1849

FIGURE 4

5. System Work Areas

a. Point Selection Table - contains the number of occurrences of each pick-up point in the selected routes and cross references the point.

b. Point Occurrence Table - contains the number of occurrences of each pick-up point.

c. Route Sequence Table - describes the sequence of points within a route.

d. Pick-up Point Used Table - cross references each pick-up point with a route.

e. Point Selection Table - contains the number of occurrences of each pick-up point.

f. Selected Route Table - contains the optimum routes of the system.

g. Conflict Adjustment Table - contains data describing conflicting routes in the system that will assist the transportation official in resolving a route conflict.

6. Operational Flow

The system is divided into two modes of operation:

a. The update option which allows the user to modify conflicting routes and to obtain preformated output and

b. the generate option which constructs and selects the route grouping which optimize the system.

Shown in detail on the following pages are the operational flow diagrams of the system.

Operational Flow

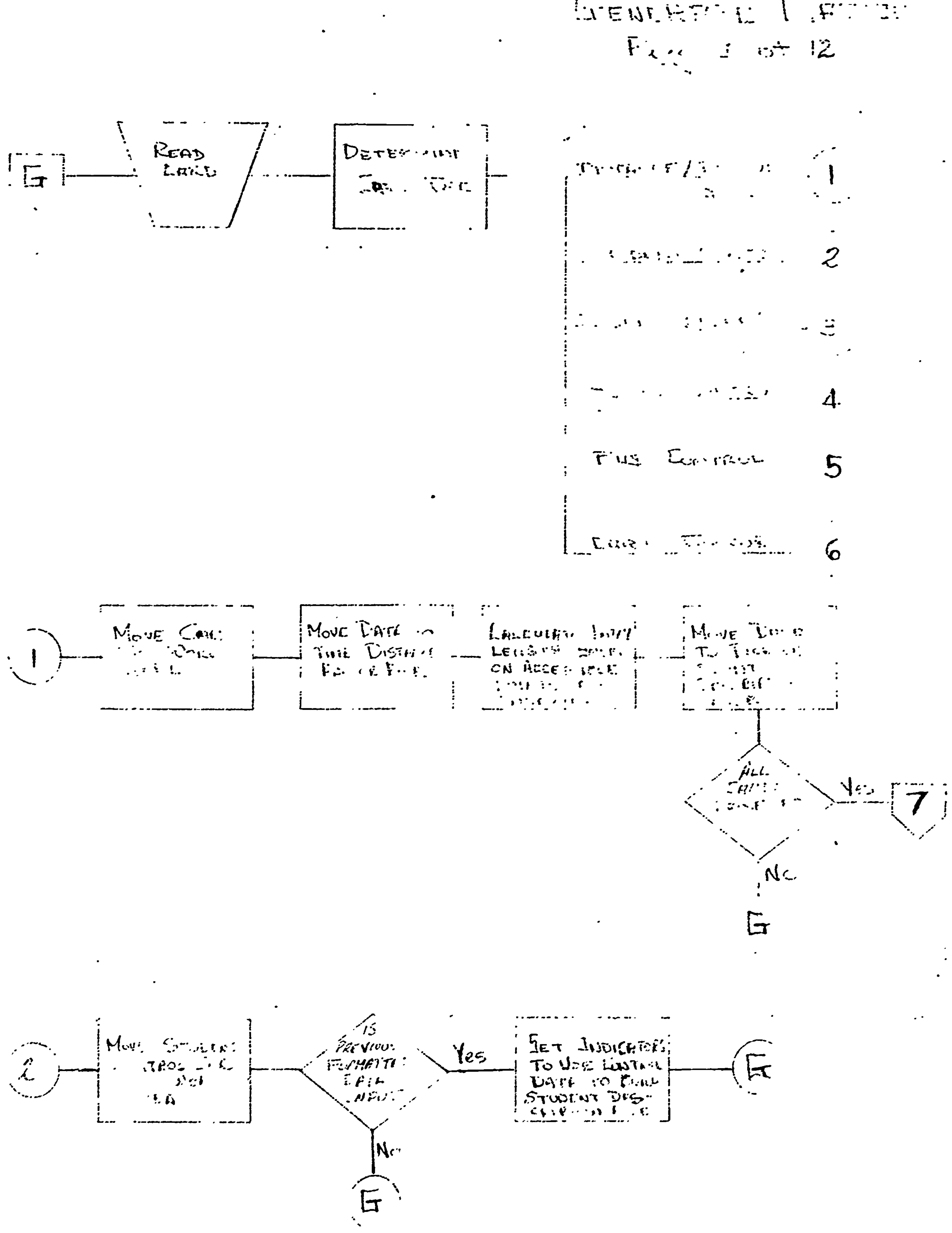
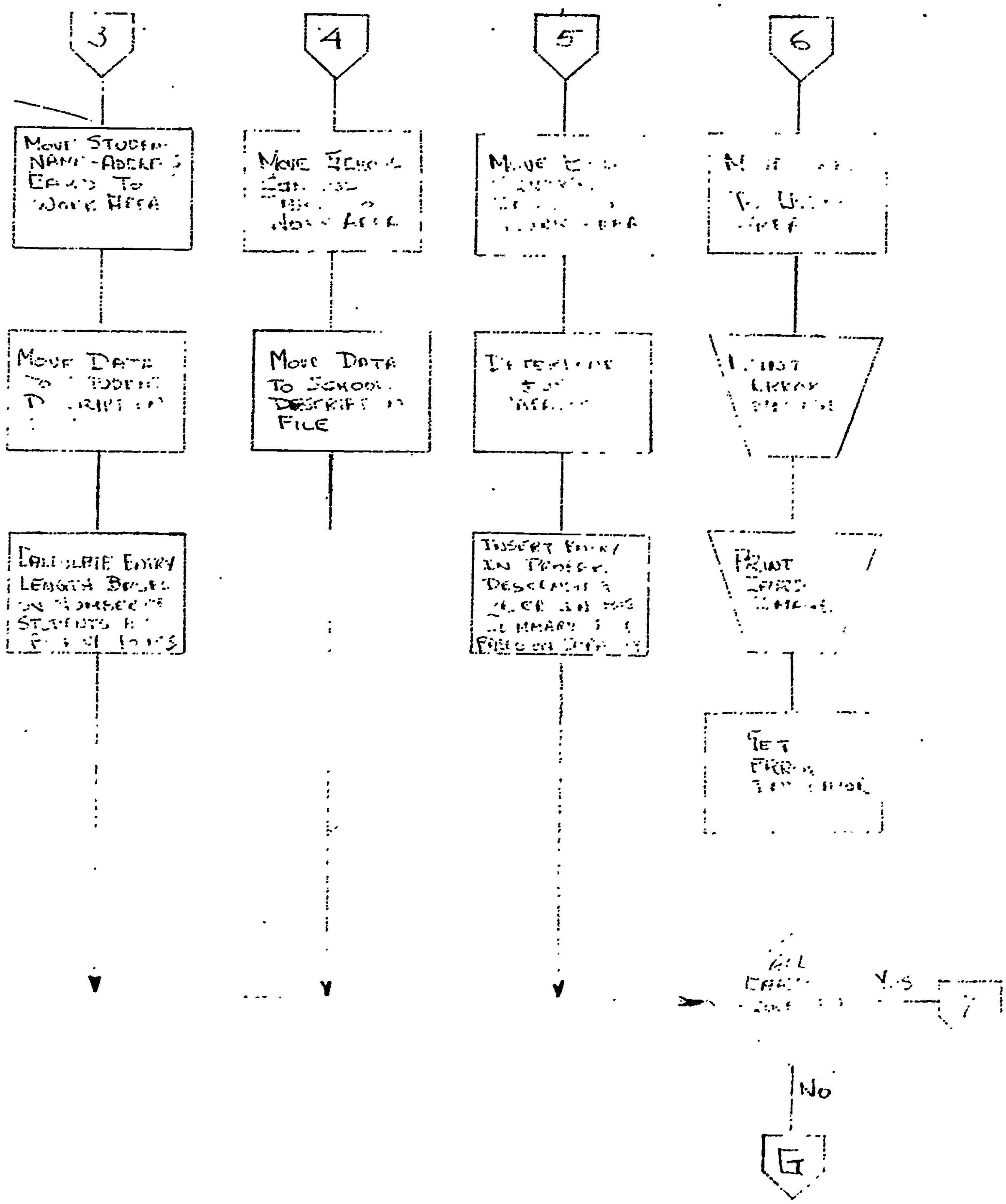
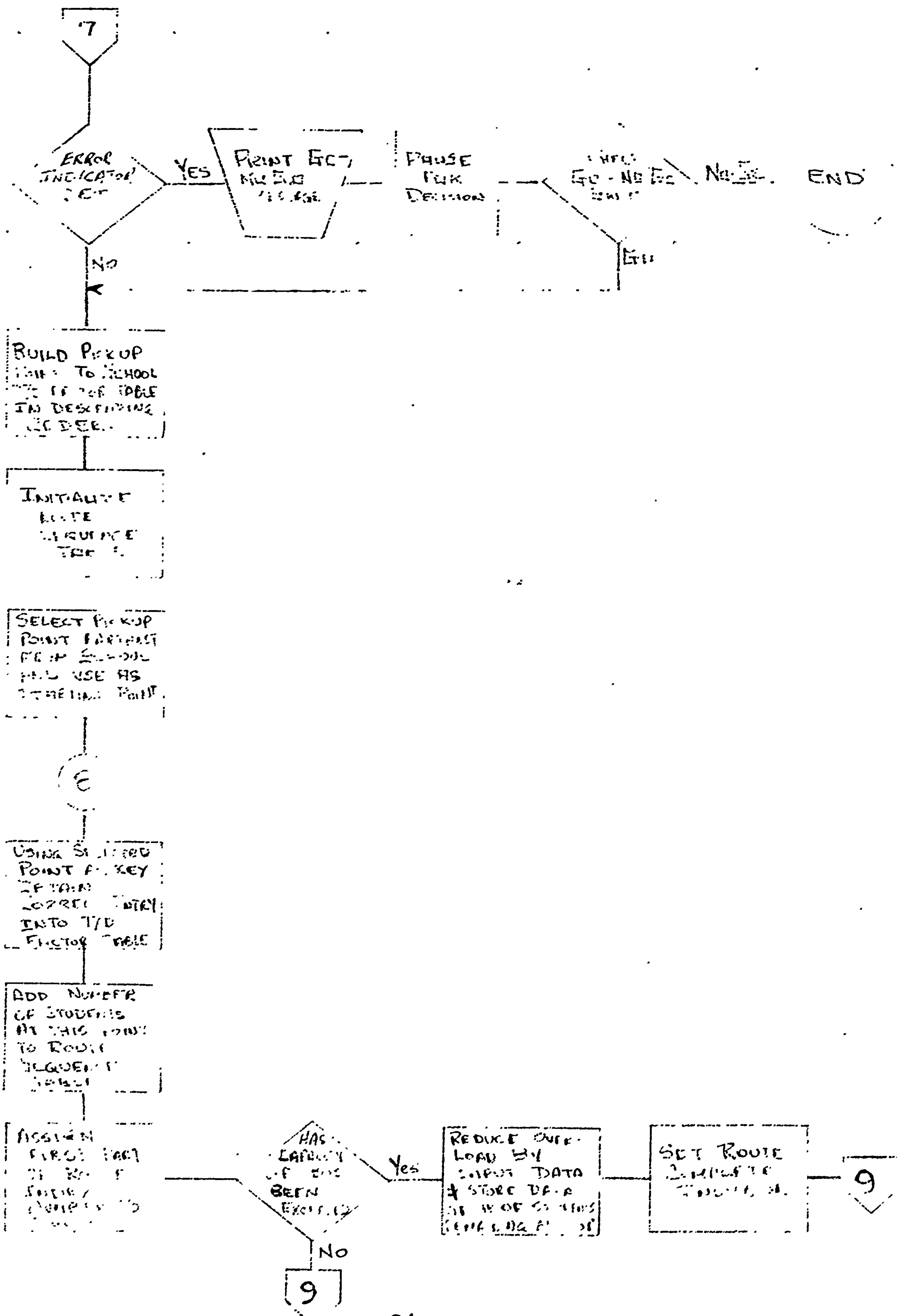
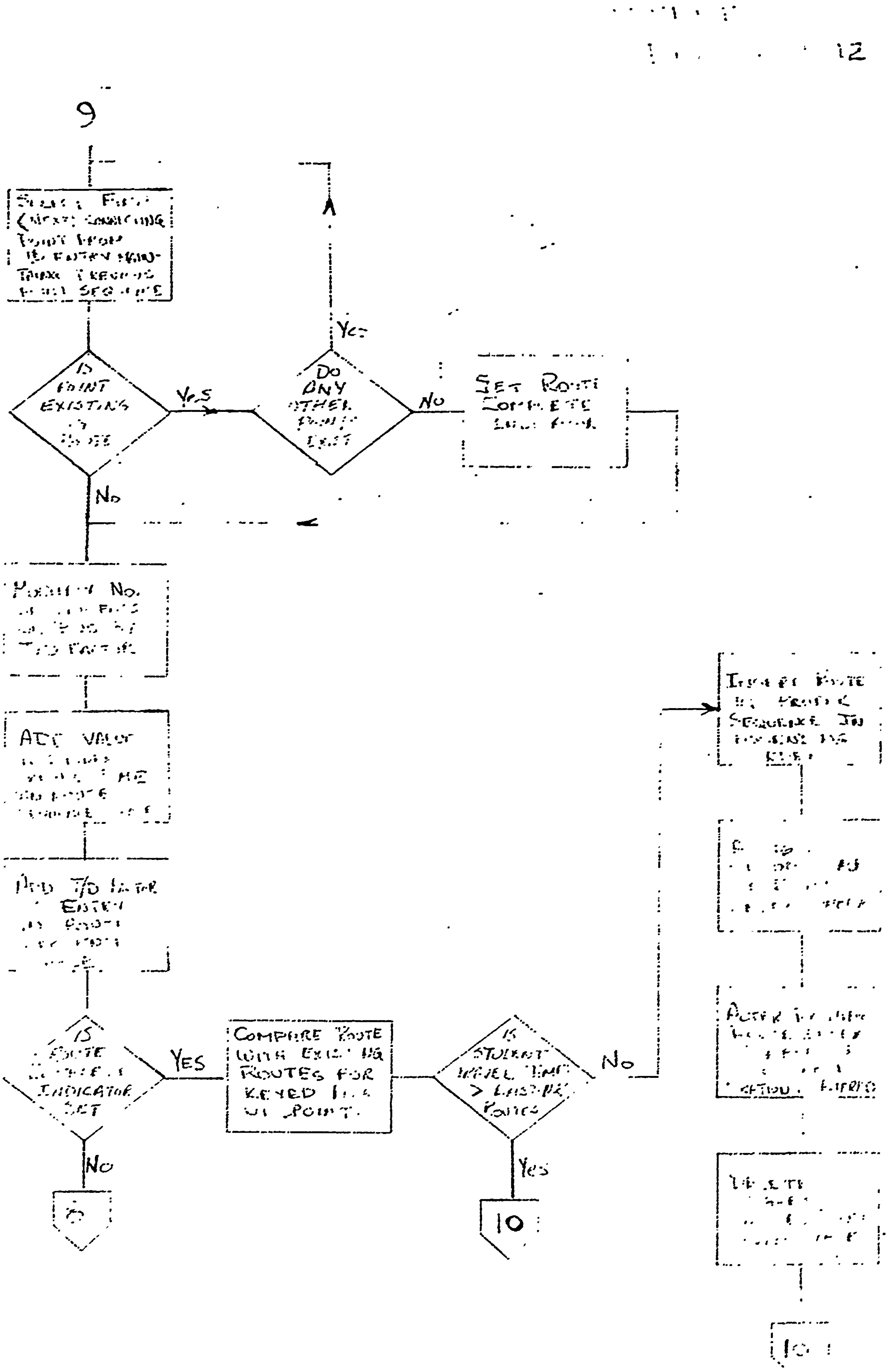


