Designing a School Transportation Management System with Public Transportation Capabilities

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Disclaimer

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1. Introduction

The safe, efficient transportation of students to and from school is a challenge faced by school districts across the country. Providers of public and human services transportation also aim to deliver their services efficiently. While there are a number of ways in which efficiency may be improved, the implementation and use of technology and coordination among transportation providers has regularly produced significant, positive results. Most of these efforts have been located in urban locations, but there have been rural successes as well. In this study, a routing algorithm is used to examine the efficiency resulting from computerized routing for a rural North Dakota school district and coordinated transportation efforts in that community are briefly explored.

In North Dakota, there has been widespread and growing concern about inefficient operation of school fleets and provision of transportation to students. In recent years, many of the state's rural communities have seen significant demographic changes including dramatic decreases in student age populations, enrollment, and school bus ridership. These trends are, in general, expected to continue. The presence of buses filled to less than capacity on rural highways and roads is a cause for criticism, appropriate or not, in many North Dakota communities. In many districts, the decline in enrollment and ridership has been paired with a steady or decreasing tax base and rising costs of education and related programs, including student transport.

In small rural school districts, student transportation is usually managed by school administrators who have additional, demanding responsibilities. As a result, these administrators often lack the time, skills, and tools needed to consider full-scale overhauls of their transportation system. Instead, small, necessary changes are made to keep the system operational.

One skill that is often absent from a rural school administrator's repertoire is that of vehicle routing and scheduling. Many school districts' routing process consists of adding or removing individual stops to existing routes as students enter or leave the district as opposed to reviewing all routes simultaneously. This procedure, repeated over time, will usually produce less-than-optimal results. When wholesale changes to a school district's routes are made, they are often done without knowledge and application of proven techniques. In districts with more than a few routes, successful routing by hand becomes cumbersome, if not impossible, and the use of advanced, software-driven techniques becomes necessary.

Agencies providing public transportation in rural North Dakota face many of the same challenges as school districts do in transporting their students. Limited resources and sparse demand result in excess capacity and community concerns about efficiency. As in pupil transportation, public and human services transportation trip purposes are usually essential to the health and well-being of riders. While most of the rural public transportation providers in North Dakota manage small systems in terms of fleet size and ridership, demand for service is growing in many areas, pushing the limits of efficiently routing and scheduling by hand.

The routing challenges facing rural school districts and community transportation providers are quite similar. As a result, a single algorithm may be sufficient for managing both systems' routing functions. In general, both pupil and public transportation in these areas face, in operations research terminology, a multiple-vehicle routing problem (MVRP), where the goal is to service multiple locations at a minimum cost. Often, time windows must be accounted for, such as when there are multiple education sites and bell timing is an issue or when community transportation riders must be picked up or dropped off at a specific time.

From a practical standpoint, the primary difference between traditional pupil transportation, which is quite similar to fixed-route service, and demand-response transportation is timeliness and the management of data. For example, the annual updating of routes for student transport is much like that for advanced reservation service. However, dial-a-ride service requires a much more robust data management system even though it is also a multiple vehicle routing problem.

Coordination in the form of commingling of students and non-students on the same vehicle may improve efficiency but is a contentious issue for many. In urban communities, this often takes the form of K-12 students making use of fixed-route public transportation in their community. In rural areas, where fixed-route service is rare, allowing non-students access to mobility on yellow school buses seems to be a more feasible alternative. The commingling of students and other community residents raises many funding, operational, safety, and legal issues. These challenges can, in general, be dealt with. One of the largest single barriers to commingling is the need for a serious paradigm shift by community members.

Given similar challenges facing rural pupil and non-pupil transportation providers and the success of the application of routing algorithm and coordination in other, primarily urban, locations, a pilot study to investigate the value of their introduction in a rural North Dakota was initiated. This report includes the findings from a pilot project in the Enderlin, ND, community.

The report begins with a review of literature in three fields. First, work in the area of school transportation, including routing from an operations research standpoint, is presented. Next, general concepts about the coordination from the fields of transit are presented. Finally, research and case studies involving the coordination of pupil and non-pupil riders are reviewed.

A profile of the Enderlin community and its reason for selection is presented. Current and projected demographic data is provided, as is information on the local economy, available services, and mobility issues. Possible high-demand locations for users of public transportation, both local and regional, are identified.

This is followed by an overview of the process and results of the application of modern routing and school transportation techniques to the Enderlin School district. The report concludes with an outline of possible next steps and opportunities for further research on the issue.

2. Literature Review

Given the multidisciplinary nature of the study, the review of literature focused on three areas. First, recent literature on the unique attributes and impacts of rural school transportation from both the educational and transportation fields was reviewed. Next, a summary of the general contemporary concepts behind coordination were considered. Finally, case studies and themes from pupil/non-pupil transportation coordination were reviewed. Given the breadth of literature on pupil/non-pupil transportation coordination, only case studies where yellow school buses are used to transport non-pupils were considered.

2.1 Rural Pupil Transportation

The unique attributes and impacts of rural pupil transportation have been the subject of a number of studies, primarily in the educational literature. An excellent, yet brief, summary of this work is presented by Howley and Howley (2001). Ripplinger (2006) recently explored the issue from an operations research-transportation standpoint in his work on vehicle routing.

Killeen and Sipple (2000), in their study on school consolidation and its impacts on pupil transportation, found that rural students spend on average twice the time in transit as their suburban counterparts. Rural school districts also spend approximately twice the amount of urban schools to deliver transportation.

