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16. Abstract

The application of automatic vehicle location (AVL) systems is becoming more widespread in the transit industry in North America. Many public transportation agencies in Texas are currently operating and implementing AVL systems and more are in the planning stage. Automatic vehicle location systems, which allow transit operators to monitor the current status and location of transit vehicles, appear to offer a number of benefits. AVL systems provide a wealth of information that can be used to improve the energy efficiency of transit vehicles, enhance customer information, and improve route and schedule planning. Further, AVL systems may assist in gathering real-time traffic and travel information in congested corridors. In addition to reducing fuel consumption by improving the efficiency of transit systems, the other applications of the information generated by AVL systems may encourage more people to use transit rather than driving alone. Thus, AVL systems have the potential for significant energy savings through reduction in the use of single-occupant vehicles.

This report examines the use of AVL systems by transit agencies throughout the country and analyzes the various benefits that may be realized from the application of AVL systems. The implementation and current use of AVL systems by transit agencies in Texas is highlighted in the report, including the development of the AVL system by the VIA Metropolitan Transit Authority in San Antonio, which was one of the first transit properties in the country to utilize an AVL system. The report further examines the benefits provided by the use of AVL technologies, including the potential for energy savings and reductions in fuel consumption. The report also identifies possible demonstration projects and other innovative applications of AVL systems with different types of transit services in the state and additional uses of the information generated from existing AVL systems.

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EVALUATION OF AUTOMATIC VEHICLE LOCATION SYSTEMS IN PUBLIC TRANSIT

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Study Title:
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IMPLEMENTATION STATEMENT

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DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the United States Department of Energy, the Texas Governor's Energy Office, or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation, and is not intended for construction, bidding, or permit purposes.

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This report was prepared as part of the research study, *Evaluation of Automatic Vehicle Location Systems in Public Transit*, funded by the United States Department of Energy through the Texas Governor's Energy Office. The project was one of the Planning and Feasibility Studies administered by the Texas Department of Transportation (TxDOT). Any mention of trade names or commercial products in this report does not constitute an endorsement or recommendation for use.

Additional staff at TTI provided assistance with this research study and deserve recognition. Sara Hubbard assisted with some of the research activities, Pat Beck produced the graphics, and Lisa Badillo and Bonnie Duke typed the report. Their assistance is both acknowledged and appreciated.

A portion of the research was utilized in the preparation of a paper that was presented at the 1993 *IVHS America Annual Meeting* in Washington, D.C. in April, 1993. The paper, *The Use of Information Generated from Transit AVL Systems*, was published in the conference proceedings.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

This report provides an overview of the current use of AVL technologies by transit systems in North America. It includes a discussion of the types of AVL technologies, current applications within the transit industry, existing uses of AVL-generated information, benefits of transit AVL systems, and the identification of further applications within Texas. Currently, a number of transit agencies in North America, including those in Texas, are utilizing AVL systems. These systems provide a number of benefits and enhance both the management and operational capabilities of the transit systems. The report also indicated that AVL systems are still in the development stages at many transit properties, and that many agencies are not using the information available through these systems to the full extent. Advancing the deployment of AVL technologies to all types of transit services and maximizing the use of information generated by these systems will require a number of actions. These are outlined in the report along with a plan for addressing these needs — utilizing Texas as a test bed.

The suggested program builds on the current use of AVL systems by transit systems in the state, the extensive opportunities offered by the diverse mix of transit providers in the state, and the numerous advance technology companies in Texas. In combination with the expertise available through the Texas Transportation Institute (TTI) and other university research organizations, TxDOT, and public and private sector groups, Texas provides an ideal location to conduct an ongoing comprehensive transit AVL deployment and research program. The report contains a summary of the major elements for consideration in such a program.

This report should be of use to TxDOT, transit agencies, and other groups interested in enhancing the efficiency and effectiveness of public transportation services. Further, the report will help ensure that transit agencies in Texas continue to utilize the best available technology and practices in the provision of safe, convenient, and reliable services.

Chapter One

Introduction

A major focus of current transportation research and development activities is on the implementation of a variety of advanced technologies being examined under the general heading of intelligent vehicle-highway systems (IVHS). Intelligent vehicle-highway systems include the application of a wide range of evolving advanced technologies that share the common goal of improving the efficiency of the overall transportation system. More specifically, IVHS technologies are directed at improving mobility, enhancing safety, increasing the productivity of the current transportation system, improving energy efficiency, and addressing air quality and environmental concerns. These efforts are being supported by major federal and state programs, private industry groups, university research institutions, and others.