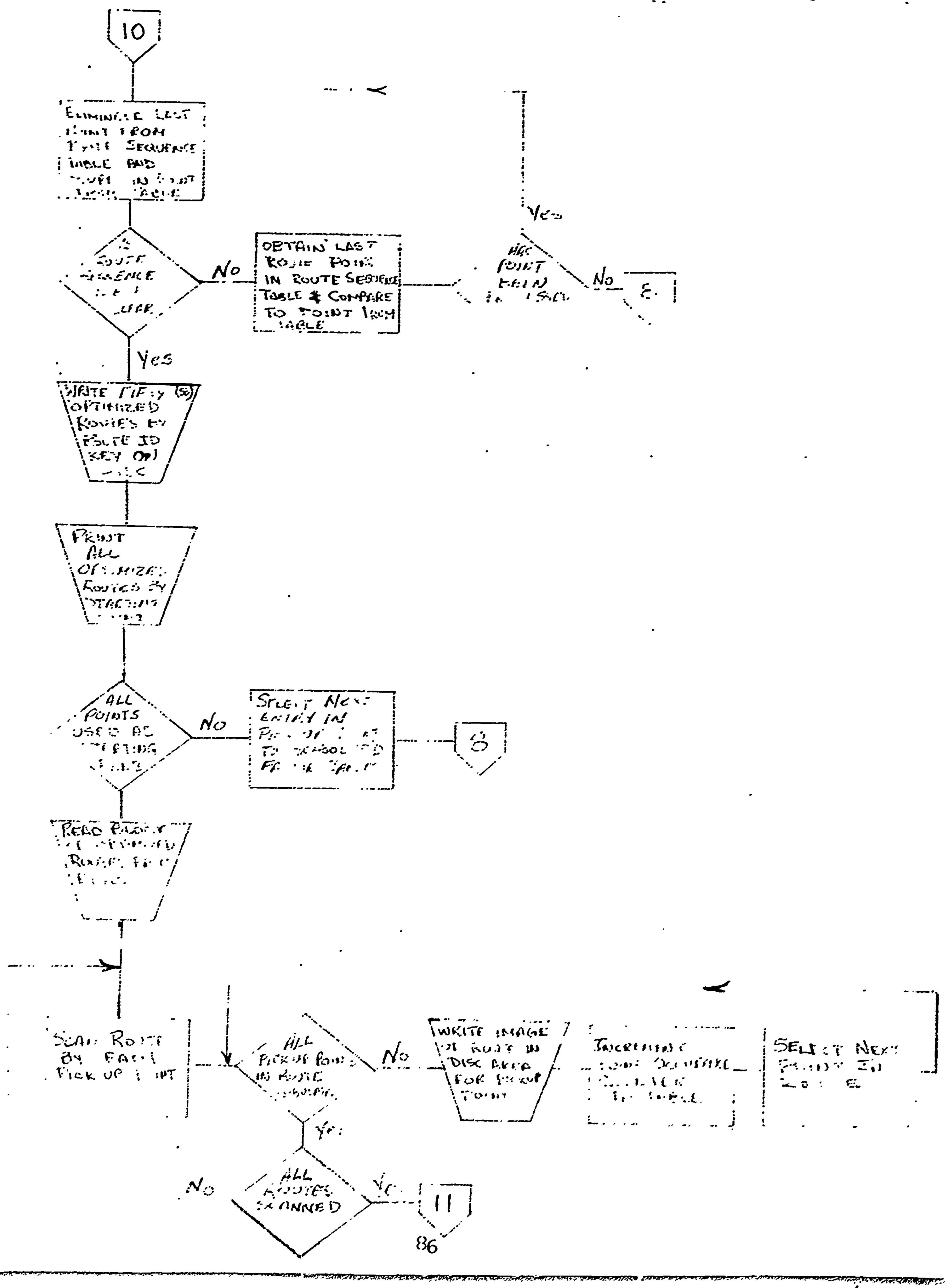
FIGURE 5

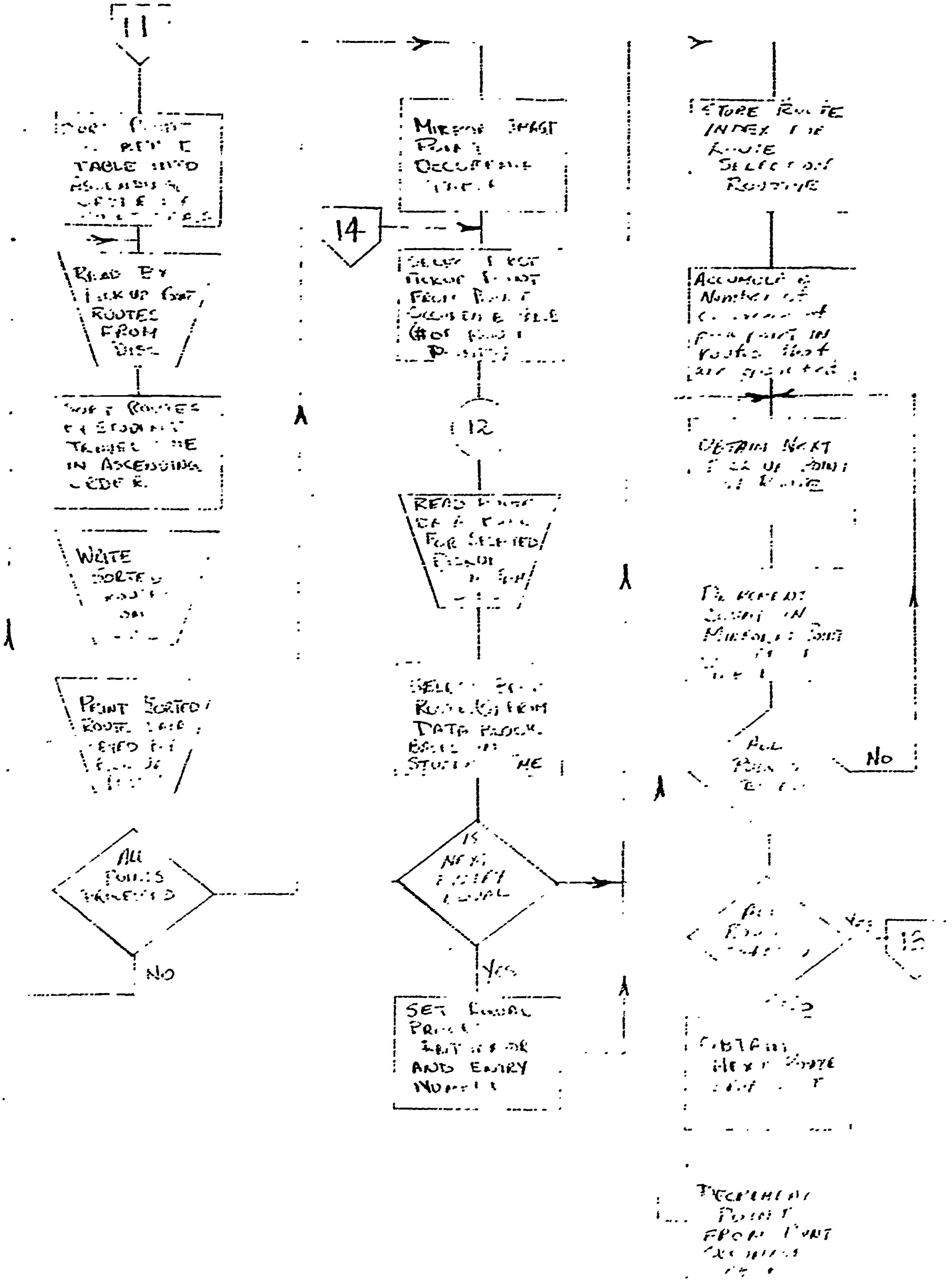

3
4
5
6
Move Data
To School
File
Print
Yes
No
G

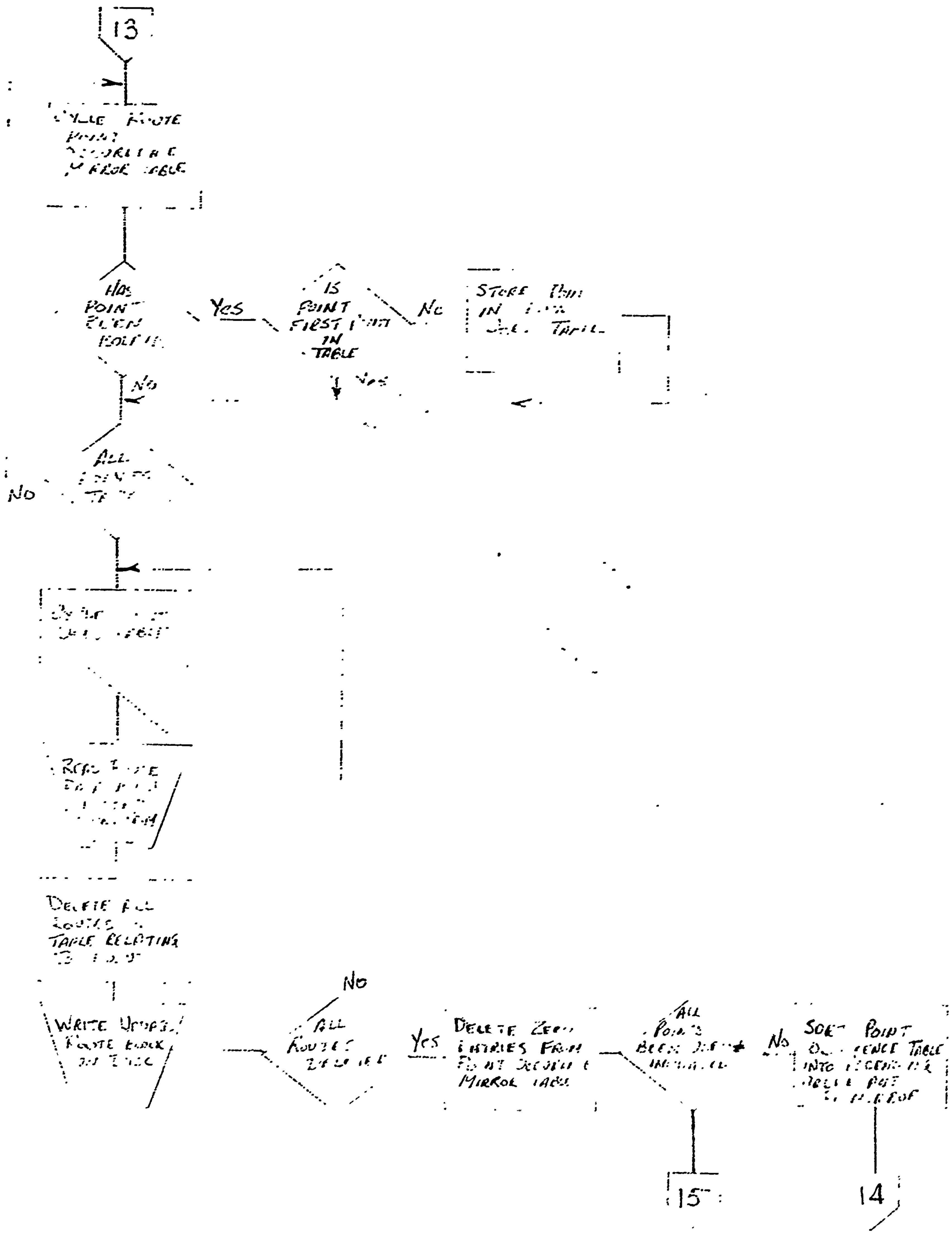

7
ERROR INDICATOR SET
YES
PAUSE FOR DECISION
END
NO
BUILD PICKUP
INITIALIZE
SELECT PICKUP POINT FARTHEST FROM SCHOOL AND USE AS STARTING POINT
ADD NUMBER OF STUDENTS AT THIS POINT TO ROUTE
HAS CAPACITY BEEN EXCEEDED
Yes
No
9
REDUCE OVER- LOAD BY INPUT DATA
SET ROUTE
9