Howley, Howley, and Shamblen (2001) identified three possible negative impacts of rural busing: unreasonable length, impacts on educational achievement, and disruptions to family life. The authors found that rural students encountered longer travel time along lower quality roads than their suburban counterparts. Many rural students were also found to be double-routed where elementary and high school students are commingled on the same vehicle, although they did not identify the impacts this policy has on students.

Ripplinger (2006) discussed a number of the unique issues facing rural school districts as part of his paper on the development of a rural school transportation routing algorithm. Primary among these is the smaller size of the problem relative to urban areas. In general, rural school districts have fewer students, stops, vehicles, transfers, and schools than their urban counterparts. In many cases, one is able to solve the routing problem by hand, or a computational effort may provide the true-optimum rather than a sub-optimum solution. Many rural school districts only have a single school.

Given the small number of students and the long distances involved, time constraints as opposed to vehicle-capacity constraints are usually binding. This is the opposite of what usually occurs in urban areas. Another consequence of the small number of students is the increased importance of fleet composition. Employing a heterogeneous fleet may be more efficient that a uniform fleet of large buses.

The relative advantage of routing by hand is likely to be true in rural districts where unique road attributes may be known only by facility users. As a result, it may not be efficient for implementing technologically advanced solutions in situations where a great deal of effort must be used to tailor fit computer-generated routes to relatively small, real world problems.

In many cases, pupil transportation is delivered door to door, eliminating the need to assign students to stops. Given the limited number of students, the assignment problem is not especially perplexing.

2.2 Coordination of Community Transportation

Coordination of community transportation services is a relatively mature field. While the literature is not particularly rigorous, it does include refined concepts; processes for design, implementation and operation; and case studies. Some of the primary themes of coordination are presented in TCRP Report 91: Economic Benefits of Human Services Transportation Coordination and TCRP Report 101: Toolkit for Rural Coordinated Transportation Services. Executive Order 13330, a milestone that can be considered the beginning of the modern era of coordination, outlines important aspects of the coordination of human services transportation.

Executive Order 13330, issued by President George W. Bush on Feb. 24, 2004, renewed the focus on coordination among human services transportation providers. The executive order recognized:

The critical role of transportation

The negative impact of many federal and state rules and restrictions on service

The fragmented, underutilized, or unavailability of many community transportation systems

The need for a responsible, seamless, comprehensive, and accessible community transportation system for mobility-dependent populations

It also mandated the creation of the Interagency Transportation Coordination Council on Access and Mobility, which included the nine cabinet members and the Commissioner of Social Security. As a result of the executive order, the Secretary of Transportation developed two initiatives, United We Ride and Mobility Services for All Americans, to meet the challenges identified. United We Ride focuses on coordination, while Mobility Services for all Americans is focused on the use of ITS to improve service delivery.

Burckhardt, Koffman, and Murray (2003) present the general concepts behind coordination, strategies for increasing coordination, and the benefits and industry-wide impacts of coordination in TCRP Report 91: Economic Benefits of Coordinating Human Service Transportation and Transit Services. The report defines coordination as "working together with people from different agencies and background." It can take a number of forms and may include one or more of the primary functions of community transportation providers: planning, procurement, maintenance, operations, and marketing. An important point identified by the authors is that coordination is a political process and may involve conflicts over power, resources, and control.

Strategies for coordination include generating new revenues by providing services to new markets, contracting with other agencies to provide services to their current clientele, and coordinating dispatching. Local benefits include increased sources of funding, increased efficiency, increased mobility, and secondary economic benefits. Summing the local benefits to find industry-wide impacts of coordination quickly enters into the hundreds of millions of dollars.

Burckhardt, Nelson, Murray, and Koffman (2004) identify three components of coordination in TCRP Report 101: Toolkit for Rural Coordinated Transportation Services:

A strategy for managing resources

A sharing of power, responsibility, management, and funding

A process involving power and control over resources

It is framed as a political process where two or more organizations work together in the delivery of their services. Potential benefits include access to additional funds and funding sources, higher quality, more efficient service, enhanced mobility for community members, and more visible transportation services.

2.3 Coordination of Pupil and Public Transportation

Three large national studies, published as TCRP Report 56: Integrating School Bus and Public Transportation Services in Non-urban Communities, Opportunities for the Coordination of General Public Transit and School Bus Transportation, and The Coordination of Pupil and Non-Pupil Transportation: Final Report, have looked at the issue of coordinating pupil and non-pupil transportation. The findings of the first two reports as well as a summary of a study from the latter are reviewed here.

In TCRP Report 56: Integrating School Bus and Public Transportation Services in Non-urban Communities, Multisystems, Transit Plus, Martin, Tull, and IBI Group (1999) identify six key factors that affect coordination of pupil and public transportation: a lack of public transportation, the presence of human services transportation, as well as funding, operational, legal, regulatory, and safety issues. Operational issues included administration, labor agreements, vehicle availability, maintenance, liability, and insurance. Transporting individuals with disabilities and unique state requirements are regulatory issues of note. Safety issues, such as vehicle standards and design, driver qualifications, screening and training, and commingling of passengers, were considered.

Included in the report are 13 in-depth case studies of coordination between pupil and public transportation. Of these, five involve the use of school transportation vehicles to transport non-students. The lead agency, the types of non-pupil riders, and if commingling of pupils and non-pupils is allowed for the five studies where coordination made use of school vehicles is presented in Table 1.

