Automatic Vehicle Location Successful Transit Applications

A Cross-Cutting Study

Improving Service and Safety

August 2000

Foreword

Dear Reader,

We have scanned the country and brought together the collective wisdom and expertise of transportation professionals implementing Intelligent Transportation Systems (ITS) projects across the United States. This information will prove helpful as you set out to plan, design, and deploy ITS in your communities.

This document is one in a series of products designed to help you provide ITS solutions that meet your local and regional transportation needs. The series contains a variety of formats to communicate with people at various levels within your organization and among your community stakeholders:

- **Benefits Brochures** let experienced community leaders explain in their own words how specific ITS technologies have benefited their areas;
- **Cross-Cutting Studies** examine various ITS approaches that can be taken to meet your community's goals;
- **Case Studies** provide in-depth coverage of specific approaches taken in real-life communities across the United States; and
- **Implementation Guides** serve as "how to" manuals to assist your project staff in the technical details of implementing ITS.

ITS has matured to the point that you are not alone as you move toward deployment. We have gained experience and are committed to providing our state and local partners with the knowledge they need to lead their communities into the next century.

The inside back cover contains details on the documents in this series, as well as sources to obtain additional information. We hope you find these documents useful tools for making important transportation infrastructure decisions.

Christine M. Johnson
Program Manager, Operations
Director, ITS Joint Program Office
Federal Highway Administration

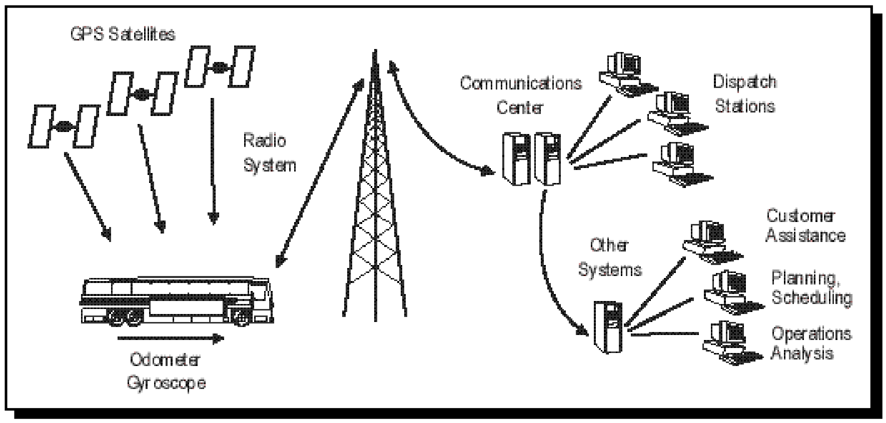
Edward L. Thomas
Associate Administrator for
Research, Demonstration and
Innovation
Federal Transit Administration

Contents

Introduction and Rationale for AVL

What is Automatic Vehicle Location?

Automatic vehicle location (AVL) is a computer-based vehicle tracking system. For transit, the actual real-time position of each vehicle is measured and its location is relayed to a control center. Actual position determination and relay techniques vary, depending on the needs of the transit system and the technology (or technologies) chosen. Typically, vehicle position information is stored on the vehicle for a time, which can be as short as a few seconds or as long as several minutes. Position information can be relayed to the control center in raw form or processed on-board the vehicle before its transmission.



Why Have Agencies Installed Automatic Vehicle Location Systems?

Transit agencies have implemented AVL systems to assist them in a number of ways. These include the following:

Operations
- Improve schedule adherence.
- Improve service efficiency.
- Achieve better command and control of system.
- Improve bus schedules.
- Pre-process data for dispatcher.
- Facilitate systems integration.
- Improve information accuracy and availability.
- Provide better operations support.
- Reduce the number of street supervisors.
- Simplify operation of vehicle for the operator.
- Provide customers with real-time service information.

Communications
- Replace aging radio system.
- Improve radio call management.
- Reduce voice communications through mobile data terminals.
- Reduce lost calls from operators.

Safety
- Improve safety on buses.
- Improve response times to incidents and emergencies.

AVL Operations

What Methods Are Used to Determine Vehicle Position?

