DEVELOPMENT OF AN ANNUNCIATION SYSTEM FOR RURAL SCHOOL BUS OPERATIONS

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Final Report

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by

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16. Abstract

The economic strength of rural areas in America requires dependable transportation, often over sparsely settled lands in all types of weather conditions. This dependency on safe and reliable mobility is certainly true for rural school bus operations that small children use daily for riding to and from school. Receiving a quality education is a necessity for the economic growth and the long-term sustainability of rural communities, and the local school bus transportation system is an integral part of this education process.

During routine rural school bus operations, these school children and their concerned parents may frequently walk long distances to their bus stop and then wait with great uncertainty for their school bus to arrive. The consequences of missing the school bus require that a student arrive early at the stop, but this early arrival often results in considerable wait times, which are further exaggerated when buses are unexpectedly delayed. This waiting exposes these children to all kinds of inclement weather conditions, roadside safety hazards, and other personal safety and security threats.

This research reviewed a variety of existing technologies in order to determine how such technologies could be cost-effectively applied to address these important issues. A private sector system developed for this purpose and field-tested during the research study period was examined, and a new system design was developed using a combination of off-the-shelf, multi-function components. It is recommended that one or both of these systems be tested in Texas for accuracy, reliability, and cost-effectiveness before widespread implementation can be considered.

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EXECUTIVE SUMMARY

The economic strength of rural areas in America requires dependable transportation, often over sparsely settled lands in all types of weather conditions. This dependency on safe and reliable mobility is certainly true for rural school bus operations that small children use daily for riding to and from school. Receiving a quality education is a necessity for the economic growth and the long-term sustainability of rural communities, and the local school bus transportation system is an integral part of this education process.

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DISCLAIMER

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INTRODUCTION

PROBLEM STATEMENT

The economic strength of rural areas in America requires dependable transportation, often over sparsely settled lands in all types of weather conditions. This dependency on safe and reliable mobility is certainly true for rural school bus operations that small children use daily for riding to and from school. Receiving a quality education is a necessity for the economic growth and the long-term sustainability of rural communities, and the local school bus transportation system is an integral part of this education process.

During routine rural school bus operations, these school children and their concerned parents may frequently walk long distances to their bus stop and then wait with great uncertainty for their school bus to arrive. The consequences of missing the school bus require that a student arrive early at the stop, but this early arrival often results in considerable wait times, which are further exaggerated when buses are unexpectedly delayed. This waiting exposes these children to all kinds of inclement weather conditions, roadside safety hazards, and other personal safety and security threats. This basic transportation problem arises out of unpredictable arrival times of the students and the buses. Moreover, the students have no knowledge, other than a pre-defined timetable and experience, as to how today's bus schedule is being followed. The school bus driver does not know if a student not at the bus stop is or is not coming. In both cases, relevant information is missing, or is not available to either party.

The envisioned solution to this problem requires the school bus to communicate, either directly or indirectly, its expected arrival time at the student's bus stop to the student at home. This notice would provide enough advance warning time so that the student may reach the bus stop at approximately the same time as the bus. There are emerging technologies currently being researched by the Texas Transportation Institute which hold new promise for the establishment of such a system. The primary goal of this project was to investigate existing technologies deemed feasible to solve this vital transportation problem.

RESEARCH OBJECTIVES [*1*]

The specific objectives of this research effort were as follows:

- To systematically investigate the various technical aspects and requirements for providing reliable arrival time information for rural school buses to the homes of its potential riders;
- To determine the needs and desires of school districts in Texas as related to the primary function of an arrival annunciation system, as well as potential secondary functions (i.e., two-way communication to inform bus driver of student's status);
- To examine the current awareness and ITS technological solutions being considered and/or deemed feasible to address such issues;
- To develop a suite of technology options for providing the needed transportation information to school children at their homes; and
- To recommend future implementation options and requirements that would resolve known technical, product design, and/or market impediments to achieving the overall research goal.

REPORT ORGANIZATION

The following chapters describe the issues relating to the development of a school bus annunciation system from a variety of perspectives and investigate some of the relevant technologies and features. Chapter 2 describes the perceived need for such an annunciation system, as determined by a survey of Texas school districts conducted as a part of this research. Chapter 3 details the requirements of and issues associated with such an annunciation system from a transportation systems perspective, while Chapter 4 enumerates the issues and requirements from a communications systems perspective. Chapter 5 then describes the features of each of the relevant technologies explored in this research, and Chapter 6 presents system designs for both an existing and proposed school bus annunciation system. Finally, overall conclusions and recommendations are presented and discussed in Chapter 7.

CHAPTER 2
SCHOOL TRANSPORTATION SURVEY

A key objective of this research, as described earlier, was to establish the importance of providing reliable school bus arrival information to riders' homes. In order to accomplish this, school districts across the state of Texas were asked for their opinion of the perceived problem, as well as for opinions about some potential systems which might be proposed to address the issue.

TEXAS SURVEY

A database of school districts and contact persons was obtained from the Texas Education Agency (TEA) Internet web site. In order to ensure that districts with sizable rural components would be the focus of the survey, random samples were selected from a screened database of only those school districts associated with communities having populations of 3,000 to 7,000 persons. This not only eliminated the larger, more heavily urbanized districts, but it also eliminated many extremely small districts which are unlikely to have an individual with sole responsibility for transportation. The latter were eliminated to improve the likelihood of a response, and to improve the chance that the survey respondent would be well-versed in the issues of pupil transportation.

Surveys were sent to 110 Texas school district superintendents, with instructions for the questionnaire to be forwarded to the person responsible for pupil transportation. A sample of the survey, cover letter, and a summary of the responses received is included in the appendix to this report. The two page survey was mailed on April 1, 1998, and was accompanied by a two page letter, which identified the Texas Transportation Institute and described the issue in question. A pre-addressed, postage-paid reply envelope was also included to facilitate easy response. A total of 42 responses were returned, representing school transportation directors and senior school management officials, resulting in a 38.2% overall response rate.

Responses were divided relatively equally among three regions, including northeastern Texas, southeastern Texas, and the Panhandle. The lack of representation of western Texas is likely due to the exclusion of the smallest districts and the less densely populated nature of the region. Among the responses received, there was no identifiable relationship between the responses to any of the questions and the geographic location of the school district in Texas.

In order to substantiate the size of the responding districts, each was queried regarding the total number of school buses operated and the number of "rural" routes which are run. The definition of a "rural" route was left to the discretion of the respondent. On average, responding districts operate 25 school buses, and serve approximately 16 "rural" runs daily. Despite the initial screening process, there was a good deal of variation in fleet size, from a minimum of just four buses to a maximum of 104 buses.

SURVEY RESULTS

In order to assess the current level of technology of the respondents, as well as to determine the widespread feasibility of using existing radio systems for data transmission, the survey inquired about the presence and type of two-way communication currently installed on the buses. Approximately three-quarters of districts responding have some form of two-way communications on most or all of their route buses. Of these, approximately half use cellular telephones and half use a traditional two-way radio system. Note that the existence of two-way communications capability on a vehicle does not mean that the vehicle is in regular contact with a dispatcher, as some vehicles simply carry cellular telephones primarily for emergency use.

The question of greatest interest to this project, however, concerns the school bus operator's perception of the issue of school children waiting with uncertainty at the bus stop. Approximately 26.8% of respondents felt that this was a significant issue facing their school district, while 73.2% did not believe so. It is important to note, however, that this is the perception of the school management or transportation director, and represents the most favorable view of the quality and reliability of school bus operations in the district. Note that expressing concern about children waiting with uncertainty about when the bus will arrive could be interpreted as an admission that the transportation system is not performing as it should, and the responsible parties, those answering the survey, may be reluctant to admit this to an outside research agency.

Some respondents further illuminated this potential bias in point of view, although unintentionally, by noting that there was not an issue about children waiting by the roadside for long periods of time because many parents also stood at the roadside for long periods of time and waited with them. This practice may resolve the safety concerns from the school manager's perspective, but it is unlikely to be popular with parents. The probable need is therefore judged to be considerably higher than that (26.8%) which was reported by the managers.

Districts were also questioned about whether or not they felt that the return of real-time bus tracking information to their office, as in the systems described previously, would be a valuable tool that could benefit the operation of their systems. Respondents were nearly equally split on this question, with a notably higher percentage (47.6%) indicating that the information would be valuable than had responded that there was an issue to be addressed in the previous question.

Since the provision of a school bus arrival annunciation system was anticipated to be relatively costly as a stand-alone system, it seems reasonable to assume that such a system would be more attractive to operators if other desirable features were also included in a package for minimal extra cost. Some suggested features were listed, and respondents were encouraged to suggest others that would be of interest to them. The capability to provide two-way voice communications over the same system and the ability to notify parents when buses will be dropping students off were both rated as highly desirable features. The latter option might take one of two forms: notifying parents when the child is to be dropped off at home after school; or notifying parents when a bus will be returning from an activity trip outside the school district, particularly at night. The ability to notify drivers en route when a student will not be taking the bus was rated as the third most desirable add-on feature, and the inclusion of a driver emergency or "panic" button was found to be less desirable.

Operators were also questioned, based on their personal knowledge of the attitudes and economic conditions of the families in their districts, about the perceived willingness of parents to pay a fee for the service provided by a school bus arrival annunciation system. The vast majority of respondents stated flatly that parents would not pay any amount, and many indicated that the school district would be expected to cover the costs of such a system. The strict budgetary limitations of school districts were also noted in these responses. Approximately 10% of respondents indicated that some parents might be willing to pay, with the general consensus being that $10 per month was a reasonable fee for such a service. This survey finding that parents would not likely be willing to pay a monthly service provider fee is in conflict with the BusCall® marketing strategy being developed by a new commercial enterprise described in a later chapter of this report.

CHAPTER 3

TRANSPORTATION SYSTEM REQUIREMENTS

The envisioned solution to this problem requires the bus to communicate, either directly or indirectly, an announcement of its expected arrival time at the bus stop to the student at home, providing enough advance warning time so that the student and the bus arrive at the bus stop at approximately the same time, as described previously. Figure 1 provides a schematic of some of the transportation and communication concepts involved.

