CONCLUSIONS

The application of the methodology to the planning of express bus and fringe parking transit to the Greenwood Drive service reveals that the low levels of patronage that have been experienced could have been expected. When the Greenwood Drive service was planned, the competing subscription bus service was not properly considered. Although the planning methodology was not designed to deal directly with such unique issues as competing bus service, we have shown that the comprehensive study approach could be adapted to special local problems, such as this competition. Accordingly, we conclude that the methodology improves the general capability for developing successful park-and-ride transit operations.

The following observations were made regarding the future potential of the Greenwood Drive lot service to attract riders:

1. The competing subscription bus service clearly dominates the market for transit to the NOB-NAS,
2. The site is somewhat isolated from the local neighborhoods,
3. The service should have been advertised continually and more directional signs should have been provided on local roads, and
4. The lot design is adequate, but better maintenance and security are desirable.

In view of the above findings plus other factors considered, it does not appear that demand for the service will grow in the near future. Only when the area to the south of the lot (Chesapeake and Suffolk) is developed will it be possible for the lot and service to be anywhere near successful.

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Bus Route Analysis Model (BRAM) Summary Report

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This describes the bus route analysis model (BRAM), a computer system that was developed to design bus routes. The computer program uses an iterative process to test various route configurations and to minimize the number of routes, the distance traveled, and the total travel time within constraints established by the parameters of maximum riding time and average speed of the bus. In the active mode BRAM designs bus routes by first dividing the district into a number of pie-shaped sectors, which are preselected by the planner, and then designing a route within each sector. Bus stops are first assigned to a sector by location and are then assigned to a route. A theoretical loop curve that represents an ideal route is used to form the routes. Bus stops are assigned to the route based on distance from the ideal curve and other constraints (such as bus capacity and student travel time). In order to test feasibility the routes are then subjected to a modeling procedure to determine travel time and travel distance. Through an iterative process various configurations of routes are tested until the best configuration is determined. BRAM is user oriented. A user's procedure manual describes the procedures for data collection and completion of coding forms, which are then keypunched. Support personnel input the data to the computer program and also establish the various parameters and constraints used. The printout is then sent back to the school district, where the routes are plotted and analyzed. The computer program also includes a management information system that can summarize daily statistics and print out monthly reports on the bus system. These reports provide information on the buses, routes, employees, and related costs. BRAM provides a design tool that can quickly investigate route alternatives for school buses or other fixed-route transit systems.

During the past several years research has been conducted at the Upper Great Plains Transportation Institute to develop a computer model to route school buses. The need for the conservation of energy is urgent in this age of increasing energy costs and dwindling resources. One area where costs can be reduced is in the transporting of students to and from school. The costs of transporting students are a particularly acute problem in North Dakota, where those school districts that responded to a questionnaire on usage of the computer indicated that there was an average of 1 student/7.8 km^2 (1 student/3 mile^2). After an extensive review of the literature (1-4) we decided that contemporary network analysis models would be too complicated for school district personnel to use. Structuring of the networks would be too expensive because many of the school bus routes in rural North Dakota are very long. Due to the severe weather and expected absences, routes change continually. The road system is everywhere—a road is available on most section and quarter-section lines.

DESCRIPTION OF THE RESEARCH

The objectives of the research were

1. To assess the state of the art of school transportation and the need for improved planning of school bus routes in North Dakota,
2. To assess the operating characteristics of a school bus system and to use these observations to develop a simulation model,
3. To develop a methodology for a computer program to design bus routes and manage a bus system, and
4. To develop a user's procedure manual so that school district personnel can use the bus route analysis model (BRAM).

The BRAM computer system designs bus routes and then models these routes to test student travel times and the distances traveled by the buses. The computer program uses an iterative process to test various route configurations in order to minimize the number of routes, distances traveled, and total travel time within constraints established by such parameters as maximum bus riding time and the average speed of the bus. In North Dakota a student cannot spend more than 1 h on a bus.