The dominant technology deployed today for locating the vehicle for AVL is the use of the Global Positioning System (GPS). GPS technology uses signals transmitted from a network of 24 satellites in orbit around the earth and received by a GPS antenna placed on the roof of each bus. A GPS receiver calculates its position based on signals received from at least three satellites. GPS works anywhere the satellites signals reach. However, satellite signals do not reach underground and can be interrupted by the presence of tall buildings ("urban canyons") or dense foliage. In areas where this is a problem, GPS is often supplemented by another method of position determination, such as dead-reckoning, for extrapolation of location from the last GPS reading until the next GPS measurement.

Dead-reckoning is a method of determining bus position by measuring the distance traveled from a known location through odometer readings and the direction of travel through compass headings. This method is less precise than the others, so it is usually employed as a supplement to the principal location technology.

Until May 2000, the accuracy of GPS data was about 100 meters. Through processing, most AVL systems achieve better accuracy than standard GPS. However, to further improve the position location accuracy, many transit agencies installed "differential GPS" (DGPS) when techniques such as signal priority were being employed or contemplated. In May 2000, the GPS accuracy was dramatically improved when the US military removed the intentional degradation to the signal that had been in place since GPS began operation. The accuracy of GPS today is between 10 and 20 meters. This improved accuracy of GPS could eliminate the need for DGPS. However, there is not enough data at this point to confirm this conclusion.

Under DGPS, a GPS receiver is placed at a stationary site where the location has been precisely determined. The difference between this known location and its GPS-measured location is applied as a correction to the GPS-determined vehicle position to improve accuracy. A Nationwide DGPS system (NDGPS), providing differential correction free of charge, is being deployed by the U.S. Department of Transportation and currently covers most cities in the U.S. The entire country will be covered by 2002. To use this system, a transit agency would only need to purchase the receiver to utilize these GPS corrections. This option is substantially cheaper than establishing a unique differential station, as was done prior to the advent of the NDGPS system.

Prior to the availability of GPS, the most common form of AVL chosen by transit agencies was the signpost system in which a series of radio beacons are placed along the bus routes. The identification signal transmitted by the signpost is received by a short range communication device on the bus. Since the location of each signpost is known, the location of the bus at the time of passing the signpost is determined. The distance traveled since passing the last signpost, as measured by the bus odometer is used to estimate the bus position along its route. However, this method is limited because signposts are placed at fixed locations. Thus, changes in bus routes could require the installation of additional signposts. Additionally, the system is incapable of tracking vehicles that stray off-route.

AVL Operations

How Are Data Transmitted to Dispatch?

The two most common methods of transmitting bus location data to dispatch are through polling and exception reporting via wireless communications. Under polling, the computer at dispatch operations polls each bus, in turn, asking for its location. This method requires the bus to be able to read or calculate its position. The bus location is then transmitted by radio to the dispatch center. Once all the buses have been polled, the computer starts again with the first bus and repeats the cycle. The amount of time it takes to complete a cycle will increase as the number of buses to be polled increases. However, because the computer can poll different buses simultaneously over different radio channels, the time to complete a polling cycle depends on the number of radio channels that are utilized. Most agencies employing polling query the buses at fixed intervals. In exception reporting, each bus reports its location to dispatch at only a few specified locations or where the bus is running off-schedule beyond selected tolerances. Exception reporting makes more efficient use of available radio channels, which are often scarce commodities. Many agencies use a combination of polling and exception reporting.