Currently, IVHS technologies are classified into six general categories. These are advanced traffic management systems (ATMS), advanced traveler information systems (ATIS), advanced vehicle control systems (AVCS), advanced public transportation systems (APTS), commercial vehicle operating systems (CVO), and advanced rural transportation systems (ARTS). Many of these categories overlap and numerous projects use combinations of the different technologies. More recently, IVHS technologies have been described by the U.S. Department of Transportation and *IVHS America* by a series of 27 user services categories. A wide range of IVHS research and development programs, operational tests, demonstration projects, and other activities are currently underway throughout the country and abroad.

A variety of advanced technologies are being implemented with public transportation systems. Many of these fall within the general APTS category. However, transit systems may also benefit from the application of technologies in other areas. The use of advanced technologies may result in the improved delivery of transit services, increased ridership levels, energy savings and greater fuel efficiency, and enhanced cost-effectiveness and efficient provision of services. Automatic vehicle location (AVL) systems represent one technology being implemented by many transit systems in North America.

Automatic vehicle location systems provide a method for monitoring the movement and location of transit vehicles. AVL systems provide a number of benefits for transit operators and transit passengers. AVL systems generate a great deal of information that can be used for a variety of purposes. For example, information obtained from AVL systems may enhance transit safety and management, produce energy savings and greater fuel efficiency, improve on-time performance, upgrade customer information capabilities, and improve route planning and scheduling. Further, AVL systems can assist in providing real-time traffic and travel time information to agencies and the general public in congested corridors.

Purpose of Report

This report documents the results of a research study conducted by the Texas Transportation Institute (TTI), a part of The Texas A&M University System, which examined the use of AVL systems by transit agencies in North America, including transit properties in Texas. The research project was funded by the United States Department of Energy through the Texas Governor's Energy Office and administered by the Texas Department of Transportation (TxDOT). The study was conducted to identify the current application of AVL technologies within the transit industry, to examine the uses and benefits of these systems, and to identify further applications within Texas.

To accomplish this a number of activities were conducted during the one year study. First, a state-of-the-art literature review was completed to identify the historical development of AVL technologies, the current use of AVL systems with public transportation, and available technologies and vendors. The information obtained through the literature review was also used to identify transit systems with operating AVL programs and those in the planning and development stage. Those transit agencies were contacted, through both letters and telephone calls, and additional information was obtained on the different applications of AVL technologies, the current uses of the data generated by the systems, the benefits realized to date from the systems, future plans for changes or enhancements, and suggestions for other transit agencies considering AVL technologies.

In addition, more detailed information was obtained and examined on the use of AVL systems by transit agencies in Texas. This information was collected through telephone calls, available reports, and site visits to selected transit systems. A major focus of the research was on examining the development of the AVL system at VIA Metropolitan Transit Authority in San Antonio. VIA was one of the first transit systems in the country to implement an AVL system and their experience provides a good case study. In addition to VIA, the experiences of Dallas Area Rapid Transit (DART) and the Metropolitan Transit Authority of Harris County (METRO) were examined. Further, other transit systems in the state considering the future development of AVL technologies were identified.

As documented in this report, the results of the research project indicate that the use of AVL systems is becoming more widespread within the transit industry. Further, the results show that AVL systems provide numerous benefits to transit operators, transit passengers, and the public. The results also indicate that many AVL systems are not yet being used to their full potential and that additional benefits may be realized as this occurs. Finally, the recent advancements in AVL technologies and the reduction in the cost of many products enhance the potential for smaller transit systems and rural operators to implement AVL systems and obtain the same benefits currently being realized by larger agencies.

Organization of Report

This report is organized into six chapters following this introduction. The next chapter provides an overview of the development of AVL systems and briefly describes the different types of AVL technologies. This is followed by a discussion of the AVL systems currently in use by transit agencies in North America, as well as those in the planning and development stages. Chapter IV examines the current uses and applications of the information generated by AVL systems and the benefits presently being realized by transit operators, transit passengers, and the public through the use of these systems. The impacts on energy savings and fuel efficiency are included in the analysis of potential benefits. Chapter V examines the factors that transit agencies and other groups should consider in selecting and implementing an AVL system. Chapter VI identifies additional applications for expanding the use of information generated by AVL systems. The chapter also outlines the potential to implement AVL technologies with smaller transit systems and identifies possible demonstration projects in Texas. Finally, the report concludes with a summary of the major elements addressed in the study and identifies areas for additional research.

Chapter Two

Automatic Vehicle Location Technologies

AVL systems provide a mechanism for monitoring the location and movement of transit vehicles. Although AVL systems have been used for military purposes and with rail systems for a number of years, applications with transit buses and paratransit vehicles are more recent (1). A variety of technologies are available for use with AVL systems. These include both ground-based approaches and satellite-based systems. A brief summary of the technologies and approaches used with both of these types of systems is presented in this section.