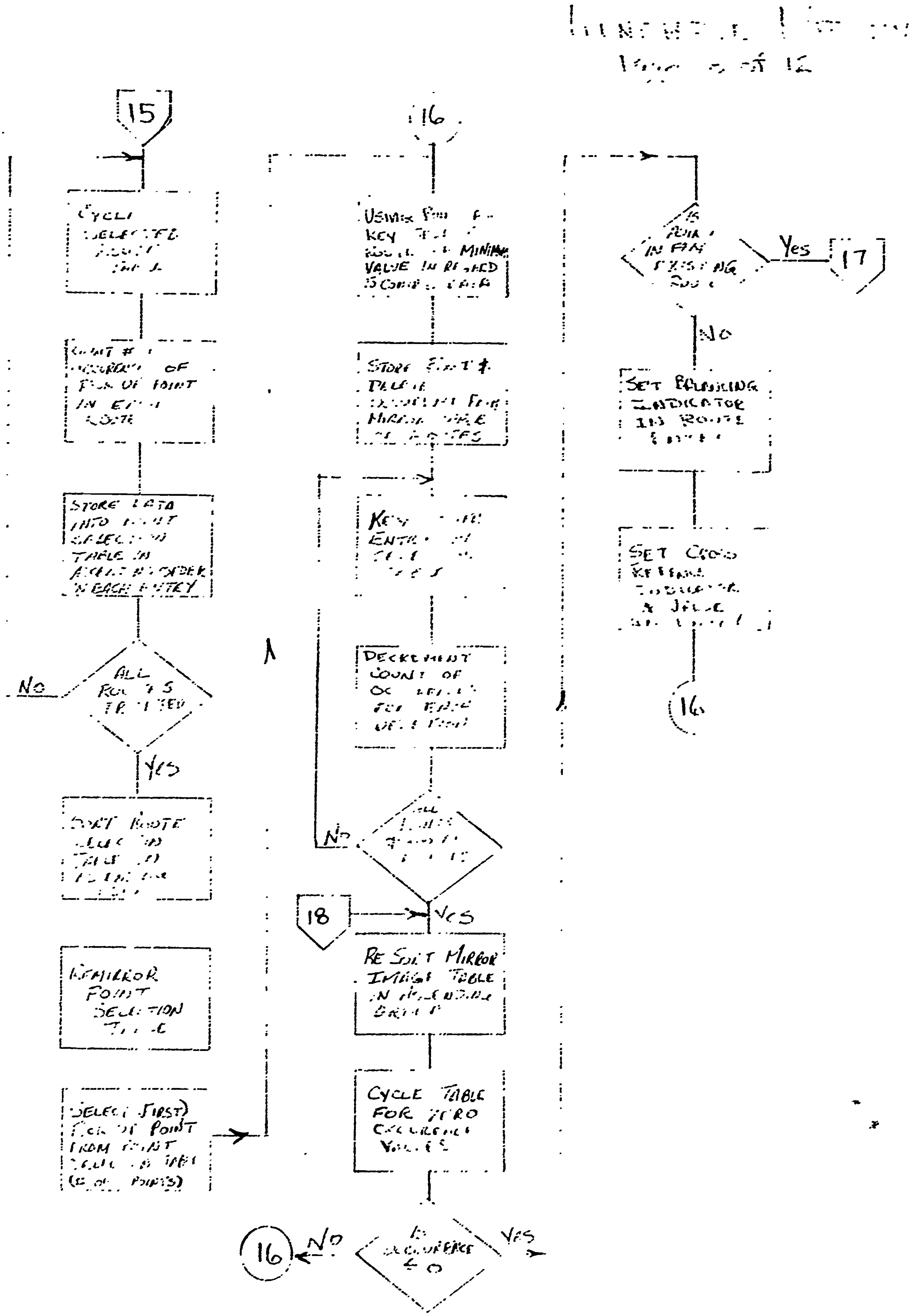


12
9
Yes
Yes
No
Set Route Complete
No
Yes
Compare Route With Existing Routes for Keyed Exit Point
No
Yes
No
10

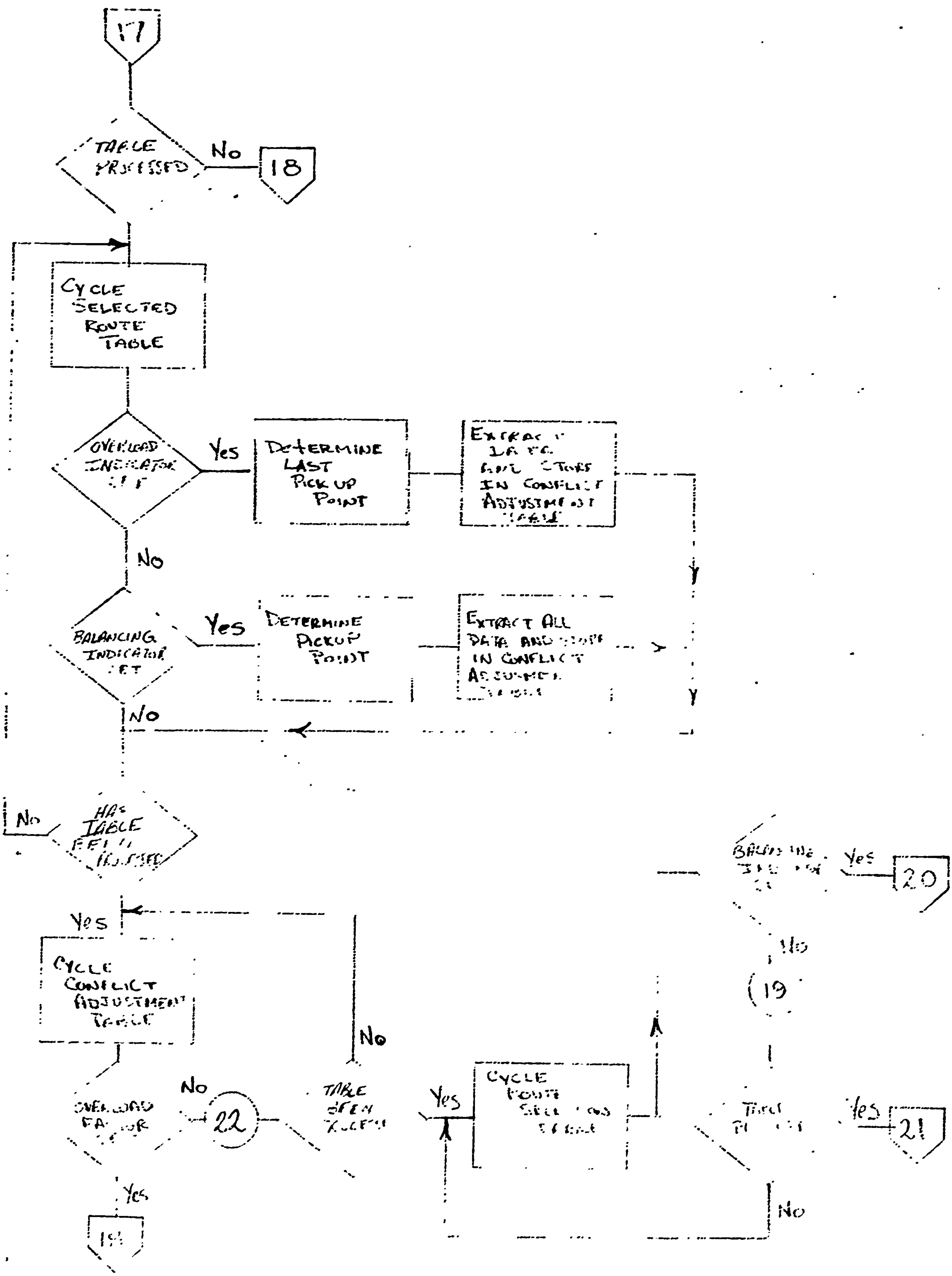

10
Yes
OBTAIN LAST ROUTE POINT IN ROUTE SEQUENCE TABLE & COMPARE TO POINT FROM TABLE
No
Yes
No
E
Yes
WRITE OPTIMIZED ROUTES BY ROUTE ID KEY ON
PRINT ALL OPTIMIZED ROUTES BY
ALL POINTS USED AS
No
SELECT NEXT ENTRY IN
8
SCAN ROUTE BY EACH PICK UP POINT
ALL PICK UP POINTS IN ROUTE
No
WRITE IMAGE OF ROUTE IN DISK AREA FOR PICKUP POINT
INCREMENT
SELECT NEXT
Yes
No
ALL ROUTES SCANNED
Yes
11

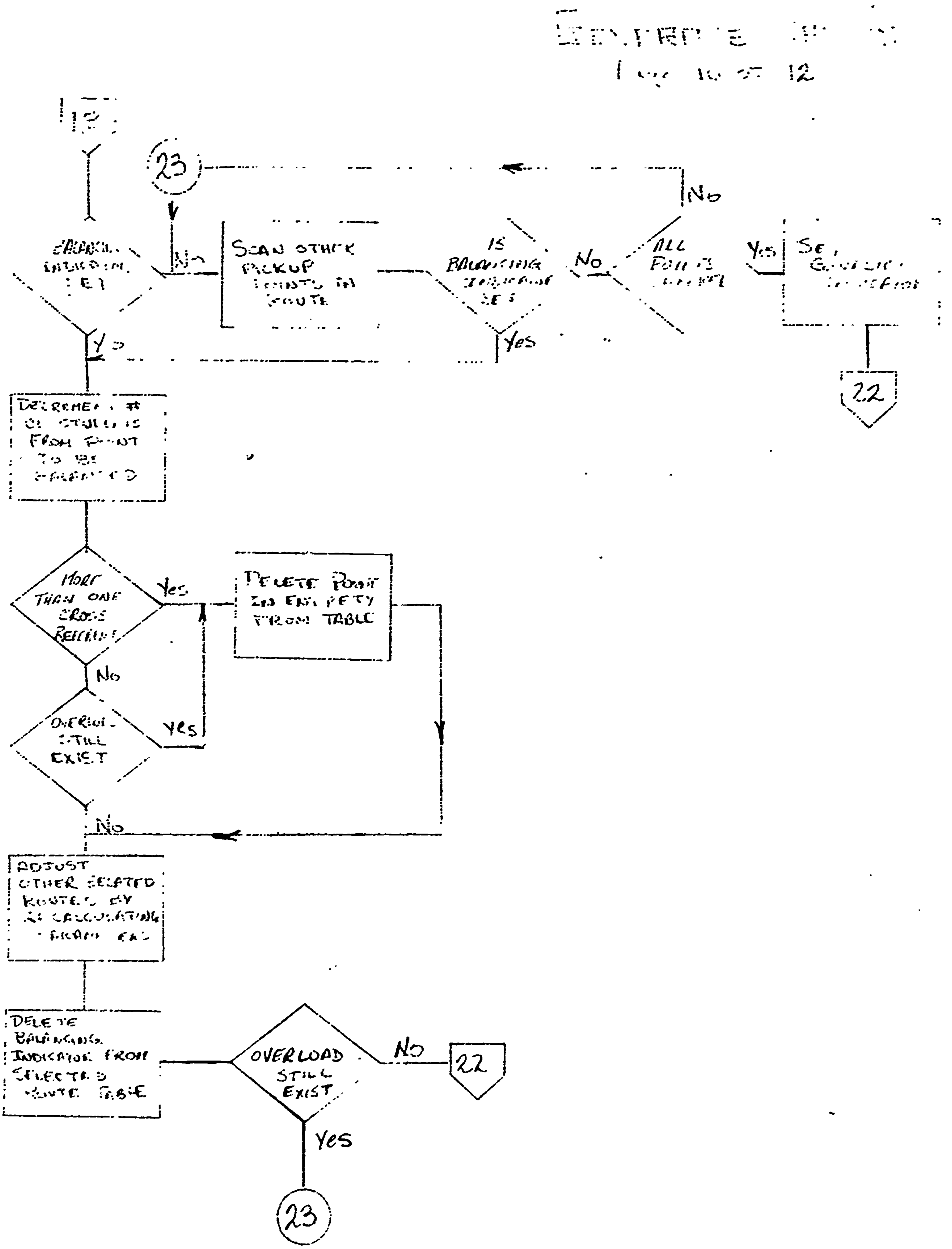

11
14
12
No
No


13
Yes
No
Is Point First ... in Table
Store ... in ... Table
No
No
Delete All ... Table Relating
Write Update ... Route ...
No
All Routes ...
Yes
Delete Zero Entries From Point ... Mirror Table
All Points Been ...
No
Sort Point ... Table into ...
15
14