BRAM designs bus routes by first dividing the district into a number of pie-shaped sectors, which are preselected by the planner, and then routes are cut within each sector. Bus stops are first assigned to a sector by location and are then assigned to a route. A theoretical loop curve that represents an ideal route is used to form the routes. Bus stops are assigned to the route based on distance from the ideal curve and other constraints (such as bus capacity and maximum student travel time). The routes are then subjected to a modeling procedure to determine travel time and distance in order to test feasibility. Through an iterative process various configurations of routes are tested until the best configuration is found.

Figure 1. Near optimum route.

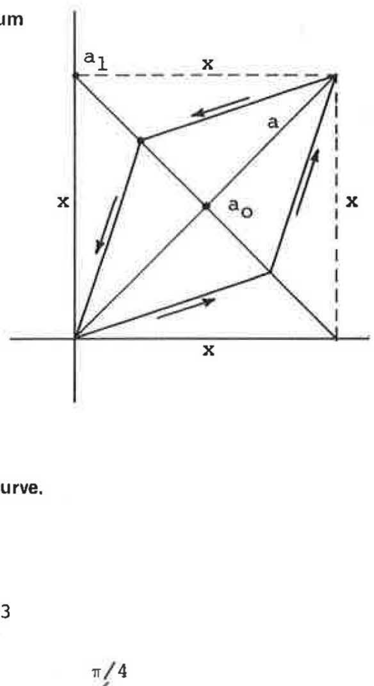
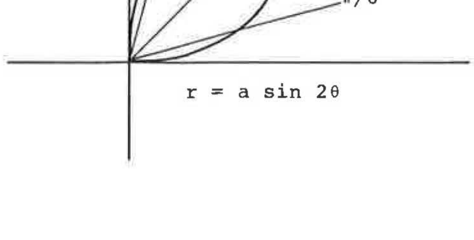


Figure 2. Rose-petal curve.



The data required by the computer program can be supplied by the school district personnel. A user's procedure manual describes the processes of data collection and completion of coding forms, which are then keypunched. Support personnel put the data into the computer program and also establish the various parameters and constraints used in the program. The printout is sent back to the school district, where the routes are plotted and analyzed.

The computer program also includes a management information system (1) that can summarize daily statistics and print out monthly reports on the bus system. These reports provide statistics on the buses, students, employees, and related costs. This system can provide monthly, year-to-date, or yearly totals so that costs can be watched closely and information provided on bus replacement or route revision.

TECHNIQUES

A false coordinate system is established on the southwest corner of each school district in order to express each student-boarding point as a positive (X, Y) coordinate. The centroid of the student population can then be established. The ideal location of the school would be this centroid; however, factors such as population density and land use trends need to be considered in the location of the school. The school district is divided into sectors. The total number of sectors is the total students divided by bus capacity. Usually three computer runs are made: (a) The first run uses two fewer than the current number of buses, (b) the second run uses one fewer than the current number of buses, and (c) the third run uses the same number of buses as are currently used.

The first route modeled is in quadrant 1. The bus is backed out of the school to the closest passenger point. In the initial research each additional passenger was picked up until either travel time or bus capacity was exceeded. This resulted in a zigzag pattern that had many crossovers. Another attempt was made to pick up passengers by use of all possible combinations. This would give more iterations than the computer could handle. For example, for a route that has 24 stops, the resultant combinations are approximately 2.3×10^{23}.

Other attempts were made. The longest route (a rectangle in which the farthest student is at the opposite diagonal of the rectangle) was tried, then the shortest route on the diagonal was tried. It was also a failure. A near-optimum kite-shaped pattern shown in Figure 1 was also attempted. This produced results but the computation time was awkward and excessive.

A continuous curve was needed to direct the bus along the route. Mathematical integration of a uniform density of students to a point is difficult. A search of a set of math tables (5) indicated sets of curves, called rose-petal curves, for which the formula illustrated in Figure 2 is

$$a = \sin n\,\theta \qquad (1)$$

where n, an even integer, results in 2n leaves and n, an odd integer, results in n leaves. A formula for any number of sectors can thus be derived. The distance from the farthest student to the origin is represented by a. Even though this is longer than the kite-shaped route (2.42a versus 2.32a), the conversion from polar to Cartesian coordinates is simple and better routes

Figure 3. Summary of BRAM methodology.