Table 1 Pupil/Non-Pupil Transportation Coordination Efforts

Agency	Non-pupil Riders	Commingling Allowed
Campbell County School District Gillette, WY	Community members	N
Chesterfield Co. Coordination Council Cheraw, SC	School employees Parents; volunteers	Y
Glendale-Azalea Skills Center Glendale, OR	Skills center participants	Y
Northeast Iowa Community Action Decorah, IA	Headstart	Y
Tri-County Community Council	Headstart	Y

Multisystems, Transit Plus, Martin, Tull, and IBI Group (1999)

The Campbell County School District allows local, nonprofit groups to rent yellow school buses in its fleet to travel to neighboring communities. Trip purposes regularly include athletic tournaments, academic competitions, and special group trips. Groups reimburse the district for actual driver and fuel costs and pay a flat rate for insurance coverage. The groups also are required to maintain personal liability coverage.

The Chesterfield County Coordination Council was working with the local school district and state to allow the general public to ride on yellow school buses. This would be in addition to the existing rides already available to parents of students and school employees and volunteers. In South Carolina, the state manages school transportation.

The Glendale-Azalea Skills Center allows participants to ride on existing school routes, if there is excess capacity. Riders are required to pass a criminal background check and serve as monitors during rides.

The Northeast Iowa Community Action Corporation has its pre-school Head Start students ride on existing school bus routes. The Tri-County Community Council worked to arrange for Head Start students to ride on yellow school buses on existing routes. It also provides feeder service to existing bus stops.

The report by Multisystems, Transit Plus, Martin, Tull, and IBI Group also presents the results of a survey conducted in conjunction with the study. Of the 140 respondents to the survey, 30 used yellow school buses to provide transportation to non-pupils. Of these, 20 did not allow commingling.

Rural respondents to the survey reported fewer barriers in general compared with their urban and suburban counterparts. They also noted having fewer insurmountable barriers.

Rural respondents were more likely to report that they were involved in integrating transportation service. One-fourth of systems reporting integration were located in areas with less than 10,000 people. Over half were located in areas with less than 50,000 people.

A study by Baltes (2001) focused on public transportation agencies that provide service to students with tripper service under either a formal or informal arrangement. Thus, many of its findings are outside of the scope of this literature review. However, some of its general findings were of value in framing the study.

The report noted a change in sentiment among transit and pupil transportation system managers which have traditionally been negative. The challenges and opportunities vary by location. Student safety remains a top priority for educational authorities and is a primary barrier to coordination.

A recent study by Anderle, Kroeger, and Mascarello (2005), The Coordination of Pupil and Non-Pupil Transportation: Final Report, looked at the efficiencies gained by coordination of transportation service delivered by schools and public agencies in Iowa. It also summarized findings on the issues of safety, vehicle configuration, and driver training. It found 23 examples of coordination between schools and public transportation providers involving 45 of the state's 371 school districts. The report identified three sources of savings: taking advantage of excess capacity, making using of specialized vehicles (specifically those with lifts), and sharing infrastructure.

The authors calculated that, on average, each Iowa school district saves a value equivalent to the cost of purchasing a lift-equipped vehicle. This was estimated at $6,000 per year for a vehicle with a 10-year life. However, nearly all of the examples of coordination involved the transporting of students on public transportation vehicles, including all but one of the eight case studies provided.

One exception was the case of the Ames Public School District and Cyride, Ames' public transportation provider. Following the introduction of U-Pass, a fare-free system for university students, early morning demand for service exceeded Cyride's peak capacity. To mitigate the situation, Cyride contracted with Ames public schools to provide vehicles to meet demand.

3. Pilot Site Selection and Overview

One of the primary concerns in the selection of the pilot school district was its location in a viable community where service provision at a minimum level is expected to continue in the future. As sub-county level economic and population projections are not available, subjective indicators were used. With these guidelines in mind, the Enderlin Public School District was selected from a list of districts that responded to a solicitation at the 2004 North Dakota School Board Association Annual Meeting.

Enderlin, ND, is a community of 1,063 located on the Maple River in southeast North Dakota (Figure 1). The characteristics of both the local school district and the community as a whole made it an ideal location for the study.