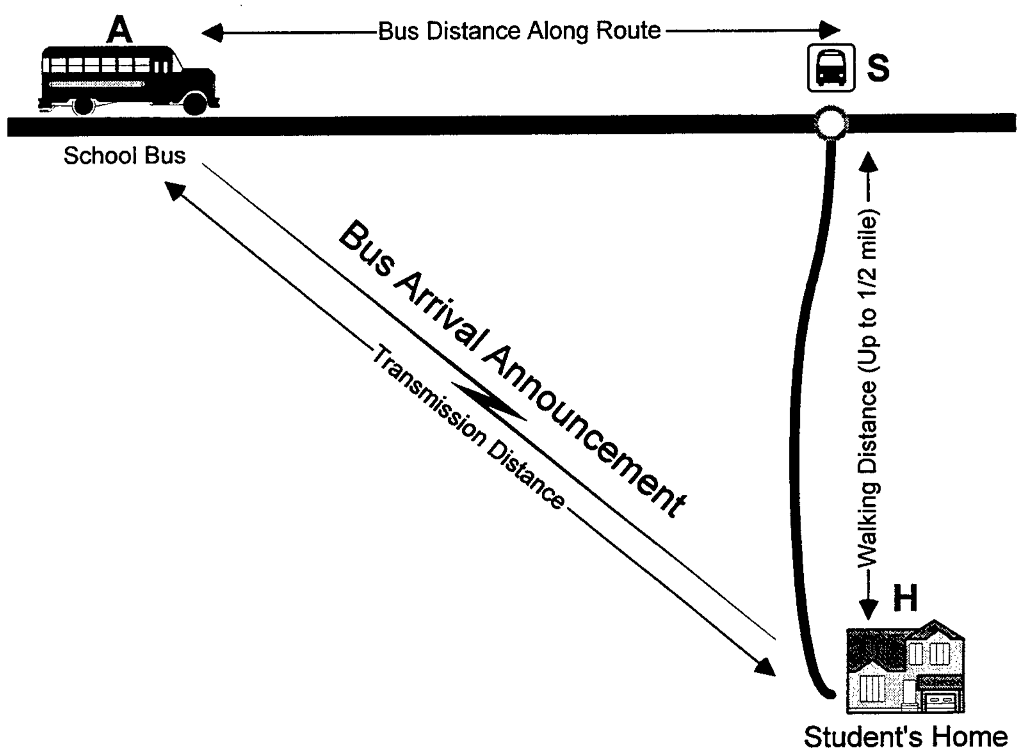

Figure 1. School Bus Annunciation Concept Schematic

The generation of such a timely announcement is not as simple as it appears at first glance. In order to determine when to send the announcement, the system (or an operator) must know how much advance warning the student requires, which is a function of many factors including the distance the student must walk from home (Point H in Figure 1) to reach the bus stop (Point S in

Figure 1). It must also be known when the bus is at a point which is the appropriate travel time away from the bus stop (Point A in Figure 1), to determine when to send the arrival announcement. Many of the issues which impact determination of these factors are described in the following section.

GENERAL ISSUES

There are many issues and potential problem areas which need to be addressed in order to provide for an accurate, reliable, and cost-effective bus annunciation system. There are numerous conditions which affect the consistency and reliability of arrival notifications, including the following:

- **Non-linear routes:** School bus routes do not necessarily approach a student's home directly, but may wind or even double back on themselves, with the bus repeatedly moving into and out of radio transmission range.

- **Intermediate stops:** Some areas have higher concentrations of bus stops or other traffic delaying factors, such as traffic signals or railroad crossings, which cause the average travel speed to vary along the route in a random manner.

- **Temporal volume variations:** Traffic volumes, and hence school bus travel times, vary by time of day, day of the week, and season of the year. The time of day issue is of particular interest in cases where the buses operate on multiple shifts through the course of the day (such as in some kindergarten programs). The seasonal volume variation is of interest in areas which experience severe weather (winter storms, flooding) or have large numbers of seasonal tourists (resort communities).

- **"Notice Time" variations:** The amount of advance notice required by the student to reach the bus stop may vary with changes in the distance from the student's home to the bus stop from one student to another, varying weather conditions, etc.

It is also important to note that these factors do not act independently of each other. The bus travel time is subject to the cumulative impacts of all of these issues, thus increasing the potential variability of travel time dramatically.

TRAVEL TIME RELATIONSHIPS

There are a number of relationships that must be recognized and understood when considering potential solutions for this project. The more important fundamental relationships are described below.

Student Arrival Time

First, it is clear that the speed at which a student walks to the bus will govern how long it takes that student to walk from his/her home to the bus stop following notification. By extension, the student's walking speed is also a factor in determining the amount of advance notification time required from the annunciation system. Walking speed clearly varies by individual, and many factors may alter any given student's walking speed on a given day. Students may walk faster downhill than uphill; students may walk faster in colder weather than warmer weather. It is important to note that, in Texas, school districts may be obligated to require the bus to drive to the home site if the walking distance from the student's home to the bus stop would be more than one-half mile, provided that adequate safe turnaround space exists.

Obviously, as the distance the student must walk increases, the amount of time required to cover that distance also increases. This relationship is illustrated in Figure 2.

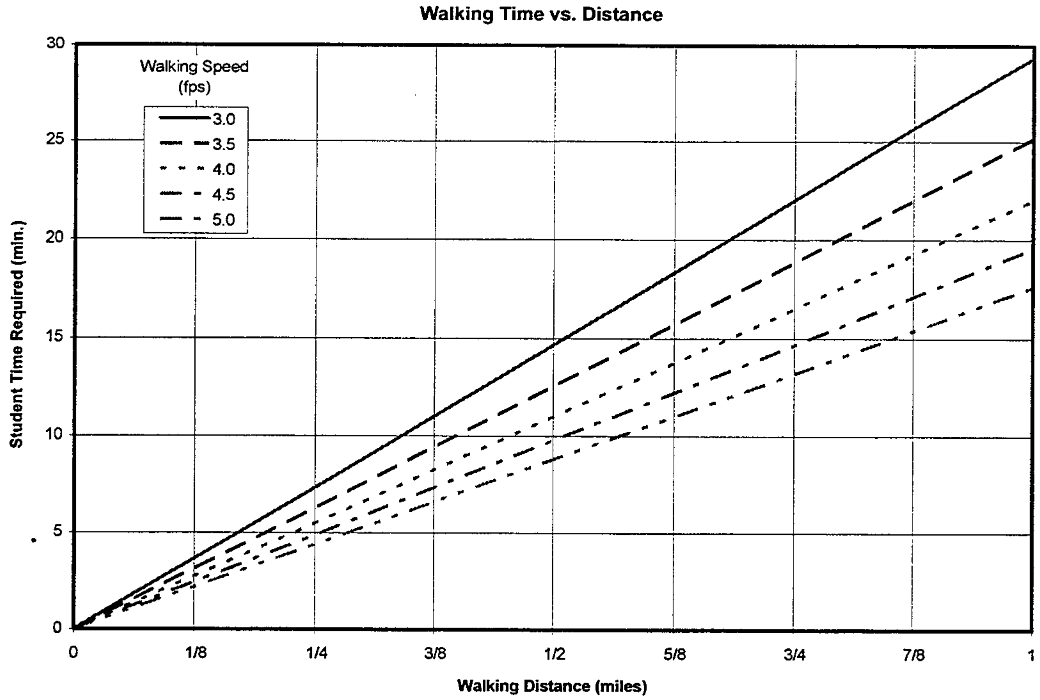

Figure 2. Student Time Required vs. Walking Distance

The walking time, however, does not necessarily represent the amount of notification time required by the student. It is also necessary to account for the time the student needs to prepare to leave the house, for such things as putting on a jacket or locking the house. One minute was allocated for these activities in the following calculation:

$$T_a = 1.0 \text{ min} + \frac{D}{v_w} \tag{1}$$

$$T_a = T_{go} + T_{walk} \tag{2}$$

where:

T_a = total time for student to reach bus stop (min.);

T_{go} = pre-departure preparation time (1 min.);

T_{walk} = student walking time required (min.);

D = distance from student's home to bus stop (feet); and

v_w = student's average walking speed (fps).

Figure 3 illustrates the relationship between the distance from the student's home to the bus stop and the amount of advance notification time required, including one minute of preparation time. Note that a five-minute advance notification time will include most students residing up to 1/4 mile from the bus stop, if they hurry.

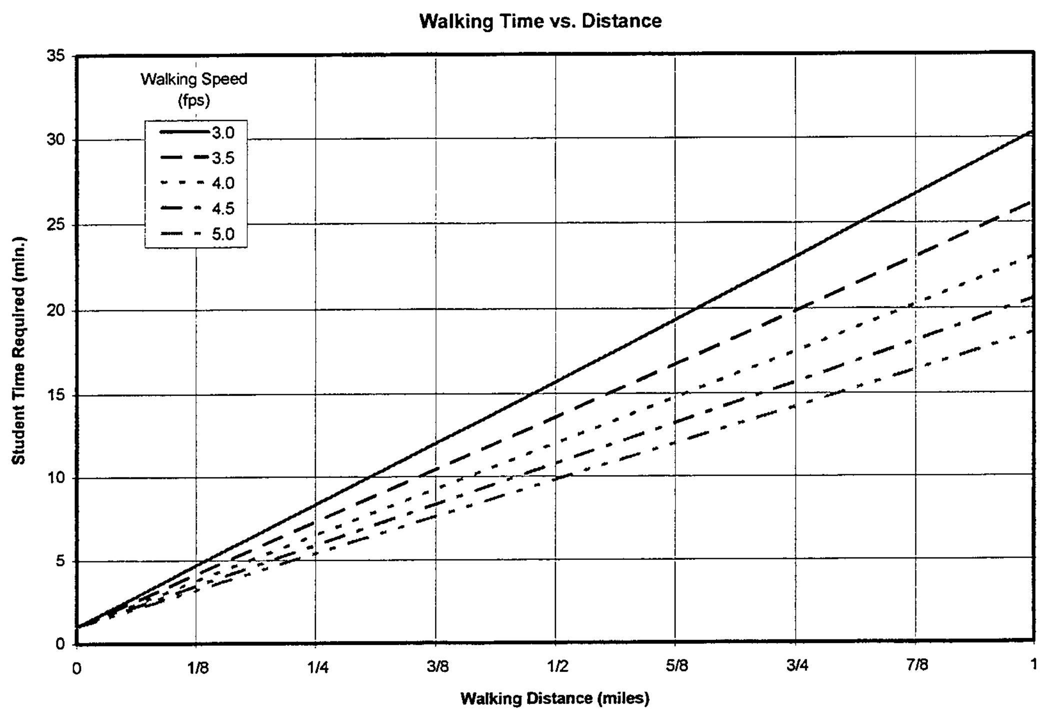

Figure 3. Student Time Required (with 1 minute) vs. Walking Distance

School Bus Arrival Time

It is also important to understand the factors impacting the travel time of the school bus from the notification point to the bus stop. There are a number of factors which reduce the average operating speed of the bus from its typical running speed, but delay caused by bus stops is the primary factor considered in this research. This is controlled by the acceleration and deceleration rates of the school bus, the lost time between the bus coming to a halt and the first student boarding, and the time required for the students to board. The figures below illustrate the average operating speed of the bus as related to the dwell time (lost time plus boarding time) and spacing between stops. Figure 4 assumes a typical running speed of 25 mph, reflecting urban conditions, while Figure 5 assumes a running speed of 45 mph, reflecting rural conditions.