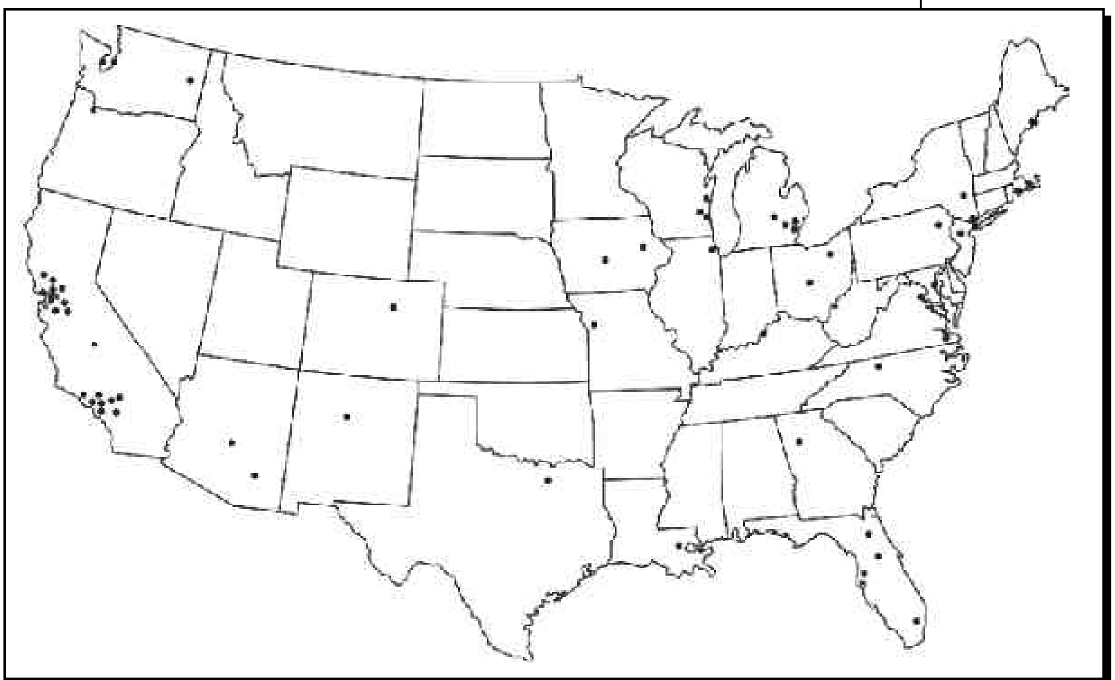
How Are Data Used By Dispatch?

Data transmitted from the transit vehicles are assimilated by Computer Assisted Dispatching (CAD) software that enables bus status, condition, position, schedule adherence, operator, and incident information to be displayed on computer screens at dispatcher workstations. CAD software also manages communications, assists the dispatcher in making operational decisions, and archives data for a variety of other transit agency needs.

Operational Systems

How Many Agencies Have Deployed AVL?

A recent study has identified at least 61 transit agencies with operational AVL systems. A hundred others are in the planning or implementation stages. The locations of operational systems are indicated on the map (below). For identification of these transit agencies, as well as those in the planning or implementation stages, see the report *Advanced Public Transportation Systems Deployment in the United States—Update January 1999,* referenced at the end of this document.



Features Integrated with AVL Systems

Transit agencies often incorporate other advanced public transportation system features in conjunction with AVL system implementations. These include the following:

Normally Integrated with AVL Systems

- Computer-aided dispatch software
- Mobile data terminals
- Emergency alarm
- Digital communications.

Sometimes Integrated with AVL Systems

- Real-time passenger information
- Automatic passenger counters
- Automated fare payment systems
- Automatic stop annunciation
- Automated destination signs
- Vehicle component monitoring
- Traffic signal preferential treatment.

Study Site Summaries

Five transit authorities were visited to collect information for this cross cutting study: Milwaukee County Transit System (Milwaukee, Wisconsin); Ann Arbor Transportation Authority (Ann Arbor, Michigan); King County Department of Transportation, Metro Transit Division (Seattle, Washington); Tri-County Metropolitan Transportation District (Portland, Oregon); and the Montgomery County Transportation Authority (Rockville, Maryland). In addition, information from the Regional Transportation District (Denver, Colorado) AVL system, which is the subject of a Federal Transit Administration evaluation, is included in this cross-cutting study. The table below contains summary information on AVL installations as well as on the other advanced public transportation system components that have been, or are expected to be, installed in conjunction with AVL at these sites. The majority of these other components are dependent upon AVL for optimum effectiveness.