Regardless of the exact technology, all AVL systems include four general components. The critical elements include a method for determining the position of a vehicle, a method for communicating this real-time information to the central dispatcher, a central processing computer for storing and transmitting the information, and a method for communicating between the central dispatcher and the vehicle operator. As discussed next, a variety of different technologies are used to perform these functions.

Ground-Based AVL Systems

Three general technologies are used with ground-based AVL systems. These are proximity beacons, dead reckoning, and trilateration. Figure 1 provides an illustration of the general configuration of ground-based AVL systems, although some differences exist between the different technologies. The advantages and disadvantages of the different approaches are also identified.

Proximity beacons, which are also referred to as signpost technologies, involve locating transmitting devices on signposts or overhead wires at strategic points along a transit route. The signposts emit a unique code identifying their specific locations. Buses are equipped with receivers and a message is sent to the central control facility each time a bus passes a signpost. The tags or receivers on the vehicle may be passive or active. Passive receivers need to be excited by the signpost before they will transmit data, while active receivers are always on. Further, receivers may be enhanced to receive, store, and process information, in addition to just transmitting a signal (1, 2, 3). Different radio frequencies or microwave signposts may also be used to enhance the accuracy and coverage of the system (4).

Many of the early transit AVL systems used signpost technologies. An advantage of this technology is that it is a relatively simple approach that can be implemented fairly quickly. In addition, signpost AVL systems are generally lower in cost than other technologies, although the cost can increase significantly if a large number of signposts are required (2, 4). Proximity beacons or signpost AVL systems also have limitations, however. For example, the system only locates vehicles at signposts. The system cannot monitor the location of a vehicle between signposts. Thus, the system has no way of knowing if a vehicle is off its route or is experiencing difficulties between beacons. In addition, maintenance may be a problem. If one or more

