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ABSTRACT

A review of significant activities in the area of computerized school bus routing is conducted. The various factors which contribute to the complexity of transporting students to and from school are first surveyed and, following this, the overall problem is formalized in terms of a system of nodes and links. An analysis of several routing systems is presented, including: 1) manual schemes, 2) punched card systems, 3) systems which are based on models drawn from other fields such as sales or warehouse shipping, 4) computerized systems and 5) randomly generated routing systems. The conclusion is advanced that the computerized systems developed for particular school districts are usually not generalizable to other districts. Since the needs of individual districts vary widely, it is recommended that each develop a computerized system which best fits its local specifications. (PB)

A SURVEY OF COMPUTERIZED SCHOOL BUS ROUTING

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INTRODUCTION

The complicated task of determining school bus routes has been one facing the school administrator since the advent of the motor vehicle in the early nineteen hundreds. During the past ten years, specialists from the data processing departments in many school districts have been asked to investigate the feasibility of using the computer to aid in this process. Consultants from industry and the universities have been called upon to assist in this effort to utilize the computational capabilities of the computer. The purpose of this paper is to review the significant activities that have occurred and the problems that are yet to be solved in this application area.

WHAT IS THE PROBLEM?

The primary objective of any school bus routing system is to transport pupils to and from school at a minimal cost subject to a number of considerations. These include the safety of the pupils, the maximum allowable riding time for a pupil, the starting and dismissal time of school, the minimization of the number of bus stops, the equalization of the lengths of the routes, the balancing of the loads on bus routes, the minimization of the number of bus routes and the numbers of buses available.

A variety of types of vehicles are used in this effort. They vary from private cars in the mountains of Colorado to taxicabs for handicapped pupils in Richmond, California. Even the capacities of the "school bus" vary over a large range. Experiments have been conducted where students engaged in learning activities while traveling to and from school by listening to audio tapes on a variety of subjects. This could be of particular value in remote areas where students must spend several hours on a school bus each day.

The problem of transporting students to and from school is directly related to a similar problem found in industry. The truck dispatching or delivery problem is the problem facing a manager who is responsible for the distribution of products or services and must determine the routes that vehicles travel in order to meet certain commitments for the delivery of these products or services. Typical examples include the delivery of milk, bread routes, the delivery of auto parts to parts houses and service calls for repair of office equipment. The objective is usually to minimize the costs associated with this transportation of

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goods and services. Using a number of limiting assumptions, solution procedures have been developed for this type of problem.

Two other related problems have been thoroughly investigated and methods for their solution found. The first of these is the traveling-salesman problem. It is stated as follows. Find the shortest route (tour) for a salesman starting from a given city, visiting each of a specified group of cities, and then returning to the original point of departure. Note that this is not quite the same as the school bus routing problem, but as will be pointed out later in this paper, it has proved to be of use. The second related problem is the transportation problem, where in its most general form, a number of warehouses have a certain type of goods that must be shipped from these warehouses to a number of customers. The unit cost of shipping from each warehouse to each customer is known and the problem is to minimize the cost of shipping all the required goods. It would seem at first glance that this might be directly related to school bus routing but the solution procedure does not generate a route. It simply specifies the amount of goods to be shipped from each warehouse to each customer. The author is currently investigating a modification to this method which may be of use in the solution of the school bus routing problem.

FORMALIZATION OF THE PROBLEM

The most effective method of looking at the school bus routing problem is to consider it to be a system of nodes and links where each bus stop is considered to be a node and the distances between adjacent bus stops the links. The assumption is usually made that the demand for service at each node is known. In other words the number of students to be picked up at each bus stop is known. At least one author (10) proposes that bus stops near each other be grouped into one logical stop since it is more efficient to have one bus pick up all the students in a given area than several buses. Experiments conducted by the author tend to indicate this may not be a valid assumption. All of the computerized bus routing systems examined by the author to-date assume the bus originates its route at a school and terminates the route at the same location. This is considered a closed loop system. Many school administrators feel this closed loop approach does not lead to a satisfactory solution to the routing problem since often a bus route will start at a bus garage or at a driver's home and end at a school. In other cases, buses may have to be routed from one school to another.