	Milwaukee County Transit System	Ann Arbor Transportation Authority	King County Department of Transportation	Tri-County Metropolotan Transportation District	Montgomery County Transportation Authority	Regional Transportation District
Location Technology	DGPS	Dead-reckoning with correction by DGPS	Signpost and odometer	DGPS	DGPS	GPS
Number of Buses equipped with AVL	535	82	1,343	659 fixed route; 179 demand response	99 installed now, 237 ultimately	800
Computer-Assisted Dispatching	Yes	Yes	Yes	Yes	Yes	Yes
Number of Dispatch Stations	8	2	5	6	2	6
Mobile Data Terminals	Yes	Yes	Yes	Yes	Yes	Yes
Automated Traveler Information	1 kiosk at airport; in-bus annunciators if funding available	2 monitors at transit center; in-bus signs and annunciators; external announcements; planning Internet interface	4 monitors at two transit centers; a few stops with real-time information; automated call-in bus stop schedules; will have trip planning with Internet interface	40 transit mall displays - ultimately real-time; soon to have trip planning software; planning Internet real-time information	1 kiosk; LCD screens showing schedule at 3 locations now - ultimately many more with real-time information	Signboards at transit mall terminal stations
Electronic Fare Payment	No	Smart cards planned for the future	Smart card regional system being developed	No	No	No
Surveillance Cameras	On 183 buses	On 51 buses	No	On 67 buses now, 118 more this year	No	No
Automatic Passenger Counters	Will be placed on 35 buses	On 9 buses	On 158 buses	On 25-30% of buses –goal is 100%	No	No
Silent Alarm	Yes	Yes	Yes	Yes	Yes	Yes
Remote Diagnostics	No	Yes	No	No	No	Yes
Signal Priority	No	No	Will test in two corridors	In future	Yes	No
Information Source	Michael Giugno Ron Rutkowski Kelley Jaynes	Greg Cook Bill Hiller	Daniel Overgaard	Kenneth Turner Ronald Jagow	Alfie Steele	Draft evaluation report - Castle Rock Consultants

Findings

AVL Systems Cost

The capital cost of an integrated installation of AVL and other advanced public transportation system components is dependent on the size of the system, its level of sophistication, and the components to be included. Systems included in this cross-cutting study ranged from those with fairly basic features (GPS or DGPS AVL, computer-assisted dispatching, mobile data terminals, silent alarms, remote diagnostics, and limited automated passenger information) to very comprehensive systems that also included automatic passenger counters, surveillance cameras, additional radio or microwave tower and extensive automated passenger information, including allowances for future smart card fare payment and traffic signal priority. The number of AVL-equipped buses identified in this study ranged from 82 to 1,343. There is a significant cost for the equipment and software that reside at the operations/dispatch center. Often, the installation of AVL coincides with a new or major upgrade to the communications system. Therefore, the per-bus cost of large fleets is less than for smaller fleets, assuming similar features, because the cost of this major infrastructure is distributed over a larger number of vehicles.

The cost per AVL-equipped bus at the six study sites ranged from $6,800 to $30,500. Four were grouped between $11,100 and $16,900, a much narrower range. The average per-bus cost for all six systems was just over $15,500. These cost figures represent the total system cost divided only by the number of transit and paratransit vehicles outfitted. In most cases, supervisory and sometimes maintenance vehicles were also equipped with AVL and mobile data terminals.

Benefits of AVL Installations

Personnel at the cross-cutting study sites reported the following benefits from their integrated implementation of AVL and other advanced public transportation system components:

Operations

- Improved schedule adherence
- Improved transfer coordination
- Improved ability of dispatchers to control bus operations
- Facilitated on-street service adjustments
- Increased accuracy in schedule adherence monitoring and reporting
- Assisted operations during snowstorms and detours caused by accidents or roadway closings
- Effectively tracked off-route buses
- Effectively tracked paratransit vehicles and drivers
- Eliminated need for additional road supervisors
- Reduced manual data entry
- Monitored driver performance
- Received fewer complaints from operators.

Findings

Communications

- Reduced voice radio traffic
- Established priority of operator calls
- Prevented radio calls from being lost
- Improved communications between supervisors, dispatchers, and operators.

Passenger Information

- Provided capability to inform passengers of predicted bus arrival times
- Helped meet Americans with Disability Act requirements by using AVL data to provide stop annunciation
- Increased number of customer information calls answered
- Eliminated need to add customer information operators.

Customer Relations

- Received fewer customer complaints
- Used playback function in investigating customer complaints
- Used AVL data to substantiate agency's liability position
- Improved image of agency.

Scheduling and Planning

- Provided more complete and more accurate data for scheduling and planning
- Expected to ultimately reduce schedule preparation time and staff
- Aided in effective bus stop placement
- Generated more accurate ridership counts with automatic passenger counters
- Expected to improve bus productivity.

Safety and Security

- Used AVL-recorded events to solve fare evasion and security problems
- Reduced the number of on-bus incidents by use of surveillance cameras
- Provided more accurate location information for faster response
- Foiled several criminal acts on buses with quick response
- Enhanced drivers' sense of safety.