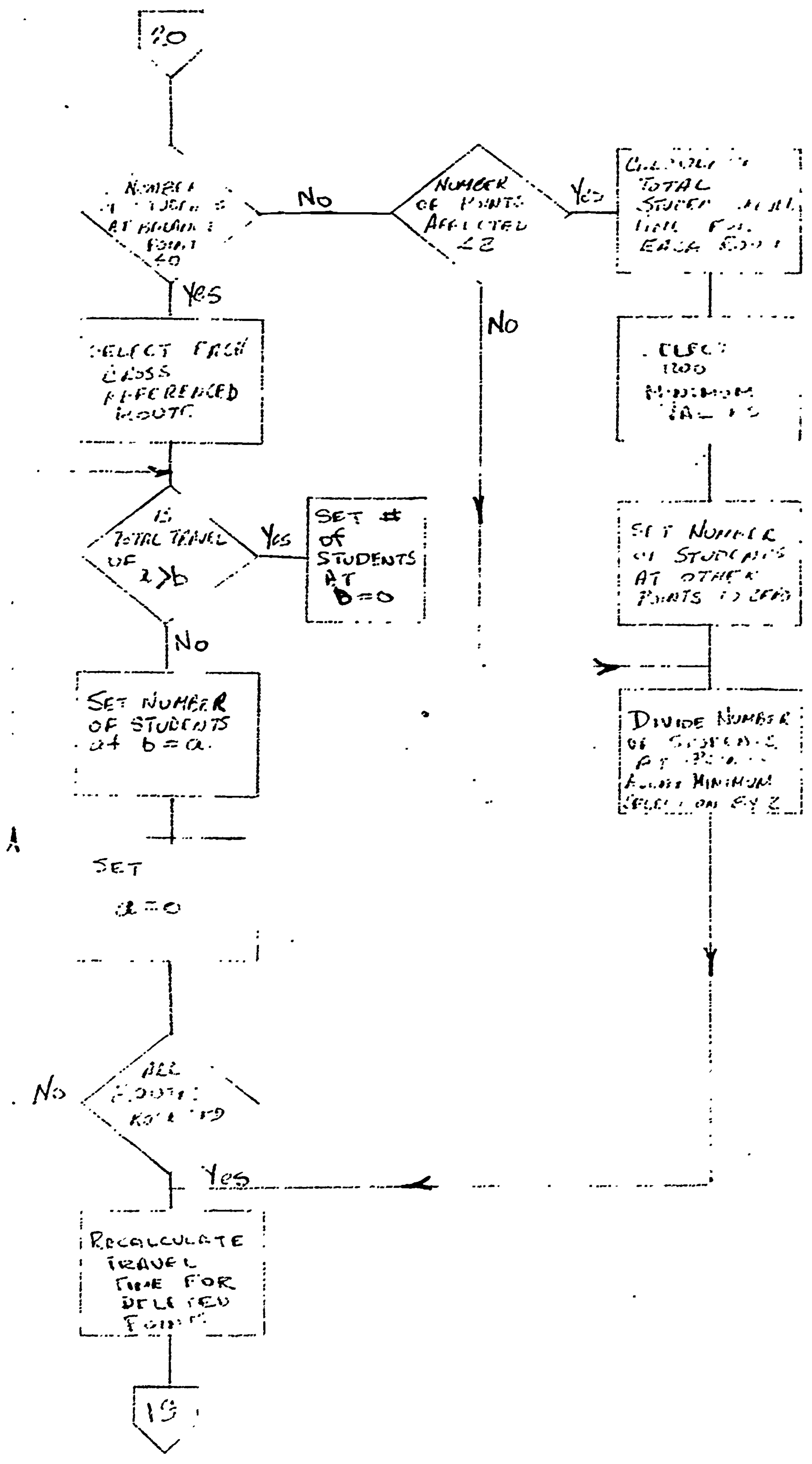


15
16
Yes
17
No
No
Yes
RE SORT MIRROR IMAGE TABLE
18
CYCLE TABLE FOR ZERO OCCURRENCE VALUES
16
SET BRANCHING INDICATOR IN ROUTE
16

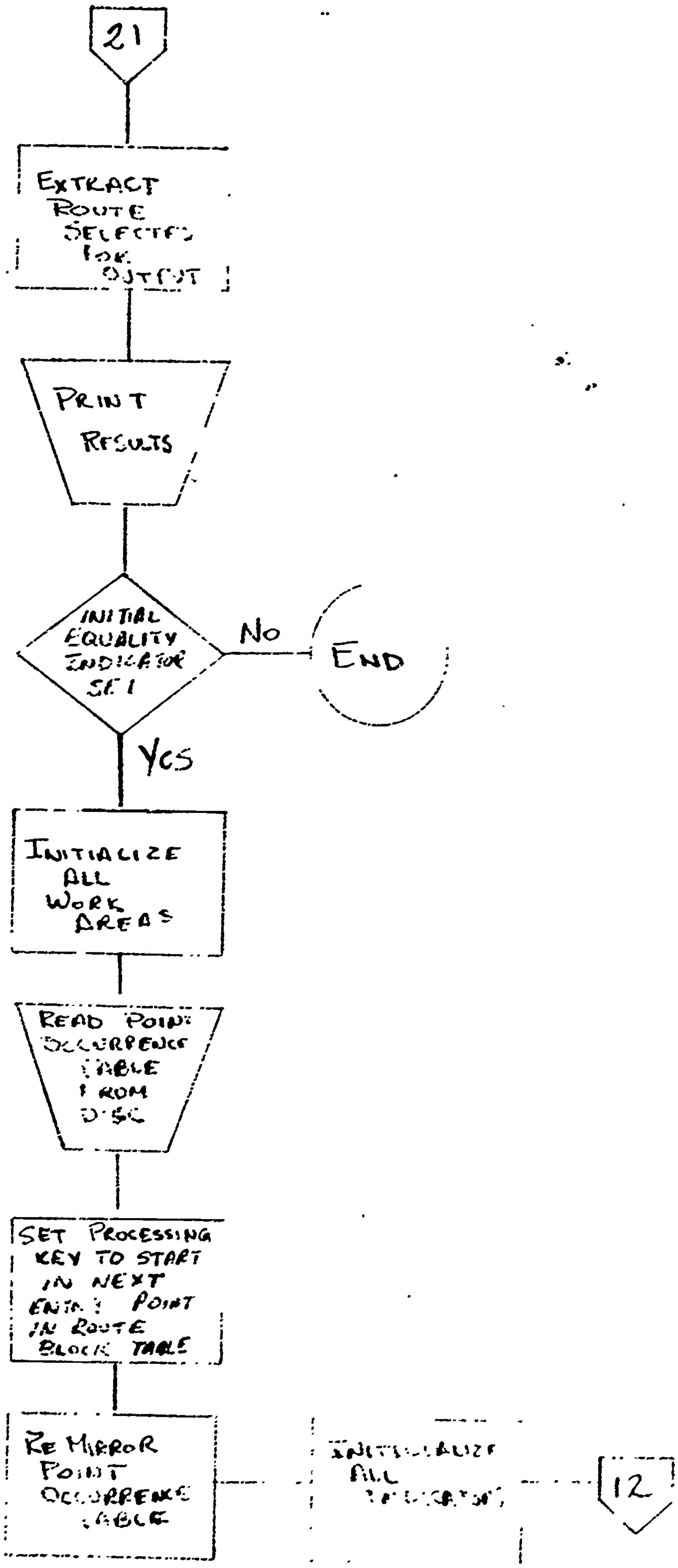

17
TABLE PROCESSED
No
18
CYCLE SELECTED ROUTE TABLE
Yes
DETERMINE LAST PICK UP POINT
No
BALANCING INDICATOR SET
Yes
DETERMINE PICKUP POINT
EXTRACT ALL DATA AND STORE IN CONFLICT
No
No
HAS TABLE BEEN
Yes
CYCLE CONFLICT ADJUSTMENT TABLE
No
22
TABLE
No
Yes
CYCLE
Yes
21
No
Yes
20
No
19
Yes



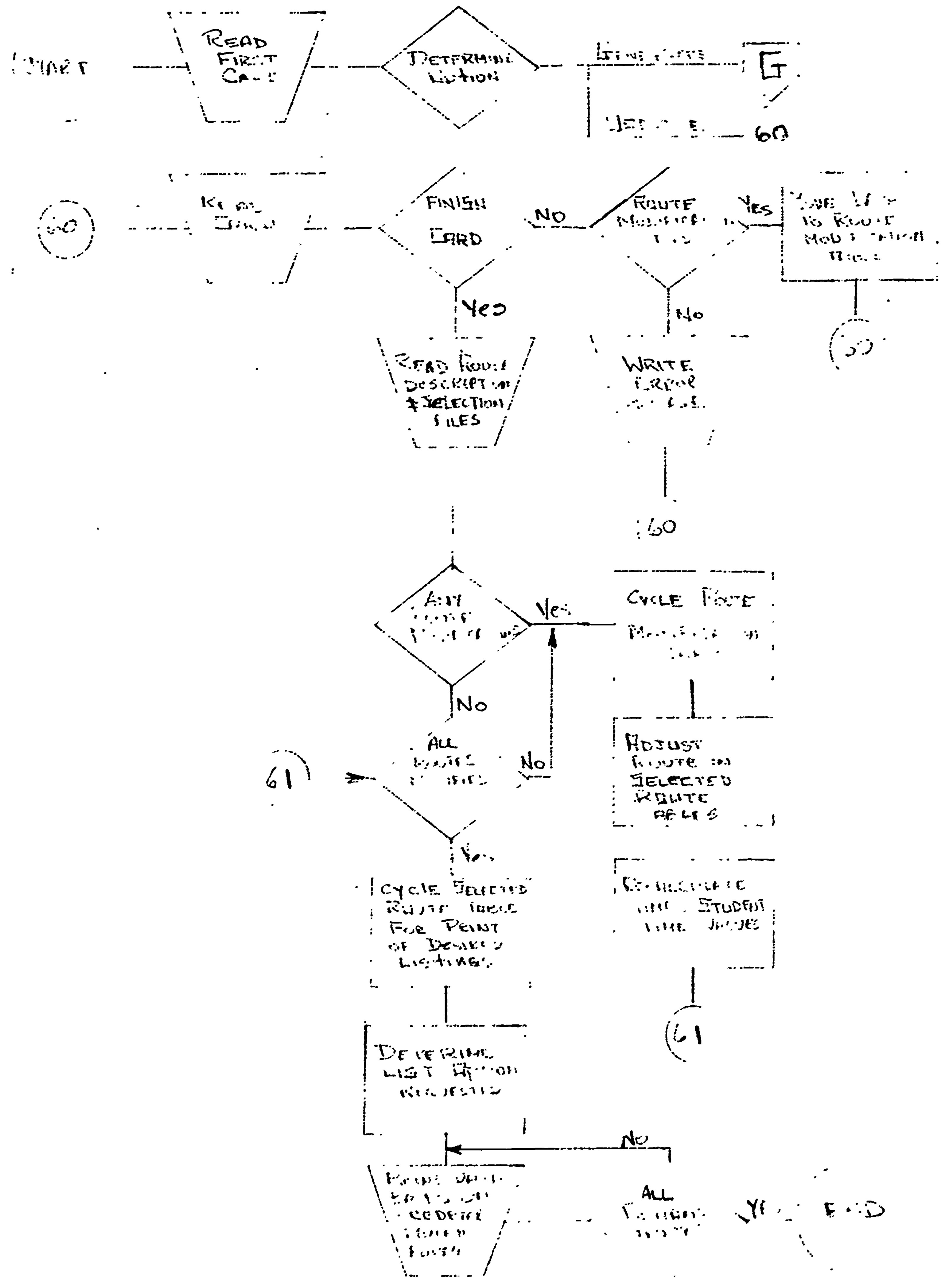
23
No
SCAN OTHER PICKUP POINTS IN ROUTE
IS BALANCING INDICATOR SET
No
ALL POINTS
Yes
No
Yes
22
MORE THAN ONE CROSS REFERENCE
Yes
DELETE POINT IN ENTIRETY FROM TABLE
No
OVERLOAD STILL EXIST
Yes
No
ADJUST OTHER RELATED ROUTES BY RE CALCULATING
DELETE BALANCING INDICATOR FROM SELECTED ROUTE TABLE
OVERLOAD STILL EXIST
No
22
Yes
23



20
No
NUMBER OF POINTS AFFECTED <2
Yes
TOTAL
Yes
SELECT EACH CROSS REFERENCED ROUTE
No
MINIMUM
Yes
SET # of STUDENTS AT b=0
SET NUMBER OF STUDENTS AT OTHER POINTS TO ZERO
No
SET NUMBER OF STUDENTS at b=a
DIVIDE NUMBER OF STUDENTS
MINIMUM
SET
a=0
No
ALL
Yes
RECALCULATE TRAVEL TIME FOR DELETED POINT
19


21
EXTRACT ROUTE SELECTED FOR OUTPUT
PRINT RESULTS
INITIAL EQUALITY INDICATOR SET
No
END
Yes
INITIALIZE ALL WORK AREAS
READ POINT OCCURRENCE TABLE FROM DISC
SET PROCESSING KEY TO START IN NEXT ENTRY POINT IN ROUTE BLOCK TABLE
RE MIRROR POINT OCCURRENCE TABLE
INITIALIZE ALL
12

UPDATE


START
READ FIRST CARD
DETERMINE
60
FINISH CARD
NO
ROUTE
YES
Yes
READ ROUTE DESCRIPTION & SELECTION FILES
WRITE ERROR
No
60
ANY
Yes
CYCLE ROUTE
No
ALL
No
61
ADJUST ROUTE IN SELECTED ROUTE FILES
Yes
CYCLE SELECTED ROUTE TABLE FOR POINT OF DESIRED LISTINGS
STUDENT
61
DETERMINE LIST
No
ALL
END

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The following set of conclusions can be made from the study performed:

1. A survey of pupil transportation of individual State Departments of Education revealed that no computer applications are presently being undertaken or in operation relating to bus routing and scheduling at the state level. These systems in effect are only punch card related.
2. The Boyer computer program, developed at the University of Mississippi, is the only computer application presently available and has been applied successfully in Dade County, Florida.
3. A review of research and development in the field of operations research reveals that no prior work has been accomplished in relation to school bus routing and scheduling. The areas of aircraft routing and railroad routing have received the deepest research but their results are not applicable to bus routing due to the change in variables (i.e. crew flight time and layover, forced maintenance schedules, fuel loads, passenger demand, scheduled departure and arrival times, etc.).

