CENTER FOR URBAN TRANSPORTATION STUDIES

Evaluation of the Benefits of Automated Vehicle Location Systems in Small and Medium Sized Transit Agencies

---

Prepared By:
Zhong-Ren Peng
Edward A. Beimborn
Simi Octania
Richard J. Zygowicz

Center For Urban Transportation Studies
University of Wisconsin - Milwaukee
PO Box 784, Milwaukee, WI, 53201-0784
Phone 414.229.4978

http://www.uwm.edu/Dept/cuts

January, 1999

Sponsored by the Wisconsin Department of Transportation

Executive Summary

This study presents an analysis of the potential benefits and application of Automatic Vehicle Location Systems (AVL) in small and medium sized transit agencies. The study includes two major elements: a technology assessment of AVL and a transit agency/ transit user assessment. The technology assessment involved an investigation of the state of the art in AVL and a survey of AVL vendors. The users assessment included a survey of small to medium transit agencies that have implemented AVL to determine their experience with the technology and the benefits it has provided. In addition, a survey was conducted of transit users in a Wisconsin community to assess the level of importance that transit users place on features of transit service which AVL can affect. This information was used to identify the costs and benefits of AVL to the transit riders and service providers.

The study reached the following conclusions:

- Automatic Vehicle Locator technology has matured to the point where it can be implemented in a wide variety of agencies. There have been sufficient field applications of the technology to resolve technical features of AVL and make it a viable option for smaller transit agencies.

- Transit users place a high degree of importance on features that minimize waiting uncertainty and increase their feeling of security. Features that AVL may provide such as: vehicles operating on schedule, knowing when a bus will arrive if late, knowing another bus can be dispatched if there is a breakdown and knowing there is an emergency communications system were rated highly by transit users in the survey done as part of this study.

- The implementation of AVL technology involves significant human factors and management issues that should not be underestimated. AVL provides more control of vehicles and may change the way in which transit systems acquire and use information. Transit agencies considering the use of AVL need to examine their entire operating procedure to assure that the maximum potential of AVL is utilized.

- AVL systems for small transit agencies may potentially be shared with other government agencies. Cooperative arrangements with public works departments, law enforcement agencies and other transit agencies should be explored before an AVL system is implemented. AVL systems should be designed to be easily adaptable to other users.

- AVL systems potentially can have large benefits, which easily exceed the costs of the systems. These benefits largely occur to transit users through reductions in vehicle waiting time even if only by a small amount. Other effects such as increased sense of security and reduced response time for incidents cannot be easily quantified but

would add to the benefits of an AVL system. Such benefits, as user benefits, may not necessarily accrue directly to the transit agency nor be directly recoverable as revenue. In addition, AVL systems have the potential for better management information that can lead to more productive service and better planning for future needs.

- The potential benefits for paratransit service are also great. AVL has the potential to increase vehicle productivity by facilitating more trip combinations reducing waiting time and increasing vehicle productivity.

- The benefits of AVL systems are chiefly a direct function of annual system ridership while costs tend to vary only slightly with ridership. The benefits are also most likely to occur on systems that have problems maintaining schedules and service reliability.

- AVL systems should be implemented in a way to maximize their impact on passenger waiting times, since this is an area of high potential benefits. Mechanisms to increase awareness of vehicle arrival times should be actively explored to provide the best use of an AVL system

Based on our analysis of the nature of AVL systems and their potential benefits, the following recommendations are made:

- A demonstration project or projects of AVL should occur in Wisconsin. These projects ideally should include a demonstration of the potential for shared AVL systems with other government agencies such as public works departments, law enforcement agencies and other transit agencies.

- AVL system design and components must be consistent with the national and regional ITS architecture and established ITS standard to ensure the compatibility with other ITS systems and expandability to include other components in the future.

- Criteria for selection of a demonstration site should include: existence of a GIS system for the municipality, agreements between departments to share services, the existence of a coordination committee to assure compliance with national architecture standards, willingness to do a "before and after" study of the effectiveness of the system, potential for paratransit/regular transit AVL coordination, needs to replace existing communications system, and availability of radio channels for an AVL system.

- Demonstration projects should be accompanied with a rigorous evaluation that includes a before and after analysis of effects. Data should be collected on user wait times, on-time performance, incidents, management practices and system usage to assist in the evaluation of the demonstration.

- Transit systems equipped with AVL should make an effort to let passengers know about the system. These agencies should actively pursue systems that provide real time bus location and arrival information to users. Such services can lead to fuller realization of AVL benefits.

Key Words: Public Transportation, Automatic Vehicle Location System (AVL), Advanced Public Transportation System (APTS), Benefits Costs Analysis, Survey Research

Table of Contents

List of Figures

List of Tables

ACKNOWLEDGEMENTS

This report was done under the sponsorship of the Wisconsin Department of Transportation. We would like to express our appreciation to Hector Gonzalez, Dixon Nuber, Linda Lovejoy and the project advisory committee for their helpful input on the project. The research reported here is the product of independent university research and the opinions expressed are not necessarily those of the project sponsor.

Project Advisory Committee

Pat McGinty, Brown’s Cab Service, Fort Atkinson, WI
Doug Gerleman, Federal Transit Administration Region V, Chicago IL
Thad Kluck , Valley Transit, Appleton, WI
Keith Carlson, La Crosse Municipal Transit Utility, La Crosse, WI
Anthony Scherer , Manitowoc Transit System, Manitowoc, WI
Greg Seubert, Wausau Area Transit System Inc, Wausau, WI
Linda A Lovejoy, Wisconsin Department of Transportation, Bureau of Transit and Local Roads, Madison, WI
Dixon A Nuber, Wisconsin Department of Transportation, Bureau of Transit and Local Roads, Madison, WI
Hector J Gonzalez , Wisconsin Department of Transportation, Bureau of Transit and Local Roads, Madison, WI
Tom Frank, Systems and Program Engineer, Federal Highway Administration - Wisconsin District, Madison, WI
Joe McCarthy, Kenosha Department of Transportation, Kenosha, WI

Project Staff

Edward Beimborn, Principal Investigator
Zhong-Ren Peng, Co-Principal Investigator
Simi Octania, Project Assistant
Rick Zygowicz, Project Assistant

Chapter I

Automatic Vehicle Location Systems (AVL) for Public transit have become readily available in the last several years and have been utilized to track the locations of transit vehicles in real time. They have been promoted as being beneficial to the transit industry by offering transit agencies more flexibility in monitoring and managing their vehicles and by reducing customers' wait time and increasing riders' (perceived) security (Gomez, Zhao and Shen, 1998**.** These systems are being implemented primarily in large transit systems where the AVL can provide obvious efficiencies in managing a large fleet of vehicles (Casey, et al. 1996, 1998).

However, there is little prior work that specifically dealt with AVL applications in small and medium sized transit agencies, i.e., transit agencies with fleet size less than 50 vehicles. In addition, there has not been much formal research work with small systems in terms of how ITS and AVL could benefit them. It is generally felt that agencies with large fleets and employment can gain efficiencies that are large enough to justify the costs to implement the technology. However, the question still remains if AVL system can benefit small and medium size transit agencies as well?

This study specifically addresses the issue of the benefits of AVL applications in small and medium sized transit agencies. The study includes two major elements: a technology assessment of AVL and a transit agency/transit user assessment. The technology assessment involved an investigation of the state of the art in AVL and a survey of AVL vendors. Under the users assessment, small to medium transit agencies who have implemented AVL were contacted to determine their experience with AVL and the benefits it has provided. In addition, a survey was conducted of transit users in a Wisconsin community to assess the level of importance that transit users place on features of transit service which AVL can affect. This information was used to identify the costs and benefits of AVL to the transit riders and service providers. This information then provides a framework for conducting benefits costs analysis. The study concludes with suggestions for transit agencies that are considering the adoption of AVL systems.

This study was conducted under the sponsorship of the Wisconsin Department of Transportation. We would like to express our appreciation to Linda Lovejoy, Hector Gonzalez, and Dixon Nuber of the Wisconsin Department of Transportation and the project advisory committee for their helpful input on the project. Active members of the advisory committee included representatives of transit agencies in La Crosse, Manitowoc, Appleton, and Watertown, Wisconsin. During the project, advisory committee members and project staff visited AVL systems operated by Milwaukee County Transit System and American United Taxicab in Milwaukee to increase their familiarity with AVL. The assistance of the agencies is gratefully acknowledged. The research reported here is the

product of independent university research and the opinions expressed are not necessarily those of the project sponsor.

Project Objectives

The objective of the project was to conduct an analysis of the potential benefits of Automatic Vehicle location Systems for small and medium transit systems in the state of Wisconsin**.**

Using this statement and comments from the project steering committee the following list of tasks was developed for the project:

1. Identify the state of the art in automated vehicle location systems, how they are used, and what are their benefits.
2. Identify current transit systems that employ AVL technology and establish how these systems are used, what benefits have been demonstrated to date.
3. Identify how on-board riders would respond to AVL technology. This includes not only how beneficial they would view such technology, but also how they would rank it along with other transit services.
4. Identify the major providers of AVL technology to the transit industry for the acquisition of information on the latest AVL abilities and how many and type of this systems have been installed.
5. Identify and develop a list of AVL benefits that show its impact to the transit agency and its riders.
6. Develop a Cost/Benefit analysis that demonstrates the impact of AVL technology on an agency.
7. Make recommendations on the deployment of AVL systems for smaller transit authorities.

Additional work was also done on combined or shared AVL systems. This work, done at the request of the project steering committee, examined and evaluated joint use of an AVL system among different departments.

Review of Literature

Many studies in the literature focus on the development of the AVL technology. For example, Cain and Pekilis (1993) in their article on the development history of AVL give a good description of the shift from Loran C, Signpost and Dead-reckoning to the present global position systems (GPS) with enhanced real time location tracking and schedule monitoring. Dana (1997), Okunieff (1997) and Khattak et al. (1993, 1996, 1998) also provide a good overview of the GPS technology and the role of AVL for bus transit. These studies on AVL systems highlighted the fact that GPS was the most popular technology available in the market at present. A wide variety of features can be added to the basic AVL system. Smart cards, electronic billing, passenger counters, maintenance monitoring system, etc., are some of the examples.

On the other hand, very limited literature is available on the cost-benefit analysis for the applications of AVL systems in transit agencies. One reason for this could be that it is a relatively new technology, and there is little data available for detailed cost-benefit analysis. Gomez, Zhao and Shen (1998) cite the example of six transit agencies in their paper and highlight the different service configurations, fleet, objectives, and other requirements that would determine the cost of an AVL system. Their survey of transit agencies using AVL and those in the implementation stage showed that improving schedule adherence, emergency response and providing real-time travel information were the three most important factors in opting for AVL technology.

Some transit agencies have compiled reports on the evaluation of their advanced public transportation systems (APTS) technology. Potomac and Rappahannock Transportation Commission (PRTC) presented their findings to the TRB in April 1996. They were successful in implementing flex-routing and feeder services because of the AVL system. They estimated annual savings of $869,148 for the Fiscal Year 1997. McKeen (1997) from the University of New Mexico cites another success story in his evaluation report on the Urban Rural Intelligent Corridor Application (URICA) prepared for the city of Albuquerque. The main factor influencing implementation of AVL technology in this case study was to determine the ability of an advanced regional management and response center. A study conducted by the University of California, Berkeley, assessed an annual saving of $488,000 from the installation of AVL at Outreach, Santa Clara Valley, California in the year 1996-97 (Chira-Chavala, 1997). However, the transit management feels that this was not an if-then relationship because the benefits are difficult to measure. While they could attribute improved efficiency and increased ridership to the new system, the task of measuring it in revenue dollars saved was perceived as difficult, because there are other factors such as increasing fleet capacity occurred at the same time.

Outreach has also successfully implemented a Broker Model to serve fifteen cities within the valley region as a shared AVL system (Chira-Chavala, 1997). This gave rise to the idea of considering a multi-agency model or AVL system shared between other departments in the city besides the transit agency. Not much information was available on this front and therefore this question was included in the survey of agencies using AVL to know if they were considering something along these lines.

Identification of AVL Benefits

AVL systems are expected to have some specific benefits to transit agencies and to transit users. The concept of a "benefit tree" provides a useful framework for the analysis of benefits. Based on our review of existing AVL systems, the literature and vendor information, a benefit tree was developed. These are illustrated in the following diagram.

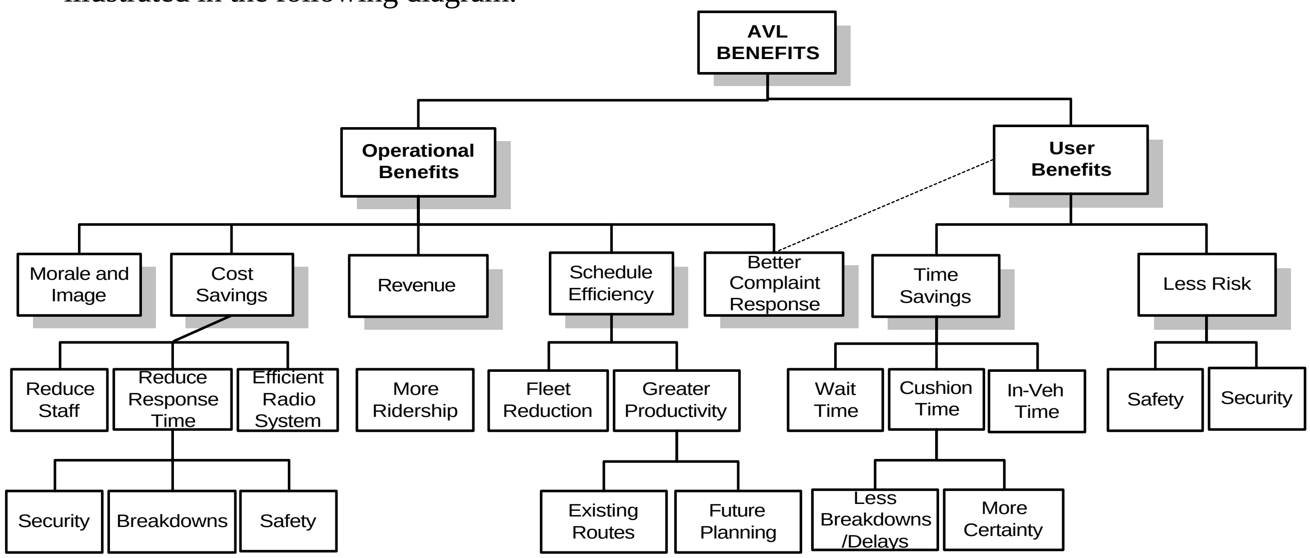


Figure 1: AVL Benefit Tree

The benefits identified were classified as either an operational benefit to the transit agency or as a user benefit that occurs to transit riders.

Operational Benefits

The advantage of AVL to the operation and management of a transit agency is centered on its ability to provide a more efficient service and to reduce costs. The benefits from an AVL system may include cost reductions by the elimination of staff and reducing response time to incidents. Also AVL systems potentially can increase the efficiency of existing routes and provide greater productivity without increased staff or vehicles. Both of these areas may lead to greater revenue generation through cost savings and the increase of potential ridership. The unmeasurable benefits of AVL to an agency have to do with the ability to use AVL to increase awareness and pride in the existing service.

Cost Savings

AVL may be effective in reducing the cost of managing a transit system in several ways. The first is the ability to reduce or reassign existing staff if their function can be handled by the AVL. For example, systems may no longer need field personnel to do on time performance checks. AVL provides an opportunity to evaluate and reassess existing staff positions. The next area of cost savings comes from the reduction in response time to incidents which may require police, fire, medical, insurance personnel, or maintenance. In this case the ability to pinpoint a location, takes much of the guesswork out of directing these people. The final area of cost savings can come in a more efficient use of radio systems. In many cases AVL reduces the need for direct communication between the base and the vehicle. Thus it saves airtime and its related expenses.