Findings

Although the six study sites have reported the previous benefits, not all can be quantified, and fewer still have actually been measured. In order to provide a larger body of evidence that AVL and other ancillary advanced technologies, many of which depend on AVL in order to function, produce real benefits to transit agencies, the limited data from the study sites has been supplemented below by data from installations at other locations.

Examples

- Schedule adherence improved by 23% in Baltimore, 12.5% in Kansas City, 8.5% in Hamilton (Ontario), and 4.4% in Milwaukee after AVL installation.
- Kansas city was also able to reduce the number of buses serving key routs without reducing service based on the analysis of AVL data.
- Customer complaints have fallen by 26% in Denver since AVL installation.
- Assaults on bus operators and passengers dropped by 20% in Denver.
- AVL playback capability confirmed that about 50% of customer complaints were invalid in Milwaukee.
- Schedule adherence reporting accuracy increased from 70% (manual checks) to 95% (AVL data) in Milwaukee.
- London (Ontario) eliminated manual schedule adherence checking and saved $45,000 annually.
- Response time to the scene of operator calls for assistance decreased from 7-15 minutes to 2-3 minutes in Kansas City after AVL implementation.
- Voice radio traffic was reduced by 70% in Ann Arbor through use of mobile data terminals.
- New Jersey Transit's interactive voice response system reduced information request telephone wait time from 85 to 27 seconds and monthly calls increased by 40,000.
- San Diego County's automated voice response system increased call handling productivity by over 21%.
- Information request calls increased by 80% in Rochester (New York) after installation of an automated transit information system. Four part-time information agent positions were eliminated because the automated system answers 70% of calls.
- New Jersey Transit's revenues increased by 12% after automated fare collection installation. The system also saves millions of dollars per year in fare media handling costs.
- Tens of millions of dollars in fare evasion are saved per year by the automated fare collection system in New York City.

Implementation Challenges

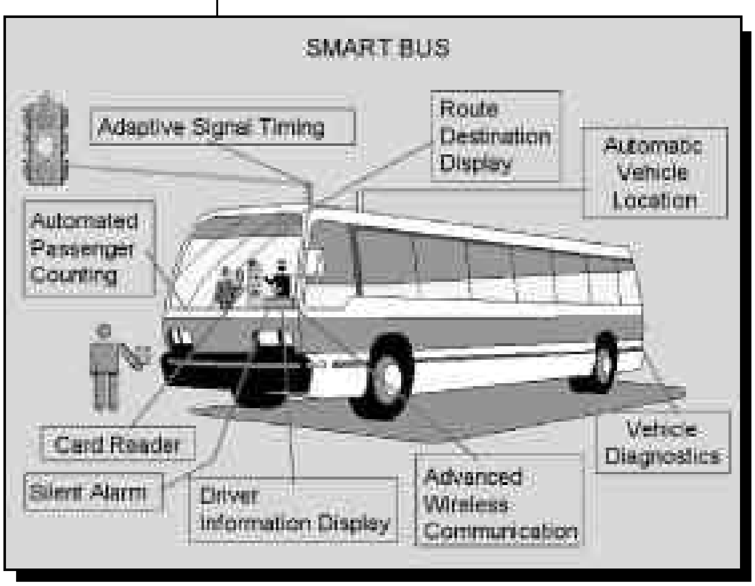
The transit agencies in this study were early adopters of AVL systems. Therefore, it would be expected that they would experience more problems than agencies implementing AVL today. For this very reason, it is advisable that agencies procuring an AVL system should attempt to use essentially an existing design, making as few changes as possible. This approach will substantially reduce the severity of problems. The study agencies reported they had experienced both unanticipated and anticipated implementation challenges. For those agencies considering AVL systems, the following issues should be considered:

Implementation

- Implementation delays are possible especially if any software development is required.
- Institutional relationships may be difficult.
- Development of new software or extensive customization of existing software can result in many possible problems.
- Considerable effort may be required to establish an accurate geographic information system database.
- Systems must be consistent with the National Intelligent Transportation Systems Architecture.

Operations

- New technical expertise is usually required at the transit agency.
- Some existing staff may be reluctant to learn the new technology.
- Additional staff may be needed in maintenance, dispatching, or programming/information processing.
- A longer connection time may result for dispatcher-operator voice communications.
- The schedule adherence function design requires careful thought.
- A global positioning system signal reception problem may occur in certain areas.