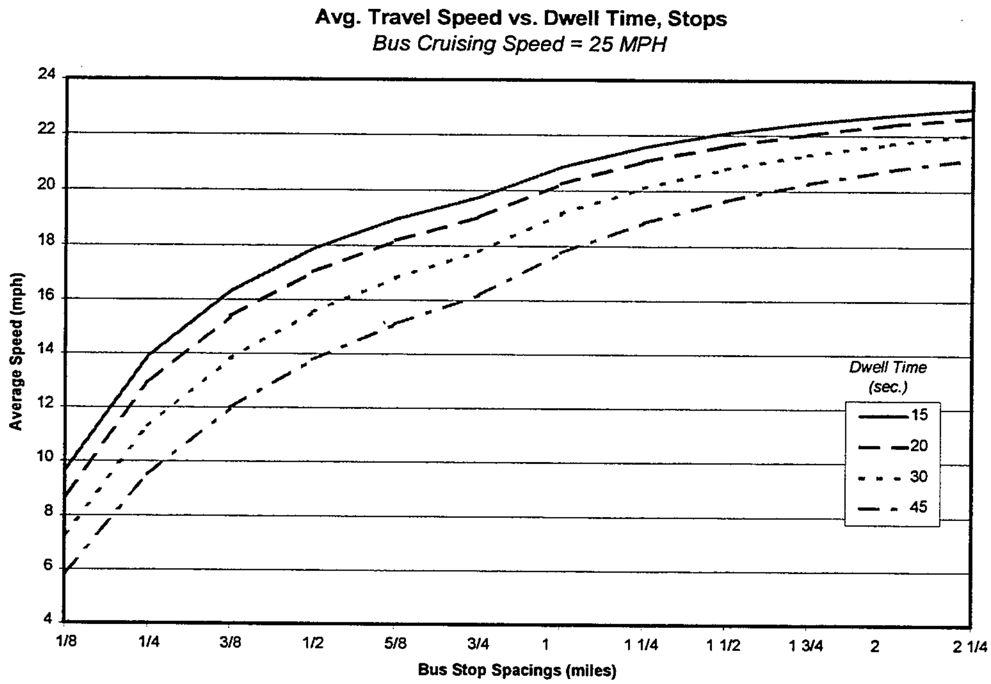

Figure 4. Bus Operating Speeds (Running Speed = 25 mph)

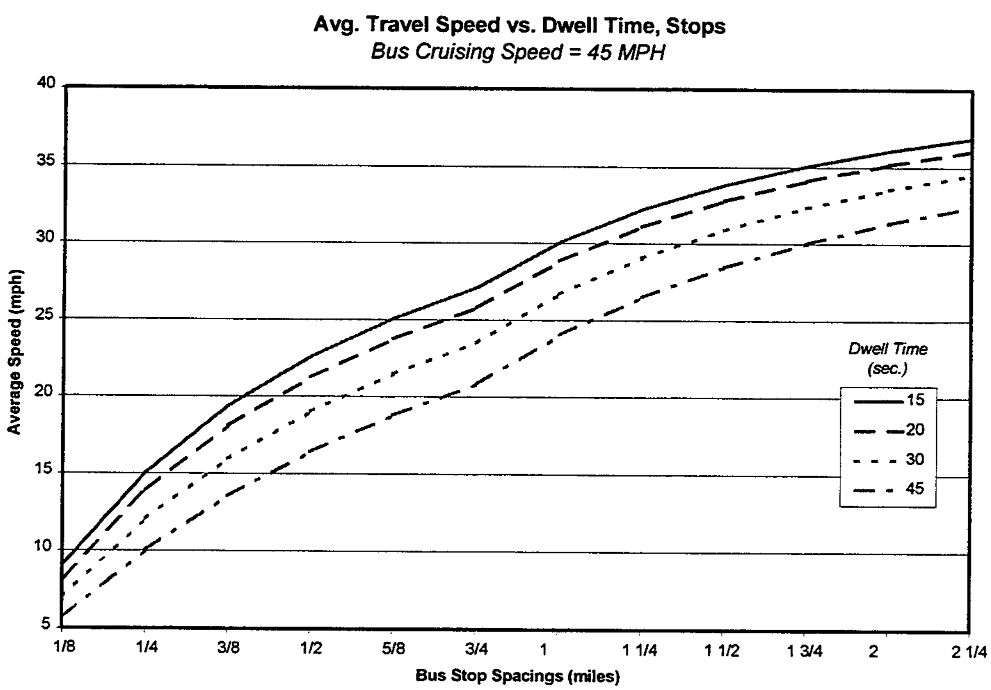

Figure 5. Bus Operating Speeds (Running Speed = 45 mph)

The values for dwell time shown on the above plots are determined as follows:

$$t_{dwell} = t_{door} + \frac{P_b}{8} + 2\,n_s \tag{3}$$

where:

t_{dwell} = total dwell time (sec.);

t_{door} = time from bus coming to stop until first student is at open door (sec.);

P_b = capacity of bus (persons); and

n_s = average number of students per stop (persons).

A default value of four seconds was assumed for the lost time between the bus coming to a stop and the boarding of the first student (t_{door}). This allows for the student to approach the bus and for the door to be opened. The term $P_b/8$ is derived in the following manner:

- It is assumed that a typical seating arrangement allows for two students per bench seat, with two bench seats forming a row. Therefore, there are four students per row. Consequently, the number of rows on the bus equals $P_b/4$.

- On average, each student will move past half of the rows on the bus before choosing an available seat.

- It is assumed that it takes the student one second to pass each row. Therefore, it takes the student $P_b/8$ seconds on the average to find a seat.

- It was also assumed that each student requires approximately two seconds to board the bus and move from the door to the first row.

The average travel speed of the bus is then found using the following formula:

$$v_a = \frac{x}{t_d + \frac{v_c}{a_d} + \frac{v_c}{a_a} + \frac{x - \frac{a_a}{2}\left(\frac{v_c^2}{a_a^2}\right) - \frac{a_d}{2}\left(\frac{v_c^2}{a_d^2}\right)}{v_c}} \quad \textbf{(4)}$$

where:

x = bus stop spacing (feet);

t_d = average dwell time (sec.);

v_c = average bus cruising speed (fps);

a_a = bus acceleration rate (fps^2); and

a_d = bus deceleration rate (fps^2).

This formula calculates the average school bus operating speed over the portion of the route which contains bus stops. It is important to remember that this is only an average operating speed, and that the running speed at any given time may be much higher.

Combining the student and bus travel aspects of the issue presented above, relationships were developed to model the direct transmission distance which would be required in order to provide various amounts of notification time to the student's home, assuming direct transmission from the school bus to a receiver in the home. This also assumes that the student walks from home to the bus stop at a right angle to the bus route, and that the broadcast distance is the hypotenuse of the right triangle, as shown previously in Figure 1. Figure 6 shows a graphical representation of this model for various average bus operating speeds.

Integrating this with a determination of the amount of time required for a student to get to the bus stop following notification, a model representing the excess notification time was developed. Excess notification time refers to the extra time available to a student after notification, getting ready (allotting one minute), and walking to the stop. Clearly, if this excess notification time is a positive number, then the student arrives at the stop before the school bus, and the bus is not delayed. A negative number would mean that the bus arrives before the student, which would delay the bus or may result in the bus leaving without the student. It is desirable for the student to arrive before the bus, but only by a small amount, so as to minimize student waiting time, which is the goal of this project.

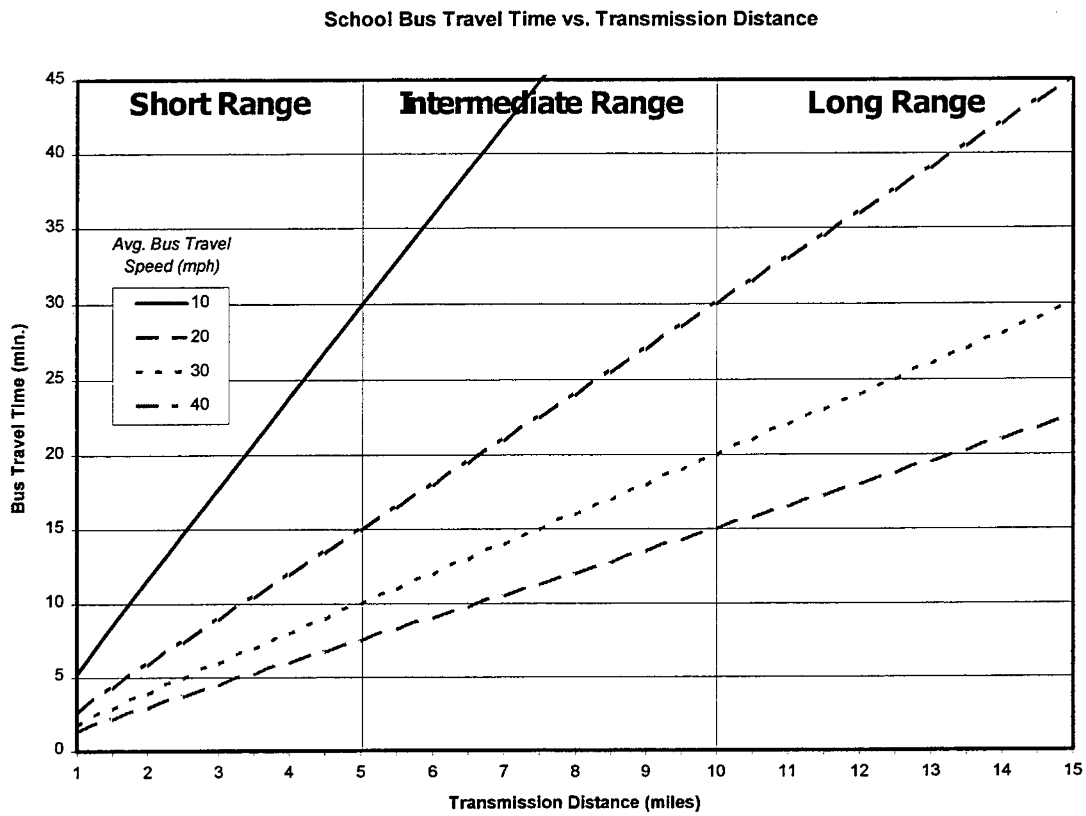

Figure 6. School Bus Travel Time vs. Transmission Distance

A typical children's walking speed of 3.5 feet per second was assumed, and one minute was allowed for the student to get ready following notification but before beginning the walk to the bus stop. Figures 7, 8, and 9 present the results of this model of excess notification time for student walking distances of 1/8, 1/4, and 1/2 mile, respectively.