Additional Revenues

Better efficiency and reliable service may also lead to additional revenue. AVL allows the agency to provide a better service that may attract more use. This better service gives it the ability to offer higher standards of service and a means to promote the system.

Schedule Efficiency

Shorter headways, better productivity, and possibly fewer vehicles are a few of the ways that AVL improves an agency through improving its schedule performance. By tracking vehicles as they move, an agency can locate ways of modifying existing routes and schedules. Relocating existing routes may also help attract more riders while modifying transfer times and headways. It can also help with signal preemption in busy intersections for transit vehicles.

Better Complaint Response

An important part of dealing with the public is having the answers to their questions. Many of these questions come in the form of complaints about the service or possible damage to personal property. AVL gives an agency a tool to validate complaints. In this fashion the management can acknowledge or dismiss claims with the documentation that AVL can provide. For example, complaints such as “the vehicle did not show up” can be verified and handled appropriately.

Morale and Image

There may be perceptions by the general public that waiting and riding on the bus is not safe, too much time is wasted waiting for the vehicles to arrive (which are never on time), and that it costs too much to ride. AVL can address many of these perceptions as well as give the agency a modern appeal, which helps to improve morale of agency staff and improves the image of the service offered. For instance, on-time performance can be shown in kiosks, display units in bus shelters or even on the Internet.

User Benefits

Benefits to transit riders are classified as those that reduce their risk and or provide time savings. Risk is reduced because communication is quicker with security personnel. Reduced incident response times as well as reducing the amount of time one waits for a vehicle are positive benefits. Time saving benefits come from a reduction in the wait-time at a stop. AVL keeps the vehicle on time and reduces uncertainty so users may need less cushion time for waiting.

Time Savings

It has been demonstrated that a rider's perception of time as they wait for a vehicle is longer than the actual time. Thus, many people believe that they are waiting more time than they really are for the transit vehicle to arrive. This is compounded by the riders arriving at transit locations early to avoid the chance of missing their ride. By providing better on time performance and increased reliability, AVL can reduce the time needed by a user to arrive early to a stop and gives them more confidence that a vehicle will arrive at its posted time.

Less Risk

Security can be an issue with many users. AVL can provide a sense of security on the vehicle when riders are made aware of how the system can pinpoint the vehicle in emergencies. Furthermore, more rapid response time with the AVL can lessen the severity of any incidents that may occur.

Procedure

The project had two major elements, a technology assessment and a user assessment. The technology assessment included a state of the art analysis of AVL technology and a survey of AVL vendors. These were conducted by telephone and by use of the Internet. The user assessment included on-board surveys of transit users in Manitowoc, Wisconsin and a phone survey of Transit Agencies which have adopted AVL technology. The results of these surveys are given in the next chapter. Survey questionnaires were tested extensively to refine the questionnaires and to decrease the response task of the respondents.

Under this project, a series of studies were conducted of the AVL technology, AVL vendors, transit agency use of AVL and transit user attitudes towards AVL attributes. This chapter provides a summary of each of these four efforts. Full reports of the state of the art and vendor studies are provided in the appendix.

AVL State of the Art Report

Introduction

AVL provides the ability to locate and track multiple vehicles as they travel in real time. AVL is used to locate, manage, and plan the movement of a fleet of vehicles by evaluating their current performance and making adjustments accordingly. Using AVL to locate vehicles in real time is beneficial for everyday operation and for critical incident response. By knowing the precise location of a vehicle, agencies can better maintain schedules and improve on time performance. AVL can also help an agency deal with criminal activity, medical emergencies, or mechanical breakdowns. Locating a vehicle while it travels is also helpful when there is a need to document its location. This can arise in cases of verifying legal claims, rider complaints, and driver performance.

AVL when used as a management tool has the ability to monitor and relay information back to the office as it occurs. Management can observe relations between bus performance for different times of the day and with different drivers. Using this data is beneficial for adjusting service schedules and managing staff. All of these applications can help management make decisions about operations.

AVL is a tool that allows an agency to evaluate and pursue new ways of adjusting their service. This includes examining how a bus performs on a new route through trial runs and adjusting the headway of current routes based on the data collected. Using AVL in planning helps an agency find areas that need improvement so service is preserved, efficiency is increased, and operating costs are cut.

AVL may also have application in cutting costs. Reducing the personnel needed to manually locate vehicles on the streets along with the ability to monitor how a vehicle is performing on a given route may provide cost savings.

Currently there are four different types of AVL technology in use. The use of these systems has evolved with the introduction of better products and newer systems. The types of systems that are in use include GPS, Signpost, radio navigation, and Dead-reckoning.

Locating Systems

In 1996 the Federal Transit Administration (FTA) listed 58 AVL systems as currently in operation or planned for installation throughout the United States. The four types of AVL systems in use were Global Positioning Systems (GPS), Signpost, Radio Navigation, and Dead-reckoning. These AVL systems can be used as a “stand-alone” or in combinations. For example, the Chicago Transit Authority utilizes not only GPS but also Dead-reckoning to locate its vehicles. Other systems such as the Milwaukee County Transit System only use deferential GPS. A description of each type of AVL technology follows.

GPS Technology

Global Position System (GPS) technology is relatively new and is considered to be a leading form of advanced technology. Global Positioning Satellites are the property of the US Department of Defense. Although originally created to serve the military’s need to locate vehicles on the battlefield and ships at sea, this technology has now moved into use by the private sector. The system utilizes a total of 24 high earth orbit satellites (11,000 miles), traveling in spherical orbits, that broadcast two signals (L1 and L2) every second. The two signals supply similar data except at different frequencies. The data consist of location identifiers and the precise time at which the signal was sent from the satellite. The time variable is essential to the success and accuracy of the system. Each clock on the satellite is capable of measuring time to better than a 10^{-9} seconds. The clock in each satellite (each satellite has four, of which three are backups) is synchronized to the clock in a receiver on the earth’s surface. Thus by utilizing the signals generated by at least 4 satellites a receiver on the earth’s surface can calculate the pseudo-range and pseudo-velocity of the satellite by using the difference between clocks. This data can then be processed to determine the latitude and longitude of the GPS receiver.

GPS has proven to be very accurate, with a few exceptions. As mentioned before, GPS is owned by the United States Department of Defense (DOD) under the NAVSTAR Joint Office, and is currently subject to its shared use policies. The DOD chooses to degrade the GPS signals. This action is referred to as “selective availability” and accounts for the majority of error in the GPS signal. Besides selective availability there are other errors that effect the accuracy of GPS. The most common error has to do with the receivers. The synchronized clocks have to be precise. Errors in the clocks of more than 10^{-2} second could result in an error of almost 1,000 miles off in any direction. Most commercial clocks however are good to the 10^{-9} second. Other sources of error can come from the atmosphere and electromagnetic interference.

Signpost Technology

An early system utilized for vehicle location was signpost. This technology tracks vehicles as they pass specific points utilizing short-range communication technology between the vehicle and the signpost. There are many types of signpost systems that are in use by different agencies. Current varieties of signpost technology include optical scanners, magnetic strips, short-range radio, and beam emission. Each type of beacon has different power consummation rates and varying effectiveness under a variety of conditions.

Currently there are two methods for utilizing signpost technology. The first method is referred to as a "traditional signpost" system. This method uses the signpost as the short-range transmitter. When a vehicle passes by a signpost it acquires the signpost's ID through a short-range signal broadcast by the device. Along with the signpost's ID the vehicle also records the odometer reading simultaneously. Later, when that vehicle is contacted by the agency to gives its position, the signpost's ID, old odometer reading, and current odometer reading will be needed. The ID will indicate the last location of the vehicle and the differences between the odometers will indicate how far the vehicle has traveled from that point. A current location of the vehicle can then be determined along the route. In the other method, referred to as the "neo-traditional signpost" system, the location device acts as the receiver. At the point a vehicle passes each signpost the vehicle's ID is transmitted to the signpost and then relayed through to the agency. By knowing the site of each signpost and each vehicle's ID the location of every vehicle can be monitored as they pass by a signpost. This method does not require additional information such as the odometer reading.

Dead-reckoning Technology

Dead-reckoning employs the use of mathematical principles for locating vehicles as they travel. In theory, if a vehicle's starting point along with its speed and direction is known, then the location of the vehicle can be calculated in respect to that original starting point. Early mariners first used this system of navigation as they traveled at sea. By using maps that located known land masses as starting points along with information on the wind and current speeds they could plot courses and arrive at a set destination. Today the electronic land navigation of Dead-reckoning is done with wheel rotation monitors (for speed) and internal compasses (for direction). Although the principles are the same, the paths are electronically monitored continuously by use of computers and data inputs for accuracy.

A Dead-reckoning system needs two different types of data, direction and distance traveled, to locate a vehicle from a given starting point. The first data type, distance, can be acquired by counting wheel rotations. Wheel rotation data can be acquired though three separate methods. The first method uses a system of tags place on the wheel and a reader on the stationary inner wheel hub. As the wheel turns the reader counts the number of times it senses the tags. These data are then used to compute speed and distance traveled. The next method utilizes a “linked” mechanism. A chain or belt device is directly linked from the vehicle wheel to a smaller wheel on the reader. The reader acquires the distance traveled and speeds of the vehicle by counting the rotation of the reader’s wheel. In the last method if the vehicle has an odometer the reader is linked directly to it. In this way the wheel revolutions have already been counted, by the odometer, so the distance traveled is known. Data on the vehicle’s direction can be acquired by using an internal compass. The onboard compass observes the direction the vehicle is positioned. Both data components are needed to estimate the location of a vehicle for accuracy.

Ground Based Radio Technology

GBR, or Ground Based Radio technology, uses radio triangulation to locate vehicles. The system can operate with one or more antennas that broadcast a signal. In most cases a broad spectrum is used to improve signal quality. The low frequency waves along with an associated timing are used to calculate the vehicle’s position. Today GBR technology is behind Loran C systems. Loran C uses a low frequency wave that is generated by several towers that are synchronized to each other. Each station will transmit in an order and at an exact time in relation to the others, forming a pattern. A receiver that picks up the signal knows what the pattern is and can calculate its position based on the deviation from that pattern.

Loran C, which is maintained by the United States Government, under the direction of the Coast Guard, will be scraped by the turn of the century. Currently only a few agencies utilize Loran C technology. No additional new systems are planned.

Communications Hardware

Good communications between the components in the field and at the office is critical to the successful operation of the total AVL package. The communication between the on board systems and the agency requires a fast rate of data exchange, since each vehicle’s location hardware is generating continuous streams of data. There are currently several types of communications packages. Some of these include traditional radio, analog cellular, and advanced digital technology.

The major communication systems available for utilization in AVL applications consist of Radio, Cellular, and Satellite technologies. In transit agencies today, the most common method for communication is analog radio. This system remains one of the cheapest forms of direct communications available. Analog systems, however, have significant drawbacks when used in AVL systems. This is because of the need to translate data from digital to sound. This process of translation requires additional time to process the data and additional airtime to send it. In the future it is more likely that digital radios with their ability to take data in its digital form will eventually replace analog.

Mapping Systems

Another component of AVL is a computer display or mapping system. Once the vehicle has been located using AVL hardware, its position calculated, and then communicated to the agency it must be located on a map. Computer maps are responsible for taking the information being supplied by the vehicle and displaying it on a digital roadway database. Many of these digital maps are sold as part of the total AVL package.

The digital map database, needed to display the vehicle locations, can be obtained by an agency in through several sources. The easiest method is to purchase the map information. Currently there are several vendors that sell digital maps throughout the United States. The maps vary in price depending on what information is required. The coverage of these maps is good but also limited to most large-scale urban regions. For smaller urban areas ready-made digital maps may not exist. Digital maps for these areas will have to be created. This is done by two methods. The first is by digitizing current street grids off local maps and creating the database from scratch. This is a time consuming process that requires a large investment in time. The other method creates a map database from data supplied from the Federal Government. The Federal Censuses Bureau compiles digital map data in “TIGER” files. These files contain roadway information that can be used to create a local map database.

Conclusion

The current AVL systems combine positioning hardware, a communication package, and a computer display system to monitor and track a vehicle’s movements in real time. The advantages to the agency that uses AVL is the ability to observe, collect, and analyze information about a fleet’s performance as it travels in real time. This data give an agency the ability to make better and more informed decisions while also providing quicker response to emergencies. The benefits to the rider mean better on time performance and less waiting.
AVL applications appear to have focused on GPS technology as the primary means of tracking vehicles. This should be sufficient in all locations except in places where large buildings, tunnels or mountains block access to satellite signals. AVL also appears to be adaptable to all forms of radio communications from analog to digital. AVL can also work with most mapping software.

Transit Agencies' AVL User Report

Introduction

In order to get information about the experiences of agencies using AVL systems; a telephone survey was undertaken of transit agencies that are currently using AVL systems. The list of agencies contacted is shown in Table 1. This survey concentrated on small transit agencies rather than large agencies. Prior to the survey, a list of probable questions was mailed to these agencies to prepare them for the questions during the telephone interview. Questions dealt with reasons for seeking AVL, AVL benefits and drawbacks, funding, pitfalls, system sharing, and cost benefit analysis. A copy of the question list is given in the appendix. Most managers were willing to share their experiences in an informal discussion following the questions in the survey.

A few agencies forwarded bid documents and reports that would be useful for other agencies considering an AVL system. The highlights of the survey have been summarized below.

City/ System	Automated dispatch & scheduling	On-time perform-ance	Real-time information	Efficient use of resources	Customer communi-cation	Automated billing & payroll
Napa, CA – The Vine	**X**			**X**	**X**	
San Jose, CA - Outreach	**X**	**X**	**X**	**X**	**X**	**X**
Santa Monica, CA - SMMBL	**X**	**X**	**X**	**X**	**X**	
Cocoa, FL – SCAT	**X**	**X**		**X**		
Palatka, FL – Arc Transit	**X**			**X**		**X**
Winston-Salem, NC - WSTA	**X**	**X**	**X**	**X**	**X**	
Albuquerque, NM - SunVan	**X**	**X**	**X**	**X**	**X**	
Rochester, PA - Beaver CTA	**X**	**X**	**X**	**X**	**X**	
Scranton, PA - COLTS		**X**	**X**		**X**	
Woodbridge, VA - PRTC	**X**	**X**	**X**	**X**	**X**	**X**
Sheboygan, WI - STS	**X**	**X**		**X**	**X**	

TABLE 1: Agencies Contacted and AVL System Highlights

Summary of Findings

1. **Reasons for seeking AVL**:

   When asked the reasons for implementing an AVL system, the following responses were given:

   - Efficient use of resources. Most small and medium sized agencies are operating on tight budgets and cannot generate enough revenue to improve the services. They felt that an AVL system would help utilize resources more efficiently.
   - Improve on-time performance through fleet tracking. The GPS output helps identify trouble areas and can be used for improving on-time performance.
   - Get real-time information about the vehicles. The 20 to 30 second feedback on the location of the vehicles helps track them. It is very useful for paratransit services where the vehicles can be guided to the correct address in case the vehicle is off-route.
   - Improved customer communication. Customers can be given the exact location of the vehicle at any given time. Even customer complaints regarding no-show vehicles can be handled with the GPS data output.
   - Automated dispatch and scheduling.
   - Automated billing and payroll.