Implementation Challenges

- The huge volume of data that an AVL system can record may overwhelm existing agency analysis capability.
- Departments sharing data may need to adapt to a standard format.

It would appear that the most disappointing aspect for agencies during AVL implementation has been the lengthy procurement and installation period. All the cross-cutting site installations have been delayed beyond their initial completion schedule, sometimes for several years for various reasons. The procurement process itself has sometimes been a cause of delay. There have been situations where multiple solicitations for proposals have been issued. Some solicitations have been withdrawn due to vendor bids exceeding the amount of funding available. A few contracts have been terminated due to contractor nonperformance. The need to develop a suitable replacement for inadequate equipment has also caused delays. The necessity of correcting faulty equipment installation has stalled progress at some sites. The integration of new technology elements has also been a major problem area. But, in many cases, the major cause of delay has been the new software development required to meet the functionality specified by the contracting agency.

If you believe new software functionality that is not available from any vendor is required for your agency, it would be prudent to buy a system that most closely meets your needs; install it and gain operational experience; then embark upon a modification effort to develop the new functionality. **This option will reduce the risk of software development.**

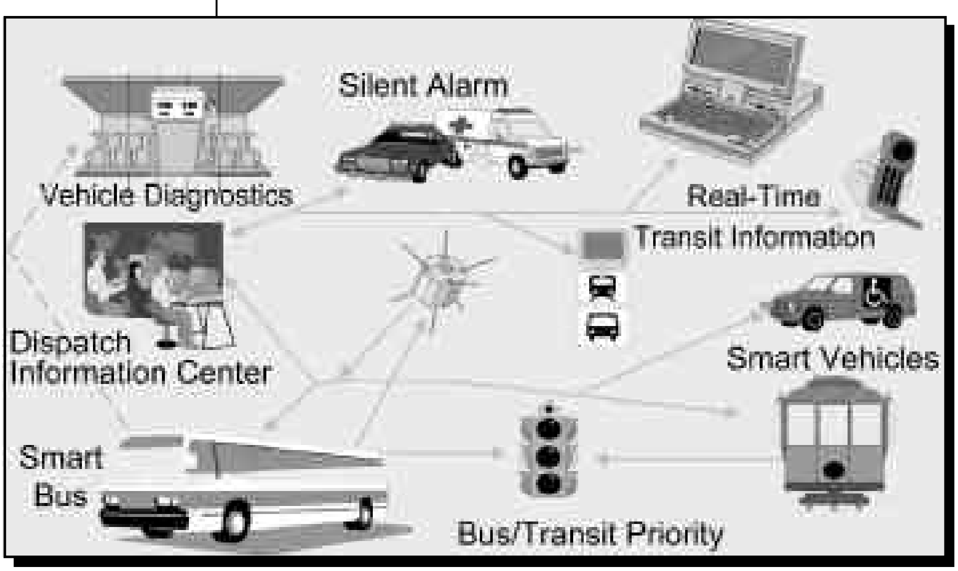
Integration Opportunities

Despite the difficulties encountered to date by the early adopters, the situation has improved. Recent implementations have experienced fewer problems. The implementation process should become faster and more trouble free as additional knowledge is gained from the experiences of others, especially as a substantial number of new AVL systems are now in the installation stages and as this experience translates into well-written specifications.

Integration of Intelligent Transportation Systems elements is a key goal of the U.S. Department of Transportation. Having AVL-equipped buses offers many possibilities for transit interface with highway and traffic organizations or transportation management centers. Opportunities include: providing transit buses with traffic signal priority; obtaining traffic congestion data at the dispatch center to allow rerouting of buses or informing customers of delay; incorporating transit information in traveler information systems; developing multi-application electronic payment systems; using buses to automatically communicate traffic speed; and reporting of roadway incidents by transit vehicle operators.

Traffic signal priority on arterials and at freeway on-ramps can substantially improve the schedule adherence of transit vehicles and reduce run times. This effort requires cooperation between transit and highway departments because traffic signals are normally the responsibility of highway departments, and giving transit vehicles priority affects other vehicle movements.

Transit information should be an important element of any regional traveler information system. Adding real-time transit information to available highway information can be helpful to travelers in making mode choice decisions and would be expected to increase transit ridership.