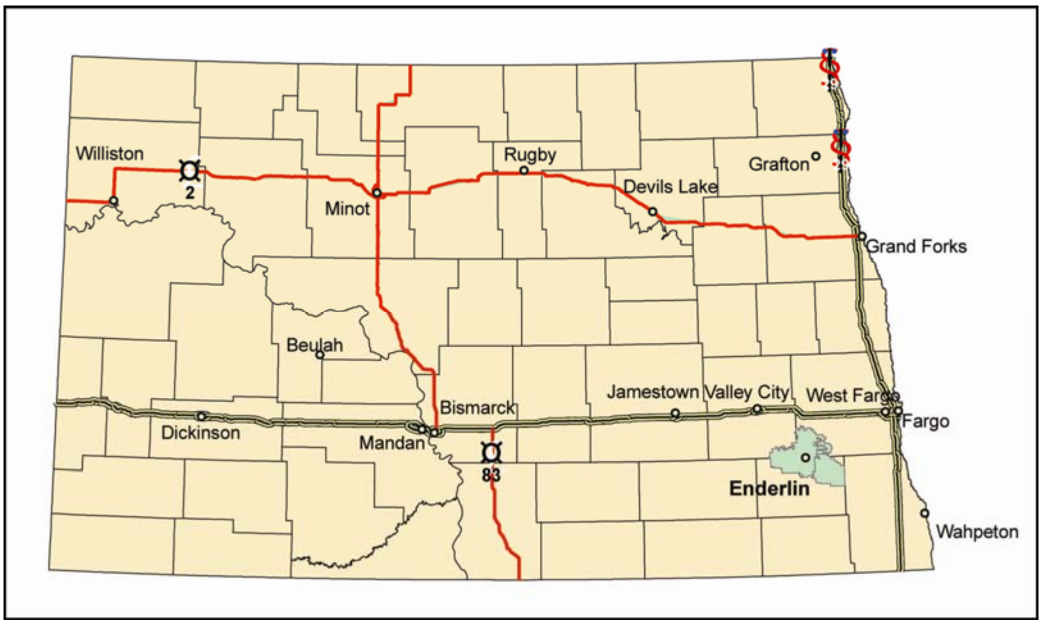

Figure 1 Enderlin, North Dakota

Following the selection of the Enderlin School District as the location of the pilot site, the Sheldon Public School District announced its intent to reorganize. The elementary school in Sheldon will become part of the Enderlin School District following the 2006-2007 school year. A map of the two districts is shown in Figure 2.

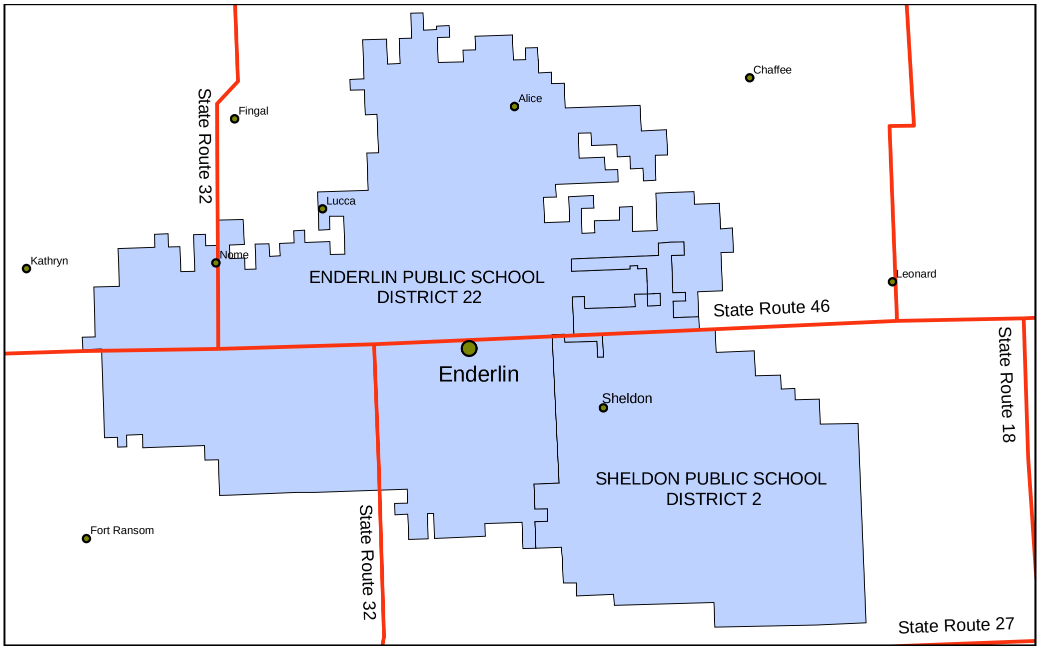

Figure 2 Enderlin and Sheldon Public School Districts

3.1 Demographic Overview

An understanding of the current demographic nature of the area is important to identify policies that will best meet its needs. Projections of its future profile aid in identifying long-term needs, including innovative changes in transportation policy such as the coordination of pupil and non-pupil transportation.

The population pyramid for the Enderlin and Sheldon school districts is presented in Figure 3. The relatively small number of residents, both male and female age 20 to 24, is particularly troubling. This is likely the result of high out-migration of high school graduates looking for employment and educational opportunities outside of the area.