2. **Benefits of the system:**

   The major benefits of the system cited by the agencies were given. From the management point of view the major benefits are:

   - Improved efficiency of the system: The feed back from the system allows the agency to re-route vehicles during peak times. Routes that show poor patronage can be rescheduled to demand-response or flex route. On-time performance can be better monitored.
   - Improved Customer Communication: Disputes about non-arrival of vehicles and similar customer complaints can be better handled because of documented evidence of the real-time location of vehicles.
   - Interviewees indicated that the most important benefit of the AVL system is for flex routing services. Because of the AVL technology, flex routing and paratransit can be incorporated into the regular service. This saves the number of vehicles needed. Agencies like Woodbridge, VT (PRTC) that operate in low density areas could encourage choice riders by offering flex route services and convenient pick-up points.
   - Decreased reservation time. Paratransit services prior to the AVL system required 24 to 48 hour advance reservations. With the AVL this time has been brought down to an hour or half in many cases. Occasionally real-time scheduling can also be done, therefore saving time and resources.

3. **Drawbacks of the system:**

The system has proved quite beneficial to most agencies although there have been problems at the implementation stage. Integrating the AVL system with automated scheduling and dispatching, the radio system and other software and hardware components have often proved to be a big hurdle. PRTC have been struggling to get their system fully operational for the past three years. The major problem zone was the integration of the AVL system with a pre-existing analog radio system. Digital radio communications fit better with the AVL system. Then again some agencies had different vendors supplying different parts of the AVL system and often the products did not integrate well. Agencies that got in entirely new systems have had no complaints. They could bring in entirely new technology. This however would hike up the price of the entire project. Agencies like Sheboygan transit have had their system for 10 years and never had a major breakdown until recently. Outreach California compares their system to a kitchen appliance in reliance and durability.

4. **Funding:**

State and local governments along with FTA have been the usual source of funding for these projects. However, in some instances like at Outreach, California, a public-private partnership was formed between the government and other corporations in the Silicon Valley to bring in extra money for operating the service.

The cost of the system varies greatly depending on the capabilities of the system. Arc Transit, Palatka, Florida had a relatively inexpensive system where the base station cost $46,000 only. This was because they cut back on their radio time and real-time information and fleet tracking capabilities.

City/ System	System Cost	Fleet Size
San Jose, CA - Outreach	$750,000	15 buses, 55 vans
Palatka, FL - Arc Transit	$50,000	14 buses
Winston-Salem, NC - WSTA	$235,000	17 buses
Scranton, PA - COLTS	$ 357,935	32 buses
Woodbridge, VA - PRTC	$ 245,000	20 buses

TABLE 2: Fleet Size and Their Related Costs

5. Pitfalls:

There are numerous vendors in the market selling AVL products. An agency has to first and foremost have a clear idea about their needs and look for a specific system. It is extremely important to bring in a reliable consultant, familiar with both transit operations and technology issues. It is worth the expense to do a needs analysis.

Outreach attributes its success to the fact that they hired an engineer for technical support from the vendor. This gave them the advantage of getting complete technical support from a person who was directly involved with the installation process. If the system is being put together by different vendors, it is essential to get some assurance of the compatibility of different software and hardware being used.

Good radio communication is also essential. Old systems like Sheboygan are updating their radio system after ten years. The Palatka, Florida, system has its own radio channel and is therefore thinking of leasing out airtime. PRTC, Virginia, have not been able to get their system working in three years because of the problems with the radio channel. High rates of owning radio channels in Washington, DC, area has led to implementation problems.

6. Sharing the system: Broker Model

Outreach, California has developed a Broker model that caters to 15 cities in Santa Clara County. The State of California put out bids for the paratransit dollar allocation in compliance with the ADA regulations. Outreach secured the contract. They in turn contract with other paratransit companies who own or lease the wheel-chair accessible vans. Outreach provides the AVL-GPS equipment for these vehicles. Outreach also handles all the scheduling, dispatch and contract management. Outreach does not own the vehicles doing the rides. The other agencies in turn pay Outreach for the services.

There are seven vendors contracting with Outreach for these services. They provide services to fifteen cities in Santa Clara County.

7. Cost Benefit Analysis:

Only one agency amongst those contacted had done a cost benefit analysis for the system. University of California, Berkeley, assessed an annual saving of $488,000 for Outreach, in the year 1996-97. However, the management feels that this is not an if-then relationship because the benefits are difficult to measure. All the other agencies shared this view. While they could attribute improved efficiency and increased rider-ship to the new system, the task of measuring it in revenue dollars saved was perceived as difficult. Often technical staff replaced lower and middle level staff, or the fleet capacity was increased; therefore, generating figures was difficult. PRTC, Virginia compiled a cost-benefit report to evaluate the flex route service and its benefits over fixed route service. This can indirectly be attributed to the AVL system, which facilitates organizing an efficient flex route service in low-density areas to encourage choice riders.

On-board Rider Survey Report

Introduction

An on-board transit survey was conducted on Friday, January 23, 1998, on the Manitowoc, Wisconsin transit system. The purpose of the study was to evaluate the importance placed on AVL features by the riders in a small sized transit agency. The results would help evaluate the value of implementing an AVL system in small sized transit agencies to help improve the services. The survey was conducted to get feedback about the riders' concerns and perceptions about improvement in services.

Manitowoc was selected because it is representative of a normal small sized agency. They operate five full-time dedicated buses and one for flex scheduling. Five surveyors from the University of Wisconsin, Milwaukee administered the survey. The survey began at 6:15am with the first trip of the day and continued to approximately 2:00 p.m. The questionnaires were handed out on board the bus and collected back during the ride. The administering team was always at hand to help the respondents. The overall response rate was around 80 percent.

Summary of Findings

1. **High proportion of Senior Citizens.**

   Senior citizens accounted for 27.1 percent of the total ridership on the day of the survey. (The survey was conducted on a day when the schools were closed.)

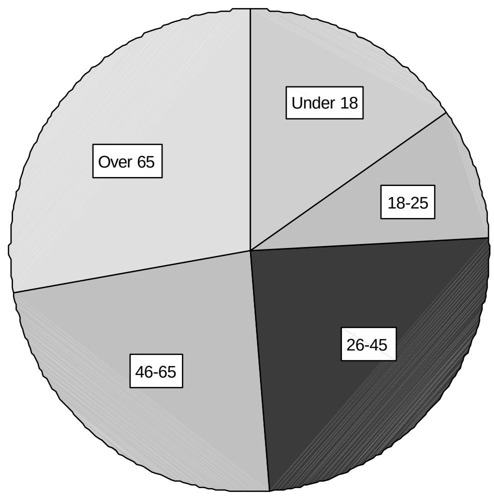


Figure 2. Manitowoc On-Board Survey: Age Group Pie Chart

2. **Frequency of using transit.**

   It was observed that 31 percent of the people riding more than 5 times a week are Senior Citizens. Therefore, any policy implication must keep in mind the needs of this Group of riders.

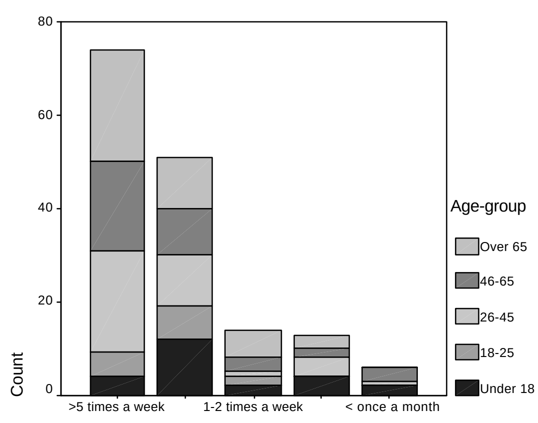


Figure 3. Manitowoc On-Board Survey: Frequency of Riding

3. **Rider perceptions**.

The responses to questions regarding the riders' rating of elements of transit service were weighted and ranked in order to identify the relative importance of the major factors that affect riders' decision to ride a bus. The most important ranking is scored 1 and the least important ranking is scored 5. These scores were then weighted using the frequency of respondents who selected the factors. As shown in table 2, bus arrivals on-time and real-time information are the two most important factors. However, it should be noted that all the factors range between 1.48 and 2.82, implying that all were important in the riders' decision in using transit. Only calling out the stop had an average rating near the middle of the scale.

Variable	Weighted Importance Score
Bus is on-time	1.48
Real-time Information	1.55
Low Fares	1.62
Replacement on breakdown	1.66
Emergency Response	1.68
Exact Delay Time	1.78
Availability of Seat	1.91
Latest technology	2.01
Display Next Stop	2.39
Calling out Stop	2.82

Table 3. Weighted Importance Index.

4. On-time performance

The on-time performance of the bus service emerged as the single most important factor for the transit riders. In fact, the occasional riders tended to mark on-time performance as very important in their decision to ride a bus. Overall, 61 percent of the respondents considered the on-time performance as a very important factor.

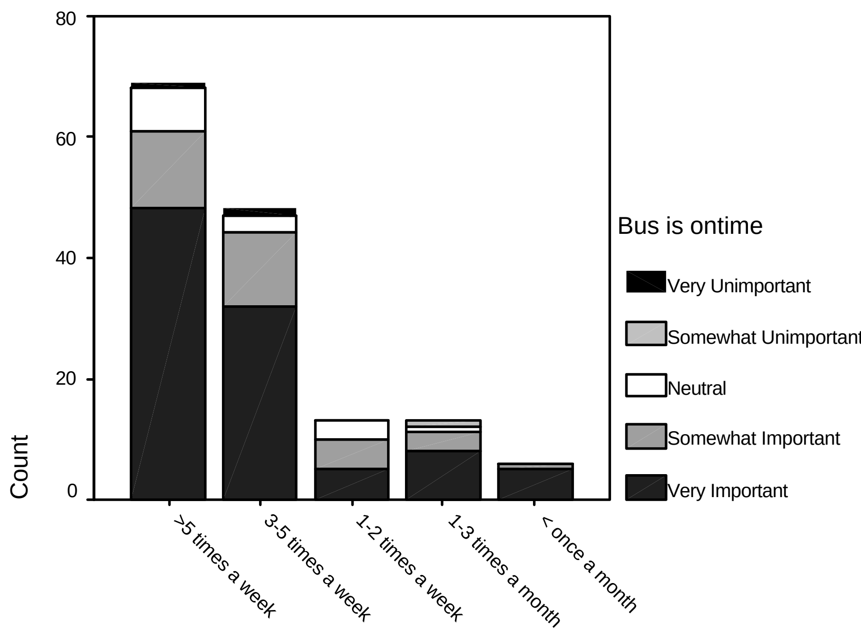


Figure 4. Manitowoc On-Board Survey: Importance of On-Time Performance

5. Real-time information.

Having real-time information on the bus service emerged as the second important factor. About half (51 percent) of the respondents felt this was very important in their decision to riding a bus. However, on cross tabulating this response with frequency of riding a bus, it was seen that this was a more important consideration for people who ride the bus frequently. For occasional riders, the availability of real-time information was not a significant factor.

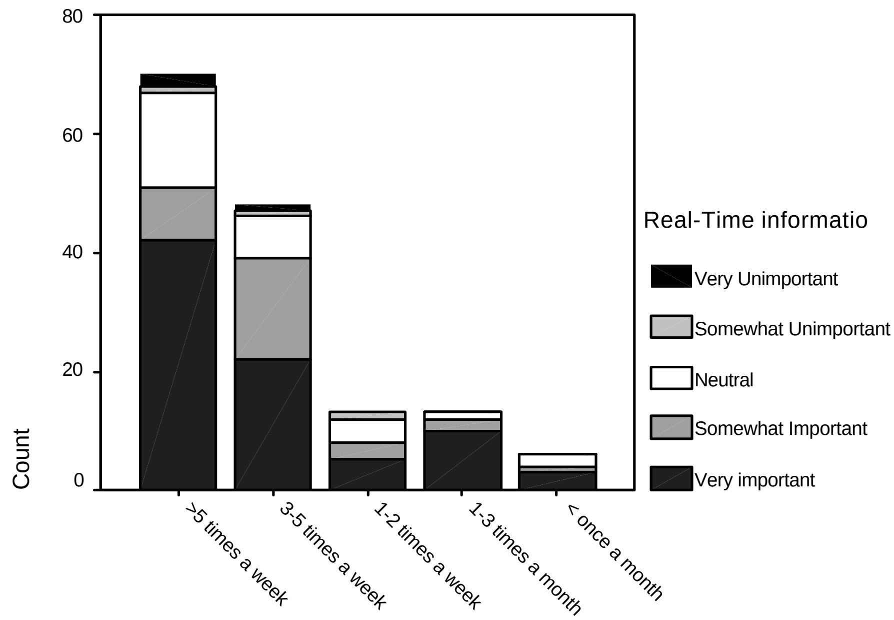


Figure 5. Frequency of riding vs. availability of real-time information

6. Low fares.

Over fifty-six percent (56.8%) of the respondents marked low fares as very important. Once again the highest proportion was in the frequent riders category. This was a surprising observation as they were mostly monthly pass holders and could get unlimited rides with their pass. The senior citizens and students got further subsidization. Further cross tabulating the response with age of respondent it was seen that age had little effect on the response. The percentage of people considering fares as very important in their decision to ride a bus was high across all age groups.

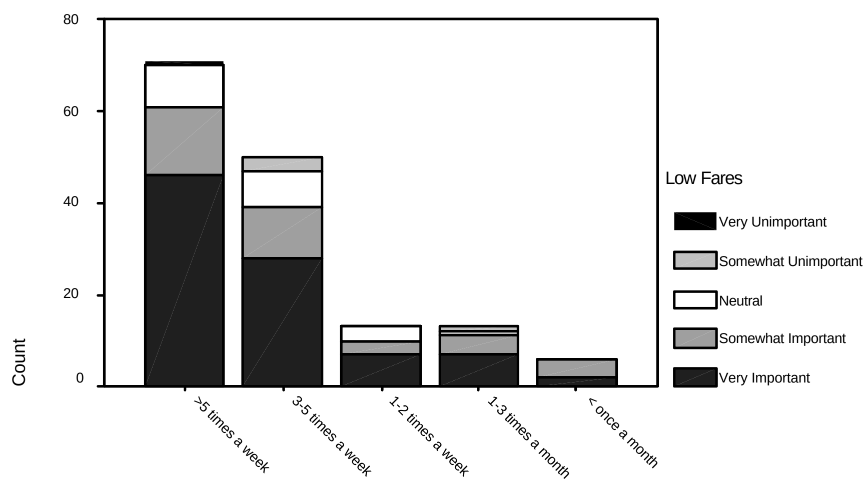


Figure 6. Importance of low fares

Age groups below 18 and above 65 both marked low fares as very important. It should be noted that both these groups had monthly passes available to them.

			Age-group					Total
			Under 18	18-25	26-45	46-65	Over 65	
Low Fares	Very Important	Count	11	7	25	20	25	88
		% within Age-group	45.8%	50.0%	65.8%	57.1%	64.1%	58.7%
	Somewhat Important	Count	6	3	9	10	8	36
		% within Age-group	25.0%	21.4%	23.7%	28.6%	20.5%	24.0%
	Neutral	Count	4	4	2	5	6	21
		% within Age-group	16.7%	28.6%	5.3%	14.3%	15.4%	14.0%
	Somewhat Unimportant	Count	3		1			4
		% within Age-group	12.5%		2.6%			2.7%
	Very Unimportant	Count			1			1
		% within Age-group			2.6%			.7%
Total		Count	24	14	38	35	39	150
		% within Age-group	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 4. Low fares vs. age group cross-tabulation
(Note: Totals in tables may differ because of different response rates to individual questions.)

7. Replacement vehicle.

Having a replacement of vehicle available for breakdowns emerged as the fourth most important factor.