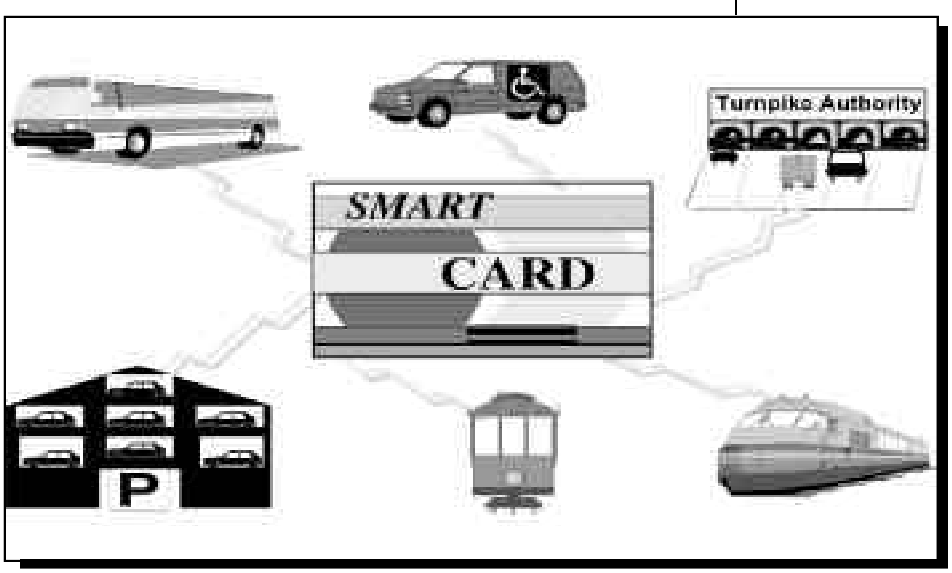


Integration Opportunities

Electronic fare payment may be one of the more appealing adjuncts to an AVL system for potential riders because of the convenience it offers the user. The greatest benefits of electronic payment systems would result from the inclusion of multiple transit agencies and integration with other activities, such as toll collection, and payment for parking and retail purchases.

AVL-equipped buses can be used as probes for determining travel speeds on freeways and arterial roadways—a valuable information resource for a transportation management center, especially one with limited traffic detection or observation capabilities, particularly on arterials. Bus operators can also be useful in reporting incidents they see during their trips. Using the known location of the bus at the time of an incident report, the response of arterial, freeway, and incident management systems and emergency services can be more quickly provided. Paratransit dispatchers would be able to more efficiently route their vehicles if they have real-time information on freeway and arterial speeds and incidents.

Even though none of the study sites have all of these elements in place now, some will be implemented soon. For example, King County Metro will be a major participant in a multiagency bus, ferry, and rail smart card system for the Puget Sound area and will be testing traffic signal priority in two corridors. The Tri-County Metropolitan Transportation District also has plans for traffic signal priority. Montgomery County is planning a transportation management center. Nevertheless, the limited amount of integration that currently exists in the U.S. indicates that the integration of transit and traffic can produce significant benefits to both agencies. However, much education needs to be conducted to institutionalize the integration of transit and highway systems, with their considerable economic, efficiency, safety, and customer service benefits.



Recommendations

Cross cutting study agency personnel provided numerous recommendations for others who are about to begin development and implementation of an AVL system:

Requirements Development

- Get input from all departments regarding what the system should do; build internal support.
- Check with your peers; make visits to other locations that have deployed similar systems.
- Ensure requirements are realistic and fit the budget.
- **Use existing software products whenever possible to avoid new software development.**

Specification Development

- **Ensure that an open architecture is developed.**
- Write functional, not design, specifications.
- Specify standards to be followed.
- Specify the ability to disable the route and schedule adherence function at certain locations.
- Specify that the software provides direct input of AVL data to scheduling and other departments in the form that is needed.
- Specify reporting functions desired.

Contracting

- Write fixed-price contract with payment milestones.
- Manage scope creep.
- Make software upgrades a part of the contract.
- Specify prototype fleet and testing of it before full fleet build; simulate entire fleet operation.
- Gain experience with AVL integrated into your operation before embarking upon major changes or upgrades to the existing software.

Technology

- Investigate the technology; gain better depth and understanding of the system to be installed.
- Buy the most perfected hardware and technology available.
- Get a technical person in-house at beginning of project to follow development of system.
- Do not get boxed in by technological constraints.
- Invest time getting the best geographic information data possible and ensure data are accurate.