4. The applicable OR and mathematical techniques that could be applied to construct a soluble model that were investigated were linear programming, dynamic programming, heuristic modeling, simulation, graph theory, network flow theory and combinatorial programming. Of these applicable techniques, combinatorial programming was selected because it presented a mathematical model that was adaptable to computer programming and readily identified itself to the problem of school bus routing.

5. The most applicable OR problems related to the bus routing problem are the transportation problem, the traveling salesman problem and the shortest route problem. Each of these OR problems overlap when applied to bus routing but individually do not offer a solution.

6. The school bus routing problem can be stated as "... the selection of an optimum combination of a grouping of routes which minimize the total travel time of students by permuting the sequence of pick-up points that establish the route, with the capacity of the carrier controlling the number of points in the route..." Therefore, combinatorial programming, which entails the construction of m number of possible arrangements of n elements taken c at a time, was selected as the

feasible technique.

7. Based on the applicability of combinatorial programming to an electronic computer, an IBM series 360 model 30 computer was selected as the object computer. The 360 was chosen due to modularity of core storage within individual computers and across computer lines, and rapid random access, large volume peripheral devices.

8. The computer system is to be coded in the FORTRAN language due to the system's scientific applicability. In addition, the major proportion of programming is related to entry manipulation of tables which results in a smaller instruction set and a reduction in check-out and code time.

9. A sample school district in Rockland County, New York was used as a test case to prove the Routing Algorithm. Data pertaining to existing routes, stops, bus capacities and students at each stop was collected and a manual solution was started applying the routing algorithm that was developed. The enormity of the hand calculations, based on 85 pick-up points, which averaged two and one-half

days per pick-up point resulted in the decision to suspend the manual solution and thereby proof of the algorithm was not obtained. A small scale model was not constructed to apply the algorithm against since the routing problem is a problem in data combinations and permutations. The small model would not supply the amount of data necessary for proof and previous experience in bus routing research has shown that while solutions are feasible on a five or ten pick-up point model, the solution decays when applied to the real life situation.

10. Even though the routing algorithm was only half tested, and based on a previous computer simulation study done in 1963, that recommended a combinatorial approach but was abandoned due to inadequacies of the computers at that time, a system was designed and flowed that would do bus routing.

11. A Bus Utilization and Scheduling System was designed that will optimally route school buses by computer. The system is comprised of four computer programs which monitor input data, construct routes, select an optimum combinations of routes and produce formatted listings for use by the school, student and bus companies.

B. RECOMMENDATIONS

The purpose of this study was the analysis and development of a semi-automated bus utilization and scheduling system. This document presents a system that would meet that end. The investigation and research performed, has revealed that the original estimation of five man-months of computer program development time which entails

1. Program design,
2. Coding of the supervisor and related programs,
3. Program checkout,
4. Data conversion,
5. System verification, and
6. Final documentation including detailed program documents and a users manual presenting system concepts, machine specifications, and operational procedures

is insufficient to complete the system.

Figure 6 presents the necessary amount of program development time that is needed to produce BUSS. As can be seen, approximately 12 man-months of time is required which is seven man-months in excess of the original estimation.

A system design and operational program flow of the system was made even though the routing algorithm as stated herein

PROGRAM DEVELOPMENT

	Program	Week Number 1–14	Time Required
1.	Supervisor Program	D, C, Ck, Dc	8
2.	Route Construction Program	D, C, Ck, Dc	13
3.	Route Selection Program	D, C, Ck, Dc	12
4.	Update Program	D, C, Ck, Dc	10
5.	System Test	Program No. 1, 2, 3, 4	5
		TOTAL TIME	48 MW

LEGEND

D - Design

C - Code

Ck - Checkout

Dc - Documentation

FIGURE 6

was not fully proven by manual methods. The system design was carried through to determine if the combinatorial programming technique was programmable for a computer solution. It is incorporated in the report as support material if a decision is made to continue the present project with additional funding.

Therefore, this report recommends suspension of the present project due to

1. The lack of future funds to successfully complete the programming and system checkout of the recommended solution as presented herein and
2. The proof of the routing algorithm as presented in the report by manual methods has not been completed due to the amount of time (approximately 10 man-months) of hand calculations that would be required.

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APPENDIX A

CONTRACTED ROUTES

FOR

CHERRY LANE ELEMENTARY SCHOOL

1966 - 1967

Route 202

From Route 202 and Wilder Road at 8:20 A.M.; thence by way of Route 202, Mayer Drive, Montebello Road, North Airmont Road, Route 59 and Cherry Lane to the Cherry Lane School, returning over the same route in reverse at 3:25 P.M.

Approximately 60 pupils

Approximate time - 25 minutes

Approximate mileage - 7.5 miles

Project Assigned Identifier	Main Stops	# of Students at Point
AA	Route 202 and Lime Kiln Road	12
BA	Route 202 and Skyland Road	8
CA	Route 202 and Grandview Avenue	5
DA	Route 202 and Keven Drive	4
EA	Route 202 and Viola Road	8
FA	Route 202 and Orchard Circle	8
GA	Route 202 and Bayard Lane	2
HA	Mayer Drive and Victory Drive	12
IA	Mayer Drive and East Mayer Drive	12
JA	Mayer Drive and Montebello Road	4
	Cherry Lane School	75

Upper Viola Route

From the intersection of Route 202 and Wilder Road at 8:20 A.M.; thence by way of Wilder Road, Willow Tree Road, Grandview Avenue, Forshay Road, College Road, Carlton Road, Spook Rock Road, and Cherry Lane to the Cherry Lane School, returning over the same route in reverse at 3:25 P.M.

Approximately 60 pupils

Approximate time - 25 minutes

Approximate mileage - 8.0 miles

Project Assigned Identifier	Main Stops	# of Students at Point
KA	Wilder Road and Lime Kiln Road	14
LA	Wilder Road and Willow Tree Road	3
MA	Willow Tree Road and Grandview Ave.	8
NA	Grandview Avenue and Forshay Road	19
OA	Forshay Road and South Parker Drive	2
PA	College Avenue and Carlton Road	7
QA	Carlton Road and Pine Road	4
RA	Carlton Road and Arrowhead Lane	6
	Cherry Lane School	63

Spook Rock Road Route

From the intersection of Spook Rock Road and Lime Kiln Road at 8:20 A.M.; thence by way of Spook Road Road, Wesley Chapel Road, Grandview Avenue, Spook Rock Road and Cherry Lane to the Cherry Lane School, returning over the same route in reverse at 3:25 P.M.

Approximately 60 pupils

Approximate time - 25 minutes

Approximate mileage - 8.0 miles

Project Assigned Identifier	Main Stops	# of Students at Route
SA	Spook Rock Road and Wesley Chapel Road	8
TA	Wesley Chapel Road and Grandview Ave.	3
UA	Grandview Avenue and Spook Rock Road	5
VA	Spook Rock Road and Margaret Ann Lane	13
WA	Spook Rock Road and Rose Hill Road	6
ED	Spook Rock Road and Viola Road	5
XA	Spook Rock Road and Carlton Road	14
YA	Spook Rock Road and Highview Road	2
ZA	Spook Rock Road and Pioneer Avenue	9
AB	Spook Rock Road and Stemmer Lane	8
	Cherry Lane School	73

Mile Road Route

From the intersection of Montebello Road and Mile Road at 8:20 A.M.; thence by way of Mile Road, Viola Road, College Road, Highview Road, North Airmont Road, Route 59 and Cherry Lane to the Cherry Lane School, returning over the same route in reverse at 3:25 P.M.

Approximately 60 pupils

Approximate time - 20 minutes

Approximate mileage - 6.0 miles

Project Assigned Identifier	Main Stops	# of Students at Point
GB	Viola Road and Mile Road	4
DB	Viola Road and Canterbury Lane	16
EB	Viola Road and College Road	12
FB	College Road and Highview Road	3
HB	Highview Road and Pine Road	8
IB	North Airmont Road and Pioneer Avenue	8
JB	North Airmont Road and Montebello Road	4
	Cherry Lane School	55

East Mayer Drive Route

From the intersection of Spook Rock Road and Wesley Chapel Road at 8:20 A.M.; thence by way of Spook Rock Road, Grandview Avenue, Route 202, Viola Road, Mile Road, East Mayer Drive, left on Mayer Drive, Montebello Road, North Airmont Road, Route 59 and Cherry Lane to the Cherry Lane School.

Approximately 60 pupils

Approximate time - 15 minutes

Approximate mileage - 5.0 miles

Project Assigned Identifier	Main Stops	# of Students at Point
CB	Mile Road and Nottingham Drive	9
KB	East Mayer Drive and Mile Road	21
LB	East Mayer Drive and Sterling Forest Lane	6
MB	East Mayer Drive and Robin Hood Lane	24
BB	Mile Road and Montebello Road	9
	Cherry Lane School	69

Airmont Acres Route

From the intersection of Campbell Road and Cragmere Road at 8:20 A.M.: thence by way of Cragmere Road to the New Jersey State Line, returning by way of Cragmere Road to Hemion Way; thence by way of Hemion Way, Augur Road, right on South Airmont Road, Marjorie Lane, left on Church Road, and then by way of Church Road, South Airmont Road, Route 59 and Cherry Lane to the Cherry Lane School, returning over the same route in reverse at 3:25 p.m.

Approximately 60 pupils

Approximate time - 20 minutes

Approximate mileage - 7.0 miles

Project Assigned Identifier	Main Stops	# of Students at Point
NB	Cragmere Road at the New Jersey State Line	8
OB	Cragmere Road and Hemion Way	8
PB	Augur Road and Farview Terrace	2
QB	Augur Road and South Airmont Road	4
RB	South Airmont Road and Majorie Lane	4
SB	Majorie Lane and Daisy Court	5
TB	Majorie Lane and Church Road	5
UB	Smith Hill Road and Church Road	3

Project Assigned Identifier	Main Stops	# of Students at Point
VB	Church Road and Utopian Place	4
WB	Church Road and Ackerman Avenue	4
XB	Church Road and South Airmont Road	6
YB	South Airmont Road and Campbell Road	9
	Cherry Lane School	61

Cherry Lane - Rustic Drive Route

From the intersection of Shuart Road and Rustic Drive at 8:20 A.M.; thence by way of Rustic Drive, Edgebrook Lane, Appleblossom Court, Rustic Drive, left on Shuart Road and then by way of Shuart Road and Cherry Lane to the Cherry Lane School, returning over the same route in reverse at 3:25 P.M.

Approximately 60 pupils

Approximate time - 15 minutes

Approximate mileage - 4.0 miles

Project Assigned Identifier	Main Stops	# of Students at Point
ZB	Edgebrook Lane and Appleblossom Court	3
AC	Appleblossom Court and Cobblestone Road	23
BC	Appleblossom Court and Rustic Drive	5
CC	Rustic Drive and Shuart Road	9
KC	Smith Hill Road and Smith Hill Court	9
DC	Shuart Road and Cherry Lane	5
EC	Cherry Lane and Beaver Hollow Road	3
	Cherry Lane School	57

Smith Hill Road - Eros Drive Route

From the intersection of Smith Hill Road and Church Road at 8:20 A.M.; thence by way of Smith Hill Road, Eros Drive, Montclair Avenue, Dale Road, Eton Place, left on Shuart Road, right on Smith Hill Road, left on Cherry Lane and then by way of Cherry Lane to the Cherry Lane School, returning by way of the same route in reverse at 3:25 P.M.

Approximately 60 pupils

Approximate time - 15 minutes

Approximate mileage - 4.5 miles

Project Assigned Identifier	Main Stops	# of Students at Point
FC	Smith Hill Road and Eros Drive	9
GC	Eros Drive and Kent Road	19
HC	Eros Drive and Montclair Avenue	2
IC	Montclair Avenue and Dale Road	3
JC	Dale Road and Eton Place	9
LC	Smith Hill Road and Smith Court	5
MC	Smith Hill Road and Cherry Lane	9
	Cherry Lane School	56

Route 59 - Laura Drive Route

From Route 59 at the main entrance to Suffern Park at 8:20 A.M.; thence by way of Route 59, New County Road, Laura Drive, Christmas Hill Road, New County Road, Route 59 and Cherry Lane to the Cherry Lane School, returning over the same route in reverse at 3:25 P.M.

Approximately 60 pupils

Approximate time - 20 minutes

Approximate mileage - 6.0 miles

Project Assigned Identifier	Main Stops	# of Students at Point
FD	Route 59 at Stage Street	5
NC	Route 59 and Highview Avenue	9
OC	Route 59 and New County Road	2
PC	New County Road and Laura Drive	6
QC	Laura Drive and Glenmere Court	16
RC	Laura Drive and Eleanor Place	2
SC	Laura Drive and Thomson Drive	18
TC	New County Road and Murray Drive	6
UC	Cherry Lane and Phillips Drive	5
	Cherry Lane School	69

Suffern Park Route

From the intersection of Campbell Road and Cragmere at 8:20 A.M.; thence by way of Campbell Road and Route 59 to the main entrance to Suffern Park; thence by way of Grandview Avenue, VanAlstine Avenue, left on Campbell Road, Mary Beth Drive, South VanDyke Avenue, East Haskell Avenue, Brookside Drive, Route 59 and Cherry Lane to the Cherry Lane School, returning over the same route in reverse at 3:25 P.M.