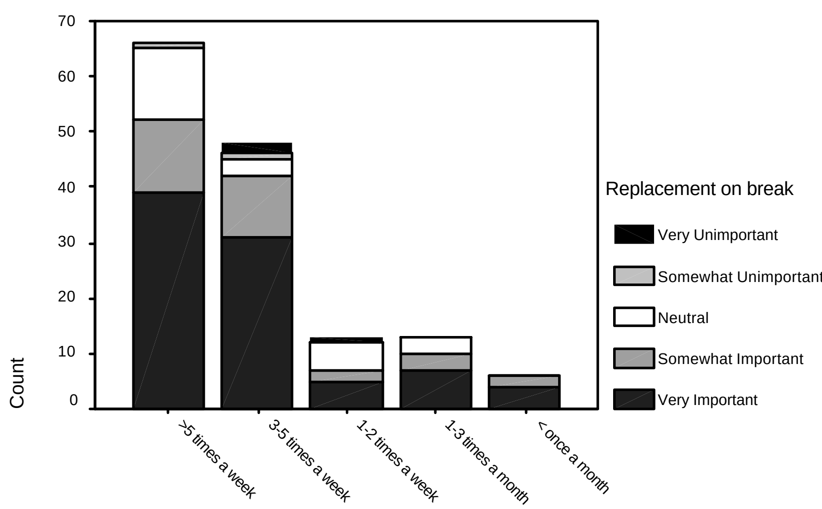


Figure 7. Importance of replacement vehicle for breakdowns

8. Emergency Response.

The idea that a bus could be equipped to contact an emergency response service was well appreciated by most riders. It appeared as the third most important factor on the list.

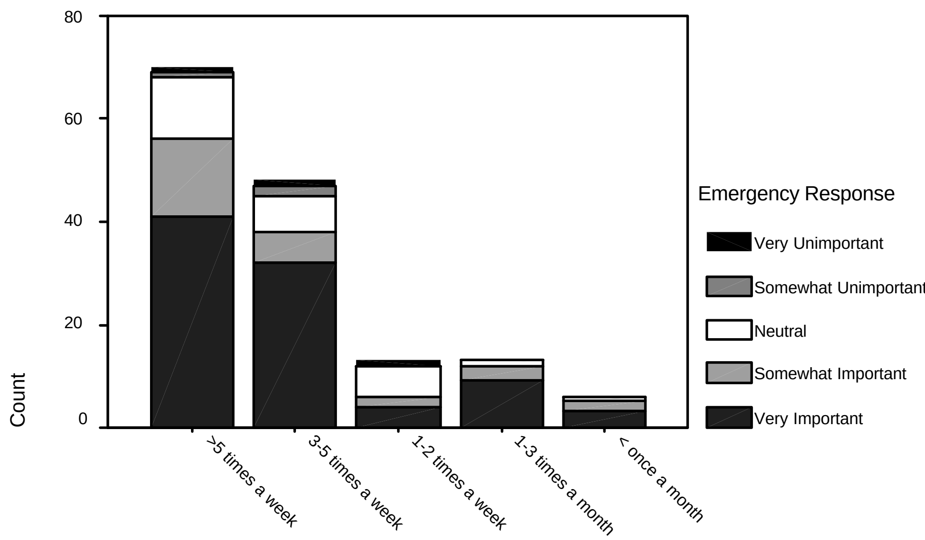


Figure 8. Importance of emergency response

9. Delay time display.

Knowing the exact delay time of a bus was marked as very important to the riders in their decision to ride a bus.

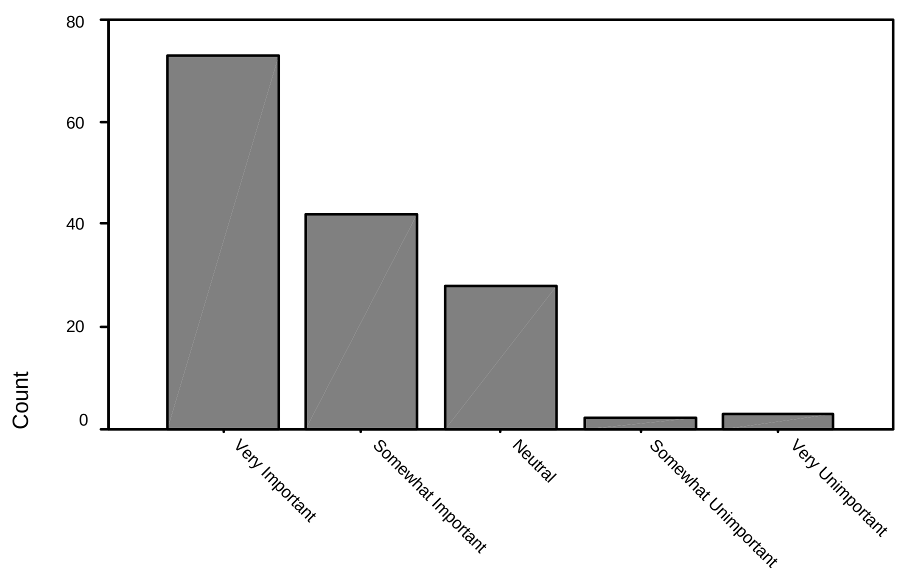


Figure 9. Importance of displaying delay time

10. Availability of seat.

Most respondents marked the availability of seats as very important. During the day of the survey the available seats exceeded the number of riders at all times. Even the morning rush hour volume of passengers was never more than 20 riders at any given time.

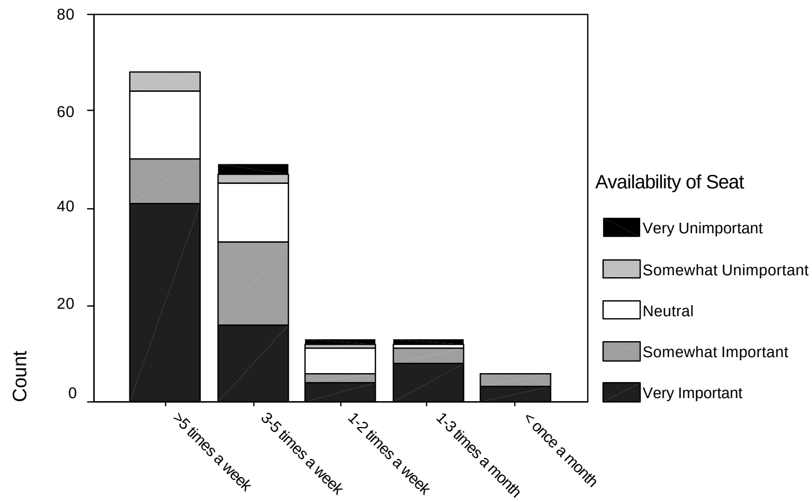


Figure 10. Importance of availability of seat

11. Latest technology.

Knowing whether the transit system used latest technology along with the need for calling out the bus stops emerged as the least important factors influencing bus ridership.

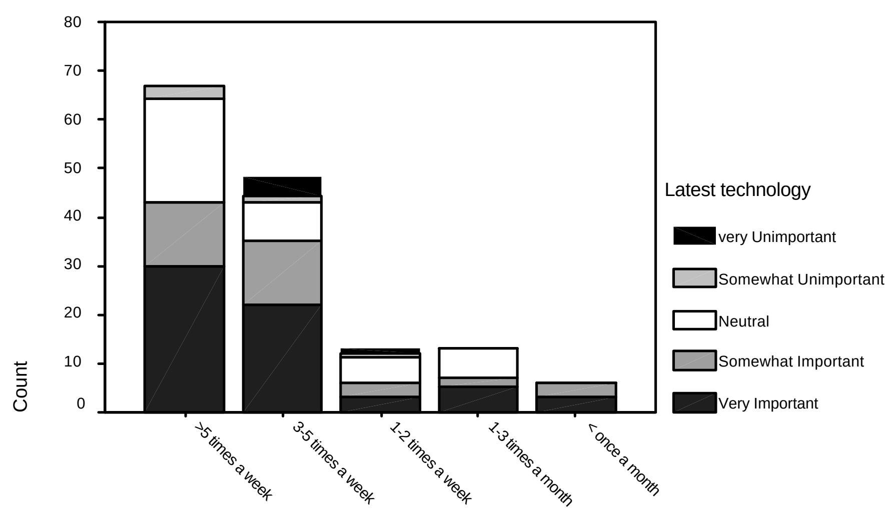


Figure 11: Importance of latest technology

12. Calling out stop.

A cross tabulation of frequency of riding the bus with importance of having the driver call out the stop, generated very interesting results. Contrary to the presumption that the less frequent riders would like to know the names of the approaching stops, it were the frequent riders who considered this as important. One of the possible explanations could be the number of senior citizens who might need help in alighting from the bus. However, most riders were neutral about the importance of this variable.

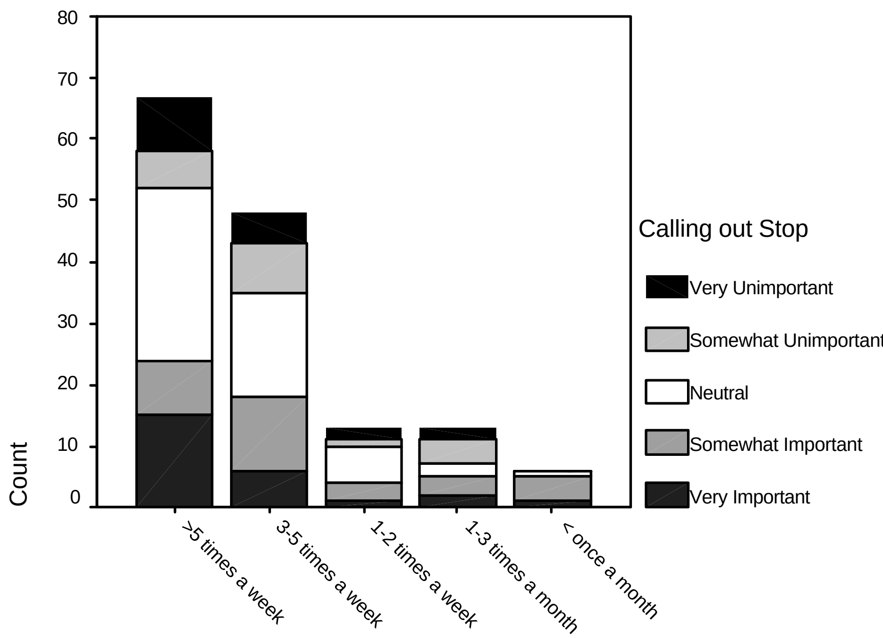


Figure 12. Importance of calling out stop

13. Stop Display.

The response to this query was similar to the one above. Thirty-six percent (36.6%) of the total respondents marked this as neutral in their decision to ride a bus.

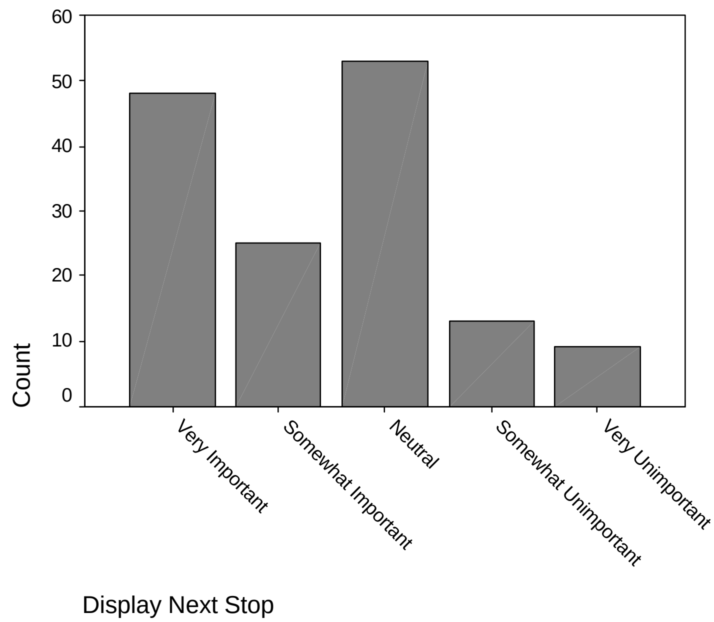


Figure 13. Importance of displaying next stop

14. Captive Riders.

In understanding the responses it is essential to note that the majority of riders were what can be termed as “captive” riders (i.e. they did not have an option to taking the bus). Eighty percent of the respondents did not have a car available to make the trip. An interesting observation in this survey was that 57 percent of the riders who said they would ride the bus more if better information was available are those who already ride the bus more than five times a week.

Frequency of Riding * Availablity of car Crosstabulation

			Availablity of car		
			No	Yes	Total
Frequency of Riding	>5 times a week	Count	61	10	71
		% within Frequency of Riding	85.9%	14.1%	100.0%
	3-5 times a week	Count	36	14	50
		% within Frequency of Riding	72.0%	28.0%	100.0%
	1-2 times a week	Count	13	1	14
		% within Frequency of Riding	92.9%	7.1%	100.0%
	1-3 times a month	Count	10	3	13
		% within Frequency of Riding	76.9%	23.1%	100.0%
	< once a month	Count	3	3	6
		% within Frequency of Riding	50.0%	50.0%	100.0%
Total		Count	123	31	154
		% within Frequency of Riding	79.9%	20.1%	100.0%

Table 5. Frequency of rides for riders with or without an automobile
(Note: Totals in tables may differ because of different response rates to individual questions.)

15. Potential targets

Finally, an interesting finding is that the majority of respondents who stated that they would ride the bus more frequently if better information about the service is printed were the ones who were already riding more than five times a week. The ‘potential targets,’ or less frequent riders, did not respond to riding the bus more. This should be taken into consideration while thinking of a policy implementation.

Frequency of Riding * More Information Crosstabulation

			More Information			Total
			Ride More	Ride less	Ride same	
Frequency of Riding	>5 times a week	Count	19	1	51	71
		% within More Information	57.6%	50.0%	42.5%	45.8%
	3-5 times a week	Count	4	1	46	51
		% within More Information	12.1%	50.0%	38.3%	32.9%
	1-2 times a week	Count	4		10	14
		% within More Information	12.1%		8.3%	9.0%
	1-3 times a month	Count	5		8	13
		% within More Information	15.2%		6.7%	8.4%
	< once a month	Count	1		5	6
		% within More Information	3.0%		4.2%	3.9%
Total		Count	33	2	120	155
		% within More Information	100.0%	100.0%	100.0%	100.0%

Table 6. Rider potential

Vendor Survey Report

Introduction

AVL is a rapidly changing technology and it is important to identify companies and products that have been around and will continue to exist in the future. This continuity or "here today still here tomorrow" allows investments in Automatic Vehicle Location (AVL) technology to take place with less risk of a company dissolving and a transit agency being left without maintenance and product support for their investment. To identify these companies a search and survey was done to compile a list of AVL vendors and their products. This section identifies companies that have a record of serving the transit market. It also provides information about company profiles, products, service plans, and the type and size of AVL systems they have installed to date. Detailed information on the survey results and the companies contacted is in the Appendix.

Summary of Findings

The following is a list of major survey findings:

1. Of all the survey participants, 80% have been offering AVL products and services to the transit industry for less than 10 years. In contrast, the average number of years that each company has been offering products and services for vehicle tracking to the United States military and private sector was 27.

2. Of the survey participants, 20% offered Signpost technology, 40% offered Dead-reckoning, and 80% offered GPS and/or Differential GPS. This shows that the trend in vehicle location technology is toward supplying the transit industry with GPS or DGPS. Of those vendors that offer products other than GPS, such as in the case of Dead-reckoning, it was found that these products are used to add accuracy to a GPS system rather than used as a stand-alone system.

3. Information varied about the accuracy of the individual AVL products offered. Even among the GPS products, accuracy ranged from 300 to 100 meters and for DGPS from 100 meters to 1 meter. This information shows that not all systems have the same performance, regardless if they are in the same category.

4. Conventional radio was the most common communication method utilized in AVL packages. This is due to the prevalence of conventional radio in the transit industry. However, it was also indicated that most AVL systems could be made to work using a variety of communication means.