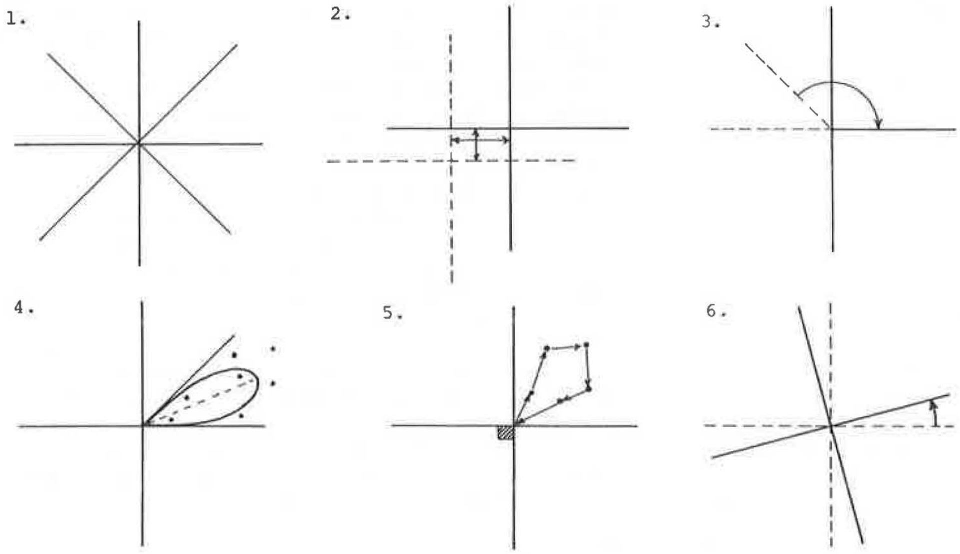
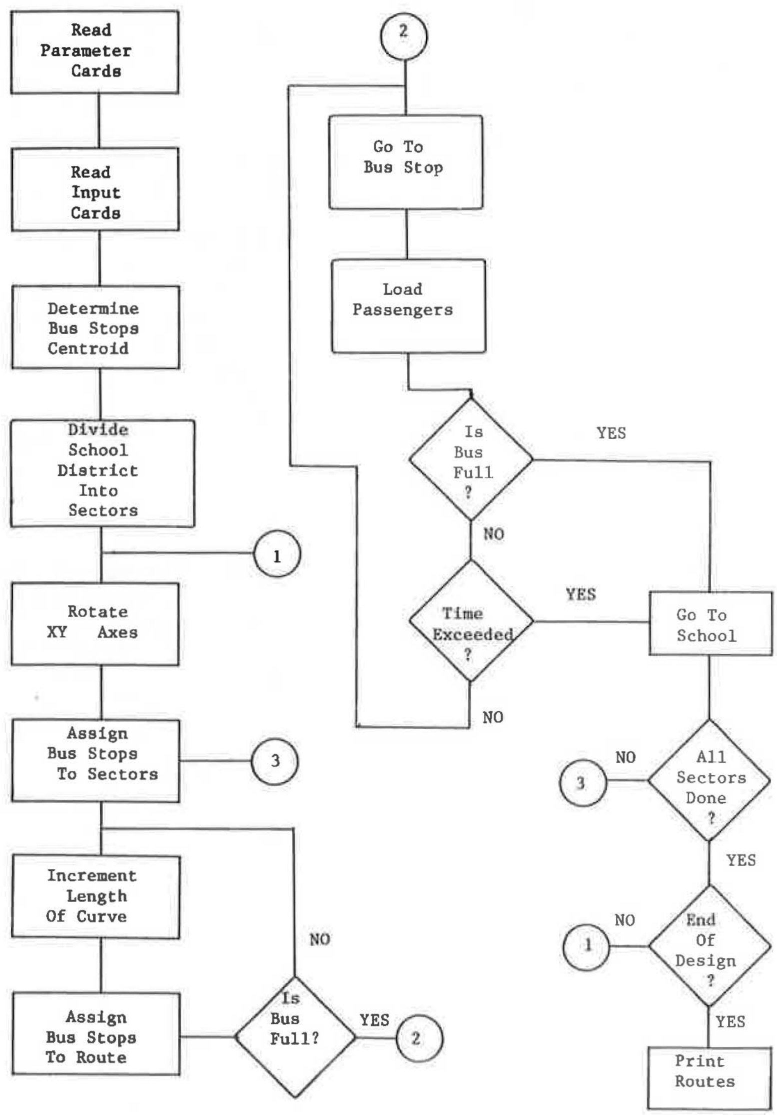


Figure 4. Internal macroflowchart.



are obtained through improved computation.