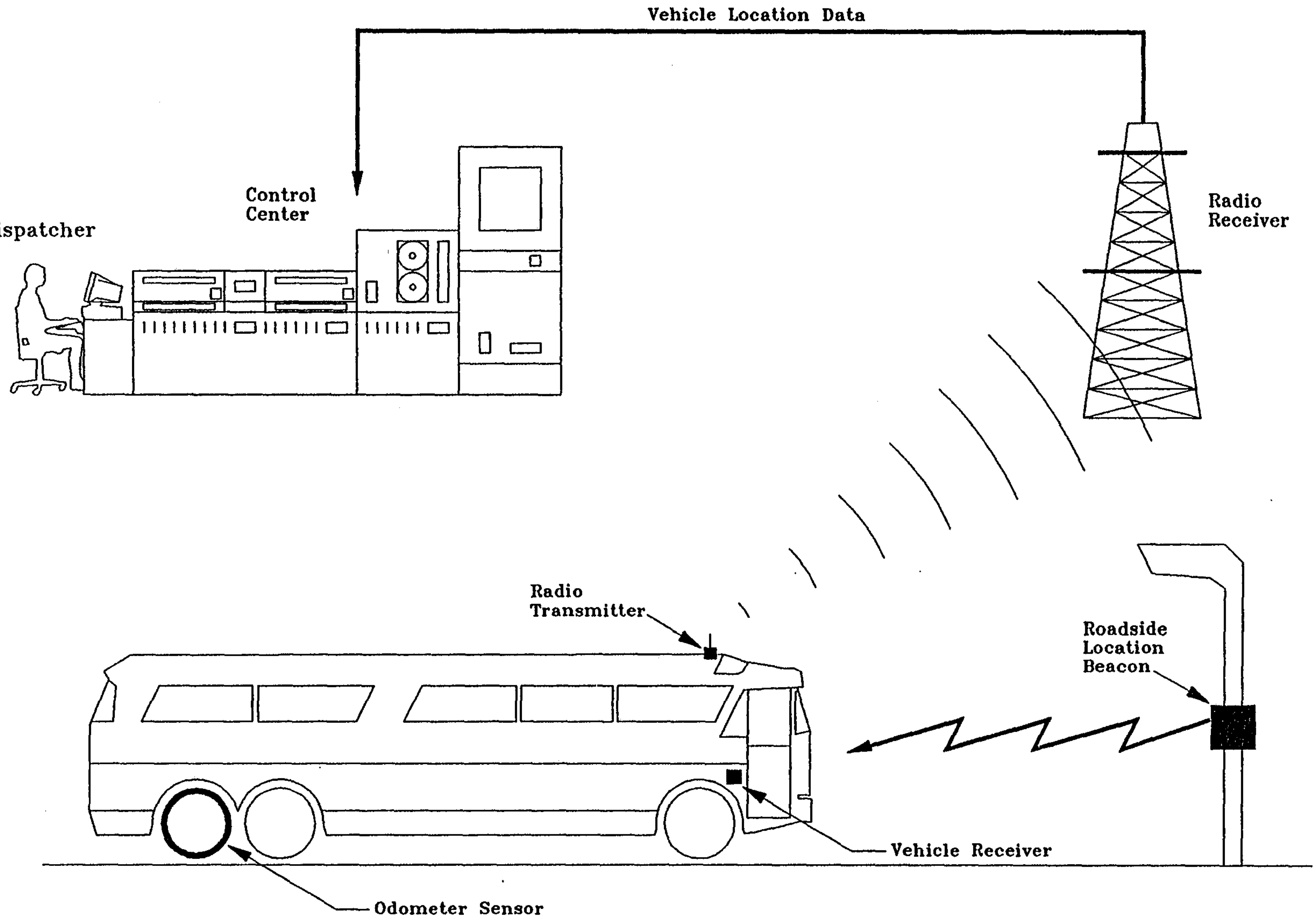

Figure 1. Example of Ground-Based AVL Configuration

Source: (2).

signposts are not working, the central computer may miscalculate the actual position until the vehicle is picked up by a working beacon (4). Further, if routes are changed, the signposts must also be relocated.

Dead reckoning AVL systems are based on measurements, made by distance and heading sensors on a vehicle, which continuously compute the location relative to a known starting point. Electronic odometers are usually used to provide the distance measurement; magnetic compasses are commonly used to provide the heading sensors for this approach (2). When a vehicle leaves a known starting point, the odometer and compass monitor both the distance and the direction traveled (2, 4).

One advantage of dead reckoning AVL systems is their relatively low cost compared to other technologies. This approach has a number of disadvantages, however. First, dead reckoning AVL systems provide the location status of a vehicle relative only to the original starting point. Further, accuracy problems may emerge, due to variations in the earth's magnetic fields, which may interfere with the compass readings. This problem, combined with the need to periodically readjust vehicle odometers, often results in dead reckoning systems accumulating errors with distance traveled. Reinitialization is usually used to overcome these concerns, or a signpost system may be used in combination with a dead reckoning system to increase the overall accuracy (2, 4).

Trilateration location techniques utilize radio frequency transmissions from three or more points. The location of a vehicle is established by calculating the differences in the position of a vehicle to a fixed point. Existing navigation networks, such as LORAN-C, are usually used with trilateration AVL systems (2). LORAN-C positioning systems have been used in both marine and aircraft navigation since the 1950s. More recently, the development of lower cost high-performance receivers has resulted in the use of this technology with commercial vehicle fleets, although costs are still relatively high at approximately $2,000 per vehicle (4, 5).

In addition, a related AVL system has recently been implemented using subscriber-based radio location systems. These systems provide both vehicle location and transmission medium for the end users that do not require a dedicated radio frequency. As illustrated in Figure 2, these systems connect the radio tuner, which provides the vehicle paging and receiving capabilities, with a central computer and central operations facility (5).

Technologies using trilateration may be lower in cost than other AVL systems, which may be an advantage in many situations. Problems which may emerge with trilateration AVL systems include the potential to lose vehicles due to signal interference from high-rise buildings or in areas with difficult topography (2). As a result, it appears that this approach is not being considered as much today as it was a few years ago.

Satellite-Based AVL Systems

As shown in Figure 3, satellite-based AVL systems follow the same principle as the trilateration systems, except that satellites, rather than ground-based transmitters, are used to establish the position of a vehicle. The Department of Defense's Navstar Global Positioning System (GPS) is being used with most satellite-based AVL systems (2). Passive receivers are used with GPS AVL systems. GPS receiver technologies have improved over the last few years and the costs have been lowered. Recent developments include smaller, low-cost, multichannel receivers that can be integrated with other system components (5).

GPS-based AVL systems are relatively accurate, with most systems currently providing the location of a vehicle within approximately 300 feet. Currently, there is no charge for the use of the satellite signals. One advantage of GPS-based systems is that they offer greater flexibility over signpost technologies. This allows vehicles to be tracked anywhere and eliminates maintenance costs associated with signpost systems.

GPS systems do have some drawbacks, however. For example, greater accuracy is provided for military users. Thus, one of the problems with this type of system is that with the new series of satellites coming on line, the military has modified the signals to prevent commercial or private users from achieving the accuracies demonstrated in the past. While this is being countered by the development of differential GPS by commercial manufacturers, the military may decide that civilian systems are too accurate and make further changes (2, 4, 5).