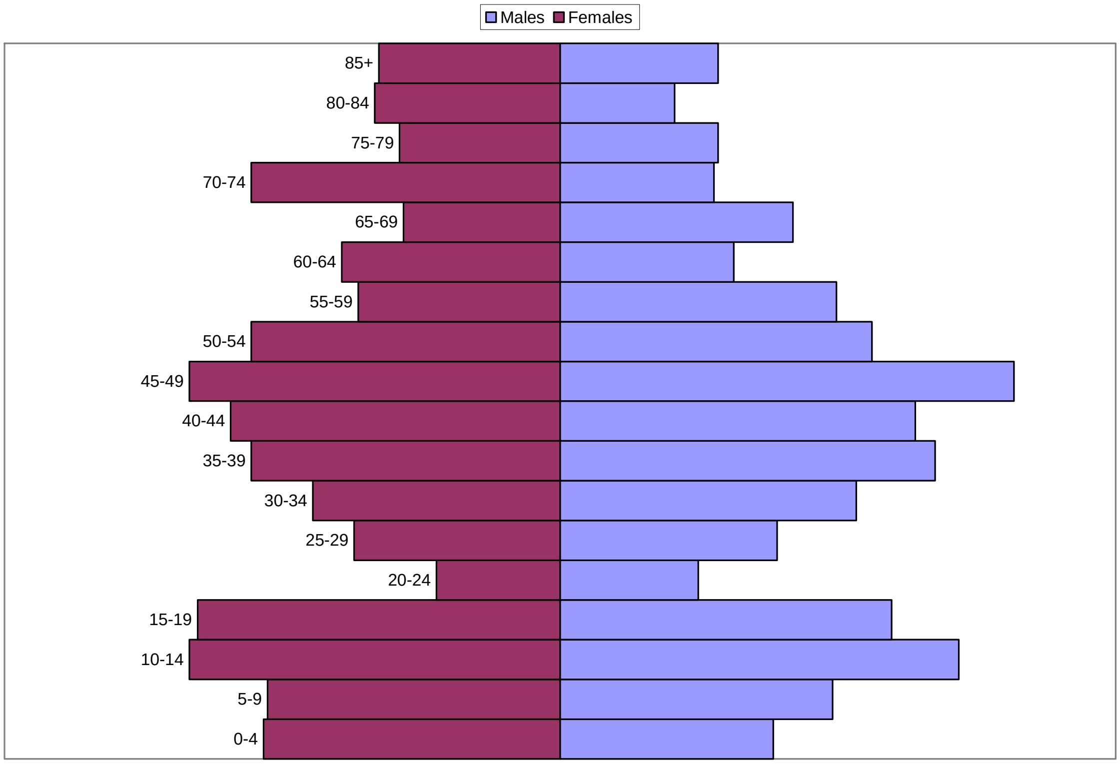

Figure 3 Enderlin and Sheldon Area Population Pyramid

The distribution of population by age is presented in Table 2. In 2000, 2,297 individuals lived within the boundaries of the Enderlin and Sheldon school districts; 629 were under the age of 20, while 448 were seniors. The area's percentage of elderly, 19.5%, is significantly higher than the statewide rate of 14.7%, but similar to many other rural areas in the state.

Table 2 School District Population by Age

0-4	2,297
5 to 19	457
20 to 64	1,295
65+	461
Total	4,510

Source: U.S. Decennial Census, National Center for Education Statistics

3.2 Community Services & Amenities

The economy of Enderlin and surrounding areas is based on agricultural production. The City of Enderlin is also home to a large sunflower crushing plant, which employs more than 75 people. Enderlin is just over 30 miles from Gwinner, ND, the home of a large manufacturing plant that draws employees from throughout southeast North Dakota. Enderlin has limited retail offerings. Fargo-Moorhead, a full service metropolitan community, is less than an hour's drive away.

A local clinic, MeritCare Enderlin, provides family and emergency medical care to Enderlin and surrounding areas. The clinic currently employs one full-time physician and four physician's assistants. It is part of the MeritCare HealthSystem, which has practices in more than 30 locations in eastern North Dakota and northern Minnesota, including two hospitals in Fargo. Enderlin is also home to a 54-bed long-term nursing care facility, Maryvale.

As a relatively small community, individuals living within the boundaries of the Enderlin and Sheldon School Districts must often travel outside the area regularly to receive the services they demand. The city of Fargo, located 60 miles from Enderlin, with a population of 91,048, provides many of the services needed. It is home to three hospitals that provide a number of medical services. Also located within Fargo is a large regional shopping center. The city also provides various social and cultural events.

3.3 Enderlin & Sheldon Public School Districts

Summary statistics for the Enderlin and Sheldon Public School Districts for the 2004-2005 school year are presented in Table 3. Enderlin, at 282 square miles, is more than twice the size of Sheldon, at 134. However, Enderlin's enrollment of 311 students is more than 10 times that of Sheldon's, which had 27 students. Although both districts saw a decrease in enrollment in the previous five years, Sheldon's decline of more than 50% is far greater than Enderlin's decrease of 17%. Sheldon also had a higher proportion of students receiving free or reduced lunch, a proxy for low-income, at 37% than Enderlin at 31%. All of Sheldon's students were reported to be transported by bus compared with 47% for Enderlin students. The average route length for both districts was 40 miles.

Table 3 School District Summary Information, 2004-2005

	Enderlin	Sheldon
Area (sq. miles)	282	134
5-Year Enrollment Trend	-17%	-53%
Total Enrollment	311	27
Free & Reduced	31%	37%
Percent of Students Transportated	47%	100%
Average Route Length (miles)	40	41
Student Contact Days	173	173

Source: North Dakota Department of Public Instruction

The Enderlin and Sheldon school districts are projected to see significant declines in student population in the next 10 years as shown in Figure 4. According to the North Dakota Department of Management Information Systems, the number of students enrolled in the Enderlin School district boundaries as of 2000 is expected to decline from 373 to 180 by 2017. Within the Sheldon district's boundaries, a decline from 57 to 13 is expected.

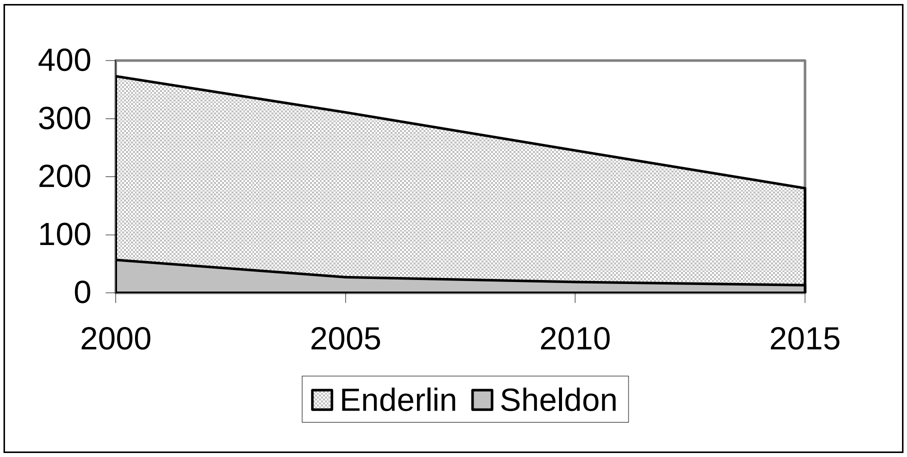

Figure 4 Enderlin and Sheldon Enrollment 2000 to 2017

This pattern is similar to those present in nearby school districts and most rural North Dakota.