Thus, the bus is backed out on the curve in a counterclockwise direction and students in the path of the curve [3.2 and 4.8 km (2 and 3 miles) are used] are picked up. The pickups are stored and, at the completion of the program, a printout is given of the information that follows (1 km = 0.62 mile):

Bus route number 1
Bus number 1
Dead haul to first bus stop = 10.0 km
Route distance = 76.8 km
Total distance = 87.7 km
Number of students loaded = 33 (bus capacity = 48)
Total elapsed time = 68.4 min
Bus stop sequence (order of pickup) 14, 11, 9, 8, 7, 3, 5, 4, 2, 1, 6, 30

After one iteration in each quadrant, the axis is rotated 5° for successive iterations. Total travel distance is computed, and the route selected for printout is based on the lowest travel distance.

A summary of the program steps is given below and described in Figure 3 and by the internal macroflowchart of Figure 4.

1. The school district is divided into sectors by dividing total students by bus capacity;
2. The centroid of bus stops is determined and translated to XY axes;
3. The sector is rotated to the first quadrant;
4. A stop is assigned to a route by using the design curve;
5. The route is simulated by loading passengers and determining travel time (the above procedure is repeated for each of the remaining sectors);
6. The next iteration is prepared by rotating XY axes and repeating steps 1-5 to create a new configuration of routes; and
7. After all iterations are complete, the best configuration of routes is printed.

RESULTS

This computer program has been used for 15 school districts and, in general, has produced a 20 percent reduction in fleet size and also a 14 percent reduction in travel distances over the manual systems that are currently used by school districts to establish bus routes. A sample of the cost savings is shown in Table 1.

A grant from the state energy office was used to fund the development of the routes for 13 districts. Currently, the engineering experiment station is working with districts on a cost-plus-fee basis. A typical cost per district for computer time, travel, and personnel is about $1000. This can be reduced if district personnel code the student locations and decipher the printout. Only one-fourth of the school districts contacted in North Dakota indicated that they would be interested in using this model. However, if all school districts used this model, North Dakota would save about $2 million in costs for buses and gasoline. The research also points out that some school buses have excess capacity because school children (especially high school students) drive to and from school. School districts shaped in oblong or egg-shaped patterns are not conducive to route development. A better geometry would be square-shaped patterns. BRAM has other spinoff effects. In the Wishek district, for example, improvement of 3.2 km (2 miles) of county road will provide substantial route savings.

Table 1. Potential savings to school districts resulting from application of BRAM.

School District	Operating Cost Savings per Year ($)	Travel Distance Savings per Year (km)	Fuel Savings per Year (L)	Equipment Savings
Butte	7 860	14 190	15 900	2[a]
Drayton	2 520	8 110	3 810	1[b]
Emerado	3 300	2 610	5 900	1[b]
Finley	12 240	16 220	7 630	1 bus
Gackle	5 220	16 800	7 910	2[a]
Langdon	9 530	22 530	9 650	1 bus
Linton	22 300	59 680	28 090	2 buses
Mayville-Portland	4 320	13 900	6 550	1 bus
Page	8 585	16 340	11 130	1 bus
Park River	2 880	9 270	4 350	1 bus
Rhame	3 920	1 450	9 270	2[a]
West Fargo	17 900	8 110	3 820	2 buses
Wishek	14 300	31 540	13 490	2 buses

Notes: 1 km = 0.62 mile; 1 L = 0.26 gal.
Potential savings are calculated based on a comparison of the present busing system to the optimum busing system arrived at through use of BRAM.

[a] Replace two large buses with two minibuses.
[b] Replace one large bus with one minibus.

Limitations of the Model

The model has several limitations, which are currently being studied in the continuing research effort. First of all, the model cannot show any savings for school districts that have three buses or less. These systems are too small to model effectively. If a school district has multiple schools that are separated by some distance, the model will not work. This can be resolved by running the program the same number of times as there are individual school sites or transfer points. In this case the last school or transfer point modeled merely becomes a bus stop for the next modeling run. This, of course, is expensive.