The Historical Development of Transit AVL Systems

The first use of AVL technology in the transit industry appears to have been undertaken in London in the late 1950s when London Transport experimented with the use of a Bus Electronic Scanning Indicator (BESI). The first recorded use of an AVL system in the United States was in Chicago during the late 1960s when the Chicago Transit Authority — in cooperation with the U.S. Department of Housing and Motorola — developed an AVL system for its bus fleet (2).

Based on this experience, the Urban Mass Transportation Administration (UMTA) sponsored a limited number of demonstration projects during the 1970s. For example, field tests of different AVL technologies were undertaken in Philadelphia and Los Angeles (2). UMTA also conducted an assessment of then-available AVL technologies during the late 1970s (6).

During the 1980s, a number of transit systems in North America and abroad began to plan for and implement AVL systems. Although ground-based technologies appear to have dominated many of the early applications, a number of different approaches were implemented. The combination of recent advances in technology and reductions in cost have led to the consideration and implementation of a wide range of AVL technologies by transit systems in North America. These are highlighted in the next chapter which summarizes the current status of AVL systems in operation, as well as those being planned, by transit agencies in the U.S. and Canada.

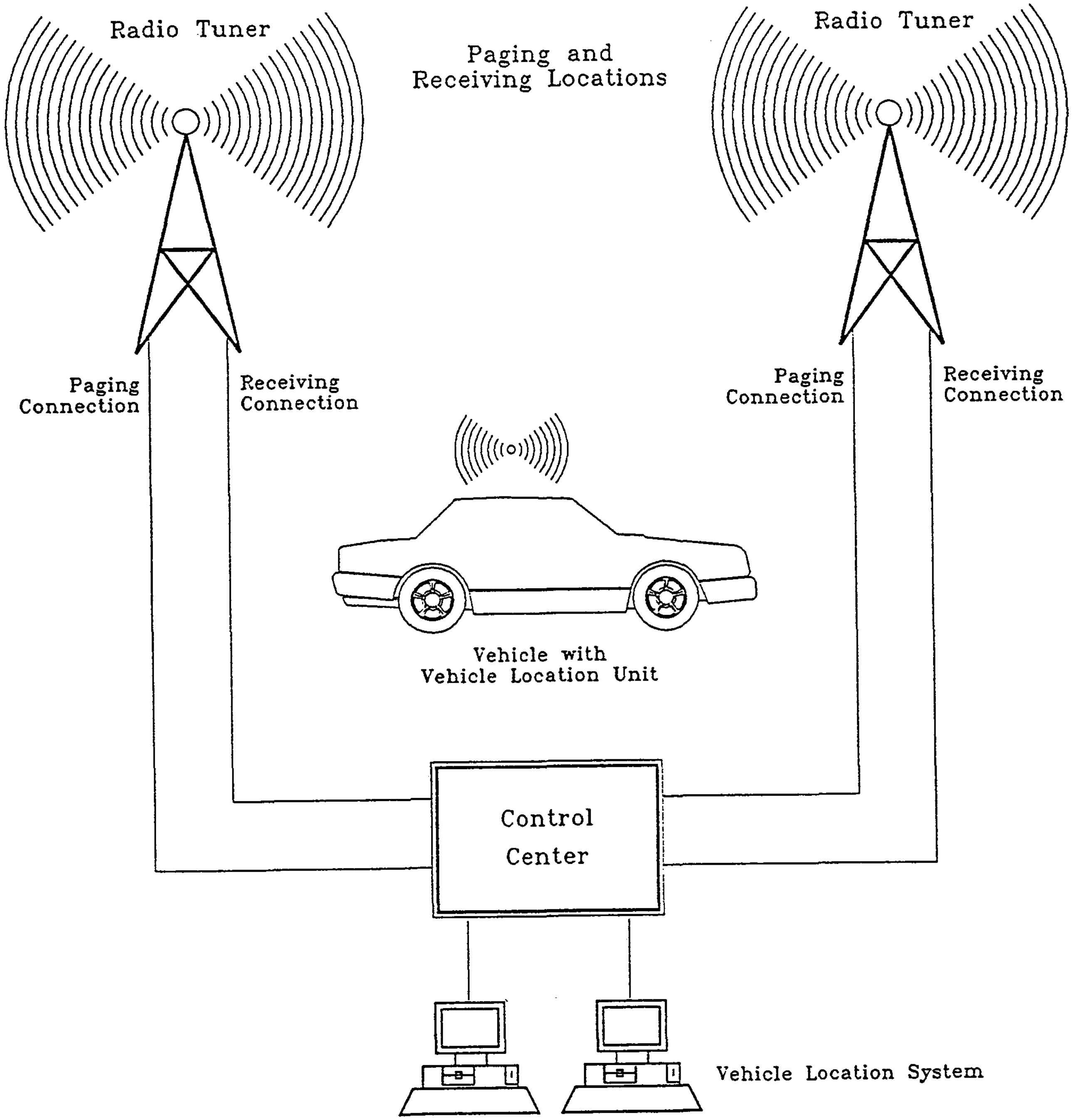

Figure 2. Example of Teletrac Subscriber-Based Radiolocation AVL System

Source: (5).