5. In the past, personal computers (PC) used with AVL have been too "under-powered" to run sophisticated software programs. This meant that specially

designed workstations were custom built and used in place of the PC. With the increasing speed and power of the microprocessor this is no longer the case. All survey participants use a PC to display vehicle movements in situations that call for tracking less than 100 vehicles. The PC operating systems used range from Windows 95 to NT. At a point between 100 and 500 vehicles the option of using a workstation or a PC should be considered. If more than 500 vehicles will be displayed, then a workstation is still recommended.

6. The maps used to display the location of vehicles as they travel are obtained through three ways. The first way is to purchase the map information from outside vendors. Most major cities have been digitally mapped by vendors. These digitized maps of cities are sold for a variety of reasons. Out of the total number of participants, 80% said that they obtain their maps in this fashion. The next possibility is for the AVL vendors to digitize their own map. This is usually accomplished through the Federal Government Census's TIGER files for less than $100. And the final possibility is to get a digitized map from a municipality that uses a Geographical Information System (GIS). Many GIS systems require the same information that an AVL systems uses to track vehicles making it very easy and inexpensive to generate the base map.

7. Service programs are consistent among AVL vendors. Information gathered from participants showed the average system warranty to be 12 months with maintenance provided through service contracts arranged between the vendor and the transit agency.

8. The average number of systems any vendor has installed and is in the process of installation was eight, with the highest number of installations being 15 and the lowest five. Out of these systems the largest single installation of vehicles in any given system was 12,000 (taxi system in Singapore) and the smallest was five (Orlando, FL demo).

Conclusion

When evaluating the results of the AVL vendor survey, one can see that there are similarities or emerging trends between different companies. With 80% offering GPS and DGPS the trend is that this will likely become the preferred way to track and monitor vehicles. The display units, which only a few years ago would have been all workstations due to the under-powered PC, is now using PC's as their speed and processing power, have increased. In addition, it will be more likely that vendors will also utilize existing digital maps as more municipalities generate city grids using GIS and as the digital map vendor's branch out from the large urban areas. In the coming years the market will continue to converge on similar products and methods for producing these systems will likely lead to lower prices. This will allow for further growth and better products.

Assessing the costs and benefits for AVL technology in public transportation is a challenging task because a large number of benefits associated with the use of AVL are not easily quantifiable and therefore it is difficult to assign a dollar value. Moreover, bringing in new technology such as AVL system often acts as a catalyst that sets in motion a whole process of changes, which is not usually accounted for in the final results of the cost-benefit analysis. For example, since Outreach, California decided to go in for expansion and brought in an AVL system, the ridership has increased significantly. But it would be difficult to attribute the increase in ridership or services to the AVL system alone in a cost-benefit analysis. The ridership and service increase could be the result of the complete revamping of the system, in which the new AVL system played a critical role. This point has been raised by most of the transit agencies and they strongly feel that this is not an 'if-then' relationship.

Examining the costs and benefits for technology changes is also best done in a comparative study that has to compare the before and after figures. This implies that in order to evaluate the benefits of an AVL system, one needs to have conducted a similar study before implementing the system, to make a direct comparison. Even there, a direct comparison is difficult because it is hard to measure the organizational impact that AVL has brought in. Furthermore, the before and after comparison also depends on the operation efficiency of the before situations. A more efficient before-operation would make the impact of new technology smaller, while a less efficient before-operation would make the impact of new technology larger.

Nevertheless, there is a need for transit agencies and decision-makers to determine if the new technology is worth the investment. A benefit-cost analysis is usually a frequently used tool.

Benefits Analysis of AVL

AVL has benefits to transit users and transit agencies. AVL can help transit agencies improve on-time performance, which can benefit transit users by reducing wait time. The time saving translates into direct benefits to transit users. AVL can also benefit transit agencies by increasing operating efficiencies, which translates into reduction of operating or administrative expense. It can also reduce the response time to vehicle incidents, thus reducing incident costs.

User Benefits

The level of user benefits depends on the number of trips made, the value of waiting time and the amount of wait-time saving. The more transit trips made, the greater the wait time saved. The number of trips, or transit ridership, can be obtained directly from transit agencies. The ridership is broken down into different trip purposes such as home to work, school, and other non-home based trips. The value of wait time for every trip purpose can be derived from a mode split model such as that developed by the Southeastern Wisconsin Regional Planning Commission (SEWPRC). The critical question is how much wait time using the AVL technology can save. This requires a detailed study on wait time changes before and after AVL is installed. Since there is no published number on wait time saving, some assumptions have to be made.

An example of a user benefits assessment is shown the spreadsheet given at the end of this section, using data from the City of Racine transit ridership for 1993 as a case study. The annual fixed-route ridership in Racine was 1,771,000 trips and paratransit ridership was estimated to be 17,731 trips. Among those, 29 percent are home-based work trips, 40 percent are school trips, 26 percent are shopping or other trips, and 4 percent are non-home-based trips. Parameters to convert time savings into dollar benefits were derived from SEWPRC's mode split model[1]. These led to a value of travel time for work trips of $2.09 per hour, and $0.41, $0.42 and $2.05 for school, shop/other and non-home based trips respectively. Since people perceive wait time longer than the actual wait time, a weighted adjustment is made to obtain a perceived wait time. The SEWRPC model implies that people who make work trips perceive wait time as about 2.62 times longer than the actual wait time. In another words, wait time is about 2.62 times more valuable than the in-vehicle time. Parameters for other trip purposes are 1.00 for school trips, 7.36 for shopping trips and 7.00 for non-home based trips.

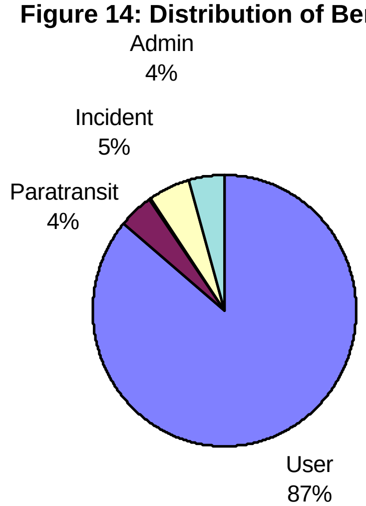
The critical question is how much wait time can users save by AVL? Since there is no hard data at this time, 2 minutes per trip are assumed in this analysis. Therefore, for the work trip there is a wait time saving of 1,037,802 minutes (518,901 trips * 2 minutes). Since wait time is 2.62 times more valuable than the in-vehicle travel time, the dollar value of the wait time saving is $94,713 (1,037,802 minutes * $2.09 * 2.62). Similar calculations are done for other trip purposes and lead to an annual user benefit of all trip purposes for fixed route service about $187,000 with an AVL system-wide saving of 2 minutes per trip to transit users.

[1] Values of time and waiting time were derived from the Southeastern Wisconsin Regional Planning Commission mode split model (SEWRPC Planning Report #41, A Regional Transportation System Plan for Southeastern Wisconsin: 2010, Chapter VII, p313, Feb, 1995). This model was calibrated by SEWRPC based on home interview survey data, to simulate how trave3lers make tradeoffs between travel time, travel cost, waiting time and other factors when they choose a means of travel. Parameters were developed from the calibrated disutility equations by factoring out the in-vehicle time multiplier and looking at the relative values of other coefficients in their model

For paratransit users, there is no data on breakdown of trip purposes, so the same proportion of trip purposes is assumed. Similarly, the weighted value time (using the proportion of trip purposes as the weight) is assumed for paratransit trips. The total benefit for paratransit users in the City of Racine is $9,730, if an AVL time saving of 10 minutes per trip is assumed.

Transit Agency Benefits

Figure 14: Distribution of Benefits



Two benefits of AVL for transit agencies can be quantified depending on the availability of data: savings on vehicle incident responses and administrative expenses. The number of vehicle incidents including vehicle breakdowns, police/fire calls and medical calls and associated costs can be obtained from transit agencies. AVL can speed up the response time to those incidents by quickly locating the incidents and informing the emergency response team. It is more difficult to determine the benefits associated with quicker response time without specific system data. In the absence of reliable data, this analysis assumes a ten-percent reduction of incident costs. In the case of Racine, if one assumes a ten-percent reduction of incident costs and a cost per incident of $1000 and three incidents per month of each type, this would save about $10,800 per year. The amount of savings is dependent on the current incident related expense and savings from adopting AVL technology.

It is widely anticipated that AVL can increase the administrative efficiency of transit agencies. Transit managers and dispatchers are able to be more responsive to incidents and schedule changes. AVL allows transit managers to check schedule and routing adherence more easily. Some work, such as manually checking on-time performance, can be eliminated. On the other hand, installation of AVL will add to administrative costs. There is a lack of detailed data to demonstrate exactly how much administrative expense is changed by AVL. In the example, a ten-percent reduction in administrative expense is assumed. In addition, a $50,000 is added as a new administrative expense to manage the AVL system. These numbers would result in a $9500 net administrative expense in the case of the City of Racine.

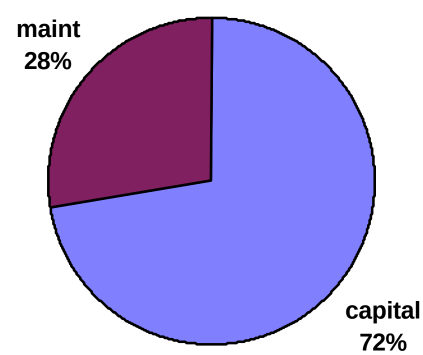
It should be pointed out that these numbers are very approximate. Furthermore, because of the very small administrative staff of most small transit agencies, there is very little flexibility in modifying administrative costs. Small transit agencies should generally expect that administrative savings and extra costs will cancel each other out for no net difference.

Figure 14, Distribution of Benefits, illustrates that the vast majority (87 percent) of AVL benefits result from time savings from transit users. Only 9 percent of savings belong to transit agencies in the form of the reduction of vehicle incident costs and administrative expenses.

Cost Analysis of AVL

The costs of AVL include capital costs and ongoing maintenance costs. The system costs include the expense of installing GPS units on buses, the expense of equipping the dispatch center, and other miscellaneous expenses. The GPS unit costs depends on the number of vehicles; the greater the number of vehicles, the less the cost per unit. The GPS cost per bus ranges from $2000 to $5000. This analysis uses $4,000 as the assumed base unit cost. The total GPS and associated other costs to equip all buses in Racine is $184,000 ($4,000 * 46 vehicles).

Figure 15: Distribution of Costs



The cost of equipping the dispatch center also varies, depending on the system requirements and complexity. It ranges from $10,000 to $50,000. $30,000 is used in this analysis. $20,000 is assumed to be other miscellaneous expense. The total initial system costs is about $234,000.

AVL maintenance is usually handled through a service agreement with the vendor who installs the system. The contract usually covers the costs of installing the system as well as maintaining the system including system update and troubleshooting. The annual maintenance expense ranges from $1500 to $20,000. $20,000 is assumed in this analysis.

To calculate the annual costs of the AVL system, it is assumed that the project will last for 5 years and that the discount rate is four percent. Therefore, the annual system cost is about $52,513 and the maintenance cost is $20,000, for a total annual cost of $72,563. The cost distribution chart (Figure 15) shows that the system cost is about two-thirds (72 percent) of the total cost and the maintenance cost is about one-third (28 percent).

Benefit Cost Analysis

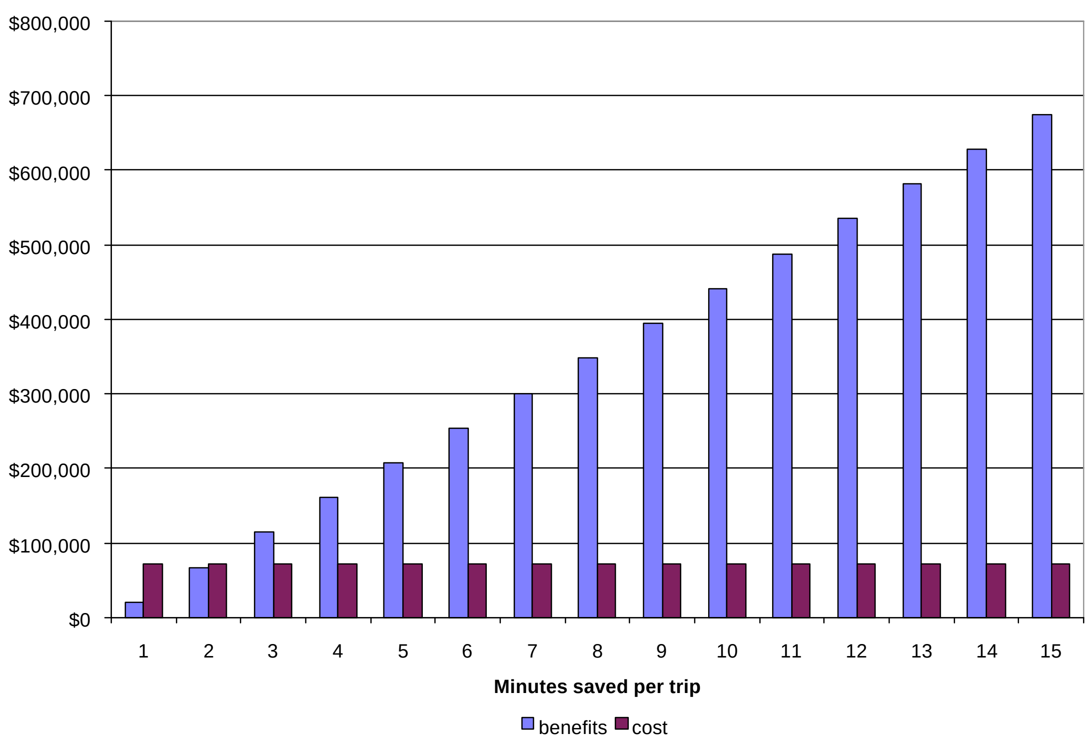
In the above analysis there are total annual benefits of $217,077 and annual costs of $72,563. The net benefits are about $144,515, with a benefit/cost ratio of about 3.0 for the City of Racine Transit System.