The model has not been tried and may not work where large physical constraints (such as badlands or lakes) are present. Current research will attempt to divide the sectors into square-shaped cells and mask those cells with geophysical constraints. Then routes can be directed around the masked cells. The decision on when to use a short route (0.5 h) or a long route (1 h) is not clear and the investigation and analysis are continuing in these areas.

Some of the districts in western North Dakota that have few roads, routes longer than 1 h, and many physical constraints may not be candidates for the modeling effort. Special studies and manual methods may be needed in these areas because model development might exceed the cost of a special study.

Future Research

During the course of the research the idea of using school buses for other purposes was developed. These purposes include

1. Package delivery in small urban and rural areas,
2. Mail delivery,
3. Library book delivery,
4. Senior citizen subscription ride services,
5. Mobile health services, and
6. Rural public transportation systems.

Research will also be conducted on the design of a multipurpose rural vehicle that could handle all of the above services.

The feasibility of using BRAM for the following will be tested:

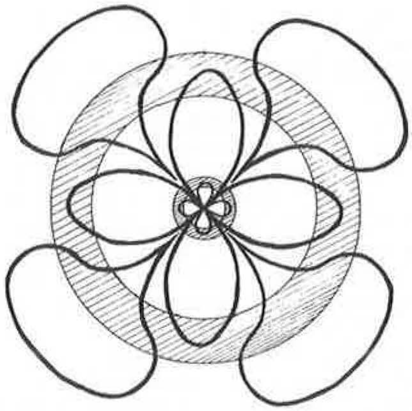


Figure 5. Bus route configuration.

1. Solid waste optimization collection systems (SWOCS)—The routing of garbage trucks is a similar problem but the delivery point is not at the centroid of the pickups.
2. Small urban fixed-route transit planning—This is a similar problem, but the coordinates change for each run on a route.
3. Small urban floating-point transit planning—Requests have been made to investigate routing of van-pools and senior citizen demand-responsive systems.

Other low-density routing problems will be investigated.

In some of the remote or very low-density areas the revival of the country school should be considered. There is a breakpoint at which the cost of operation of these schools approaches the cost of transportation. The psychological factors involved in riding a bus 2 h/day needs to be considered. In 12 years of school, a student could spend as much as 0.5 year on a bus. The four-day school week and study-at-home packages need to be considered. The use of vans to collect distant passengers could reduce riding time. Also, near and far loops need to be investigated.

The major disadvantage of the loop-shaped route is excessive riding time for the first students on the bus, who travel away from their destination half of the time. This route is, therefore, not suitable for long routes but is satisfactory for short- and medium-length routes. Outlying stops should be serviced by more direct routes.

In order to keep travel time under 1 h, the riding distance should be no more than 48-56 km (30-35 miles). By using the design curve (rose petal) with a length of 56 km, the radius of a cell around the central school location can be determined. Loop-shaped routes can be used within a radius of 19 km (12 miles). This is represented in Figure 5. The small circle represents the area in which double-tripping is feasible (a bus unloads after servicing a medium-length route and then immediately services a short route on the outskirts of a town). The radius is approximately 3 km (2 miles). The West Fargo school district uses several short routes of this type. The large circle represents the area in which loop routes of a medium length can be used. Stops in the area beyond the larger circle must be serviced by more direct routes of a general configuration, shown in Figure 5.

CONCLUSION

The development of this model has shown that an expensive network analysis is not needed to route school buses. The coordinates from the computer printout can be easily plotted on an overlay by school district personnel, and decisions on which routes to take are then based on local knowledge in the school district. This leaves the decision on final bus routes and schedules where it should be—at the local level.

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Estimating the Effects of Alternative Levels of Service on Rural Transit Ridership

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This paper deals with the need to assess public response to alternative levels of service and travel flexibility on proposed rural transportation systems. A public opinion survey was conducted in rural Otsego County, New York, among 254 households, 30 of which had no telephones. The survey presented three public transportation options (fixed route, dial-a-bus, and mobility club) and asked questions about possible use of such