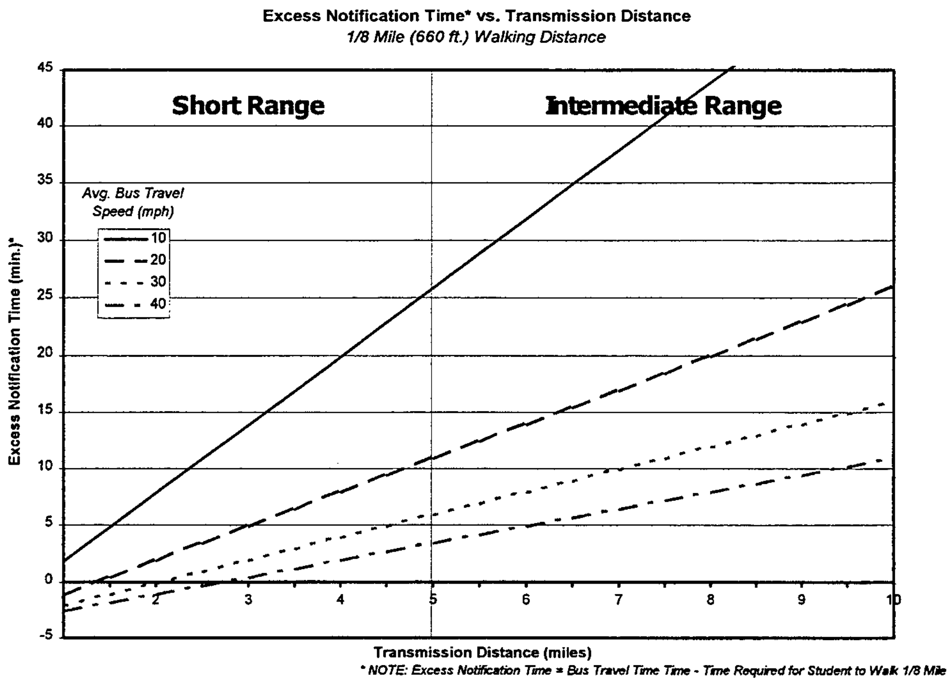

Figure 7. Excess Notification Time vs. Transmission Distance (1/8 Mile Walking Distance)

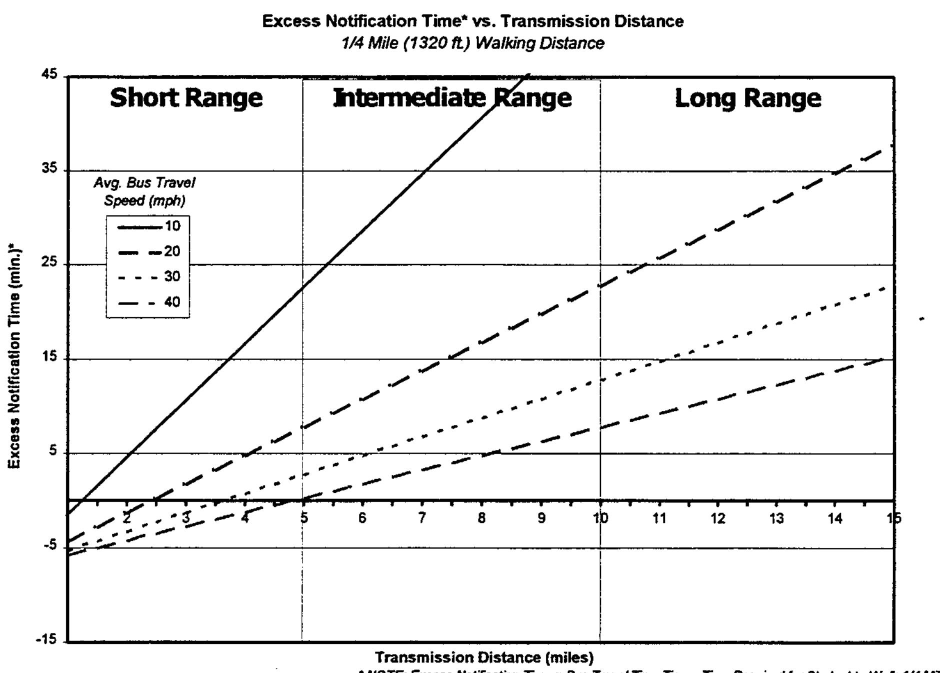

Figure 8. Excess Notification Time vs. Transmission Distance (1/4 Mile Walking Distance)

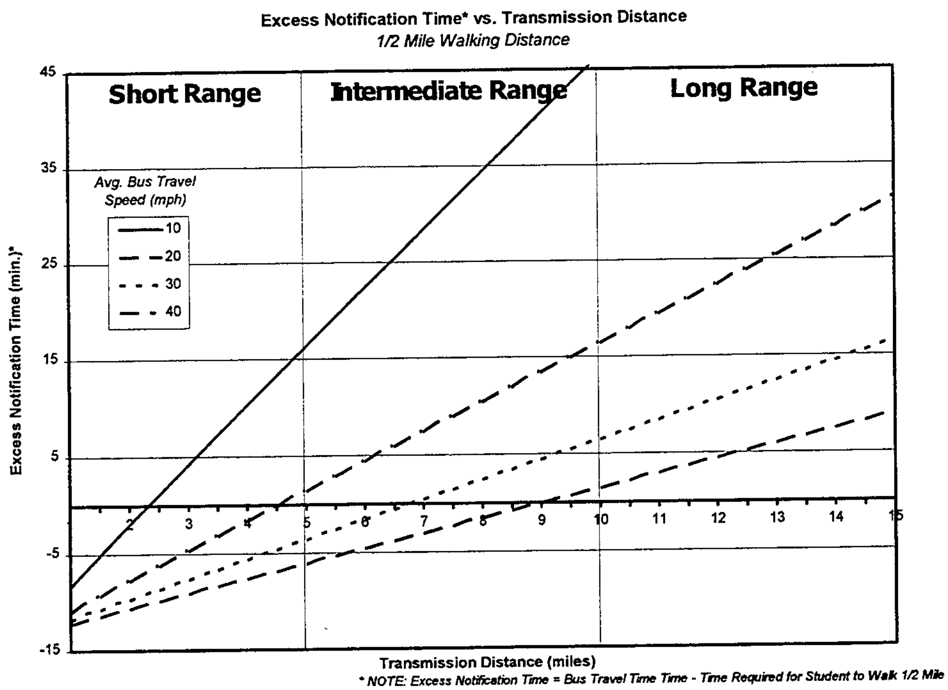

Figure 9. Excess Notification Time vs. Transmission Distance (1/2 Mile Walking Distance)

Discussion

The previous discussion of student walk time to the bus stop shows that, for the widest range of reasonable walking distances (1/8 to 1/2 mile) and walking speeds (3.0 to 5.0 fps), between five and ten minutes of advance notification time would be required for the student to reach the bus stop just before the school bus. Furthermore, the discussion of school bus travel time showed that the required transmission distance, for a range of reasonable average bus travel speeds (10 to 40 mph), varied widely from one to seven miles. It is clear that the significant variability in both student and school bus travel times, when considered cumulatively, produces a highly uncertain situation for an operator attempting to coordinate both arrivals at a multitude of fixed point bus stops.

Although the factors which affect the travel speed of the bus are random in nature and might vary from one bus stop to another from one day to another, the variability in student travel time is not as great at any given bus stop from day to day. For example, although the distance the student must walk to the bus stop may vary from one student to the next (1/8, 1/4, 1/2 mile, etc.), the distance remains the same for that particular student from day to day. Similarly, although a student's walking speed may vary greatly from person to person (3.0 to 5.0 fps), the range of variation is narrower for any given individual. Other factors such as weather, mood, and the sense of urgency ("Am I late for the bus?") can affect an individual's walking speed, but, generally speaking, the same people are consistently associated with the same bus stops, the same required walking distances and roughly the same walking speeds, and so may have similar travel times to the bus stop from day to day.

CHAPTER 4
COMMUNICATIONS SYSTEM REQUIREMENTS

AVAILABLE OPTIONS

Several possibilities exist for the development of such an annunciation system, with numerous technology options available to support each possibility. The annunciation systems considered for this project can be defined in terms of two basic types of systems, distributed and centralized, each of which is described below in detail.

Distributed System

Under a distributed system, a short-range radio transmitter would be placed on the school bus, and a receiver would be placed with the student at home. The school bus would transmit a direct radio signal upon reaching predefined waypoints, which would be received by the student's receiver, signaling the student to go to the bus stop at the appropriate time.

It is also possible that a bus might transmit estimates of the time remaining until its arrival at the bus stop, either continuously or periodically. Combined with a portable receiver, this would allow a student to know the status of the bus while walking to or waiting at the bus stop.

A major problem area with a distributed system is the transmission range of the low power transmitter carried aboard the school bus. The reliable transmission range may vary significantly with terrain, weather conditions, vegetation level, etc. It is important to remember that, as a moving transmitter, the bus will travel through a variety of terrain, even within a localized area.

Centralized System

Under a centralized system, an Automatic Vehicle Location (AVL) system would be utilized to track the location of the school bus in real time, with this information being returned to a central processing facility. Students would then be contacted at the appropriate time from the central location by one of several available communications methods.

Although transmission range from the bus to the student's home is not an issue in a centralized system, some of the same factors do affect the reliability of radio communications between the school bus and the central processing facility, which is an equally vital communications link. All of the same issues which hinder the accurate determination of the time at which to send an arrival announcement also apply in this case as well.

BUS TRACKING

Regardless of the system used for communicating the bus arrival announcement to the student at home, it appears necessary to accurately track the location of the school bus in order to determine the appropriate time at which to notify the student. There is a vast array of technologies available to accomplish this task, of which several technologies are described below.

One possible method of vehicle tracking is the use of dead reckoning which utilizes an electronic odometer to track bus progress along a predefined route. This requires a computer onboard the school bus to process the distance traveled information for conversion to location on the route, and to initiate the communications system upon arrival at a waypoint. The accuracy of this type of location system is questionable if the vehicle's position is not periodically updated by reference against a fixed object of known location (ie. - roadside beacon).

Another method which has come into common use in many urban areas is the use of signpost radio systems. A radio transmitter or receiver is attached to a fixed object, such as a signpost, utility pole, or other structure, and the bus to be tracked is outfitted with the complementary unit. These short-range radio frequency devices then communicate only when the vehicle is in close proximity to the mounted unit, allowing operators to know when a vehicle passes a known point. A similar technology is frequently applied to electronic toll collection and has also been used successfully to monitor traffic flow characteristics.

It is also possible to combine dead reckoning with signpost radio in order to "fill in the gaps" between radio equipped locations. This improves the accuracy of the system to a level greater than would be possible with either system operating independently, and provides a method of checks and balances.

The primary method for vehicle location and tracking today, however, is the global positioning system (GPS). This system makes use of a constellation of satellites to determine the location of a special receiver to within a few hundred feet almost anywhere in the world. Since this satellite system is funded by the United States government for defense purposes, use of the system is available to the civilian community, with limited accuracy, at no charge. There is a wide range of GPS receivers available, spanning a broad spectrum in terms of features, accuracy, and cost. Several classes of equipment along this spectrum hold promise for application to this research.

One possible configuration, which would allow for onboard data processing, is to connect a GPS receiver to a portable computer. Specialized software is available for both handheld personal computers (HPCs) and notebook computers in order to facilitate this link. In this case, all information is collected and utilized onboard the vehicle, and announcements are broadcast from a mobile transmitter.

At the higher end of the spectrum, in terms of both cost and features provided, is the option of installing a GPS receiver onboard the school bus and returning the position information to a central processing station via radio or satellite communications. Position information would be returned at periodic intervals by means of two-way packet data radio or cellular digital packet data (CDPD), both of which rely on networks established by commercial telecommunications service providers.

This GPS location tracking method, generally known as automatic vehicle location (AVL), is presently in widespread use by many transit agencies, delivery and trucking companies, and emergency service providers, although it is more prevalent in urban areas, due to the limited service coverage for the required communications services in rural areas.

Regardless of the tracking method used, a map-matching algorithm would need to be included in order to improve the accuracy and reliability of the bus tracking process. Map-matching combines data describing the current position of the bus with a description of the known routes or possible road network to more precisely describe the position of the bus. These algorithms make the assumption that the bus must be traveling on the pre-defined network, thereby limiting the possible position to a strictly defined service area.