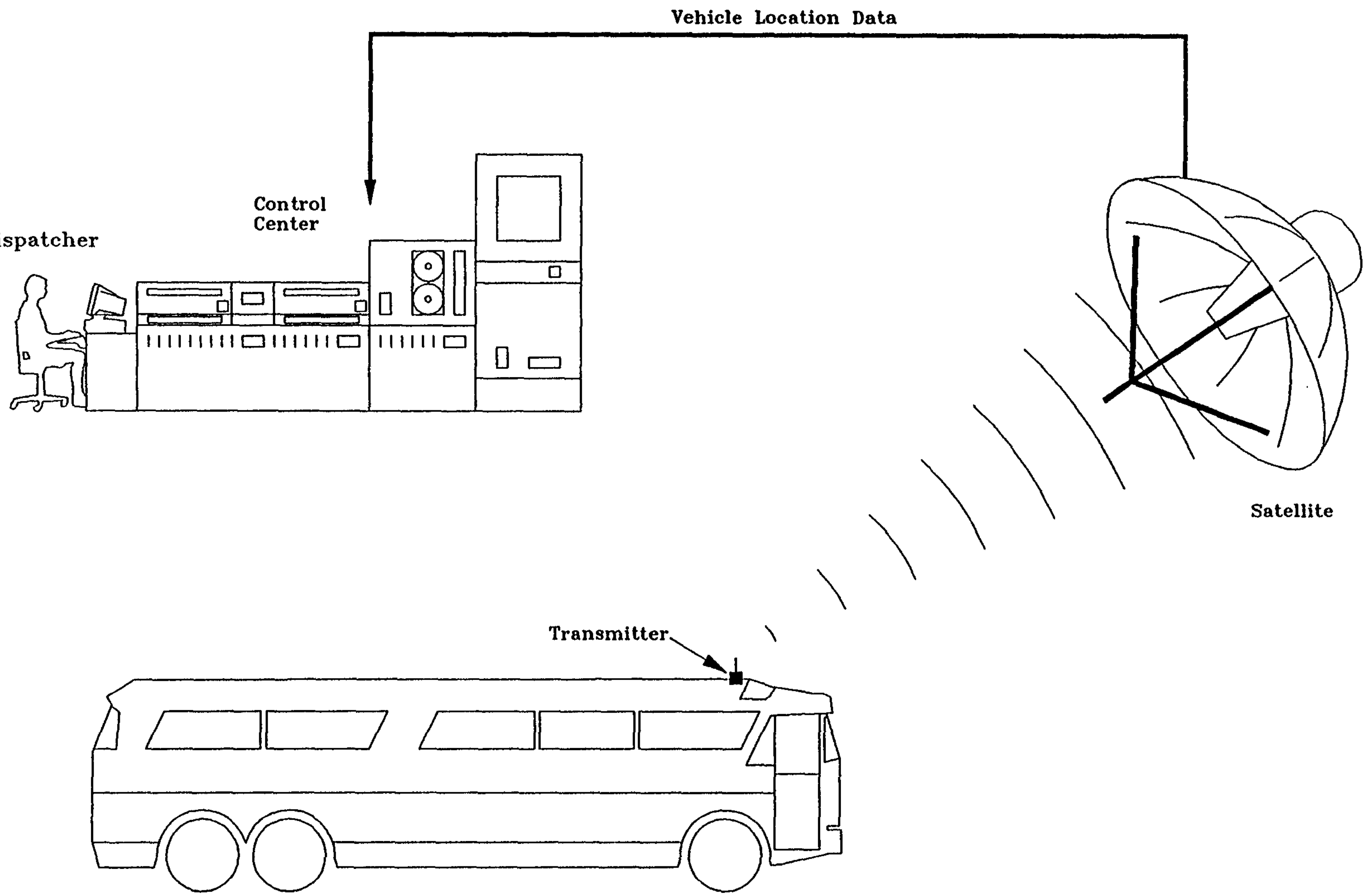

Figure 3. Example of Satellite–Based AVL Configuration

Chapter Three

Overview of Transit AVL Systems

A number of transit properties in North America have implemented AVL systems and many more are considering the use of AVL technologies. The first systems to be implemented, including those in San Antonio, Toronto, Ottawa, and Norfolk used ground-based AVL technologies. More recent applications, including the systems being implemented in Baltimore, Dallas, Denver, and Milwaukee, use satellite-based techniques. Examples of a few transit AVL systems are briefly described in this section. This information is provided to illustrate the different types of AVL systems that have recently been implemented by transit properties in North America.