Table 4 shows enrollment projections for 10 districts in southeast North Dakota. Only two school districts are expected to see an increase in enrollment: Maple Valley and Litchville-Marion. These are relatively small, low density districts. The Valley City school district, currently the 15th largest in the state, is expected to see a decrease of more than 400 students, just under 1/3 of its current size. Fort Ransom, which only provides elementary education, is expected to have 13 students in 2015.

Table 4 Actual and Projected Public School Enrollment, 2000 to 2015

	2000	2005	2010	2015
Enderlin	373	311	245	180
Sheldon	57	27	19	13
Central Cass	828	827	757	585
Fort Ransom	29	12	15	13
Kindred	732	720	623	520
Lisbon	694	636	555	491
Litchville-Marion*		173	187	200
Maple Valley	249	256	254	260
Valley City	1285	1175	978	858
Wyndmere	338	257	206	178

*Consolidated after 2000

Source: North Dakota Department of Public Instruction

Because much of the revenue for North Dakota K-12 education is received via the state and is a function of enrollment, the projected decrease in the number of students at the Enderlin, Sheldon, and neighboring school districts is sure to add additional financial pressure. At the same time, the density of students in rural areas will also drop, resulting in a further decrease in relative efficiency as shown by various performance measures, including student trips per mile.

4. Pilot Project Process and Results

Following selection of the Enderlin Public School District as the site of the pilot project, relevant district transportation operation data and specific concerns from its administrators were collected. Data was used as input in the routing algorithm used. Administrators were strongly interested in using the routing algorithm to estimate the impacts of operating under different scenarios.

The pilot project consisted of two parts. First, four scenarios of special interest to Enderlin Public School administrators were tested. The second part of the project consisted of identifying the most efficient system of routes.

It should be noted that the pilot project focused on the practicality of using a routing algorithm, not the implementation and use of routing software, to increase efficiency. The technical aspects of the routing algorithm are outside the scope of this paper.

4.1 Enderlin Public School District Transportation Operation

Like nearly all school districts in North Dakota, Enderlin Public School District owns and operates its own fleet of vehicles to transport students to and from school and other enrichment activities. Table 5 presents the five Enderlin routes used during the 2004-2005 school year, the capacity of the vehicles assigned to them, and the number of assigned riders. Route 1 has a capacity of 35 students and picks up 25 riders at rural stops, as well as picking up students at the Broadway & Grand stop inside Enderlin city limits. Route 3 picks up 26 rural students and serves as a shuttle between the Sheldon and Enderlin schools. Like Route 1, Route 8 serves an in-town stop in Enderlin referred to as 'West Town.'

Table 5 Routes, 2004-2005

Route	Capacity	Riders
# 1	35	25*
# 3	59	46**
# 5	53	42
# 8	53	38***
# 10	48	27

* Does not include Broadway & Grand stop riders
** Includes 20 Sheldon shuttle students
*** Does not include West Town stop riders

In most North Dakota school districts, riders have a reserved seat on a bus. This is done to guarantee the students a ride to and from school. The actual number of riders varies greatly from day to day with a number of factors, including the weather and other family travel plans, playing a role.

Table 6 presents the number of miles traveled by Enderlin Public School District buses during the 2004-2005 school year. During that time, 81,311 miles were traveled transporting students to and from school, 79% of the total miles traveled. Travel for enrichment activities covered 21,708 miles, 21% of the total miles traveled.

Table 6 Miles Traveled, 2004-2005

	Miles	Percentage
Route	81,311	79%
Activity	21,708	21%
District Total	103,019	

Table 7 presents the cost attributed to the delivery of route and activity transportation for the Enderlin Public School District in 2004-2005. The total cost of transporting students to and from school was $116,229. Activity-related transportation cost $30,896. The total cost of Enderlin Public School's transportation operation during the 2004-2005 school year was $147,125.

Table 7 Transportation Costs, 2004-2005

	Total Cost	Cost per Mile
Route Costs	$ 116,229	$ 1.43
Activity Costs	$ 30,896	$ 1.42
Transportation Costs	$ 147,125	$ 1.43

4.2 School Transportation Concerns

During initial meetings with Enderlin Public School District administrators, the importance of issues other than cost minimization in school transportation management was identified. These included driver recruitment and retention, route balancing, and bus location. The labor issues were deemed to be outside of the scope of the project. Route balance and bus location were taken into account and were the subject of the first phase of the pilot project.

Route balancing in rural areas, where routes are relatively long, is important for two reasons. First, parents and guardians of students are concerned about trip length, as are education providers. Second, drivers have an interest as most work is performed under contract; unbalanced workloads may lead to animosity between those who work longer or shorter hours.

Enderlin administrators were particularly interested in studying the housing of its school buses. While Enderlin has the facilities to house its vehicles, it allows drivers to keep vehicles at home. This decision may have significant impacts on routing and operational performance. It should also be taken into account that the practice results in the vehicle being used for pseudo-personal transportation, as drivers deadhead from their last drop-off back to their residence in the morning and deadhead back before beginning their afternoon route. Such practice may devolve into true personal use as errands may be run using school property.