COMMUNICATIONS WITH THE STUDENT

Distributed System

In a distributed system, as stated above, a transmitter on the school bus communicates directly with a receiver in the possession of the student at home. This system minimizes the costs of communications provided by private service providers, since it is not necessary for the bus to communicate its location, or any other data, over long distances to a central processing facility on a regular basis. Instead, a short-range transmitter conveys only the minimum necessary information to the student's receiver. However, the cost of providing and maintaining numerous receivers, one for every student served, plus spares and surplus units, is an important cost consideration.

There are numerous possibilities for how the distribution of the receivers may be handled, including requiring interested students to purchase, lease or rent the units. Receivers could also be provided free of charge to students meeting specific needs criteria, with costs paid by the school district. The receiver unit may be left in the student's home, or carried to the bus. The latter option would be particularly desirable if the unit is capable of receiving continuously updated reports from the transmitter. These are primarily administrative and economic issues to be determined on an individual basis by the school districts.

There are numerous range and reliability concerns associated with all forms of wireless communication, and with this form of short-range radio in particular. Another advantage of these portable devices which is worth noting is the lack of requirement for licensing by the Federal Communications Commission (FCC).

Centralized System

In a centralized system, information describing the bus' position would be returned to a central facility for processing and distribution. It is analytically possible to "backtrack" along the bus route the appropriate distance (or vehicle travel time) to determine the notification point for each individual student. Once this notification point is known, there is a wide array of communications options available to the central facility, since this facility is fixed and is not constrained solely to short-range wireless technologies.

The option which does not require any special equipment at the student's home is standard telephone notification. At the appropriate time, a computer would automatically call the student's home phone and play a recorded message. Unless a distinctive ring or call were employed, this method would require someone to answer the phone at the student's home, which parents may be reluctant to allow in cases where the child is home alone. Distinctive ring is a commonly available add-on service from most local telephone companies.

Wireless communication is still a viable option, even for a centralized annunciation system. The most reasonable wireless communication for this application is in the form of pagers, with service provided by commercial paging service providers. These organizations are equipped to provide short text messages at relatively low cost, using equipment which is widely available on the open market in most areas of the country. Additionally, this option does not require any special equipment on the part of the school district at its central processing facility, since pagers can be activated by means of a normal telephone call. Again, a properly equipped computer could be programmed to automatically notify students at the appropriate times.

Specific features of wired and wireless communications technologies are discussed in the following chapter.

CHAPTER 5
RELEVANT TECHNOLOGIES

FEATURES OF VARIOUS POTENTIAL TECHNOLOGIES

There are a wide variety of possible technologies that can be applied to each of the major facets of this research. The following section addresses some features of each of the key technologies considered. Table 1 describes the features which correspond to each selected technology.

Table 1. Functions / Features of Applicable Technologies

	Applicable Technology														
Functions / Features	Odometer / Dead-reckoning	Signpost Radio	Global Positioning System (GPS)	Radio Triangulation	Radio Network (Private)	Mobile Packet Data Radio (Commercial)	Cellular Digital Packet Data (Commercia	Cellular Telephone (Commercial)	Custom Radio Receiver	Radio Data System Receiver Only	Radio Data System-Equipped Radio	Pager (Commercial)	Telephone Voice Message	Voice Mail Information Posting	Internet (WWW) Information Posting
Vehicle location															
continuous update	X		X	X											
periodic update		X													
off-route tracking			X	X											
Communications with center															
voice															
two-way															
emergency					X	X	X	X							
continuous					X										
periodic					X	X	X	X							
data															
one-way															
continuous					X	X	X								
periodic					X	X	X								
two-way															
continuous					X	X	X								
periodic					X	X	X								
Communications with student															
one-way															
continuous									X	X	X			X	X
periodic									X	X	X	X	X	X	X
two-way															
continuous									X						
periodic									X				X	X	
portable															
home-based									X	X	X	X			
transportable									X	X	X	X			
landline													X	X	X

Bus Location

Odometer / Dead-reckoning

This system allows for continuous tracking of vehicle location with limited accuracy. No external infrastructure is required, and software allows for relatively easy route modifications. Vehicles may be tracked only along the predefined route as map-matching algorithms are needed to identify the bus location.

Signpost Radio Beacons

This system features improved accuracy over pure dead-reckoning, but with the requirement for equipment placement at regular intervals along each route. This creates high capital costs, maintenance requirements and limits route flexibility, while providing only periodic exact vehicle position updates. Vehicles cannot be tracked when off the predefined routes.

Radio Triangulation

This system allows for continuous vehicle tracking over a limited service area using a system of strategically placed radio towers. Although a high degree of accuracy can be achieved, the limited range and high susceptibility to electromagnetic interference are serious drawbacks. Vehicles may be tracked on or off route within the limited coverage area.

Global Positioning System (GPS)

This system also allows for continuous tracking of vehicle location with a high degree of accuracy and minimal equipment. No external infrastructure is required, as the satellite system is maintained by the U.S. government. Software allows for flexible routes, and vehicles can be tracked on or off route without regard for service areas.

Communications with Central Facility

Radio Network (Private)

This type of system allows for two-way voice and data communications. The high setup and maintenance costs, as well as limited range, are notable drawbacks, although the operator has complete control over the system. Note that many school districts already maintain a two-way voice radio system.

Cellular Telephone (Commercial)

This system allows for periodic or emergency communications between vehicles and the center. Since it uses existing commercial infrastructure, setup and maintenance costs of cellular are minimal and are shared with many other users. The high cost per use, however, prohibits regular use of this service for the operation of large fleets.

Mobile Packet Data Radio (Commercial)

This system allows for continuous two-way data communications using infrastructure operated and maintained by a commercial service provider. Use of a commercial provider allows the high costs of the infrastructure to be shared by many users, as with cellular. Data is transmitted in small packets or bursts to allow for efficient use of periods of inactivity on the network.

Cellular Digital Packet Data (Commercial)

As with mobile packet data radio, CDPD allows for continuous two-way data communications. CDPD makes use of normally unused cellular air time to transmit packets of data, allowing for lower costs than traditional cellular voice communication. Note that CDPD requires specialized equipment at the cellular provider's site, and so the coverage area is a limited subset of the conventional cellular telephone service area.

Communications with Student (from Central Location)

Custom Radio Receiver

Development of a custom receiver allows the most desirable options and features to be incorporated into the communications system. The receiver can receive continuous or periodic transmissions, and could, at significantly higher cost, allow for two-way communications. This would allow the student to respond to the transmissions from the bus, informing the bus driver of the student's status (en route, not coming today, etc.)

Radio Data System (RDS)

This newly emerging technology makes use of available radio spectrum on the FM subcarrier in order to transmit voice and data messages over short distances. Voice and text messages are recorded on a microchip, and so various messages could be stored and sent at the appropriate times. This system does not readily facilitate two-way communications and is limited in range.

Communications with Student (from Mobile Transmitter)

Pager (Commercial)

Pagers are widely available in most areas and are quite inexpensive. These units can provide periodic updates in the form of text messages displaying the expected time until arrival of the bus. Since they are rugged and lightweight, these units can also be carried by the student to the bus stop to provide continuous updates to the student after leaving home. Pagers can be automatically activated by a computer with automated telephone software operating at the central facility.

Telephone Voice Message

Similar to pagers, a computer can automatically call the student's home and play a recorded message. This does allow for very limited two-way communication, as the student can use the touch tone number pad to respond. This response information must then be conveyed from the central facility to the bus, which is the more challenging part of providing for two-way messaging.

Voice Mail Information Posting

A student can dial into a voice mail system and determine the location of his or her school bus at any given time. This eliminates the need for the student to answer the phone at home but requires considerably more initiative on the part of the student.

Internet Information Posting

As with the voice mail system above, the student must take action in order to determine when the bus will arrive. For those homes with computers, however, this would allow for graphical representation of the vehicle's location. Additionally, use of the Internet may be more interesting to the students than use of the voice mail system, potentially encouraging higher participation rates.

DESCRIPTION AND BENEFITS OF FEATURES

Bus Location

Continuous Position Update

Continuous updating of a vehicle's position along a route allows for more precise prediction of the estimated time of arrival at the bus stops. It also allows the notification to be transmitted at the moment the vehicle reaches the notification point, rather than awaiting the next update or extrapolating along the route.

Periodic Position Update

This allows vehicle position information to be transmitted with considerably reduced communications requirements. Since the vehicle's position is not known at all times, its location along a route can be extrapolated based on the last known travel speed and then updated when new data is received.

Off-Route Tracking

GPS and radio triangulation technologies allow vehicles to be tracked regardless of whether or not they are following an assigned route. This is useful if the vehicle must leave a route for short periods of time (driver breaks, construction detours, etc.), or in emergency situations. It also allows for easy reconfiguration of vehicle routes without the relocation of roadside equipment.

Communications with Center

Voice

Voice communications are best suited primarily for emergency communications. Under some circumstances, two-way voice communications would be useful for informing a bus driver, from a central facility, if a student will not be picked up that day. Voice communication must be used cautiously to avoid creating a distraction for the driver.

Data

One-way data communication (bus to center) allows transmission of vehicle position information without bus driver intervention. Two-way communication could return information regarding student status to the driver or be used periodically for polling purposes. The amount of data transmitted should be kept to a minimum to reduce communications requirements, and hence, costs, as well as to prevent driver distraction.

Communications with Student

One-way

One-way communications (bus or center to student) satisfies the primary annunciation objective of this project.

Two-way

Two-way communications would allow the student to respond to a bus arrival notification with his or her status. For example, the student could respond from a set of preprogrammed choices, including "On my way" and "Sick - Not coming today". This helps to ensure that a bus does not leave without a student that is en route and does not waste time waiting for a student that is not coming.

Portability

Although any device used by the student to receive bus arrival announcement must be relatively inexpensive, easy to use, and portable, there are varying degrees of each of these characteristics. If the device is lightweight and rugged enough, the student could carry it to the bus stop, receiving updates while walking. This would allow a student to gauge the urgency with which he or she should be traveling and would be reassuring if the student arrives at the stop before the bus.

CHAPTER 6
ANNUNCIATION SYSTEM DESIGNS

This section describes two system designs which address the issues described previously. The first section describes an existing system developed by a private sector company which was discovered during the research process, and the second section describes a system developed by a group of student designers in telecommunications at Texas A&M University.

BUSCALL® BY GLOBAL RESEARCH SYSTEMS, INC. [2]

Service Description

In order to address the issue of long and uncertain wait times for school children at bus stops facing inclement weather and unsafe conditions, Global Research Systems, Inc. (GRS) has developed BusCall®. This system uses the global positioning system (GPS) to track the location of each equipped school bus and relays schedule adherence data by cellular service provider to the offices of the vendor, which is intended to be the local telephone service provider. The telephone company uses an advanced messaging system developed by GRS to notify the student at home of the expected arrival time of the bus. A wide variety of notification techniques and service configurations can be provided by this system.

Key Features

The BusCall® system incorporates several key features in the provision of this notification service, which are described below. Each school bus is equipped with a BusCall® computer, which includes a GPS transponder and means to return the location data to a central office via Cellemetry® Data Service. Additionally, these in-vehicle computers can also be equipped with driver assistance buttons, allowing the transportation director to locate and track the buses in an emergency.