VIA Metropolitan Transit — San Antonio, Texas

VIA Metropolitan Transit in San Antonio was one of the first transit systems in the country to implement an AVL system. VIA first developed specifications for an AVL system in 1983 (7). The selected system, developed by General Railway Signal (GRS) Communications System, utilizes a ground-based technology based on signposts and odometer readings. Buses are tracked by transmitters mounted on streetlight poles. The transmitters send out coded identification signals that are picked up by location antennas mounted on VIA buses. As the buses pass a sign post, the transmitters read the bus code: information on the status of individual vehicles is then transmitted to the central control computer.

The transmitters, which act as low-powered radio transmitters, are located throughout VIA's service area. The signposts reflect coded messages to the on-board computer or vehicle logic unit. Information on all VIA routes, schedules, and the distances between signposts is stored in the central control computer. Bus locations are polled every minute. The actual performance data are then compared to the scheduled information to determine the status of vehicles (8).

Components of VIA's AVL system include the roadside signposts, the on-vehicle equipment, and the central communications center. In addition to the vehicle antenna, the on-board equipment consists of the Driver Display Unit (DDU) and a two-way radio. The DDU is located near the operator and provides easy access to needed information. The central control facility includes four dispatcher stations. Each station is equipped with a radio console, a small monitor for messages, and a large color monitor that shows real-time information.

The total cost of the system, which was initially implemented in 1987 and was fully accepted by VIA in 1989, was approximately $3.7 million (8). This included the development and installation of the system on 537 buses and street cars in the VIA fleet. The cost also covered the two-way radios, the AVL computer hardware and software, some 2,000 signposts, seven base stations, two uninterruptable power supplies, and training and documentation (8).

The VIA AVL system provides for three types of two-way communication between the central dispatch center and the bus operator. First, routine messages can be sent in brief text format. The messages, which are typed using the operator and dispatcher keypads, are sent by coded radio transmission and displayed on the in-vehicle and central control monitors. If voice communication is needed, a second option allows for direct radio contact between operators and dispatchers. Finally, the third option allows operators to activate a silent alarm in emergency situations. This alarm, which is unnoticeable to passengers, provides priority access to the central dispatch center (7).

The development and implementation of the VIA AVL system occurred over a seven year time period. In 1981 VIA was awarded a grant from UMTA to equip all buses with two-way radios. This represented a major improvement from the existing communication method between the vehicle operators and the central dispatch center. Prior to the AVL system, the only communication links available for VIA operators were off-vehicle telephones located at the end of routes or direct conversations with on-street supervisors along the routes.

VIA utilized a two-step procurement process to select an AVL technology and a vendor. The first step in the process, which occurred in the summer of 1983, was to issue a request for proposals (RFP) to determine the capabilities of existing technologies and vendors. In the fall of 1983 UMTA awarded VIA a grant to purchase and install a bus communication and schedule adherence system. At the same time, VIA hired a consultant to assist with the review of the initial RFPs and to provide on-going project management assistance.

The responses to the first-step RFP were used to develop the second-step invitation to bid. A total of five responses were received to this second-step request. The bids ranged in cost from approximately $3 million to $7 million. General Railway Signal (GRS) company was selected as the system supplier based of the final evaluation criteria. Development of the system was initiated in December of 1986, with the installation of the two-way radios. Acceptance testing of the system began in mid-1987, and final acceptance occurred in early 1989 (8).

The use of the VIA system is briefly summarized here as an example of how one transit system is currently utilizing this technology. The system is activated before starting a run by the driver entering their route, block, and badge number into the Driver Display Unit (DDU) located next to the steering wheel. The start key on the DDU is pressed which signals the central control facility that the bus is in operation and tracking is starting. Relief operators or driver changes require only entering a new badge number, as these changes are programmed into the system. The badge number, route, and run block must be entered or the system signals the dispatcher that an unauthorized vehicle is in operation.

The system polls vehicles at 60 second intervals and provides operators with feedback on schedule adherence every three minutes. If no vehicle movement is recorded in three consecutive one minute polls, the system alerts the dispatcher. This allows the dispatcher to identify potential problems early and to communicate with the operator to determine their exact nature. The dispatcher can then take appropriate corrective action. Depending on the problem, this might include notifying an on-street supervisor, a maintenance vehicle, or a replacement bus, or rerouting other buses. The frequent polling also helps prevent operators from making unauthorized stops. More detailed information on the use of the information collected by the VIA AVL system and those in use at other transit authorities is provided in Chapter IV.