There are a number of factors which increase the complexity of school bus routing. The demands for service may differ in the morning and evening. Several schools may have to be serviced with the same group of buses thus necessitating the dual routing of buses. Pupils may have to be transferred from one bus route to another to reach school. Loads may fluctuate from day to day due to absenteeism and during the school year due to pupils moving in and out of the attendance areas.

Any computerized bus routing scheme requires that a considerable amount of work be expended on data collection and organization. Usually the location of each student must be determined, the location of bus stops specified, pupils must be assigned to the closest bus stop and the distances between adjacent bus stops measured. A scale map of the school district can play a very important role in this data collection and organization.

The procedures outlined above are usually accomplished by manual means. Mechanical devices such as an x-y digitizer could be very helpful in preparing input into a computer based school bus routing routine. As the state-of-the-art of computer technology continues to develop other types of devices such as cathode ray tubes may prove to be very useful for input of coordinate data into the computer. The author has conducted experiments displaying the output from a bus routing program on a cathode ray and found it was a very effective method.

REVIEW OF THE STATE OF THE ART

Manual methods of varying degree of sophistication have been used by school personnel for years. Some of these systems are no more complex than the bus driver mentally keeping track of his bus route and its modifications year by year. The majority of school districts keep some type of official records of their bus routes. Larsen (8) of Robbinsdale Area Schools in Minnesota uses a well organized manual method. This system includes the use of color coding schemes, plastic milar sheets, rolodex card files, district maps and numerous worksheets.

Soule (13) outlines a punched card method of bus routing which would seem to be useful. The designing of bus routes in his method involves the sorting of punch cards by street address then hand plotting the location of bus stops on a transparent overlay of the district map. The actual route selection is done manually. The main advantage of punch cards is their versatility in the production of listings and reports.

As previously mentioned the solution procedures for the traveling-salesman problem have proven useful in the school bus routing problem. Boyer (1) was one of the first to apply this technique to school bus routing. His work was funded during the early 1960's by two Office of Education Cooperative Research Grants. The method requires that the bus stops be plotted on a map and a bus route which visits all stops in the system be manually drawn through these stops. Thse data are then fed into the computer and this initial route is partitioned into segments with each segment containing a number of pupils equivalent to the capacity of the buses used in the system. The computer is then used to generate all possible routes through each set of points. These possible combinations are output and then the analyst selects the routes he feels are most appropriate. The program was written in the assembly language for the IBM 1620. The current status of this program is not known.

Another method of attack also based on the traveling-salesman problem was developed by Newton (9) during the mid 1960's. In a manner similar to Boyer's, a route is determined which visits all bus stops in the system. Unlike Boyer's procedures, this initial route is generated by the computer and is nearly optimal. In other words, it possibly is the shortest route which visits all the bus stops. This initial route is then partitioned into smaller routes which reflect the capactiy of the buses. The order of the bus stops in the initial route is preserved during the partitioning process. The program is written in FORTRAN and a listing with documentation appears in Newton's thesis (9). A modification of this method has been developed by Godfrey (4). He uses the technique developed by Newton but in order to construct the best possible set of routes calculates the initial route using each bus stop as a starting point. The length of the initial route is highly dependent upon the starting point of the route.

A third method of solution which has found widespread use is one developed by Clarke and Wright (2) for the routing of a fleet of delivery trucks. The technique used in this method is to place each customer on a separate route. This assumes there are as many delivery vehicles as customers. Then the "savings" in distance or time is computed for each pair of delivery points if they are placed on the same delivery route. The pair which produces the greatest savings are joined. This process is continued until all delivery points have been assigned to a route. The capacities of the delivery vehicles, maximum traveling distance or time, and other constraints are all considered when the delivery routes are generated.

This method of determining delivery routes is the basis for a number of bus routing programs. Tracz and Norman (15) have successfully developed a program based on this method which has been used by several boards of education in Ontario, Canada. Program listings, and complete documentation are available from The Ontario Institute for Studies in Education at a nominal cost. Noonan and Whinston (10) have also developed and tested a program based on the Clarke and Wright method. They report that their program runs on a CDC 6500 and can accommodate problems with up to 200 stops. The program requires 32K of storage. Execution times for a typical problem are reported to be twenty seconds to develop the routing matrix and twenty seconds for each set of bus routes generated.