The location data determined using GPS is compared against a stored calibration run of the given route that the school bus is following. Information indicating when a bus is ahead or behind schedule is then communicated to the offices of the local telephone company, which offers the service to the public as an enhanced telephone service, similar to Caller ID or Call Waiting. When the bus reached a predetermined point, located a preset travel time before the bus stop, a notification is made. This preset travel time is generally set to five minutes, but it can be changed from four to more than ten minutes by a telephone call to the automated messaging system.

Notification can be made by any of several methods, or by combinations of methods, as requested by the customer. The primary means of notification is by telephone, with a distinctive ring being employed as an alarm. If this call is answered, a computer generated message states the time until bus arrival. The automated messaging system automatically redials up to three times if it receives a busy signal. This service would work in a similar manner for cellular telephones as well.

Pagers can also be used as either a primary or secondary means of notification. This eliminates any concern about a busy signal, but it does not guarantee that the message was received. E-mail can also be used, with the time until bus arrival being accompanied by a time stamp indicating when the message was sent. This is useful if the telephone line is busy due to an Internet connection, but again it does not guarantee prompt arrival of the message.

An additional feature notifies all students along the route that have yet to be picked up when the bus is more than 12 minutes behind schedule. This feature does not use the distinctive ring, in order to prevent confusion with the arrival notice for customers that choose not to answer the call. The anticipated market price for the service is $4-6 per month and would be included on a subscriber's local telephone bill. The school district would incur no cost.

Patents Pending

Global Research Systems, Inc., the developers of the BusCall® system, have registered several patents in the United States for components of this type of advance school bus notification system. Each patent is focused on a specific component of the advance notification system, including the user-definable notification time period, the vehicle progress report generator, and the passenger calling report generator.

It is important to note that, although global positioning systems are mentioned in the early patents as potential options, the systems described rely on switches actuated by the bus driver at each bus stop. The actuation of these switches is correlated with a clock, which was reset by the driver upon commencing the route. The route is driven once under normal conditions, with the driver actuating the switches at the appropriate times, and this data is recorded. During routine operation, the times of switch actuations are compared against the initial calibration run, and determination of schedule adherence is calculated as the relative difference between the runs. All storage and processing is handled by the on-board vehicle control unit (VCU).

Additional techniques are described to supplement the driver actuated switch, including a door sensor, swing-arm sensor, and odometer measurements. The BusCall® system has several advantages over the patented system, including the notably reduced need for driver action during operations. Additional components of the GPS-based system are currently in the patenting process.

Field Testing

This system underwent prototype field-testing phase in the Bemidji school district in northern Minnesota. During initial testing, the system was installed on seven school buses, and the notification service was offered, at no charge, to approximately 60 families. The system began operations on December 16, 1997, and the no-charge product-testing phase ended in April, 1998. Testing had originally been intended to continue throughout the academic year, ending in June, but was terminated early in order to begin refinement and development of production units.

Although there was little feedback from the trial subscribers, the testing was generally considered to be successful. Some minor problems were experienced with the prototype equipment installed on the buses. This was primarily found to be due to vibration and was expected to be resolved through a redesign of the equipment before production. Conceptually, the system was shown to effectively track the buses and notify riders with reasonable accuracy and reliability. Anecdotal evidence suggests that the arrival announcement was accurate to within 30 seconds, although no scientific study results were available at the time of this report.

The presence of a personal computer in the school transportation office which could track vehicles and their status was well-received by school officials. The lack of need for driver action was also noted as a benefit by the Bemidji school transportation director. Display screens in the buses were used to display schedule adherence information to the drivers, and, despite some minor visibility issues, this was also found to be a useful tool.

It is important to note that the system was tested for a relatively short period of time, and that the weather conditions in northern Minnesota were unseasonably mild throughout the winter 1997-98 testing period. Mild conditions reduce environmental stresses on the vehicle-mounted equipment, and likely reduce the occurrence and magnitude of delays in operations, making reasonable arrival time prediction less challenging.

Potential Issues

There are several areas of concern or potential weaknesses in the BusCall® system which need to be explored. First, with regard to wireless communications, not all rural areas have complete coverage, particularly in areas with dense vegetation and tree cover. In order to minimize the communications requirements, and the resulting costs, the BusCall® computer transmits its location to the central processing facility only when it is determined to be "off schedule". Consequently, the tolerance of the system to missed communications is a potential area for concern.

The system, as it is described, is dependent on the Cellemetry® Data Service to return location data from the bus to the office. This service, however, makes use of cellular maintenance channels, and has limited bandwidth. Although the amount of data to be transmitted can be kept to a minimum, the equipping of more buses in the fleet will add to the stress placed on this limited communications facility. Use of other higher bandwidth facilities, however, entails higher costs.

Also, in order for a customer to receive a notification, that household must have telephone service, or access to one of the other notification methods. In rural areas, the number of households without telephone service is not insignificant, and the likelihood of a household without telephone service having access to one of the secondary communications methods is remote.

No definite information is available, at present, to describe the accuracy of the arrival time predictions made by the BusCall® notification system. The forecasting of arrival times is based on a lifelong history of average travel times over segments of the route. The degree to which this method would be vulnerable to variations in bus travel speed or frequency of intermediate stops was not determined in the field-testing process.

The overall reliability of the BusCall® system, which is impacted by the factors described above, as well as many other issues, is of great interest. If any component in the system, from the GPS transponder to the customer's home telephone, should fail, the notification message will not get through as intended. If this happens with significant frequency, the customer will not be able to rely on the system, and its intended function will not be accomplished.

System Ownership [3]

As stated previously, the BusCall® system was developed by Global Research Systems, Inc., which is a privately-held company based in Rome, Georgia. GRS specializes in the development of proprietary advance notification systems for the telecommunications industry, among others, as well as Interactive Voice Response systems for schools. During the course of this research effort, GRS formed a 50%/50% joint-venture with LaBarge, Inc., a publicly-traded company (LB-AMEX) based in St. Louis, Missouri. LaBarge designs and manufactures electronic systems for specialized applications in a wide variety of industries, including the telecommunications, aerospace, defense, and medical fields. The resulting joint-venture operates under the name NotiCom, L.L.C., and is based in Destin, Florida. NotiCom also plans to expand the use of its advance notification system from school buses to other types of passenger vehicles, including vans and taxis.

TEXAS A&M UNIVERSITY EXAMPLE [4]

In order to gain the benefits of an outside perspective on this problem, Dr. Pierre Catala, Telecommunications Course Leader for the Department of Engineering Technology at Texas A&M University, was approached for guidance. After some initial consultation, this school bus notification problem was tackled by a group of three seniors in the Telecommunications Program as a final design project. The following section summarizes the final report and recommendations submitted by the design team. The design team was not informed of the existence of the GRS prototype system in order to prevent potential bias, although it was uncovered during their research.

Design Process

The student design team conducted an extensive review of the features and functions of various applicable communications technologies. A comparison of these technologies is presented in Table 2. The system recommended for this application was chosen based on the features and functions of the various technologies explored by the design team.

Table 2. Comparison of Applicable Communications Technologies

	CDPD	Family Radio	SRBR	Trunked Radio	VTU	Ricochet	GSM	Digistar	Mobile Satellite
Technology	Cellular	RF	RF	RF	Satellite	RF	Cellular	RF	Satellite
Frequencies	800-900 MHz	462, 467 MHz	49, 461 MHz	Multiple	N/A	Cellular	Cellular	N/A	137-150 MHz
Channels		14	N/A	Many	N/A	N/A	N/A		N/A
License		N	Y	Y	N/A	Y	Y		N
Software Available	N	N	N	N	Y	Y	N/A	Y	Y
Xmit Range	Coverage Based	1 mi.	400 m	Approx. 2 mi.	Radio Based	Unlimited	N/A	N/A	1/3 Earth
Available Adapters	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lowest Xmit Rate	2400	N/A	N/A	300	1200	9600	N/A	N/A	2400 up
Highest Xmit Rate	19,200	N/A	N/A	2400	9600	28800	N/A	N/A	4800 down
Global Positioning	(Y)	N/A	N/A	N	Y	N	N	Y	Y
Data Transmission	Y	N/A	Y	Y	Y	Y	Y	N/A	Y
Analog Transmission	N	Y	Y	Y	Y	N	Y	Y	Y
Multiple Users	Y	Y	Y	Y	Y	Y	Y	Y	Y
Total Users	Large	Large	License	Large	Large	Large	Large	Large	Large
Centralized System	Y	Y	Y	Y	Y	Y	Y	Y	Y
Dispersed System	Y	Y	N	N	N/A	N	N	N/A	N

System Design

Following the technology review and research efforts, a centralized, or indirect, design was proposed. The recommended design consists of three primary components, including the automatic vehicle locator (AVL), the base station, and the auto-dialer. As shown in Figure 10, the bus uses the global positioning system (GPS) to find its location, and transmits this information by radio to the base station. The base station uses a standard telephone connection, or Public Switched Telephone Network (PSTN), to contact the student's home. This system mirrors the BusCall® system described previously in terms of capabilities and overall design, but, as described below, is an assembly of off-the-shelf, commercially available components. Figure 11 depicts the system components.

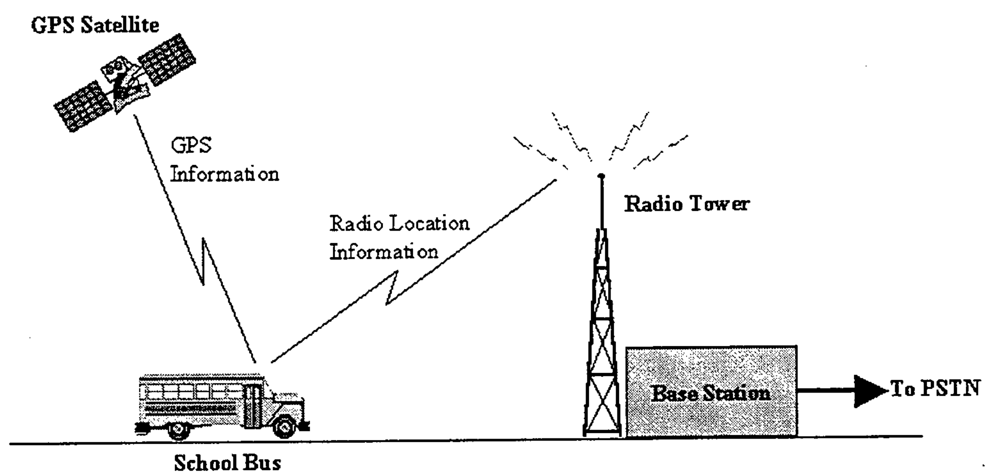

Figure 10. Example School Bus Annunciation System Design

Several Automatic Vehicle Location (AVL) systems using the global positioning system were studied as possible choices to track the positions of the buses. The fundamentals of GPS were described previously. The primary features of each system are outlined in Table 3.