Contractor Interface

- Visit vendor's plant; provide on-site inspectors.
- Develop partnership relationship with system integrator; maintain good communications; work with them.
- If possible, perform testing yourself; do not accept vendor's word.

Conclusions

All cross-cutting study sites have stated that they are pleased with their AVL systems. Most of the sites are planning enhancements, especially in the area of automated traveler information.

According to the report *Advanced Public Transportation Systems Deployment in the United States - Update January 1999*, a total of more than 27 percent of transit operators receiving Federal funds either have operational AVL systems or are in the planning or implementation stages of their installation. This activity is testimony to the belief by transit agencies that AVL systems provide worthwhile benefits.

Belief in the value of AVL is substantiated by statements of benefits contained earlier in this study. Even so, none of the study agencies are making full use of the voluminous amount of AVL data automatically recorded by the system. Efforts to make better use of these data are under way at most of the sites. Also, the vendor community has developed several tools to better utilize such data in decision making and operational efficiencies and produce service delivery. With the implementation of these techniques, transit agencies should be able to achieve substantial additional improvements in their on-street performance, schedule development, service efficiency, and customer interface capability. It is the belief of these transit agencies that their best hope of increasing or at least maintaining current levels of transit patronage and minimizing future cost escalation is through the improved customer service that AVL systems and other associated technologies help them provide.

For further information on AVL systems and where they are being installed, see:

Advanced Public Transportation Systems: The State of the Art, Update '98, Volpe National Transportation Systems Center for the Federal Transit Administration, January 1998, FTA-MA-26-7007-98-1, DOT-VNTSC-FTA-97-9; EDL number 3334.

Advanced Public Transportation Systems Deployment in the United States - Update January 1999, Volpe National Transportation Systems Center for the Federal Transit Administration, January 1999, FTA-MA-26-7007-99-1, DOT-VNTSC-FTA-99-1; EDL number 8165.

These reports are available on the Electronic Document Library (EDL) at http://www.its.dot.gov/welcome.htm.

For further information, contact:

Federal Highway Administration Resource Centers

Eastern Resource Center
10 S. Howard Street
Suite 4000 – HRC-EA
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201 Mission Street
Suite 2100 – HRC-WE
San Francisco, CA 94105
Telephone 415-744-3102

Federal Transit Administration Regional Offices

Region 1
Volpe National Transportation Systems Center
Kendall Square
55 Broadway, Suite 920
Cambridge, MA 02142-1093
Telephone 617-494-2055

Region 2
Alexander Hamilton Federal Building
1 Bowling Green, Room 429
New York, NY 10004
Telephone 212-668-2170

Region 3
1760 Market Street, Suite 500
Philadelphia, PA 19103-4124
Telephone 215-656-7100

Region 4
Atlanta Federal Center
61 Forsyth Street, SW
Suite 17T50
Atlanta, GA 30303-3104
Telephone 404-562-3500

Region 5
200 West Adams Street
24th Floor, Suite 2410
Chicago, IL 60606-5232
Telephone 312-353-2789

Region 6
819 Taylor Street
Room 8A36
Fort Worth, TX 76102
Telephone 817-978-0550

Region 7
901 Locust Street, Suite 40
Kansas City, MO 64106
Telephone 816-329-3920

Region 8
Columbine Place
216 16th Street, Suite 650
Denver, CO 80202-5120
Telephone 303-844-3242

Region 9
201 Mission Street, Suite 2210
San Francisco, CA 94105-1831
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"It is apparent that the installation and use of the computer-assisted dispatching/automatic vehicle location system has resulted in significant improvements in the operation of the Milwaukee County Transit System. The ability to monitor bus location and schedule status from a central dispatch office has improved on-time performance, reduced street supervision, improved response time to emergencies, and reduced the number of schedule-related public complaints."

—Michael Giugno, Director of Transportation, Milwaukee County Transit System

INTELLIGENT TRANSPORTATION SYSTEMS

U.S. Department of Transportation
400 7th Street, SW
Washington, DC 20590

Federal Highway Administration
Room 3416, HOIT-1
Phone: (202) 366-0722
Facsimile: (202) 493-2027

Federal Transit Administration
Room 9402,TRI-10
Phone: (202) 366-4991
Facsimile: (202) 366-3765

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