Approximately 60 pupils

Approximate time - 20 minutes

Approximate mileage - 4.5 miles

Project Assigned Identifier	Main Stops	# of Students at Point
VC	Campbell Road and Cragmere Road	5
GD	Campbell Road and Reigate Place	8
WC	Grandview Avenue and Park Place	13
XC	Grandview Avenue and VanAlstine Avenue	4
YC	Campbell Road and Mary Beth Drive	6
ZC	Mary Beth Drive and South VanDyke Avenue	3
AD	South VanDyke Avenue and Dell Court	8
BD	South VanDyke Avenue and East Haskell Ave.	2
CD	East Haskell Avenue and Brookside Drive	9
DD	Brookside Drive and VanOrden Avenue	8
	Cherry Lane School	66

APPENDIX B

ROUTE CONSTRUCTION TABLE

POINT AA (12)

ROUTE SEQUENCE NUMBER 1	2	3	4	5	6	7	8	9	10	# OF STUDENTS	TOTAL TRAVEL TIME	STUDENT TRAVEL TIME AT BUS CAPACITIES OF 66	65	64	RANK TIME	RANK STUDENT TIME
AA	BA	SA	CA	DA	EA	GB	DB			65	106	--	5060	5011		
							CB	KB		79	109	5264	5215	5166		
								LB		64	119	--	--	5582		
						FA	GA	HA		67	118	6022	5958	5894		
				UA	TA	MA	LA	KA		66	118	6612	6543	6474		
								NA		71	108	5332	5280	5228		
							NA			68	100	4914	4862	4810	44	
							OA	NA		70	111	5465	5413	5361		
								EB	ED	68	121	6022	5978	5934		
									PA	70	118	5815	5777	5739		
					VA	WA	ED	XA		76	91	4338	4316	4290	14	18
								EB		84	113	5810	5757	5704		
								DB		78	101	5030	4981	4932		
							DB			73	100	4948	4899	4850	45	
				VA	UA	TA	MA	LA		65	119	----	6054	5995		
								NA		81	111	5585	5533	5481		
								OA		64	111	----	----	5569		
					WA	ED	XA			71	88	4391	4365	4339	7	21
							EB			69	110	5888	5835	5782		
							DB			73	98	5168	5119	5070	33	
						DB				68	97	5091	5042	4993	26	
			UA	TA	MA	LA	KA			61	116	----	----	----		
							NA			66	96	4821	4769	4717	24	50
						NA	LA			66	102	5251	5192	5133		
						OA	NA			65	99	----	4882	4830	40	
							EB	ED	XA	77	109	5336	5310	5284		
									WA	69	121	6266	6216	6166		
									DB	79	119	6140	6091	6042		
								PA		65	106	----	5232	5194		
			TA	MA	LA	KA				56	113	----	----	----		
						NA	OA	EB		75	111	6737	6684	6631		
					NA	LA	KA			75	119	6447	6378	6309		
						OA	EB			72	103	5383	5330	5377		
					OA	NA	LA	KA		77	130	6892	6813	6744		
						EB	ED	XA		72	106	5345	5319	5393		
								WA		64	118	----	----	6133		
								DB		74	116	6109	6060	6011		

AA BA SA TA MA OA EB PA FB HB	71	107	5456	5427	5398		
OC	65	101	-----	5857	5837	50	
QA HB	70	107	5446	5417	5388		
RA	68	105	5326	5296	5266		
UA CA DA EA GB DB	73	125	5912	5863	5814		
CB	66	129	6267	6215	6163		
FA GA HA	75	137	6901	6837	6773		
VA WA ED	65	107	----	5030	4986		
VA CA DA EA	66	146	6896	6830	6764		
WA ED XA	74	92	4372	4346	4320	16	19
EB	72	114	5754	5701	5648		
DB	66	102	5010	4961	4912		
DB	71	101	4930	4871	4822	49	
LA KA	66	136	6539	6470	6401		
NA	68	108	4848	4796	4744		
OA NA	70	119	5399	5347	5295		
EB ED	79	129	5845	5801	5757		
PA	70	119	5176	5145	5114		
VA WA ED XA	76	99	4272	4246	4220	34	17
EB	74	121	5744	5691	5648		
DB	78	109	4984	4935	4886		
DB	73	108	4902	4853	4804		
TA MA LA KA	61	133	----	----	----		
NA	66	113	5301	5249	5197		
NA LA	66	119	5831	5772	5713		
OA	65	106	----	4927	4880		
OA NA	65	116	----	5472	5420		
EB ED XA	77	126	5826	5800	5774		
DB	79	136	6525	6476	6427		
UA VA WA ED	65	112	----	4981	4937		
DB	76	121	5595	5546	5497		
DA EA GB DB ED XA	76	104	4584	4558	4532		32
EB	74	126	6056	6003	5950		
WA	68	116	5424	5374	5324		
WA VA	66	121	5694	5641	5588		
ED XA	72	115	5019	4993	4967		
EB	70	137	6707	6654	6601		
GA HA IA	71	116	5596	5538	5480		
JA IA	75	132	6572	6514	6456		
BB	72	126	6176	6124	6172		
UA SA TA MA LA KA	66	139	6845	6776	6707		
NA	71	119	5467	5415	5363		
OA NA	70	117	6250	6198	6146		

AA BA CA UA SA TA MA OA EB ED	68	127	5996	5952	5908		
PA	70	124	5789	5751	5713		
TA SA	41	118	----	----	----		
MA LA KA	58	126	----	----	----		
NA OA	65	107	----	4928	4871		
NA LA KA	77	132	6750	6681	6612		
OA EB	74	116	5686	5633	5580		
OA NA LA	65	123	----	5878	5819		
EB ED XA	74	119	5263	5237	5211		
WA	66	131	6199	6149	6099		
PA FB	65	116	----	5153	5122		
QA	66	118	5308	5277	5246		
VA WA ED XA	67	89	3642	3616	3590	8	5
EB	65	111	----	5306	5253		
DB	69	99	4671	4622	4573	38	36
DB	64	98	----	----	4500	29	29
VA UA SA TA MA LA	65	126	----	6270	6211		
NA	81	118	5802	5750	5698		
OA	64	118	----	----	5688		
TA SA	54	125	----	----	----		
MA LA KA	71	123	6811	6742	6673		
NA	76	103	5518	5466	5414		
NA	73	105	5065	5013	4961		
OA NA	75	116	5661	5609	5557		
EB	68	122	6007	5954	5901		
WA ED XA RA	69	91	4100	4070	4040	13	13
YA	65	82	----	3491	3467	2	2
EB OA NA	82	120	6041	5989	5937		
MA	71	136	7076	7015	6954		
PA	68	105	5044	5006	4968		
DB GB CB	68	126	6179	6127	6075		
EA	67	138	6985	6919	6853		
DB GB CB KB	74	119	5674	5625	5576		
LB	69	129	5322	5267	5212		
EA DA	66	148	7586	7512	7438		
FA	70	139	7009	6939	6870		
ED XA	69	106	4680	4654	4628		39
EB	67	128	6187	6134	6081		
UA SA CA DA EA GB DB	70	126	5779	5730	5681		
CB KB	84	129	5969	5920	5871		
LB	69	139	6559	6504	6449		
FA GD HA	72	141	6677	6613	6549		
VA WA ED XA	76	108	4764	4738	4713		50
EB	74	130	6236	6183	6130		

AA BA UA SA CA VA WA ED DB	78	118	5475	5427	5378		
DB	73	117	5394	5345	5296		
TA MA LA KA	61	133	----	----	----		
NA	66	125	6162	6096	6030		
NA LA	66	117	5740	5681	5622		
OA	65	104	----	4838	4791		
OA NA	65	114	----	5181	5129		
EB ED XA	77	124	5729	5703	5677		
WA	69	136	6563	6513	6463		
DB	79	134	6434	6385	6336		
PA	65	121	----	5429	5391		
TA SA CA DA EA GB CB	66	143	6536	6484	6432		
FA GA HA	75	151	7173	7109	7045		
VA WA ED	65	121	----	5111	5067		
DB	76	130	5769	5720	5671		
MA LA KA	53	120	----	----	----		
NA OA EB	72	118	5771	5718	5665		
NA LA KA	72	126	6415	6346	6277		
OA EB	69	110	5351	5298	5245		
OA NA LA KA	74	137	6857	6788	6719		
EB ED XA	69	113	4846	4820	4794		
WA VA	74	131	6137	6084	6031		
DB	77	134	6318	6269	6220		
DB	71	123	5653	5604	5555		
PA FB HB	68	114	4967	4938	4909		
OC VC	67	99	4387	4378	4369	35	22
NC	71	108	5153	5137	5121		
PC	68	102	4701	4680	4659		
AB	68	109	5231	5211	5191		
CA SA TA MA LA KA	68	145	7023	6954	6885		
NA	75	125	5739	5687	5635		
NA	70	117	5310	5258	5206		
OA NA	72	128	5793	5741	5689		
EB	65	134	----	6161	6108		
DA EA GB DB ED	67	116	5141	5097	5053		
WA	68	127	5847	5797	5747		
CB KB	76	119	6117	6068	6019		
LB MB	85	131	6060	6004	5948		
FA GA HA	64	128	----	----	6083		

AA BA UA CA VA WA ED XA	68	98	4106	4080	4054	28	14
EB	66	120	6618	6565	6512		
DB	70	108	4922	4873	4824		
DB	65	107	----	4799	4750		
VA CA SA TA MA LA	65	136	----	6632	6573		
NA	71	128	6167	6115	6063		
OA	64	128	----	----	6053		
DA EA GB DB	75	127	6060	6011	5962		
CB	68	131	6317	6265	6213		
FA GA	65	138	----	6814	6774		
SA BA CA DA EA GB DB	65	104	----	5016	4967		
CB KB	79	107	5234	5185	5136		
LB	64	126	----	----	5752		
FA GA HA	67	116	5982	5918	5854		
UA TA MA LA KA	66	126	6565	6496	6427		
NA	71	106	5287	5235	5183		
NA	68	98	4874	4822	4770	31	
OA NA	70	109	5425	5373	5321		
EB ED	68	119	5971	5927	5883		
PA	70	116	5764	5726	5688		
VA WA ED XA	76	89	3851	3825	3799	10	7
EB	74	111	5770	5717	5664		
DB	78	99	5010	4961	4912	42	
DB	73	98	4928	4879	4830	32	
UA VA CA DA EA GB	67	127	6603	6545	6487		
FA	71	134	7077	7008	6939		
WA ED XA	71	83	3915	3889	3863	3	9
EB	69	105	5412	5359	5306		
DB	73	93	4692	4643	4594	18	38
DB	68	92	4615	4566	4517	17	30
CA BA UA TA MA LA KA	66	140	6867	6798	6729		
NA	71	120	5589	5537	5485		
NA	68	112	5176	5124	5072		
OA NA	70	123	5827	5775	5723		
EB ED	68	133	6273	6229	6185		
PA	70	130	6066	6028	5990		
VA WA ED XA	76	99	4468	4442	4416	36	24
EB	74	121	5940	5887	5834		
DB	78	109	5180	5131	5082		
DB	73	108	5098	5049	5000		
DA EA GB DB ED XA	76	104	4692	4666	4640		43
EB	74	126	6164	6111	6058		
WA	68	116	5532	5482	5432		
WA VA	76	121	5829	5776	5723		
CB KB	71	107	4950	4901	4852		
LB KB	77	117	5490	5441	5392		

AA SA CA DA EA GB CB LB MB	80	119	5568	5512	5456		
FA GA HA IA	71	116	5604	5546	5488		
JA IA	75	132	6580	6522	6466		
BB	72	116	5524	5482	5440		
UA BA	38	----	----	----	----		
TA MA LA KA	58	----	----	----	----		
NA LA KA	77	132	6758	6689	6620		
OA EB	74	116	5694	5641	5588		
OA NA LA	65	123	----	5876	5817		
EB ED XA	74	119	5333	5307	5281		
WA	66	131	6197	6147	6097		
DB	76	129	6071	6022	5973		
PA FB	65	116	----	5149	5118		
QA	66	118	5306	5275	5244		
VA WA ED XA	68	89	3874	3848	3822	9	8
EB	66	101	5386	5327	5268		
DB	70	99	4690	4641	4592	39	37
DB	65	98	----	4567	4518	30	31
VA UA TA MA LA KA	71	137	6919	6850	6781		
NA	76	117	5626	5574	5522		
NA	73	109	5173	5121	5069		
OA NA	75	120	5779	5727	5675		
EB	68	126	6125	6072	6019		
WA ED XA RA	69	95	4208	4178	4148	20	15
YA	65	86	----	3599	3575	4	4
EB OA NA	82	124	6149	6097	6045		
NA	71	140	7184	7122	7064		
PA	68	109	5152	5114	5076		
DB	65	96	----	4511	4462	22	27
DB GB	64	113	----	----	5459		
ED	65	95	----	4367	4323	21	20
UA BA CA DA EA GB DB	70	124	5759	5710	5661		
CB KB	84	127	5939	5890	5841		
LB	69	137	6587	6532	6477		
FA GA HA	72	136	6657	6593	6529		
VA WA ED XA	76	106	4744	4718	4692		47
EB	74	128	6216	6163	6110		
DB	78	116	5456	5407	5358		
DB	73	117	5374	5325	5276		
TA MA LA KA	48	----	----	----	----		
NA OA EB	67	109	5329	5276	5223		
NA LA KA	67	117	6073	6004	5935		
OA EB	64	101	----	----	4903		
OA NA LA KA	74	128	6460	6391	6322		