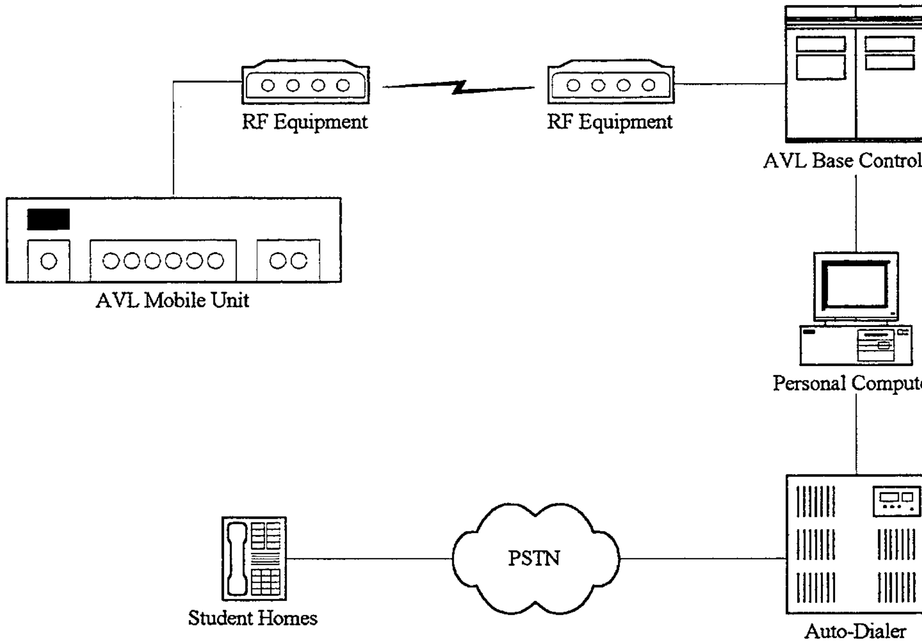

Figure 11. Detailed System Diagram

Table 3. Automatic Vehicle Location Systems Comparison

Product **Company** **Features**	**AutoTracker** PacComm	**SkyTracker** NSR	**RMI** Datalink Int.	**SkyMark II** Cimarron Technologies
Mobiles	Y	Y	Y	Y
Base	N/A	Y	Y	Y
2-Way	Y	Y	N	Y
CDPD	N	Y	Y	Y
GPS	Y	Y	Y	Y
Software Incl.	Y	Y	Y	Y
RS-232 Interface	Y	Y	Y	Y
PC Architecture	IBM	IBM, UNIX, PDA	IBM	IBM
Zone Setup	N/A	Y	N/A	Y
Mobile Price	$995-$1,195	$1,095	$1,299	$1,100
Base Price	N/A	N/A	$3,680	$11,000
Software Price	$995	N/A	Included	Included

The Skymark II system from Cimarron Technologies in Escondido, California was chosen as the most appropriate for this particular application based on price and features. The Skymark II is a complete system, including mobile units, base units, modems, and management software.

The selected system utilizes a packet modem to transfer data between the mobile unit and the base station. This modem can interface with the existing two-way voice radio system already in place on many school buses. It makes use of normally unused time between voice communications to transmit brief packets or bursts of data, and so it does not interfere with the normal operation of the voice system. The system will also allow for the use of cellular digital packet data (CDPD) communications in an upcoming version.

Packet data transmitted from the mobile units is received over the two-way base radio and passed to a radio frequency (RF) channel controller. This component, a part of the recommended Skymark system, is only active when the push-to-talk (PTT) button on a voice radio is not depressed, and so it does not interfere with other communications. The RF channel controller's function is to decode the RF signal and transform the data into ASCII strings for later processing. The data received typically includes a unit identification code, GPS-determined latitude and longitude coordinates, vehicle speed, direction of travel, and a message type. The RF channel controller then sends the decoded data via an RS-232 serial connection to a personal computer (PC). Figure 12 provides a representation of this process.

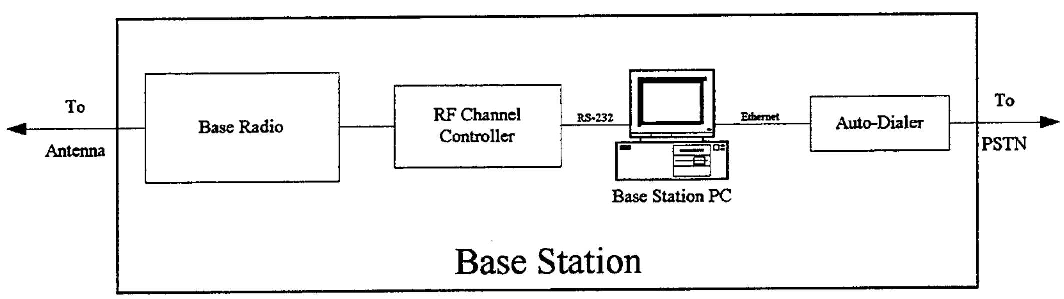

Figure 12. Example Base Station Configuration

The RF channel controller also processes instructions from the base station PC and codes the data for RF transmission over the voice system to the mobile units. Such instructions may include polling instructions or special messages, such as weather or route advisories. If the voice radio (on the school bus) is in use, the transmissions are queued and transmitted at the first available period of inactivity.

The base station PC requirements are quite modest given the current rate of computer technology advancement. To support the communications system and fleet management software, a Pentium 133 with at least 16 megabytes of memory (RAM) was recommended.

The fleet management software included in the Skymark package tracks each bus location relative to its route and initiates the telephone calling process at the appropriate time. The software polls each registered AVL unit and displays the vehicle's location on a map based on the telemetry data received in response. Each vehicle is represented by an icon and is accompanied by vehicle identification, speed, direction of travel, and status information. The software is Microsoft Windows® based and utilizes a user friendly graphical user interface (GUI).

This software determines when to place a notification telephone call by means of a series of user-defined "electronic fences". An electronic fence is a rectangular region surrounding an area on the map, and it exists only in the software. When a registered vehicle is inside one of its electronic fences, the appropriate alarm flag is set. This flag or trigger is the mechanism which will initiate the telephone call. Consequently, careful placement of the electronic fences across the route is critical.

At the present time, the software does not have the capability to initiate a telephone auto-dialer based on the alarm flag, although this should be a relatively simple enhancement. The software development team at Cimarron Technologies has agreed to assist with the addition of this improvement should the system be implemented. The enhanced software would be capable of retrieving a list of phone numbers associated with each electronic fence from a database of student information and of sending the appropriate telephone number and message type to the auto-dialer.

The final component of this system is the auto-dialer, which serves to relay the alarm code generated by the tracking software to the student at home in an inexpensive and widely accessible manner. The auto-dialer selected by the design team was the ASUDISYS by Galaxy, Inc. Many other auto-dialers also offer similar functionality, however.

The auto-dialer is connected to the base station computer by means of an Ethernet connection, allowing for reliable and high speed communication. This unit simply receives the telephone numbers and messages from the computer and makes the appropriate calls. The unit is capable of supporting up to 24 simultaneous phone lines and can store over one million telephone numbers and 1,000 unique digital messages. If a busy signal is received, the unit can call the other students associated with that electronic fence, if any, and then continue redialing the busy number.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This section describes the conclusions which were reached as an outcome of this research project, and the resulting recommendations which can be made.

CONCLUSIONS

School District Interest

The results of the survey of Texas school district officials showed a modest level of concern about the issue of school children waiting with uncertainty for their school bus to arrive. As explained previously, however, it is reasonable to believe that the need for an annunciation system to address these concerns could be greater than that reflected in the survey due to the inherent biases of the respondents. It was also concluded through this contact with school transportation officials that the return of real-time bus location information to the school district's transportation center was desirable, with nearly half of respondents expressing an interest in such information.

Consequently, there is sufficient interest and concern to warrant the development of a school bus annunciation and location system so that the capability would be available to those Texas school districts with the need and desire for one. It was also concluded that the inclusion of additional features, such as two-way communication, would be beneficial and would increase the desirability and cost efficiency of an annunciation system.

Transportation Issues

It was found in the course of this research that there are many factors which cause variation in the arrival time of the school bus at a bus stop, as well as many factors that cause variation in the student's travel time to the bus stop. The combination of these variables was found to lead to the potential for significant variation in the wait time of students at the school bus stop.

It was also found that the variation in student travel time to the bus stop was less significant for any given individual at their given bus stop, thereby reducing some of the uncertainty in the coordination process. Consequently, it can be concluded that a different amount of advance notification time is required for each given bus stop, and that, if chosen conservatively, such a time would serve the same stop with reasonable consistency over time. It was found to be less desirable to choose a single advance notification time to be applied on a system wide basis.

The use of stop-specific, individualized advance notification times can best be implemented by allowing the user (student or parents) to customize the amount of advance notification received, thereby allowing users to adjust according to their personal preferences and characteristics through a trial-and-error process. A reasonable default value can be implemented on a system wide basis as a starting point, but the ability to customize this initial value is critical. A reasonable value for the default notification time, as calculated in this research and explained previously, was found to be approximately five minutes. Note that the BusCall® system described in this report also uses five minutes as an example notification time, and also allows for individual users to customize the amount of notice given, within reasonable limits. The capability to customize advance notification time on a site-specific basis was judged to be critical to the practical implementation of an annunciation system.

RECOMMENDATIONS

System Design / Features

Given the rate of technology advancement and the continually decreasing costs of computer-based systems, there are many more technologies available to address the annunciation system demand that are suitable, cost-efficient, and promise to be accurate and reliable. However, given the specific demands of the school bus transportation system, and those characteristics which are unique to it, certain technologies are more applicable, and those are discussed below.

Overall, given the need for variable notification times, in combination with the varying distances of students from the bus route and the existence of non-linear bus routes, an indirect annunciation system is recommended. As described in this report, an indirect system requires the school bus to send its location or schedule adherence information to a central processing facility for distribution at the appropriate times to the appropriate students.

The recommended method of school bus tracking is the global positioning system (GPS). The relatively low initial investment and recurring maintenance costs, unlimited coverage area, high level of accuracy, and lack of subscriber or service charges make GPS the most suitable location technology for an increasing variety of applications today. This research highlights just one of many potential uses for GPS in the general area of vehicle tracking.

There is no single communications method or technology which can be recommended for application in all cases. Communications is heavily dependent on the available services in each individual school's area. However, for the most part, cellular technologies were found to hold the most promise for this type of application, and are recommended for serious consideration. Both the Cellemetry® Data Service and cellular digital packet data (CDPD) systems transmit data in short bursts using otherwise wasted bandwidth in the cellular telephone system. These systems also require specialized hardware to be provided by the cellular service provider, and so the choice between them is dependent on system availability in a particular locale.

The standard telephone network, supplemented by pagers, is the recommended means of disseminating bus arrival announcements to students at their homes. This method does not require any specialized equipment on the part of the customers, and it is known to be highly reliable and inexpensive. The added benefits gained by portable radio systems in terms of continually updated announcements do not warrant the expense of distributing them to a number of students at this time.

Financing is an issue which should initially be handled on a case-by-case basis. As described in this report, the majority of school districts do not believe that parents will pay a monthly fee for such an annunciation service, but a commercial enterprise is currently underway believing that the market does exist and that service can be provided at no cost to the schools. Since the commercial notification service has thus far been provided at no charge to consumers, due to the field-testing in Minnesota, it is unclear whether or not this marketing strategy is in fact viable. It might be possible for selected school districts to prove the fundamental concept in Texas through a cooperative funding arrangement, which could foreseeably involve the school district, service providers, and state or federal education funding sources. This would permit developers to establish some of the benefits to students and parents without the consumers being required to pay a service fee. Once the benefits are clearly established, fee-for-service systems could be implemented on a more widespread basis.