A unique set of issues face all providers of rural school transportation, including those at the Enderlin Public School District. Primary among these is a required understanding of the community highway infrastructure. This information is needed to insure that new routes are feasible. The construction of routes along unsuitable roads in rural areas will lead to criticism of the routing process and those involved. While a road may be present on a map, it may not be in a condition suitable for daily travel by a large vehicle, such as a school bus. At the same time, road conditions may greatly affect travel time. Also, in North Dakota some roads are not maintained year round. As a result of these issues, changes to routes often include consultation with drivers and other community members who are familiar with road conditions as well as time tests prior to their finalization.

In rural areas, the crossing of streets by students is not as great a concern as in urban areas. In those rural areas routing vehicles to only collect students on the right hand of the street would be unnecessarily cumbersome.

Administrators at Enderlin Public Schools did not express great interest in exploring movement to a heterogeneous fleet of vehicles. Fleet mix and vehicle size issues are of greater concern in rural areas as routes usually hit time constraints before capacity constraints. Thus, placing vehicles with lower operating costs on longer routes, given route capacity, results in increased efficiency. However, the operating costs of smaller vehicles is not substantially less than for large ones. Fleet size and mix decisions must be made in light of greater system needs and constraints.

4.3 Information Needed

The routing algorithm requires school transportation system specific information regarding the fleet, riders, road network, and school district policies. With respect to fleets, information on the number of vehicles, their capacity, and condition are needed. The stops and schools to which riders are assigned are also needed.
Information regarding the area's road network, including condition, speed limit, and maintenance, is required. School policies, such as maximum ride time, are valuable factors.

Enderlin had this information available in electronic form. Most information was available in the form of route sheets. Each sheet included the vehicle and driver assigned to the routes, the stops visited, the number of students at each stop, and the order of pickup. Also provided was financial information on the district's transportation costs.

4.4 Scenario Testing

Based on comments received from the Enderlin School District, the first phase of work consisted of estimating the impacts of requiring school buses to be housed on school property in Enderlin and the addition of a sixth route.

The routing algorithm generated routes, including the annual route length and maximum time any student could be transported on the bus. The maximum time on a bus was found by multiplying the distance the longest riding student was transported in miles by two. This equates to an average traveling speed of 30 miles per hour. This resulted in a significant overestimation, and was corrected during the second phase of the project to 40 miles per hour.

Annual route miles were multiplied by $1.50, the estimated variable cost of transporting students, to estimate the cost of service. This value is higher than the $1.43 reported for the 2004-2005 school year to account for a general rise in transportation prices, fuel in particular.

The estimates for a five-route system where vehicles are allowed to be housed at drivers' residences are presented in Table 8. The cost of service is estimated to be $124,335 annually. The maximum time any student was on the bus was 97 minutes.

Table 8 Estimates for Five-Route Home-Start Service

	Route Length (miles)	Max Time on Bus (minutes)	Variable Cost
Route 1	16,650	85	$24,975
Route 2	13,446	58	$20,169
Route 3	16,542	97	$24,813
Route 4	16,632	68	$24,948
Route 5	19,620	80	$29,430
Total	82,890		$124,335

Estimates for five-route service, where all routes begin and end in Enderlin, are presented in Table 9. The impact of the change in vehicle housing policy resulted in a significant decrease in cost, approximately $13,000, to $111,129. The longest any student would remain on a vehicle is estimated to be 92 minutes.

Table 9 Estimates for Five-Route Enderlin-Start Service

	Route Length (miles)	Max Time on Bus (minutes)	Variable Cost
Route 1	13,364	72	$20,046
Route 2	11,607	58	$17,411
Route 3	16,607	92	$24,910
Route 4	14,657	68	$21,986
Route 5	17,851	80	$26,776
Total	74,086		$111,129

The estimated impacts of adding a sixth route, but allowing drivers to house the vehicles at their residence, are presented in Table 10. These changes resulted in a cost savings of just over $1,000 for a total cost of $123,091. The longest any student was on a vehicle under this option is estimated to be 82 minutes.

Table 10 Estimates for Six-Route Home-Start Service

	Route Length (miles)	Max Time on Bus (minutes)	Variable Cost
Route 1	12,439	69	$18,658
Route 2	9,419	52	$14,129
Route 3	17,293	76	$25,940
Route 4	17,940	80	$26,910
Route 5	18,615	82	$27,922
Route 6	6,354	35	$9,532
Total	82,061		$123,091

Estimates for six route service and required bus housing in Enderlin are presented in Table 11. Estimated cost savings are approximately $8,000 per year with an estimated total annual cost of $116,893. The maximum time any student is estimated to be on the bus is 92 minutes.

Table 11 Estimates for Six-Route Enderlin-Start Service

	Route Length (miles)	Max Time on Bus (minutes)	Variable Cost
Route 1	6,525	36	$9,787
Route 2	14,241	79	$17,411
Route 3	11,408	63	$17,112
Route 4	14,761	82	$22,141
Route 5	16,506	92	$24,759
Route 6	14,488	80	$21,732
Total	77,928		$116,893

4.5 Optimal Route Generation

The second portion of the pilot study utilized the routing algorithm to identify the near-optimal system of routes for the Enderlin Public School District. Here the term near-optimal is used as the actual optimal solution, and is not and possibly cannot be known with certainty. A number of constraints were removed. Routes could be added or removed, and vehicles could be housed in town or at the drivers' residences. A soft cap on maximum ride time, 75 minutes, was imposed. The results are shown in Table 12. Figure 5 presents a map of the near-optimal routes.