The most widely used bus routing program seems to be IBM's Vehicle Scheduling Program (VSP) (6,7). This program was initially developed during the early 1960's and has progressed through various versions since that time. The Clarke and Wright method is the basis for this program package which has been developed and heavily used in a large range of industrial problems as well as school bus routing. It is interesting to note that the application package was written in Germany with the combined efforts of Germans, British, and Americans. Clarke and Wright are both British. The original VSP release has been augmented with a newer version, VSP-Extended (VSPX) which has a monthly rental charge associated with it of $175.00 per month. The original VSP release is no longer being supported by IBM.

The usefulness of VSP for routing school buses varies with the particular peculiarities of the school district attempting to use it. Some districts have been successfully using it for a number of years, others have tried and found it does not meet their particular needs.

At least two researchers have developed methods of selecting bus routes which involve random or Monte Carlo methods of selecting the bus stops which are placed on each route. Both systems can only be used in closed route routing systems. OPTIBUS, a program developed by the author, (11) has been used experimentally with data from a number of school districts. Hayes (5) also developed a system with a little more sophistication as part of his doctoral dissertation. There does not seem to be any indication that this system has been tested with real data.

This general approach of random selection of bus routes seems to be the most feasible of the methods investigated by the author. The basic procedure is similar to a manual method. The first stop on a route is selected according to some decision rule. Hayes uses the one farthest from the school. The author selects one at random from all unassigned stops. The remaining stops are selected using another decision rule, such as the closest stop, distance the stop is from the school, distance it is from another unplaced stop or even by random selection. Richards (12) reports on some of the methods of selection used in experiments conducted by him. Once a set of stops has been generated that fill a bus, the procedure is terminated and another route is generated using the same procedures. In order to insure that the stops on every route are ordered in such a manner such that the total distance required to visit them is minimum, it is necessary to use the traveling-salesman method to reorder the stops. This also eliminates any assignments where the system loops back to a stop it may have by-passed. The above procedure is repeated over and over again each time randomly selecting a new set of routes and keeping track of the total distance in each set of routes. The set of routes with the minimum distance is then selected as the "best" and used for routing the buses.

Various versions of OPTIBUS have been run on the CDC 3600, CDC 6400, IBM 360 and IBM 370 computers. Details of its operation appear in a recent issue of the AEDS Monitor (11). Operating instructions are available from the author. The closed loop routing of school buses used in this program does not seem to satisfy the requirements of most school districts. The author is currently developing a method that will allow point to point or open loop routing. It is hoped this method will be completed and tested during the next six months.

Many other methods of solution to the routing problem have been attempted. Often the particular method proves feasible for a small test case, but infeasible when they are tried on actual data. Both Hayes and Newton discuss the problems associated with some of these techniques. The methods include integer linear programming which is not feasible for the same reason, dynamic programming has not been used successfully, branch and bound was attempted by Davis (3) and has been formulated by Tillman (14) and Hayes.

CONCLUSIONS

This survey of the state-of-the-art of computerized school bus routing has shown that several computer programs are readily available for closed loop routing of school buses. From talking to school administrators and attempting to utilize his own program the author has found that this type of routing does not meet the needs of many school districts. Programs are not available which solve the problem of open loop bus routing, that is, where the origin and destination points of the bus routes do not correspond.

The author has also observed that the bus routing requirements of school districts differ to a considerable extent. This makes the development of a generalized program package very difficult. One approach which would seem to offer a feasible solution would be to develop a series of bus routing subroutines which could be put together to fit the needs of each individual school district. This is the approach some firms are using in developing class sectioning programs. This type of effort could best be undertaken by a software firm, by a consulting firm, as a funded research project, or perhaps even by schools. Perhaps some of the members of AEDS would like to participate in such an activity.

As the above discussion has pointed out, ample documentation of the methods useful in solving the school bus routing problem are presented in some of the readily available journals. None of these methods require any great sophistication in mathematics and it would seem feasible for a person with FORTRAN programming skills to develop his own programs from scratch. In other words a do-it-yourself approach to bus routing. This in the author's estimation is the route that should be followed by any district which has its own computing equipment. The programs can then be tailored to fit both the school district requirements and its equipment.

In any event, computerized bus routing is a tool which will prove useful to many school districts during the coming years. Its application has not been as readily implemented as some of the other applications but the problem is not as easily solved or defined. For the school district which is willing to expend the time and money necessary to develop or obtain a bus routing package, a significant savings of transportation costs can be realized.

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