AA SA TA MA OA EB ED XA	64	104	----	----	4286		
WA VA	69	122	5608	5555	5502		
DB	72	125	5836	5777	5728		
DB	66	114	5226	5173	5124		
PA FB HB QA	67	111	4899	4868	4837		
YA	65	105	----	4446	4422		25
OC NC	66	103	4586	4570	4554		34
PC QC	79	106	4868	4843	4818		
TC	69	112	5249	5223	5197		
AB	65	104	----	4659	4639		42
UC MC	71	109	4940	4931	4922		
NC	71	107	4850	4834	4818		
AB	70	115	5356	5336	5316		
QA RA XA	76	104	4427	4401	4375		23
HB	64	105	----	----	4425		26
UA BA CA DA EA GB DB	73	137	6317	6268	6219		
CB	66	141	6472	6420	6368		
FA GA HA	75	153	7318	7254	7190		
VA WA ED	65	119	----	5191	5147		
DB	76	128	5805	5756	5707		
CA BA	41	---	----	----	----		
DA EA GB DB	65	123	----	5416	5367		
CB KB	79	126	5630	5581	5532		
LB	64	136	----	----	6148		
FA GA HA	67	135	6378	6314	6250		
VA WA ED XA	71	109	4609	4583	4557		35
EB	69	131	6106	6053	6000		
DB	73	119	5386	5337	5288		
DB	68	118	5309	5260	5211		
VA CA BA	54	---	----	----	----		
DA EA GB DB	78	134	6397	6348	6299		
CB	71	138	6657	6605	6553		
FA	66	141	6927	6858	6789		
WA ED XA	66	90	3805	3779	3753	12	6
EB	64	110	----	----	5157		
DB	68	101	4647	4598	4549	49	33
DB GB	67	117	5736	5678	5620		
ED	68	99	4560	4516	4472	37	28
KA LA NA MA TA SA	67	118	6290	6222	6154		
UA	64	105	----	----	----		
OA EB	70	112	5777	5725	5673		
OA MA TA SA	69	129	6872	6804	6736		
UA	66	116	6039	5979	5919		

AA KA LA NA OA EB ED	67	102	5143	5099	5055	
PA	69	99	4943	4905	4867	41
MA TA SA BA CA DA	65	139	----	7238	7164	
UA	66	124	6327	6267	6207	
VA	74	121	6109	6056	6003	
UA CA	66	133	6891	6825	6759	
VA	74	118	5911	5858	5805	
CA BA	61	---	----	----	----	
DA EA	65	139	----	6014	5948	
UA BA	66	156	7423	7354	7285	
VA	71	134	6120	6067	6014	
VA	66	121	5925	5872	5819	
UA BA CA	66	141	7249	7181	7115	
CA BA	66	140	7205	7136	7067	
DA EA	70	145	7287	7221	7155	
VA	71	127	6442	6389	6336	
VA	66	112	5463	5410	5357	
UA BA SA CA	66	130	6675	6609	6543	
CA SA	66	141	7251	7183	7115	
DA EA	70	150	7560	7494	7428	
VA	71	132	6397	6344	6291	
SA BA CA	66	124	6389	6323	6257	
CA DA EA	70	142	7385	7319	7253	
VA	71	124	6305	6239	6173	
VA CA BA SA	66	127	6421	6353	6285	
DA EA GB	66	132	6631	6573	6515	
FA	70	139	7109	7040	6971	
VA WA	69	114	5514	5464	5414	
VA CA BA	71	138	7628	7559	7490	
SA	71	138	7625	7557	7489	
DA	67	143	8002	7928	7854	
WA	64	99	----	----	5064	43
NA OA EB	70	108	5421	5368	5315	
OA NA	53	---	----	----	----	
EB ED XA	70	111	4950	4924	4898	
WA VA	75	129	6246	6193	6140	
DB	78	132	6416	6367	6318	
PA FB HB	69	112	5065	5036	5007	
OC NC	72	116	5268	5252	5236	
PC	69	110	4904	4883	4862	
AB	71	117	5343	5323	5303	
UC	68	107	4680	4671	4662	46
QA RA	68	110	4943	4913	4883	
HB	70	112	5063	5034	5005	

AA SA UA TA MA LA KA	53	---	----	----	----		
NA OA EB	72	112	5499	5446	5393		
NA LA KA	72	120	6303	6234	6165		
OA EB	69	104	5239	5186	5133		
OA NA LA KA	74	131	6805	6736	6667		
EB ED XA	69	107	4738	4712	4686		48
WA VA	74	125	6043	5990	5937		
DB	77	128	6206	6157	6108		
DB	71	117	5541	5492	5443		
CA BA	38	---	----	----	----		
DA EA GB DB ED XA	77	11[illegible]	4881	4855	4829		
EB	75	132	6354	6301	6248		
WA	69	122	5715	5655	5605		
WA	64	121	----	----	5527		
CB KB	72	113	5125	5076	5027		
LB KB	78	123	5671	5622	5573		
MB	81	125	5748	5692	5636		
FA GA HA IA	72	122	5889	5831	5773		
JA	64	122	----	----	5741		
VA WA ED XA	68	92	3994	3968	3942	15	10
EB	66	114	6506	6553	6500		
DB	70	102	4810	4751	5469		49
DB	65	101	----	4687	4638	48	41
VA CA BA	51	---	----	----	----		
DA EA GB DB	75	123	5998	5949	5900		
CB	68	127	6255	6203	6251		
FA GA	65	138	----	6752	6682		
WA ED XA RA	69	88	4048	4018	3988	6	11
YA	65	79	----	3439	3415	1	1
DB	65	89	----	4250	4201	11	16

TOTAL NUMBER OF ROUTES - 394

POINT KA (14)

ROUTE SEQUENCE NUMBER 1	2	3	4	5	6	7	8	9	# OF STUDENTS	TOTAL TRAVEL TIME	STUDENT TRAVEL TIME AT BUS CAPACITIES OF 66	65	64	RANK TIME	RANK STUDENT TIME
KA	AA	BA	SA	CA	DA	EA	FA		67	124	6586	6517	6448		
							GB	DB	79	117	6069	6020	5971		
								DB	72	121	6330	6278	6126		
					UA	TA	MA	LA	66	119	6273	6214	6155		
								NA	82	111	5748	5696	5644		
								OA	65	110	----	5602	5556		
						VA			65	102	----	5150	5097	37	
					VA	UA			65	113	----	5849	5789		
						WA			66	99	5009	4959	4909	30	
				UA	TA	MA	LA	NA	75	107	5599	5547	5495		
							NA		72	99	5114	5062	5010	31	
							OA	NA	74	110	5764	5712	5660		
								EB	72	116	6130	6077	6024		
					CA	DA	EA		64	123	----	----	6407		
					VA	CA			65	116	----	6191	6125		
						WA			66	90	4601	4551	4501	5	29
				TA	MA	LA	NA		70	104	5348	5296	5244		
						NA			67	96	4903	4851	4799	17	50
						OA	NA		69	107	5498	5446	5394		
							EB		67	113	5839	5786	5733		
					UA	CA	DA	EA	67	136	7190	7124	7058		
							VA		68	112	5695	5642	5589		
						VA	CA		68	129	6887	6821	6755		
							WA		71	103	5201	5151	5101	50	
			CA	SA	UA	TA	MA	LA	66	127	6491	6432	6373		
								NA	82	119	5966	5914	5862		
								OA	65	119	----	5904	5857		
						VA			65	110	----	5368	5315		
					TA	MA	LA	NA	80	124	6225	6173	6121		
							NA		77	116	5740	5688	5636		
							OA	EB	72	131	6756	6703	6650		
						UA	VA		67	123	6077	6024	5971		
				DA	EA	GB	DB		71	115	5645	5596	5547		
							CB		64	119	----	----	5794		
						FA	GA	HA	73	127	6540	6476	6412		
				UA	SA	TA	MA	LA	66	130	6649	6590	6531		
								NA	82	122	6124	6072	6020		
								OA	65	122	----	6062	6015		

KA AA BA CA UA TA SA	55	---	----	----	----		
MA LA NA	77	117	5837	5785	5733		
NA	74	109	5376	5324	5272		
OA NA	76	120	5993	5941	5889		
EB	69	126	6244	6191	6138		
VA WA ED	68	100	4876	4832	4788	34	48
DB	79	109	5458	5409	5306		
VA UA SA	65	127	----	6501	6433		
TA MA	68	121	6167	6106	6045		
WA ED XA	77	97	4609	4583	4557	21	32
EB	75	119	6082	6029	5976		
DB	79	117	5314	5265	5216		
DB	74	106	5231	5182	5133		
UA SA CA DA EA	64	137	----	----	6877		
VA	65	119	----	5806	5753		
TA MA LA NA	80	134	6140	6088	6036		
NA	77	127	5704	5652	5600		
OA NA	79	137	6305	6253	6201		
EB	72	143	6671	6618	6565		
TA SA	50	---	----	----	----		
MA LA NA	72	111	5363	5311	5359		
NA	69	103	4942	4890	4838	46	
OA EB	64	120	----	----	5724		
CA SA TA MA LA	77	136	6883	6824	6765		
NA	82	128	6358	6306	6254		
OA	65	128	----	6296	6249		
DA EA GB DB	76	127	5853	5804	5755		
CB	69	131	6111	6059	6007		
FA	64	134	----	----	6671		
VA WA ED	68	109	5232	5188	5144		
DB	79	118	5810	5761	5712		
VA CA SA	65	133	----	6852	6784		
DA EA	69	137	7151	7086	7021		
WA ED XA	77	94	4483	4457	4431	13	25
EB	75	116	5950	5897	5844		
DB	79	104	5182	5133	5084		
DB	74	103	5099	5050	5001	49	
SA BA CA DA EA GB DB	79	115	5993	5944	5895		
CB	72	119	6254	6202	6150		
FA	67	122	6510	6441	6372		
UA TA MA LA	66	117	6197	6138	6079		
NA	82	109	5672	5620	5568		
OA	65	109	----	5610	5563		
VA	65	100	----	5074	5021	36	
VA UA	65	111	----	5703	5643		
WA	66	97	4863	4813	4763	23	46

KA AA SA BA UA TA MA LA NA	80	111	5737	5685	5633		
NA	77	103	5484	5432	5380		
OA NA	79	114	6052	6000	5948		
EB	72	120	6418	6365	6312		
CA DA EA	64	127	----	----	6572		
VA	65	109	----	5501	5448		
VA CA	65	120	----	6347	6281		
WA	66	94	4755	4705	4655	15	41
CA BA UA TA MA LA	66	131	6695	6636	6577		
NA	82	123	6170	6118	6066		
OA	65	123	----	6108	6061		
VA	65	114	----	5572	5519		
DA EA GB DB	71	115	5633	5584	5535		
CB	64	119	----	----	5782		
FA GA HA	73	127	6528	6464	6400		
UA BA	52	---	----	----	----		
TA MA LA NA	77	117	5845	5793	5741		
NA	74	109	5384	5332	5280		
OA NA	76	120	6001	5949	5897		
EB	69	126	6352	6299	6246		
VA WA ED	68	100	4882	4838	4794	35	9
DB	79	109	5396	5347	5298		
VA UA BA	65	132	----	6850	6781		
TA MA	68	120	6235	6174	6113		
WA ED XA	77	96	4683	4657	4631	19	40
EB	75	118	6150	6097	6044		
DB	79	106	5382	5333	5284		
UA BA CA DA EA	64	135	----	----	6829		
VA	65	117	----	5758	5705		
TA MA LA NA	72	105	5267	5215	5163		
NA	69	97	4846	4794	4742	22	43
OA NA	71	108	5408	5356	5304		
EB	64	114	----	----	5628		
CA BA	52	---	----	----	----		
DA EA GB DB	76	121	5957	5908	5859		
CB	69	125	6215	6163	6111		
FA	64	128	----	----	6475		
VA WA ED	68	103	5039	4995	4951	47	
DB	79	112	5621	5572	5523		
VA CA BA	65	127	----	6664	6595		
DA EA	69	132	7023	6957	6391		
WA ED XA	79	98	4287	4261	4235	25	16
EB	75	118	5754	5701	5648		
DB	79	106	4986	4937	4888		
DB	74	97	4903	4854	4805	24	

KA AA SA TA MA LA NA	67	102	5040	4988	4936		
NA	64	94	----	----	4555	14	31
OA NA	66	105	5166	5114	5062		
EB ED	64	115	----	----	5552		
PA	66	112	5421	5383	5345		
UA BA CA DA EA	67	148	6450	6384	6318		
VA	68	130	6285	6232	6179		
CA BA	55	---	----	----	----		
DA EA GB DB	79	135	6694	6645	6596		
CB	72	140	7018	6966	6914		
FA	67	149	7312	7246	7180		
VA WA	66	116	5595	5545	5495		
LA NA MA TA SA BA AA	75	128	6875	6797	6717		
CA	68	116	6053	5987	5921		
UA	68	113	5866	5806	5746		
AA	67	126	6685	6607	6529		
CA BA	68	129	6791	6722	6653		
DA	64	134	----	----	6973		
UA	65	119	----	6077	6017		
VA	73	116	5905	5852	5799		
UA BA	68	129	6806	6737	6668		
CA	65	122	----	6302	6236		
VA	73	113	5750	5697	5644		
UA BA AA	72	135	7391	7318	7240		
SA	68	116	6191	6123	6055		
CA	65	123	----	6533	6467		
SA BA	68	112	5997	5928	5859		
AA	72	129	7076	6998	6920		
CA	65	119	----	6333	6267		
CA BA	65	122	----	6490	6421		
SA	65	122	----	6482	6414		
DA EA	69	127	6847	6781	6715		
VA	70	109	5674	5621	5568		
OA EB ED XA	79	106	5229	5203	5177		
WA	69	118	6057	6007	5957		
DB	79	116	5928	5879	5830		
PA	65	103	----	5023	4985	48	
OA MA TA SA BA	65	120	----	6194	6125		
AA	69	137	7313	7235	7157		
CA BA	70	140	7453	7384	7315		
DA	66	145	7783	7709	7635		
UA	67	130	6797	6737	6677		
VA	75	127	6583	6530	6477		