Sensitivity Analysis

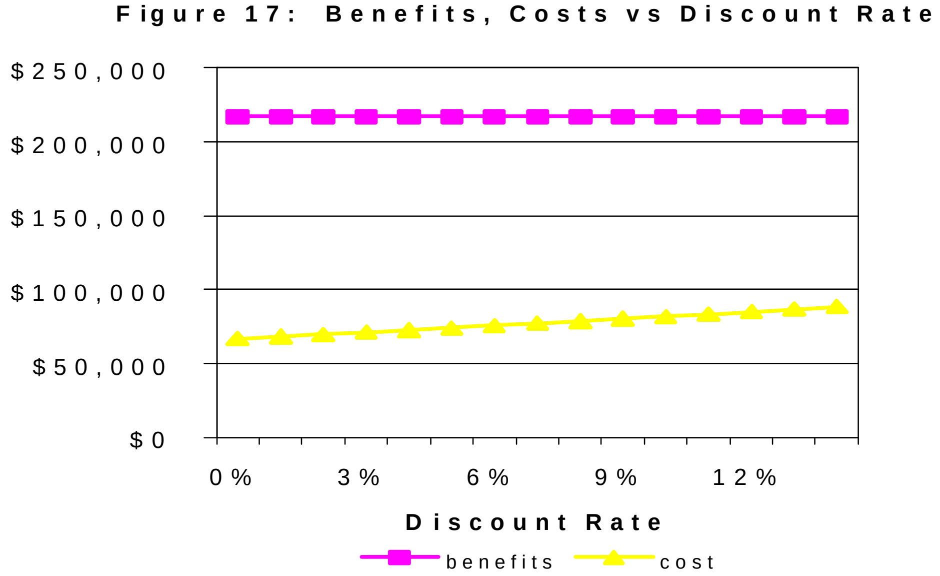
Because of the lack of reliable before and after data, many of the numbers used to calculate costs and benefits are assumed. Therefore, it is important to have a sensitivity analysis to test how sensitive the analysis is to the underlying assumptions. The sensitivity analysis has been conducted for the following factors: the wait-time savings, discount rate, projected project life, and transit ridership. Sensitivity analysis helps to indicate how important the different assumptions are and how different assumptions might affect the benefits and costs of the system

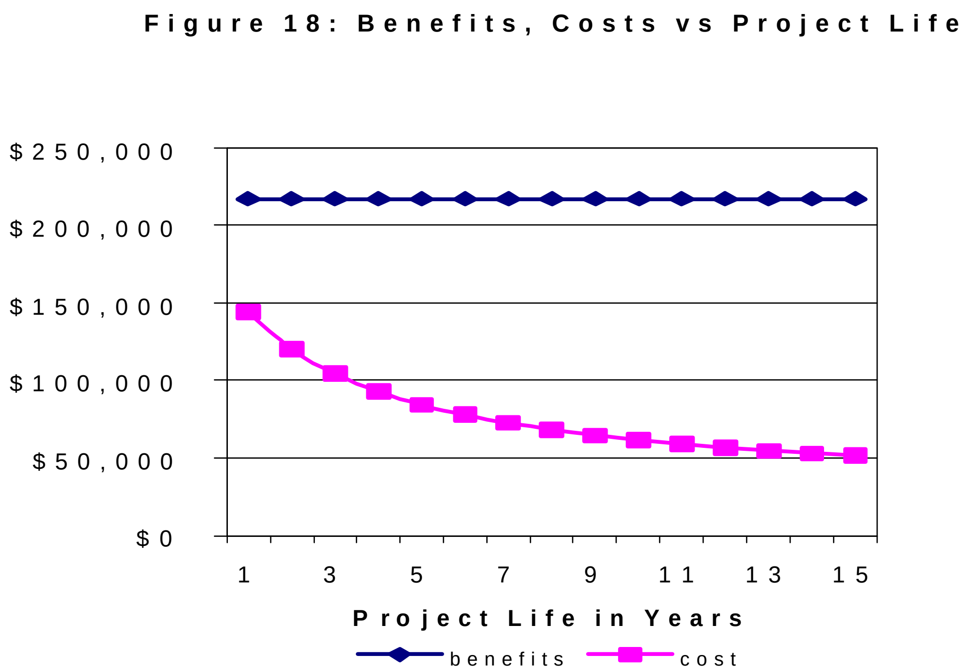
As shown in Figure 16, Benefit vs. User Time Saved/Trip, user benefits are very sensitive to the wait-time savings. As the wait-time savings increase, the user benefits increase dramatically. In the example given, the break-even point is when the wait-time saving is about 0.45 minute or 27 seconds per trip. Given that this is a very small number, it indicates that the potential for AVL wait time savings to exceed its cost is high. It is not difficult to imagine an AVL system to increase the on-time performance to reduce the wait time by less than a half minute.

Figure 16: Benefits vs. user time saved/trip



As shown in Figure 17, the discount rate has a very small impact on the annual cost estimation. The projected system life, Figure 18, has a larger impact on the annual costs. Systems that last for very short time periods will have much higher annual costs. In the example shown, if the project life is over 1 year, the benefits of AVL exceed the costs.





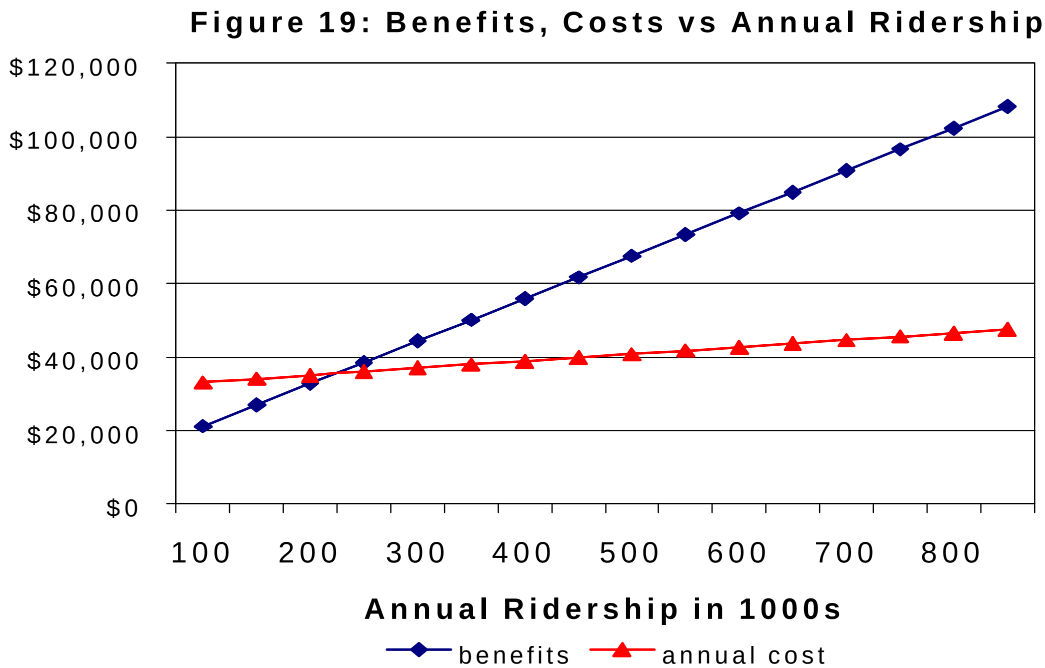


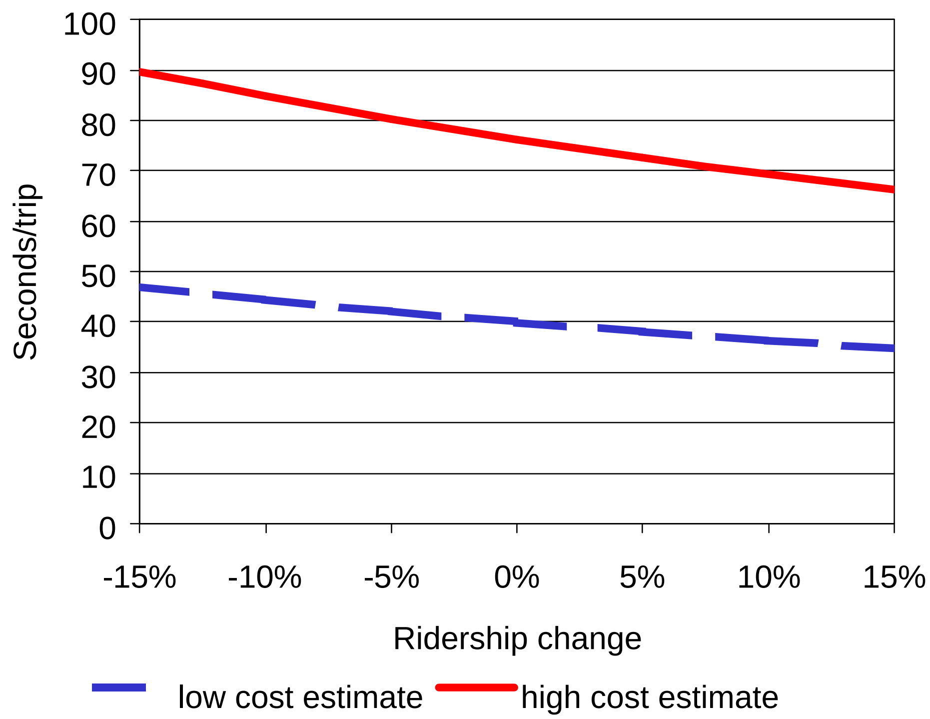
Figure 19 shows that the increases of transit ridership will increase both benefits and costs, but the increase of benefits occurs faster than the increase in costs. These calculations were made assuming that user benefits, incident benefits and fleet size will vary directly with annual trips. With the assumptions made in the example, the break-even point is at about 220,000 trips per year, or 4200 trips per week. Smaller transit systems should take careful consideration of potential thresholds of usage when considering adoption of AVL technology.

Additional insight to the effects of waiting time and ridership can be seen in Figure 20. In this analysis, we determined the breakeven wait time savings at different levels of ridership in Racine and with different estimates of costs. Ridership was varied within plus or minus 15 percent range of the current ridership, with an assumption that the number of buses will remain the same. To estimate the breakeven points of the time saving under different ridership scenarios, we set the benefits equal to the low and high ends of the costs and solved for the corresponding wait time savings.

With ridership changes from -15 percent to +15 percent, the time saving needed to break even with the low estimate of costs ranges from 35 to 47 seconds, and from

67 to 90 seconds with the high estimates of costs. Naturally, as ridership goes up, the breakeven point goes down.

Figure 20: Breakeven Wait Time Savings vs Ridership



Breakeven Analysis of Administrative Costs

Many of the benefits AVL provides are difficult to quantify. Two benefits of AVL for transit agencies, which may quantified are savings on vehicle incident responses costs and administrative expenses. The number of vehicle incidents including vehicle breakdowns, police/fire calls and medical calls and associated costs would have to be obtained from transit agencies. AVL can speed up the response time to those incidents by quickly locating the incidents and by reducing the time to inform the emergency response team. The amount of savings is dependent on the current incident related expense and the potential reduction in costs from adopting the AVL technology.

It is anticipated that AVL can increase the administrative efficiency of transit agencies. AVL allows transit managers check schedule and routing adherence more easily, and thus allow them to be more responsive to incidents and schedule changes. Some routine work, such as checking on-time performance manually can be eliminated by the information generated from the AVL. On the other hand, the installation of AVL will add expense to administrate AVL equipment.

If we don't consider user benefit and only consider savings from administrative expense and reductions of incidents responses, to break even, the savings from these two items must equal to the annual total AVL system costs. The current total administrative budget for Racine Transit System is about $703,000. To break even from administrative cost savings alone, the savings need to be between 9.3 to 17.8 percent of the current total administrative budget. This is clearly an ambitious cost reduction goal to achieve.

Some Caveats

This analysis is based on limited data and assumptions. It is intended as an analysis framework only. More rigorous analysis needs more detailed and reliable data. One shortcoming of the sensitivity analysis is that only one variable is changed at a time. For example, when we analyze the sensitivity of ridership, we assume the wait-time savings are constant. It is more difficult to vary ridership and timesaving at the same time to see their impacts on benefits and costs.

Furthermore, many potential benefits have not been taken into account in this analysis because of the lack of data or because of the difficulty of quantification. For example, the installation of a silent alarm system can increase the sense of security for both passengers and drivers. This psychological effect is difficult to put a dollar value on. The introduction of AVL may provide a basis for other new technologies, which may further help the transit agency realize further efficiencies. This effect is also difficult to quantify. Other non-quantifiable benefits include improved agency image, employee satisfaction, better handling of customer complaints and reduction in their number.

System Information	Fixed	Paratransit	Total							
Annual ridership	1,770,993	17,731	1,788,724							
Fleet size	38	8	46							
			SEWRPC mode split #'s		AVL effect		AVL savings per			
						year				
User Benefits	Pct	Trips	Value Time	Wait wt	wait min/trip	min	wait min	dollars		
Work trips	29%	518,901	$2.09	2.62	2.00	1,037,802	2,719,041	$94,713		
School Trips	40%	715,481	$0.41	1.00	2.00	1,430,962	1,430,962	$9,778		
Shop/other	26%	464,000	$0.42	7.36	2.00	928,000	6,830,082	$47,811		
Non-Home based	4%	72,611	$2.05	7.00	2.00	145,221	1,016,550	$34,732		
	100%	1,770,993			Totals	3,541,986	11,996,636		$187,034	86.16%
Paratransit Users			$0.97	3.39	10	177,310	600,545		$9,730	
					AVL effect					
Vehicle incidents/yr	before AVL	Cost /incident	Annual cost		pct reduced					
Breakdowns	36	$1,000	$36,000		10%			$3,600		
Police/fire calls	36	$1,000	$36,000		10%			$3,600		
Medical calls	36	$1,000	$36,000		10%			$3,600		
	108		$108,000						$10,800	4.98%
					AVL effect					
Administrative Expense					pct reduced					
Fixed route	$495,134				10%			$49,513		
Paratransit	$100,000				10%			$10,000		
AVL admin	$0							($50,000)	$9,513	4.38%
AVL system costs								Total benefits	$217,077	
Capital		total								
Cost /vehicle	$4,000	$184,000					Annual cost			
Equipment	$30,000	$30,000				capital	$52,563			
Other	$20,000	$20,000				maint	$20,000			
		$234,000						total	$72,563	
Annual Maintenance	$20,000							net	$144,515	
Project life-yrs	5							Benefit/cost	2.99	
Discount rate	4.00%						Break even min/trip		0.45	

Refs: Bellebus spreadsheet derived from Racine transit data, SEWRPC Planning Assistance Report #79, table 20, Parameters derived from SEWRPC mode Split model Parameters are derived from SEWRPC mode split models

Grey cells are estimates used as input to calculations

Consistency with the National ITS Architecture

The National ITS Architecture provides a common framework for the design and implementation of ITS. It defines the functions that are performed in implementing ITS, where these functions reside, and the interfaces and information flows that are exchanged between ITS subsystems. Based on the requirements from the National ITS Architecture a set of ITS standards has been designed to ensure that ITS subsystems in different areas with different components from different vendors can communicate with each other.

To ensure that everything "plays together" the way it should, a regional ITS architecture tailored to regional characteristics and transportation needs is desirable. A regional architecture maps out how the various ITS components are ultimately tied together and integrated -- both physically and institutionally. The National ITS Architecture provides a common framework on which to build. It becomes a resource and a tool to help agencies identify and plan for the many functions and information sharing possibilities which may be desired within a particular region.

An AVL system can be a part or subsystem of a regional ITS architecture. Its consistency with the national ITS architecture will facilitate the integration of individual agency systems to enable information from one agency to be shared with others across jurisdictional and agency boundaries. This is especially important if the AVL system is to be shared with other agencies. The system consistency allows individual components of AVL and other ITS programs to work together.

In addition to facilitating integration and future national compatibility, using the information and tools made available by the National ITS Architecture can also save time and money (by cutting design time and costs) in the development of a regional ITS architecture and individual project designs. The National ITS Architecture supports a wide range of functionality and can be tailored to meet local transportation needs and problems. Since the National ITS Architecture is also serving as the common foundation for ongoing ITS standards development work, factoring it into current system enhancements will facilitate the transition to a standard interface definition in the future.

Employing the National ITS Architecture and ITS standards in local AVL system design is the best means of spurring increased competition, thus lowering costs and reducing reliance on single vendors, ensuring future expandability (by using open standards), and promoting the efficient use of resources. If the components of AVL are compliant with the National ITS Architecture and ITS standards, they can be easily updated, expanded and exchanged with other vendors. When the time comes for update, there may not be a necessity to replace the whole system. Rather, individual components can be purchased and replaced. Similarly, the system could be expanded to include other components and connected with other systems because those ITS-standard-compliant components can directly communicate with each other.

To ensure consistency with the National ITS Architecture and ITS standard, system compliance in AVL design should be addressed at both the planning and project levels.

At the planning level – the deployment of the AVL system should take into account the following:

1. Participation by a broad range of governmental agencies that have interest in using AVL technology and other ITS technologies.
2. Description of existing & planned AVL and other ITS enhancements, including both:
   - Physical inventory (e.g., automatic passenger counter, on-board display);
   - Sharing of information (e.g., sharing information with traffic control center and with police stations and emergency dispatch center)
3. Definition of a regional ITS architecture, defined at the level of:
   - Subsystems (e.g., AVL system, Traffic Management, Transit Management)
   - Architecture flows (information exchanges between subsystems)

Additionally, the ITS element may include:

1. Roles and responsibilities for different agencies in sharing AVL technology,
2. Linkages with capital improvement projects,
3. Phasing considerations, both geographic and functional,
4. Regional technology agreements.