The longest route is 52 miles, the shortest 33, for near-optimal service. The estimated maximum time any student is in transit is 76 minutes. The estimated annual cost of service is $110,631. This is significantly less than the actual cost of pupil transportation, $116,229 in the 2004-2005 school year, even though the per mile cost is $.07 higher for near-optimal service. Miles of service decrease from 81,311 to 77,364 for near-optimal service

Table 12 Estimates for Near-Optimal Service

	(Miles)
Rt. 1 miles	41
Rt. 2 miles	53
Rt. 3 miles	42
Rt. 4 miles	33
Rt. 5 miles	46
Max time on bus	76 minutes
Est. Daily Miles	215
Est. Annual Miles	77,364
Est. Annual Cost	$110,631

All routes except for Route 5, which is located in the eastern part of the district, begin and end in Enderlin. Route 5's morning route begins at the driver's residence and then picks up students on its way toward Sheldon. Students attending elementary school in Sheldon depart, while students who attend school in Enderlin (that were picked up by Sheldon vehicles) are shuttled to Enderlin on the vehicle assigned to Route 5.

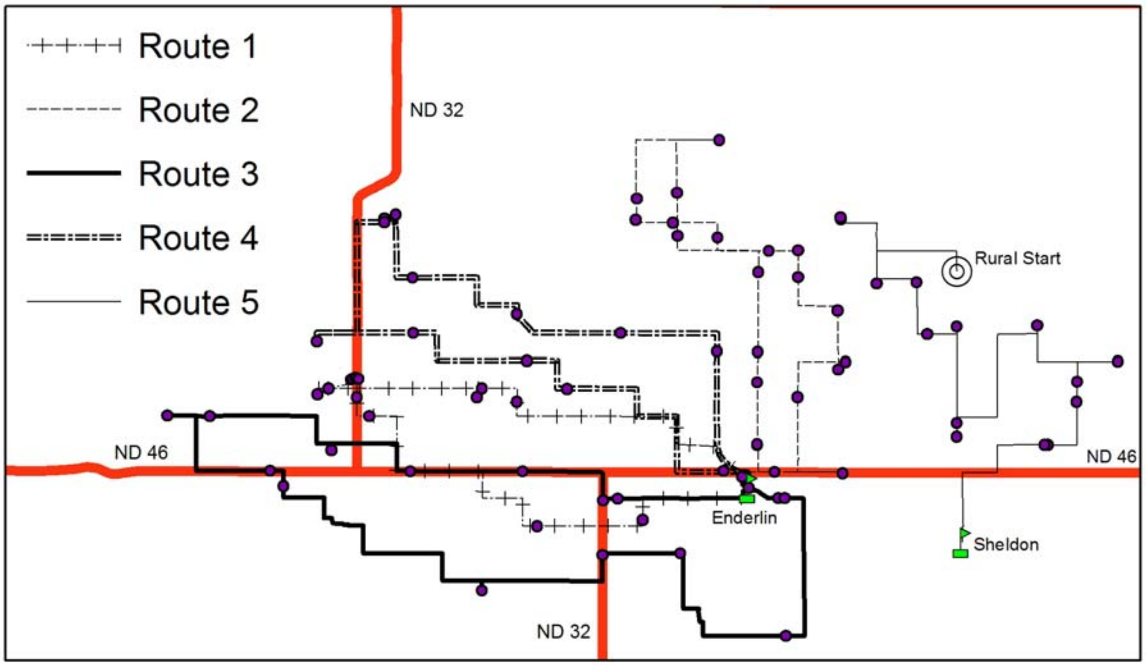

Figure 5 Map of Near-Optimal Service Routes

4.6 Implementing New Routes

Additional work is needed before the routes generated by the algorithm can be finalized and implemented by the district. Most important is the need to physically travel and verify the time requirements of the routes to ensure that they are feasible. This is especially important in rural areas where the road network may not be suitable for school transportation. Ultimate finalization of the new routes is a school district decision.

5. Summary and Conclusions

A pilot project was initiated to explore efficiencies resulting from the implementation of computerized routes in school transportation, and to identify opportunities for coordinated pupil/non-pupil transportation in the pilot community. Given their shared characteristics, the routing algorithm used to study the selected districts routes shows promise of being able to provide solutions to both pupil and non-pupil transportation providers. A routing algorithm was used to estimate the impacts of changes in school policy regarding the number of routes and the location of housing for district vehicles. It was also used to identify the near-optimal service for the district.

A number of lessons for pupil and non-pupil transportation providers and researchers and policy makers in transportation and education regarding the implementation and use of computerized routing tools were learned during the pilot project.

Successful multi-agency routing efforts require a strong working relationship. This includes identifying the true needs of local transportation providers. Often, solutions must be tailored to meet unique needs. Regular and open lines of communication are needed throughout the design and implementation process.

Route identification and finalization is a labor-intensive process. While technology plays a key role, work by those with knowledge of computerized software and others involved in transportation agency management is necessary. The task of routing may not simply be passed on to a group or organization, it must be managed with input from managers. As the route finalization process is iterative, communication of interim results and feedback is important.

Routing tools provide secondary benefits to transportation providers. As noted in this study, routing tools can aid in strategically managing an agency’s transportation operation. This may include testing operational scenarios, such as different vehicle starting points or fleet size and mix considerations. In K-12 education, routing tools may be used in estimating the impacts of consolidation.

There are opportunities for increased efficiency from using computerized routing tools in rural school districts. Although the routes produced by the study have not been put into effect as of the time of the publication of this report, significant improvements in efficiency were identified. This may be the case for many rural North Dakota public transportation providers as well.

Given the challenges facing both pupil and non-pupil transportation providers in the state, it is likely that a formal introduction of computerized routing techniques and increased levels of coordination will occur in the coming years.

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