Further Study

The need and desire for such an annunciation system on the part of a reasonable percentage of Texas school districts warrants the system development, but further field testing is required. Production units of the BusCall® system are expected to be available by the winter of 1998-99, and so field testing by Texas school districts, in cooperation with local telephone service providers, is recommended. This research has also shown that an annunciation system can also be assembled using off-the-shelf components, but field testing is recommended in order to determine the accuracy, reliability, and durability of such a system, as compared to the commercially available counterpart.

Additionally, before and after wait time studies should be conducted in concert with any new system implementation in order to gauge whether or not the provision of arrival time information has actually altered the students' behavior, and whether this has resulted in reduced roadside wait times. This will allow other school districts to better evaluate the cost-effectiveness of any annunciation system under consideration.

REFERENCES

1. Messer, C.J. *Southwest Region University Transportation Center Project Proposal: Development of an Annunciation System for Rural School-Bus Operations*. Texas Transportation Institute, Texas A&M University, July 1997.
2. BusCall. <http://www.buscall.com> (Accessed February 6, 1998)
3. LaBarge, Inc. News Releases. <http://commerce.datamade.com/labarge/cgi-bin/3anews_releases.asp#title1> July 23, 1998. (Accessed October 1, 1998)
4. Kovar, B., R. Linnabery, and W. Smith. *Rural School Bus Notification System (RSBNS)*. Department of Engineering Technology, Texas A&M University, April 1998.

APPENDIX

TEXAS SCHOOL DISTRICT SURVEY

TEXAS TRANSPORTATION INSTITUTE

Transportation Systems Division
CE/TTI Building, Suite 304
Texas A&M University

Telephone (409) 845-9871
Fax (409) 845-6481

April 1, 1998

School Transportation Director
c/o FIELD(Full Name), Superintendent
FIELD(Address)
FIELD(City), FIELD(State) FIELD(Zip Code)

Dear School Transportation Director:

The economic strength of rural America requires dependable, high quality education for all school children. The provision of quality school bus transportation in all types of weather is a vital component of the education process.

POTENTIAL PROBLEM

During routine rural school bus operations, we are concerned that many rural school children may frequently walk long distances to their bus stop and then wait with great uncertainty for their school bus (yellow dog?) to arrive. The consequences of missing the school bus require that a student arrive early at the stop, but this early arrival often results in considerable wait times, especially when the bus is delayed. This waiting exposes these children to potential inclement weather conditions, roadside safety hazards, and other personal safety and security threats.

One envisioned solution to this potential problem requires the school bus to communicate, either directly or indirectly, its expected arrival time at the bus stop to the students waiting at home. This notice would provide enough advance warning time so that each student would reach the bus stop at approximately the same time as the bus. There are emerging technologies currently being researched by the Texas Transportation Institute which hold new promise for the establishment of such a system.

Texas Transportation Institute

The Texas Transportation Institute (TTI) is a part of the Texas A&M University System. The headquarters of TTI - a separate state agency - are located in College Station. TTI is the largest university-based transportation research organization in the United States.

School Survey

With regard to the transportation of school children specifically, TTI is presently conducting a study to assess the needs and wants of the school transportation community in several key areas. The primary focus of the attached survey is to determine the need for a school bus arrival announcement system.

We at TTI are interested in your opinions regarding the need for such a system, the features that you might want to see incorporated into such a system, as well as any additional features that you may suggest to be added in order to add value to the overall design.

Please complete the following survey and return it to us in the postage-paid envelope provided. Feel free to provide additional suggestions as desired. If you have any questions or concerns, please contact me by telephone (409) 845-9893, fax (409) 845-6481, or Internet e-mail `c-messer@tamu.edu`. We are very interested in receiving your input and thank you in advance for your timely response.

Regards,

Carroll J. Messer, Ph.D., P.E.
Senior Research Engineer

SCHOOL BUS SURVEY

1. How many school buses do you operate? How many routes could be considered "rural"?

____

____

2. Are your buses equipped with two-way communications?
If so, what type of system do you use and are most or all of your buses equipped?
Do you use the system for emergencies only, or as part of routine operations?

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3. Do you believe that the issue of young school children waiting at their bus stop is a significant issue facing rural areas of <u>your</u> school district? Why or why not?

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Two techniques could be used to provide a school bus arrival announcement system:

Direct System - A short-range radio transmitter would be placed on the school bus, and a receiver would be placed with the student at home. The school bus would transmit a direct radio signal upon reaching predefined waypoints, which would be received by the student's receiver, signaling the student to go to the bus stop at the appropriate time.

A bus might also transmit estimates of the time remaining until its arrival at the bus stop, either continuously or periodically. Combined with a portable receiver, this would allow a student to know the status of the bus while walking to or waiting at the bus stop.

Indirect System - An automatic vehicle location (AVL) system would be used to track the location of the school bus, with this information being returned to a central location. Students would then be automatically contacted at the appropriate time by one of several computer dialing methods.

Since an indirect system returns bus location information to a central location, it could also be made accessible to the transportation director for purposes of tracking bus schedule adherence, locating buses in an emergency, on school activities, etc.

4. Would you consider having school bus location information in real time at your office to be valuable data? Does your district already have this capability using another system? If so, please describe.

____

____

____

5. There are other features which a school bus notification system could include which might make it more desirable. Please rate each of the following on a scale of 1 (worst) to 5 (best), according to its potential usefulness to your operations and parents satisfaction.

	Unnecessary . . .				*Extremely Useful*
	1	*2*	*3*	*4*	*5*
Include Driver Assistance (Panic) Button	❑	❑	❑	❑	❑
Provide Two-Way Voice Communications	❑	❑	❑	❑	❑
Notify Driver When Students Are Not Coming (i.e., Sick, Driven by Parent, Etc.)	❑	❑	❑	❑	❑
Notify Parents of Expected Bus Return at Home or School (i.e., Activity Buses Returning Late)	❑	❑	❑	❑	❑

6. What additional features could be added to such a school bus notification system that would make it more valuable, either from your perspective or the parents?

____

____

7. Do you think that the parents living in rural areas of your district would be willing to pay a private company for such a notification service? What do you believe would be a reasonable monthly fee for such a service, given the demographics/income of the families served by your district?

____

____

8. Please provide your current contact information so that we may maintain accurate records.

Name: ____

Position: ____________________ School District: ____________________

Address: ____

Telephone: ____________________ Fax: ____________________

Texas School Bus Survey Results

Survey Number	Date Reply Received	School District Name	Region in Texas	No. of Buses Operated	No. of "Rural" Routes	Two-Way Communications?	Waiting - Significant Issue?	Valuable Information?	Driver Button	Two-Way Voice	Driver Notice	Parent Notice	Parents Willing to Pay?	Amount to Pay (Monthly)?
1	4/6/98	Navasota	SE	36	21	Partial - cellular	no	yes	1	5	1	4	no	10
2	4/6/98	Smithville	SE	21	16	All - cellular	yes	yes	5	5	4	4	few	
3	4/6/98	Luling	SE	4	4	Yes - cellular	no	maybe (cost?)	4	4	3	3	no	
4	4/7/98	Pittsburg	NE	22	22	Yes	no	yes	4	5	5	4	no	
5	4/7/98	Friona	PH	7	7	Partial - cellular	no	no	1	3	3	2	no	
6	4/7/98	Unknown		19	10	Yes - cellular	no	no	1	3	3	3	no	
7	4/8/98	Bastrop	SE	104	55	Yes - radio	yes	yes	4	3	5	5	maybe	10
8	4/8/98	Marlin	SE	25	7	Partial - radio/cell	no	yes	3	4	5	5	no	
9	4/8/98	Post	PH	7	6	No	no	no	3	3	4	4	unknown	
10	4/9/98	Littlefield	PH	17	6	No	no	yes	2	3	2	2	no	
11	4/9/98	Fredericksburg	CT	33	17	Yes - radio	no	yes	1	1	3	4	no	
12	4/13/98	Bonham	NE	17	17	No	no		1	3	3	1	no	
13	4/13/98	Cotulla	SC	36	13	All - cellular	no		1	1	5	5	no	
14	4/13/98	Seymour	NC	7	7	No	no	no	2	2	5	3	no	
15	4/13/98	Edna	SE	14	8	Yes - radio		yes	3	5	2	3	no	
16	4/13/98	Granbury	NC	96	72	Yes - radio	yes	yes	3	2	1	5	no	
17	4/13/98	Ballinger	CT	9	9	No	yes	yes	3	5	5	5	maybe	10-15
18	4/13/98	White Oak	NE	3		Yes - cellular	yes		1	1	1	3	no	
19	4/13/98	Frisco	NE	20	2	Yes - radio	no	no					no	
20	4/13/98	Carthage	NE	41	31	Yes - radio	no	no	1	5	5	5	no	
21	4/13/98	Unknown		17	14	No	no	no	4	4			no	
22	4/13/98	Columbus	SE	12	12	Yes - cellular	no	no	2	2	1	3	no	
23	4/13/98	Floydada	PH	9	9	No	no	no	1	3	2	2	no	
24	4/13/98	Diboll	SE	19	12	Yes - cellular	no	yes	3	1	3	4		
25	4/13/98	Boerne	SC	42	20	Yes - cellular	no	yes	3	5	3	3	no	
26	4/13/98	Yoakum	SE	28	9	Yes - cellular	no	no	2	1	1	2	no	
27	4/13/98	Lumberton	SE	35	22	Yes - cellular	yes	yes	3	3	1	4	no	
28	4/13/98	Eastland	NC	6	6	Yes	no	no	3	3	4	3	maybe	25
29	4/14/98	Harmony	NE	13	13	Yes - radio	no	yes	4	5	5	5	no	
30	4/14/98	Rusk	NE	25	18	Yes - radio	yes	no	5	5	3	3	no	10-15
31	4/14/98	Whitehouse	NE	30	26	Yes	no	no	5	5	5	1	no	
32	4/15/98	Crane	SW	7	4	Yes	no	yes	3	3	4	5	no	1-5
33	4/16/98	Muleshoe	PH	14	14	No	yes	yes	4	5	4	4	no	
34	4/16/98	Spearman	PH	10	5	No	yes	yes	4	5	5	5	maybe	
35	4/16/98	Gilmer	NE	30	27	Yes - cellular	no	no	5	3	4	4	no	
36	4/16/98	La Grange	SE	32	13	Yes - cellular	yes	yes	5	3	4	5	no	
37	4/22/98	Leander	CT	90	45	Yes - radio	no	no	2	5	4	3		
38	4/23/98	Giddings	SE	22	10	Yes - radio	no	no	3	5	3	3	no	
39	4/28/98	Seminole	PH	34	17	Yes - radio	no	no	3	4	4	5	no	
40	4/29/98	Whitesboro	NE	15	9	No	yes	yes	3	5	5	5	no	
41	5/1/98	Poteet	SC	8	8	Yes - cellular	no	no	1	5	1	1	no	
42	5/4/98	Slaton	PH	10	4	Yes - radio	no	no	4	4	4	4	no	
43														
44														
38.2%	RESPONSE RATE					YES	11	26.8%						
						NO	30	73.2%						