At the project level – All projects should ensure that they are consistent with the national and regional ITS architecture. In addition, at the end of the design phase, the responsible agency or their contractor should provide architecture consistency documentation. This consistency documentation should provide a "mapping" of the project terminology to the relevant portions of the National ITS Architecture, at the subsystem and architecture flow level of detail, and should ensure that "what went into the design process also came out". Rationale should be documented for any architecture flows and subsystems omitted in the project design but provided for in the regional ITS architecture. Additionally, the state could require that approved ITS standards be specified in the design of the project if they are applicable. The federal government may require that the contracting agency be responsible for ensuring that Federal-aid requirements, including ensuring consistency with the National ITS Architecture, are met. For transit-related projects using federal funds, FTA will have the same role as that already employed based on the category of funding (e.g., whether it comes from a discretionary or formula-based funding line) and the agreements with contracting agencies.

To ensure consistency at the project level, the state should verify that project scope is consistent with the ITS element of the local transportation plans prior to authorization for procurement and review the project's consistency documentation as part of the plans, specifications, and estimates (PS&E) package prior to purchase authorization

Collective Sharing of the AVL Systems

Over the past decade the majority of the AVL systems installed have been on large fleets of vehicles. In these instances the cost of implementation for systems that were at the time "state of the art" were only affordable and justifiable for larger fleets. In many cases these fleets served major metropolitan areas where the need to manage resources efficiently made installing AVL systems practical. In agencies with smaller fleets the complexity of control is not so great and installation and operation of early AVL systems was limited.

As technology has improved the overall costs of installing and maintaining AVL systems has decreased but continues to favor the economy of scale in larger transit agencies. Large transit agencies were some of the earliest adopters of AVL technology, although a few smaller agencies also adopted the technology.

To increase the economy of scale and to reduce the cost of installing AVL, efforts are under way and have been carried out in smaller transit agencies to share AVL systems with other fleets or departments outside the transit agency. This collective sharing of AVL systems can reduce the expense of installation, operation and maintenance of any single agency. It not only provides a means to justify the cost of a system but also promotes better utilization of the AVL system's capacity.

Current Examples of Combining and Collective Sharing

The following example demonstrates the different ways that can be used to share AVL technology and their benefits.

<u>ARTIC: Advanced Rural Transportation Information and Coordination</u>
Minnesota Department of Transportation ITS District 8

Number of vehicles: 34
Number of agencies involved: 5

The ARTIC project combines the Minnesota Department of Transportation, State Patrol, Minnesota Public Safety, Arrowhead Transit, and City of Virginia/Dial a ride into one multifunctional multipurpose system. The project utilizes computerized mapping and AVL to assist in locating and collecting information on public vehicles. Public service vehicles during the winter months are monitored to observe and track the placement of salt, for the purpose of better planning and coordination. The state patrol can more efficiently respond to and locate incidents reported to the ARTIC center. The fixed route transit vehicles work with the dial-a-ride system to form a network of reliable public service. In the future fixed wing aircraft and/or helicopters are to be added to assist in responding to and identifying incidents. The project has been functioning since December of 1996, with a budget of $1.8 Million.

Sweetwater County Transit Authority, Wyoming

Number of vehicles: 12
Number of agencies involved: 20

The Sweetwater County Transit Authority serves a vast rural area that is roughly the size of Vermont. Its major services focus on providing transit access to youth and senior citizen homes, child development centers and various other agencies. The AVL project's goals were to establish a dispatching center that could coordinate the efforts of several different departments into a regional network. This regional network provides access to any point in the county. The system has been in place for the past seven years and ridership has since increased by five times. To control the cost, the system was not assembled with customized components. Rather many of the system hardware and software products are "over the counter" and readily available. Several different components have been pieced together to form the overall vehicle tracking and dispatching system. The workstations used to monitor and manage the vehicles are PC-486's with expanded memory. The dispatching software is "Rides Unlimited" with 10 out of the twelve vehicles utilizing AVL. Sweetwater County demonstrates that even with limited resources AVL and vehicle dispatching are possible.

To implement AVL technology at the small and medium-sized transit agencies in a cost-efficient manner, sharing the AVL system with other transit agencies and other governmental agencies such as public works and emergency response system has potentially great benefits. While all vehicles still need to install GPS receivers, it needs only one central data processor that receives, processes and disseminates vehicle location data. This centralized information processing and dissemination is cost-efficient in installation, system management and maintenance. This is especially important for small transit agencies where computer-skilled workers are in short supply.

AVL/ITS Service Provider

One way to implement an AVL system for a variety of agencies would be to create an AVL service provider. Such a provider could be modeled after Internet service providers (ISP). An ISP provides access to the Internet at a fixed monthly rate that usually includes unlimited access and the ability to store files on the ISP's computer systems. Equipment must be purchased by individual users to provide terminals and connections to the ISP. An AVL service provider would be similar in that they would provide AVL services for a monthly fee per vehicle to individual agencies that have their own on-board and dispatch equipment. The AVL service provider would present an opportunity to concentrate technical and maintenance expertise at one location. Dispatch stations could be located at individual agency locations according to their needs.

The AVL service provider could also provide more general ITS services such as traveler information, if appropriate in an area. The service provider could be initiated by a transit agency or by a different agency, depending on the availability of expertise and willingness to initiate such a program. Creation of an AVL service provider or having an agency take on that role may be a useful way to implement a coordinated AVL system for a number of agencies.

Contracting Documents

The Request for Proposal documents used by different Transit agencies has had a similar format. Each document outlines the concept, method, equipment capabilities, training, warranty and backup support. These are important parts of the proposal submission as they dictate the price.

The Agency needs to clearly state their main objectives in acquiring the new technology. The objective should emphasize this goal. For example COLTS defines their objectives as:

1. Interconnection of GPS receiver units and antenna system.
2. A tracking and display system located at the dispatch center.

The next step would be to detail the scope of work. Most agencies have outlined the following requirements:

1. In-Vehicle Units,
2. Communications Link,
3. Dispatch center console,
4. Documentation,
5. Services to be provided.

In addition, the RFP should require that the system design and components should be consistent with the national and regional ITS architecture and established ITS standard to ensure the compatibility with other ITS system and expandability to include other components in the future. System support is another important item that is detailed in the contracting document. Most transit agencies require 3 years of system support that including trouble shooting and software update.

A sample of a complete RFP or bid document has been attached in the appendix as a guideline for future procurements.

Conclusions

Automatic Vehicle Locator technology has matured to the point where it can be implemented in a wide variety of agencies. There have been sufficient field applications of the technology to resolve technical features of AVL and make it a viable option for smaller transit agencies.

Most purchasers of AVL systems appear to have focused on GPS technology as the primary means of tracking vehicles. This should be sufficient for nearly all applications, with the only exception being locations where large buildings or natural features block direct satellite signal access. AVL is adaptable to all forms of radio communications systems from digital to analog. AVL can also work with most mapping software.

The number of vendors of AVL technology has undergone significant change in the past several years through mergers, new startups and discontinuance of product lines. It is important to select an AVL vendor with a significant track record in AVL for transit and likelihood for continuance in the AVL business. Vendor service and assistance at startup is extremely important to the success of an AVL system.

Transit users place a high degree of importance on features that minimize waiting uncertainty and increase their feeling of security. Features that AVL may provide such as: vehicles operating on schedule, knowing when a bus will arrive if late, knowing another bus can be dispatched if there is a breakdown and knowing there is an emergency communications system were rated highly by transit users based on the survey done as part of this study.

AVL system design and components should be consistent with the national and regional ITS architecture and established ITS standard to ensure the compatibility with other ITS system and expandability to include other components in the future.

The implementation of AVL technology involves significant human factors and management issues that should not be underestimated. AVL provides more control of vehicles and may change the way in which transit systems acquire and use information. Transit agencies considering the use of AVL need to examine their entire operating procedure to assure that the maximum potential of AVL is utilized.

AVL systems for small transit agencies have the potential of sharing the system with other government agencies. Cooperative arrangements with public works departments, law enforcement agencies and other transit agencies should be explored before an AVL system is implemented. AVL systems should be designed to be easily adaptable to other users.

The costs of an AVL system include a fixed cost for dispatch center equipment and a cost per vehicle for on board equipment. In addition, there would also be an annual cost for maintenance and dispatch center operation. The actual cost will depend on the features included, the extent to which existing radio systems can be used and the availability of existing base maps. The life of the project is an important variable in project costs. Discount rate has a small effect on annual costs.

AVL systems potentially can have large benefits, which easily exceed the costs of the systems. These benefits largely occur to transit users if their vehicle waiting time can be reduced by even a small amount. Other effects such as increased sense of security and reduced response time for incidents cannot be easily quantified but would add to the benefits of an AVL system. In addition, AVL systems have the potential for better management information, which can lead to more productive service, and better planning for future needs.

The potential benefits for paratransit service are also great. AVL has the potential to increase vehicle productivity by facilitating more trip combinations. In addition, AVL can reduce the advance time needed for a trip reservation and reduce the uncertainty of vehicle arrival time.

The benefits of AVL systems are chiefly a direct function of annual system ridership while costs tend to vary only slightly with ridership. Benefits are also most likely to occur on systems that have problems maintaining schedules and service reliability.

AVL systems should be implemented in a way to maximize their impact on passenger waiting times. This is an area of high potential benefits. Mechanisms to increase awareness of vehicle arrival times should be actively explored to provide the best use of an AVL system

Recommendations

Based on our analysis of the nature of AVL systems and their potential benefits, we recommend the following:

- A demonstration project or projects of AVL should occur in Wisconsin. These projects ideally should include a demonstration of the potential for shared AVL systems with other government agencies such as public works departments, law enforcement agencies and other transit agencies.

- Criteria for selection of a demonstration site should include: existence of a GIS system for the municipality, agreements between departments to share services, the existence of a coordination committee to assure compliance with national architecture standards, willingness to do a “before and after” study of the effectiveness of the system, potential for paratransit/regular transit AVL coordination, needs to replace existing communications system, and availability of radio channels for an AVL system.

- Demonstration projects should be accompanied with a rigorous evaluation that includes a before and after analysis of effects. Data should be collected on user wait times, on-time performance, incidents, management practices and system usage to assist in the evaluation of the demonstration.

- Transit systems equipped with AVL should make an effort to let passengers know about the system. These agencies should actively pursue systems that provide real time bus location and arrival information to users. Such services can lead to fuller realization of AVL benefits.

- AVL system design and components must be consistent with the national and regional ITS architecture and established ITS standard to ensure the compatibility with other ITS systems and expandability to include other components in the future.

REFERENCES

Cain, David A. and Pekilis, Barry R. 1993. AVLC Technology Today: A Developmental History of Automatic Vehicle Location and Control Systems for the Transit Environment. IEEE-IEE Vehicle Navigation & Information Systems Conference, Ottawa.

Casey, R. F., et al. 1996. Advanced Public Transportation Systems. State of the Art Update '96. United States Department of Transportation, Washington DC.

Casey, R. F., et al. 1998. Advanced Public Transportation Systems. State of the Art Update '96. United States Department of Transportation, Washington DC.

Chira-Chavala, T., Venter, C. and Gosling, G. 1997. Advanced paratransit System: An Application of Digital Map, Automated Vehicle Scheduling and Location Systems. Institute of Transportation Studies, University of California at Berkeley.

Dana, P. H. An Overview of the Global Positioning System (GPS). Http://www.utexas.edu/depts/grg/gcraft/notes/gps.

Farwell, Randall G., and Marx, Eric. Planning, Implementation and Evaluation of OmniRide Demand Driven Transit Operations: Feeder and Flex Route Services. TRB, April 1996.

Gomez, A., Zhao, F., and Shen, L. D. 1998. Benefits of Transit AVL and Transit AVL Implementation in the U.S. Paper presented at the 77th annual meeting of the Transportation Research Board, Washington, DC.

Khattak, A., H. Noeimi, H. Al-Deek, and R. Hall. 1993. Advanced Public Transportation Systems: A Taxonomy and Commercial Availability, Partners in Advanced Transit and Highways (PATH) Research Report UCB-ITS-PRR-93-9, Institute of Transportation Studies, University of California at Berkeley, California.

Khattak, A., H. Noeimi, and H. Al-Deek. 1996. A Taxonomy for Advanced Public Transportation Systems, Journal of Public Transportation, 1 (1): 39-64.

Khattak, A. and M. Hickman. 1998. Automatic Vehicle Location and Computer Aided Dispatch Systems: Commercial Availability and Deployment in Transit Agencies. Paper presented at the 77th annual meeting of the Transportation Research Board, Washington, DC.

McKeen, R. G. 1997. Urban/Rural Intelligent Corridor Application (URICA) Evaluation Report. ATR Institute, University of New Mexico.

Nelson, John D., 1995. "The Potential for Real-Time Passenger Information as Part of an Integrated Bus-Control/Information System", *Journal of Advanced Transportation*, Vol. 29, No. 1, pp. 13-25.

Okunieff, Paula E. *TCRP Synthesis 24: AVL Systems for Bus Transit*. Transportation Research Board, Washington DC: National Academy Press, 1997.

Tellechea, Suzanne B. and John R. Stone. 1998. AVL Planning for the Winston-Salem Mobility Manager. Paper presented at the 77th annual meeting of the Transportation Research Board, Washington, DC.

Appendix A:
AVL STATE OF THE ART REPORT

Appendix B:
AVL Vendors Report

Vendor Survey Final Report

Abstract

AVL is a rapidly changing technology and it is important to identify companies and products that have been around and will continue to exist in the future. This continuity or "here today still here tomorrow" allows investments in Automatic Vehicle Location (AVL) technology to take place with less risk of a company dissolving and a transit agency being left without maintenance and product support for their investment. To identify these companies a search and survey was done to compile a list of AVL vendors and their products. The following section of this report identifies companies that have a record of serving the transit market. It also provides information about company profiles, products, service plans, and the type and size of AVL systems they have installed to date.

Summary of Findings

The following is a list of major survey finding:

1. Of all the survey participants 80% have been offering AVL products and services to the transit industry for less than 10 years. In contrast the average number of years that each company has been offering products and services for vehicle tracking to the United States military and private sector was 27.

2. Of the survey participants 20% offered Signpost, 40% offered Dead-reckoning, and 80% offered GPS and or Differential GPS. This shows the trend in vehicle location technology is toward supplying the transit industry with GPS or DGPS. Of those vendors that offer products other than GPS such as in the case of Dead-reckoning, it was found that these products are used to add accuracy to a GPS system rather than used as a stand-alone system.

3. Information varied about the accuracy of the individual AVL products offered. Even among the GPS products, accuracy ranged from 300 to 100 meters and for DGPS from 100 meters to 1 meter. This information shows that not all systems have the same performance, regardless if they are in the same category of AVL systems.

4. Conventional radio was the most common communication method utilized in AVL packages. This is due to the prevalence of conventional radio in the transit industry, although it was also indicated that most AVL systems could be made to work using a variety of communication means.

5. In the past, personal computers (PC) used with AVL have been too "under-powered" to run sophisticated software programs. This meant that specially designed workstations were custom built and used in place of the PC for many years. With the increasing

speed and power of the microprocessor this is no longer the case. All survey participants use a PC to display vehicle movements in situations that call for tracking less than 100 vehicles. The PC operating systems used range from Windows 95 to NT. At a point between 100 and 500 vehicles the option of using a workstation or a PC should be considered. If more than 500 vehicles will be displayed, then a workstation is still recommended.