KA LA NA OA MA TA SA UA BA	70	140	7468	7399	7330		
CA	67	133	7022	6956	6890		
VA	75	118	6040	5987	5934		
UA BA AA	74	146	7877	7999	7921		
SA	70	127	6659	6591	6523		
CA	67	137	7283	7214	7145		
SA BA	67	123	6455	6386	6317		
AA	74	140	7545	7467	7389		
CA	67	130	6877	6811	6745		
TA	65	127	----	6610	6549		
CA BA	67	133	6987	6918	6849		
SA	67	133	6970	6902	6836		
DA EA	71	138	7293	7227	7161		
VA	72	120	6108	6055	6002		
VA	67	111	5607	5554	5501		
EB ED XA	69	91	4249	4223	4197	6	14
WA VA	74	109	5554	5501	5448		
DB	77	112	5717	5668	5619		
DB	71	101	5052	5003	4954	41	
PA FB HB	68	92	4366	4337	4308	7	18
OC NC	71	96	4542	4526	4510	18	30
PC	68	86	4200	4179	4158	2	10
AB	70	93	4630	4610	4590	9	35
UC	67	83	3966	3957	3948	1	4
QA RA	67	90	4247	4217	4187	4	13
HB	69	92	4366	4337	4308	7	18
MA TA SA BA AA	56	---	----	----	----		
CA DA EA GB	65	119	----	6290	6232		
FA	69	123	6674	6608	6542		
UA VA	67	104	5275	5222	5169		
VA UA	67	115	6289	6229	6169		
WA	68	101	5381	5331	5281		
UA CA DA EA	66	131	6091	6025	5959		
VA	67	113	5929	5876	5823		
VA CA	67	124	6795	6729	6663		
WA	68	98	5119	5069	5019	28	
AA BA CA DA	65	137	----	7466	7392		
UA	66	122	6555	6495	6435		
VA	74	119	6342	6289	6236		
UA CA	66	131	7119	7053	6984		
VA	74	116	6139	6086	6033		
CA BA AA	61	---	----	----	----		
UA	64	118	----	----	5935		

KA LA MA TA UA BA CA SA AA	66	149	7521	7443	7365		
DA EA GB DB	78	135	6497	6448	6399		
CB	71	138	6757	6705	6653		
FA	66	139	6829	6763	6657		
VA WA	65	117	----	5406	5356		
SA BA AA	61	---	----	----	----		
CA DA EA	66	131	6697	6631	6565		
VA	67	113	5537	5484	5431		
AA BA CA	66	131	6671	6605	6539		
CA BA AA	66	145	7405	7327	7249		
CA BA AA SA	66	134	6639	6551	6483		
SA AA	66	135	6899	6821	6743		
SA BA AA	66	137	6991	6913	6835		
AA BA	66	136	6805	6736	6667		
DA EA GB DB	70	121	5775	5726	5677		
CB KB	84	124	5959	5910	5861		
LB	69	134	6607	6552	6497		
FA GA HA	72	133	6673	6609	6545		
VA WA ED XA	78	93	4660	4634	4608	11	38
EB	74	115	6132	6079	6026		
DB	78	103	5372	5323	5274		
VA CA BA AA	71	146	7819	7741	7663		
SA	67	127	6428	6360	6252		
SA BA	67	129	6545	6476	6407		
AA	71	138	7139	7051	6973		
DA EA GB	67	132	6653	6595	6537		
FA	71	136	6929	6863	6797		
WA ED XA	73	88	3965	3939	3913	3	3
EB	69	110	5462	5409	5356		
DB	73	98	4742	4653	4604	26	37
DB	68	97	4665	4616	4567	20	33
NA OA EB ED XA	79	101	4867	4841	4815	39	
DB	79	111	5566	5517	5468		
WA	69	113	5695	5645	5595		
PA	65	98	----	4661	4623	27	39
OA NA	46	---	----	----	----		
EB ED XA RA	66	109	4494	4464	4434		26
YA IB	70	103	4108	4083	4058	45	9
HB	70	110	4558	4529	4500		28
ZA	71	100	3910	3888	3866	32	2
WA VA UA	68	132	6337	6277	6217		
CA	68	144	7011	6945	6879		
DB	66	121	5420	5371	5322		
DB GB	64	128	----	----	5894		
WA	66	121	5542	5492	5442		

KA LA MA TA SA CA DA EA CB DB	73	119	6019	5970	5921		
CB	66	123	6274	6222	6170		
UA BA AA	66	145	7663	7585	7507		
CA DA EA	71	151	8035	7696	7903		
VA	72	133	6850	6796	6744		
VA WA	65	104	----	5196	5146		
VA UA BA	64	137	7310	7231	7162		
WA ED	65	101	----	4993	4949	40	
DB	76	110	5607	5558	5509		
UA BA AA	61	---	----	----	----		
CA DA EA	66	139	7353	7287	7221		
VA	67	121	6193	6140	6087		
CA BA AA	66	139	7487	7409	7331		
DA EA GB DB	78	135	6455	6406	6357		
CB	71	139	6715	6663	6611		
FA	66	132	6985	6916	6847		
VA UA	64	121	----	----	6190		
WA	65	107	----	5364	5314		
VA CA BA	67	131	7093	7024	6955		
DA EA	71	143	7927	7853	7779		
UA	64	121	----	----	6330		
WA ED	65	92	----	4639	4595	10	36
DB	76	101	5253	5204	5155	42	
UA BA AA SA CA	66	137	6885	6819	6753		
SA AA	61	---	----	----	----		
CA DA EA	66	137	6911	6845	6779		
VA	67	119	5751	5698	5645		
OA EB PA FB HB QA RA	67	107	4424	4394	4364		22
YA IB	67	104	4208	4183	4158		11
ZA	68	101	4010	3988	3966	38	6
OC NC JB	64	144	----	----	6452		
AB	68	118	4872	4852	4832		
YB	69	146	6648	6612	6576		
FD	65	139	----	6177	6144		
XC	64	143	----	----	6322		
DD	68	149	6870	6827	6784		
UC	65	94	----	3957	3948	12	5
PC QC	73	108	4386	4361	4336		21
TC SC	81	115	4806	4788	4770		47
RC	65	115	----	4744	4718		42
QC	79	118	5016	4991	4966		
AB ZA	68	110	4529	4507	4485		27
NC	68	111	4446	4430	4414		24
UC	64	105	----	----	3995		7

KA LA MA OA EB PA FB OC UC MC	65	105	----	----	3995		7
NC	65	109	----	4286	4270		17
AB	64	117	----	----	4750		44
QA RA XA	70	100	4049	4023	3997	33	8
HB FB OC NC	72	117	4984	4968	4952		
PC	69	111	4621	4600	4579		34
AB	71	118	5059	5039	5019		
UC	68	108	4396	4387	4378		23
YA XA	74	105	4279	4253	4227		15
IB	68	104	4213	4188	4163		12
ZA	69	99	3883	3863	3843	29	1

TOTAL NUMBER OF ROUTES - 320

APPENDIX C

SYSTEM DATA BASE

SYSTEM INPUTS

1. Distance and Pick-Up Point ID Card

Column Number	Card Description
1	Card Type
2-3	Card Number
4-5	Pick-up Point ID (if necessary)
6-7	Number of students at Pick-up Point
8-9	Blank
10-28	Pick-up Point Street Address
29-30	Distance factor to School
31-32	Connecting Point ID #1
33-34	Distance factor to Connecting Point ID #1
35	Blank
36-39	Group data for Connecting Point ID #2
40	Blank
41-44	Group data for ID #3
45	Blank
46-49	Group data for ID #4
50	Blank
51-54	Group data for ID #5
55	Blank
56-59	Group data for ID #6
60	Blank
61-64	Group data for ID #7

Column Number	Card Description
65	Blank
66-69	Group data for ID #8
70	Blank
71-74	Group data for ID #9
75	Blank
76-79	Group data for ID #10
80	Blank

2. Student Control for use if format of names and addresses already exists on previously punched cards

Column Number	Card Description
1	Card Type
2	Use - do not use Student Control Card
3-4	Starting column number of Name field
5-6	Ending column number of Name field
7	Field justification (left or right)
8	Card sequence number where data appears
9	Blank
10-11	Starting column number of Address field
12-13	Ending column number of Address field
14	Field justification (left or right)
15	Card sequence number where data appears
16	Blank
17-18	Starting column number of Grade Field

Column Number	Card Description
19-20	Ending column number of Grade field
21	Field justification (left or right)
22	Card sequence number where data appears
23	Blank
24-29	Data grouping for Miscellaneous fields
30	Blank
31-36	Data grouping for Miscellaneous fields
37	Blank
38-39	Grade if necessary
40-41	School ID code if necessary
42-43	Pick-up Point ID assigned to student
44-80	Blank

3. Student Address - Name Card

Column Number	Card Description
1	Card Type
2-8	Student Index Number if any
9-11	Blank
12-23	First name and middle initial
24-39	Last name
40-59	Home address street
60-74	Home address city
75-76	Grade
77-78	School ID code
79-80	Pick-up point ID assigned to student

4. School Control Card

Column Number	Card Description
1	Card Type
2-3	School ID
4-35	School Name
36-55	School Address Street
56-75	School Address City
76-80	Blank

5. Bus Control Card

Column Number	Card Description
1	Card Type
2-3	Card Number
4	Blank
5-6	Bus capacity (groupings are by capacity)
7-9	Number of buses with related capacity
10-11	Desired load if below capacity
12-13	Number of allowable standees if applicable
14	Blank
15-23	Bus capacity Grouping # 2
24	Blank
25-33	Bus capacity Grouping # 3
34	Blank
35-43	Bus capacity Grouping # 4
44	Blank

Column Number	Card Description
45-53	Bus capacity Grouping # 5
54	Blank
55-63	Bus capacity Grouping # 6
64	Blank
65-73	Bus capacity Grouping # 7
74-80	Blank

6. Route Modification Card

Column Number	Card Description
1	Card Type
2-6	Route ID
7	Blank (if 7-80 blank, card is a deletion)
8-9	Pick-up Point # 1
10-11	Number of students (if blank data retrieved)
12	Blank
13-17	Pick-up Point # 2
18-22	Pick-up Point # 3
23-27	Pick-up Point # 4
28-32	Pick-up Point # 5
33-37	Pick-up Point # 6
38-42	Pick-up Point # 7
43-47	Pick-up Point # 8
48-52	Pick-up Point # 9

Column Number	Card Description
53-57	Pick-up Point # 10
58-62	Pick-up Point # 11
63-67	Pick-up Point # 12
68-72	Pick-up Point # 13
73-80	Blank

7. Option Card

Column Number	Card Description
1	Card Type
2-5	Blank
6-13	Generate or Update
14-15	Blank
16-20	Date of Run
21	Blank
22	Listing Option Codes

SYSTEM FILES

1. Time/Distance Factor File

Relative Position	Description
1-2	Pick-up Point ID
3-4	Time factor to School
5-6	Length of Entry
7-8	Number of connecting points
9-10	Connecting Pick-up point ID
11-12	Time/distance factor
13-14	Number of students at pick-up point

2. Pick-Up Point Description File

Absolute Position	Description
1-2	Pick-up Point ID
3-4	Number of students at pick-up
5-23	Pick-up Point Street Address

3. Student Description File

Relative Position	Description
1-2	Pick-up point ID
3-5	Length of entry
6-17	First name and middle initial
18-33	Last name
34-53	Home address street
54-68	Home address city
69-70	Grade

Relative Position	Description
71-72	School ID Code
73-80	Index number, if any

4. School Description File

Absolute Location	Description
1-2	School ID
3-34	School Name
35-54	School Address Street
55-74	School Address City

5. Bus Summary File

Absolute Location	Description
1-2	Bus capacity in descending order
3-4	Number of buses with related capacity
5-9	Total number of students that can be transported
10-11	Desired load if below capacity
12-13	Number of allowable standees

6. Selected Route File

Relative Location	Description
1-5	Route ID
6-8	Number of pick-up points
9-10	Pick-up point ID
11-12	Accumulated number of students

Relative Location	Description
13-14	Accumulated travel time
15-18	Accumulated student travel time

SYSTEM OUTPUTS

1. Bus Routing List

   a. Assigned Route Number

      1) Pick-up point ID

      2) Location of pick-up point

      3) Distance/time factor from last point

      4) Accumulated distance/time factors

      5) Number of students boarding

      6) Accumulated number of students boarding

      7) Number of students remaining at pick-up

      8) Student travel distance/time units

      9) Accumulated student travel distance/time units

   b. Capacity Bus Assigned to route

2. Student Route List

   a. Assigned Route Number

      1) Pick-up point ID

      2) Location of pick-up point

         a) Student name

         b) Student address

         c) Student grade

      3) Number of students at pick-up point

INTERNAL WORK AREAS

1. Point Selection Table

Position	Description
1-2	Pick-up Point ID
3-6	# of Occurrences (Entry Control).
7-11	Assigned route ID
12-15	Value of controlling parameter

2. Point Occurrence Table

Position	Description
1-2	Pick-up Point ID
3-6	# of Occurrences

3. Route Sequence Table

Position	Description
1-5	Route ID
6-8	Number of pick-up points (Entry control)
9	Overload/Underload factors
10-11	Number of students overload/underload
12-13	Pick-up Point ID
14-15	Accumulated number of students
16-17	Accumulated travel time
18-21	Accumulated student travel time

4. Pick-Up Point Used Table

Position	Description
1-2	Pick-up Point ID
3-6	Number of routes (Entry Control)

Position	Description
7-11	Route ID

5. Point Selection Table

Position	Description
1-2	Pick-up Point ID
3-6	# of Occurrences

6. Selected Route Table

Position	Description
1-5	Route ID
6-8	Number of pick-up points (Entry Control)
9	Overload/Underload factor
10-11	Number of students overload/underload
12	Balancing Indicator
13-14	Number of cross references
15-19	Route ID Cross reference
20-21	Pick-up point ID
22-23	Accumulated number of students
24-25	Accumulated travel time
26-29	Accumulated student travel time

7. Conflict Adjustment Table

Position	Description
1-2	Pick-up point ID
3	Overload indicator

Position	Description
4-5	Number of students overloaded
6	Balancing indicator
7-8	Number of cross references
9-13	Cross reference to Route ID