6. The maps used to display the location of vehicles as they travel are obtained through three ways. The first way is to purchase the map information from outside vendors. Most major cities have been digitally mapped by vendors. These digitized maps are sold for a variety of reasons. Out of the total number of participants, 80% said that they obtain their maps in this fashion. The next possibility is for the AVL vendors to digitize their own map. This is usually accomplished through the Federal Government Census's TIGER files for less than $100. And the final possibility is to get a digitized map from a municipality that uses a Geographical Information System (GIS). Many GIS systems require the same information that an AVL systems uses to track vehicles making it very easy and inexpensive to generate the base map.

7. Service programs are consistent among AVL vendors. Information gathered from participants showed the average system warranty to be 12 months with maintenance provided through service contracts arranged between the vendor and the transit agency.

8. The average number of systems any vendor has installed and is in the process of installation was 8, with the highest number of installations being 15 and the lowest 5. Out of these systems the largest single installation of vehicles in any given systems was 12,000 (taxi system in Singapore) and the smallest was 5 (Orlando, FL demo).

Methodology

The process of compiling information on various vendors required several steps. The first step was to identify the possible vendors that are servicing or could service the transit industry. This was done three ways, through industry publications, Federal Government documents, and through Internet search engines. Through industry publications, only a handful of vendors was obtained. Federal documents, especially those gathered through the Federal Transit Administration, yielded a more detailed list of over 15 possible companies. The Internet search yielded more vendors. The following information was obtained from these searches and compiled into lists of possible AVL vendors.

APTS Co. Name Other Information

From Publications

AVL-GPS	Orbital Science Corporation - ITS	20301 Century Boulevard	Germantown	MD
AVL-GPS	Harris Corporation	P.O. Box 5100	Melbourne	FL
AVL-GPS	3M Intelligent Transportation Systems	3M Center, Building 225-4N-14	St. Paul	MN
AVL-GPS	Rockwell International	Dept.120-130, 350 Collins Road NE	Cedar Rapids	IA
AVL-GPS	Transportation Management Solutions	800 International Drive, Suite 110	Linthicum	MD

From Federal Transit Administration

AVL-GPS	Rockwell Int'l	SunTran	Tucson	AZ
AVL-SO	General Roadway Signal	LAMTA	Los Angeles	CA
AVL-GPS	3M Corp.	The Vine	Napa	CA
AVL-SO	Motorola	Muni	San Francisco	CA
AVL-GPS	UMA, Trimble	Outreach	San Jose	CA
AVL-GBR	Teletrac (lease Co.)	SMMBL	Santa Monica	CA
AVL-GPS	Traffic Management Solutions	RTD	Denver	CO
AVL-GPS	Harris Corp.	SCAT	Cocoa	FL
AVL-GPS	Ericson	MDTA	Miami	FL
AVL-GPS	Management Analysts	Arc Transit	Palatka	FL
AVL-SO	Glenayre	Municipality	Louisville	KY
AVL-GPS	Orbital Science	Ride-On	Montgomery	MD
AVL-GPS	GMSI	WSTA	Winston-Salem	NC
AVL-SO	F&M Global	TRT	Norfolk	VA
AVL-LC	II Marrow	STS	Sheboygan	WI
AVL-SO	Siemens	LTC	London	ON

From Internet Search

AVL-GPS	II Marrow Inc.	2345 Turner Road SE	Salem	OR
AVL-GPS	Ashtech	1170 Kifer Road	Sunnyvale	CA
AVL-GPS	Locsys Inc.	2016 East Broadway Boulevard	Tucson	AZ
AVL-GPS	Orbital Science Corporation - ITS	20301 Century Boulevard	Germantown	MD
AVL-GPS	Glenayre Electronics, Inc.	5935 Carnegie Blvd.	Charlotte	NC
AVL-GPS	Harris Corporation	P.O. Box 5100	Melbourne	FL
AVL-GBR	Teletrac			
AVL-GPS	Motorola			
AVL-GPS	3M Intelligent Transportation Systems	3M Center, Building 225-4N-14	St. Paul	MN
AVL-GPS	Rockwell International	Dept.120-130, 350 Collins Road NE	Cedar Rapids	IA
AVL-GPS	Pacific Arepco	3195B Airport Loop Drive	Cosa Mesa	CA
AVL-GPS	CES Wireless Technologies	925122 S. Semoran Boulevard	Winter Park	FL
AVL-GPS	Datalink Systems Inc.		Vancouver	B.C.
AVL-GPS	Matrixmedia-Unicom	P.O. Box 3486	Winter Springs	FL
AVL-GPS	AVL Information Systems Inc.	16135 Harper Avenue, Suite 210	Detroit	MI
AVL-GPS	PacComm Packet Radio Systems, Inc.	4413 N. Hesperides Street	Tampa	FL
AVL-GPS	Thorcom Systems Limited	Unit 4, 96B Blackpole Trading Estate West	Worcester	U.K.
AVL-GPS	American Technologies Inc.	460 Cedar St.	Fond du Lac	WI
AVL-DR	Andrew Corporation	10500 W. 153rd Street	Orland Park	IL
AVL-GPS	International Road Dynamics Inc.	702-43rd Street East	Saskatoon	SK
AVL-GPS	Advanced Research Corporation	8195 Spire Ct.	Colorado Springs	CO
AVL-GPS	Transportation Management Solutions	800 International Drive, Suite 110	Linthicum	MD
AVL-GPS	Automatic Vehicle Location Systems Ltd.	6130 3rd street SE, Suite 500	Calgary	Alberta
AVL-GPS	Trimble Navigation Limited	675-J Tollgate Road	Elgin	IL
AVL-GPS	General Railway Signal Corp.	P.O. Box 20600	Rochester	NY
AVL-GPS	Position Inc. USA	16155 Park Row, Suite 190	Houston	TX
AVL-GPS	Starlink, Incorporated	6400 Highway 290 East, Sutie 202	Austin	TX
AVL-GPS	GMSI Inc.		Schaumberg	IL
AVL-GPS	ElectroCom Communications Systems	2910 Avenue F	Arlington	TX

On these lists several companies appeared more than once. However, several others appeared only on a single list such as many of the vendors obtained from the Internet. At this point, a decision was made to focus on companies that appeared in more than one list and to draw heavily from the list obtained through the FTA. In this way, information would be gathered from vendors that maintain a presence in the transit industry. This decision allowed information gathered to be more relevant to the project. A final list of the vendors contacted appears below.

APTS	***Company***
AVL-GPS	3M Corp.
AVL-GPS	Ericson
AVL-GPS	GMSI
AVL-GPS	Harris Corp.
AVL-GPS	Management Analysts
AVL-GPS	Orbital Science
AVL-GPS	Rockwell Int'l
AVL-GPS	Traffic Management Solutions
AVL-GPS	UMA, Trimble
AVL-LC	II Marrow
AVL-SO	F&M Global
AVL-SO	General Roadway Signal
AVL-SO	Glenayre
AVL-SO	Motorola
AVL-SO	Siemens

After the final list was compiled, the focus of the project shifted to identifying information about individual vendors and the AVL industry as a whole. Information gathered looked to answer basic questions such as: What industries do their products serve? How many systems have they installed? Do they have any experience doing work for government agencies? Etc. Firms on the final list were contacted with a survey that focused on information about their products for transit agencies.

The survey used had four categories of questions. These categories were *company profile, product profile, service profile,* and *installed systems profiles*. Each area category had a specific purpose as outlined below.

COMPANY PROFILE

Survey questions in this area dealt with the company's organization and background to give insight on where the company has been and its future.

PRODUCT PROFILE

Questions in this area highlight the products and services offered by the agency. Information is narrowed to AVL hardware, Communication Packages, and Mapping or Display Systems.

SERVICE PROFILE

In this area the vendor will have the opportunity to explain how individual systems are serviced after they are installed.

INSTALLED SYSTEMS PROFILE

The final area of the survey addressed the size and location of installed systems. Included in this area were questions on the feasibility or knowledge of any regional AVL system in planning or operating.

A copy of the survey form used for this step of the project appears in the Appendix.

Results of the Survey

Since most of the vendors used in the survey were obtained through Federal documents there was a problem in locating a person to contact at each firm. This was due to the lack of a phone numbers and addresses in the original documents. It was also found that some companies have merged, been bought out, or no longer have the same address or phone number. Out of the initial 15 vendors that were picked for the survey 3 where found to no longer be in business or no longer offer AVL products. Other companies have one primary salesperson that handles all questions and comments on their products which made it difficult to acquire information. Two other companies declined to participate in the survey. Out of those that remained the following information was generated, results are presented here broken down into the categories used on the survey form.

Company Profile

Of all the survey participants approximately 80% of them have been offering AVL products and systems to the transit industry for less than 10 years. However, several of these same vendors have been offering vehicle-tracking technology to the US military and commercial fleet sectors for the past two decades. In fact, one of the current vendors that participated in the survey was responsible for helping the US military deploy the first GPS constellation.

Product Profile

AVL Hardware:

The survey originally listed GPS, DGPS, Signpost, and Dead-reckoning as the different AVL hardware systems that are on the market. From contacts made with the vendors 80% of them offered GPS or DGPS systems, 40% offered Dead-reckoning (mostly as a backup to GPS systems), and 20% offered Signpost technology. This may be surprising considering that GPS is the newest of the available technologies. Accuracy of these systems was also listed by vendors as between 100 to 300 meters for GPS systems and for DGPS 100 to 1 meter. This shows that among different vendors there is a difference in the products available even though they are using the same satellites.

Communication Packages:

Of the participants in the survey, all expressed the ability to use the transit agency's existing communication systems as a means for linking the vehicle with the monitoring station. The most common communication system encountered by the vendors is conventional radio.

Mapping and Location Display Systems:

The number of vehicles that need to be tracked and a transit agency's location will affect an AVL vendor's decision on what hardware and mapping systems that it will provide. In situations where the number of vehicles is more than 500, many vendors recommend an especially designed workstation over the personal computer (PC). This is due to the speed and memory restrictions of most PC's. However, when the number of vehicles is less than 500 or as little as 100, a PC is the most commonly used system. When a PC is used the most commonly used operating system is Windows NT, however, Windows 95 is also utilized. And in larger urban areas AVL vendors will elect to purchase available digital maps from a supplier or inquire if that municipality has a Geographic Information System (GIS) file with a digital map that can be utilized. In areas where no digital maps exists a vendor may choose to construct their own digital map through TIGER files obtained through the Census Department of the Federal Government.

Service Profile

Survey participants listed a 12-month period as the standard AVL system warranty. If during that time the system should fail or not perform to expectations, the cost of adjusting or fixing is still included in the original purchase price. The one-year is the industry standard; however, service contracts, which a vendor negotiates with the transit agency, vary greatly depending on the individual needs of the agency.

Installed Systems Profile

The number of systems a company has installed and is in the process of installing was not as many as would be expected. The average number of systems any vendor has installed for transit agencies was 8. The largest number of AVL systems that any vendor had installed was 15 and the lowest 5. However, when looking at the number of vehicles that were outfitted with AVL technology in any given contract, the largest number appears to be 12,000 for a taxi system in Singapore and the smallest 5, which was a demonstration project done for Orlando Florida.

Conclusion

When evaluating the results of the AVL vendor survey one can see that there are similarities or emerging trends between different companies. With 80% of the vendors offering GPS and DGPS, the trend shows that this will likely become the preferred way to track and monitor vehicles. The display units, which only a few years ago would have been all workstations due to the under-powered PC, are now PC's, as their speed and processing power have increased. In addition, it will be more likely that vendors will also utilize existing digital maps as more municipalities generate city grids using GIS and as the digital map vendors branch out from the large urban areas. In the coming years, the market will continue to converge on similar products and methods for producing these systems which will lead to competition growing and lower prices. This will allow for further growth and better products.

Appendix C: Survey Forms

The purpose of this survey is to assess the impact of using improved technology in transit facilities to provide better service to the riders. By filling out this form you are giving informed consent to be in this study. All information will be anonymous.

1. **How often do you ride the bus?**

❒ More than 5 times a week. ❒ 3-5 times a week. ❒1-2 times a week

❒ 1-3 times a month. ❒ Less than once a month

2. **What is the purpose of your trip today?**

❒ Work ❒ Shopping ❒ School ❒ Medical ❒ Other

3. **How do you get information about the bus service?** (check all that apply)

________I have a copy of the bus schedule

________I call the bus company

________From other people

________From information displayed at the bus stop

________ Other____________________________

4. **Do you use the bus schedule for planning your trip?**

❒ Yes ❒ No ❒ Sometimes

5. **How long did you have to wait for the bus today?**

❒ Less than 5 min ❒ 5-10 min ❒ 10- 15 min ❒ More than15 min

6. **Is the schedule information displayed on-board the bus adequate?**

❒ Yes ❒ No

7. **How would better information about when the bus actually arrives at the stop affect your use of transit?** ❒ Ride more ❒ Ride less ❒ Ride the same

8. **Please rate how important the following are in your decision to ride the bus**.

	Very Important	Somewhat Important	Neutral	Somewhat Unimportant	Very Unimportant
To have information at the bus stop on when the bus will actually arrive	❒	❒	❒	❒	❒
Bus arrives at the scheduled time	❒	❒	❒	❒	❒
Knowing how late the bus is in case of a delay	❒	❒	❒	❒	❒
Displaying the next stop inside the bus	❒	❒	❒	❒	❒
Having the driver call out the stops	❒	❒	❒	❒	❒
Knowing the bus is equipped with a 911 emergency system	❒	❒	❒	❒	❒
Knowing that another bus can be immediately dispatched if there is a breakdown	❒	❒	❒	❒	❒
Knowing the transit system uses the latest vehicle location technology	❒	❒	❒	❒	❒
Having a seat available at all times	❒	❒	❒	❒	❒
Low bus fares	❒	❒	❒	❒	❒

9. **Did you have a car available that you could have used for the trip you are making today?**

❒ Yes ❒ No

10. **Are you a:** ❒ Male ❒ Female

11. **What is your age group:**

❒ Under 18 ❒ 18-25 ❒ 26-45 ❒ 46-65 ❒ Over 65

12. P**lease use the back of this page to let us know if you have any additional suggestions or information you think will be helpful in providing better bus service.**

Page 1 of the Vendor Survey

Vendor Survey "Draft I"

The following survey is being done for the Wisconsin Department of Transportation as part of the "Evaluation of Automated Vehicle Location Systems" project. The purpose of this survey is to gather knowledge on available Automatic Vehicle Location vendors and suppliers. Please take a few minutes to complete this form, your assistance and help are greatly appreciated.

COMPANY PROFILE

Name of Company: ________________________________

Mailing Address: ________________________________

City: ______________ State: ____ Zip: ______

Years your company has offered AVL technology: ________

Services or products offered before marketing AVL: ______________________

____

____

PRODUCT PROFILE

AVL Hardware

Current AVL technology that you offer (circle):

GPS *DGPS* *Signpost* *Dead-reckoning*

Other explain: ______________________________

List of products offered:

____

____

____

____

____

(please mail informational brochures along with survey on the products listed.)

Accuracy range in systems available: ______________________

Special conditions that effect accuracy: ______________________

Communication Packages

What form of communication package (vehicle to agency) **is not** compatible with your AVL hardware technology: ________________________________

What is the most commonly used communication package your products utilize:

____

Mapping or location display system

Briefly describe how vehicle locations are displayed at an agency's control room:

____

____

____

____

Page 2 of the Vendor Survey

Briefly describe how base map information is acquire for this operation:

____
____
____
____

SERVICE PROFILE

How many months is the standard warrantee for a system once installed:

____

How are updates to the technology handled: __________________________
____
____

INSTALLED SYSTEM PROFILE

How many systems has your company completed installing to date: __________

What is the largest number of vehicles your company has installed during a single contract:

____

What is the smallest: _____

List references that could be contacted to address questions on how your systems are performing:

____
____
____
____
____

To your knowledge has your company or any other installed a regional AVL system that is shared by multiple agencies: _______

If yes can you indicate who to contact for additional information: __________
Phone: __________

Survey conducted by the Center for Urban Transportation Studies