Toronto Transit Commission — Toronto, Ontario

The Toronto Transit Commission, which is responsible for the bus, streetcar, subway, and light rail transit (LRT) systems serving the Toronto area, identified the need for some type of advanced communication and control system in the 1970s (9). The system, called the Communications and Information System (CIS), was developed by TTC and the Province of Ontario in the late 1970s and early 1980s (9, 10). A signpost/odometer system, based on the same approach described with the VIA AVL system, is used. Buses are polled every six seconds and the information is reported to the central control facility (1). The CIS was initially tested between 1980 and 1984 with buses operating out of one garage. In 1986, a decision was made to equip the complete bus fleet (10).

The Toronto AVL system allows for communication between the operator and the central control center in a number of ways. First, messages can be typed and displayed on a small unit inside the vehicle. Second, direct communication between operators and dispatchers is possible. Buses are also equipped with internal and external boom microphones that allow control center personnel to talk directly to passengers. This approach is used in fare disputes. Finally, two safety alarms can be activated by the driver. One alarm is used for non-emergency situations, while the second silent alarm is used in emergency cases. In addition, some buses are equipped with automatic passenger counters. This system uses the same signposts as the CIS system to collect non-real time passenger boarding data but is not currently integrated with the CIS system (1, 10).

Ottawa-Carleton Regional Transit Commission — Ottawa, Ontario

The Ottawa-Carleton Regional Transit Commission (O-C Transpo) has implemented a demonstration project to test the use of AVL technology on the Ottawa Transitway system. The demonstration focuses on two routes operating on the Transitway. Buses on these routes are equipped with AMTECH automatic vehicle identification (AVI) transponders. The transponders are read by signpost detectors located at strategic points along the Transitway. Information from the transponders is sent to the central computer system for storage, analysis, and dissemination. Currently, eleven detectors are in operation and an additional fifteen will be installed in 1993. The objective of the pilot project has been to determine the accuracy and reliability of the technology and to examine different uses for the information provided by the system (11).

The first phase of the demonstration tested the hardware, software, and information processing capabilities of the system. The second phase focuses on integrating the AVL system with the overall transit control system and the central control staff. This phase will focus on staff training, developing the capabilities to model the progress of buses, and developing and evaluating different transit control strategies. A third phase will involve full implementation of an AVL system. This may involve the use of a GPS based system to complement the current ground-based approach (11, 12).

The AVL system represents just one of the advanced technologies being implemented by the Ottawa-Carleton Regional Transit Authority. Other elements include the Automatic Passenger Counting System, the *560 Telephone Information System*, and the cross-based bus reference system. Each of these components is being coordinated or integrated with the AVL system. The Automatic Passenger Counting System includes 90 buses that are equipped with microprocessors and infrared light beam detectors to record the movement of passengers and buses. This is not a real-time system, but the information obtained is used for a variety of planning and scheduling activities. The *560 System* is an automated telephone passenger information system. It allows individuals to obtain information on the scheduled time for the next two buses that will arrive at a particular transit stop. The cross-based reference system is being developed by adding a second tag, or run plate, to the front of buses. These tags are read as a bus leaves a garage and the resulting information will be used to match specific vehicles with actual run segments. O-C Transpo is also exploring future applications of transit priority treatments at traffic signals (11).

Tidewater Transportation District Commission — Norfolk, Virginia

The AVL system implemented in Norfolk, Virginia by the Tidewater Transportation District is another example of a ground-based system. The signpost/odometer system was developed by F&M Global. The cost of the system, which includes 151 total buses and a peak-hour fleet of 115 buses, was approximately $2 million. Vehicles are polled every 40 seconds and the resulting information is transmitted over dedicated radio frequencies to the central control facility. In addition, the system includes an emergency alarm and monitors the brake air pressure, engine temperature, and oil pressure on the transit vehicle (1, 13).

Mass Transit Administration — Baltimore, Maryland

The Mass Transit Administration (MTA) in Baltimore has been developing an AVL system since 1988. An initial demonstration project used an AVL system based on LORAN-C, supplemented by bus odometer readings and map matching. This project was sponsored by the FTA to test the feasibility of using off route tracking systems. The system was developed for the MTA by Westinghouse Electric Corporation. Approximately 50 buses and 4 supervisory vehicles were equipped with AVL tags during this demonstration. Equipment used included a LORAN-C receiver, a vehicle logic unit, a transit control head, and a radio (1, 14, 15).

Buses were polled every 20 seconds, with the data transmitted over dedicated radio frequencies. A digital map was used to display the real-time status of vehicles. Two screens were available to dispatchers. Using color coding, information relating to on-time performance, off-route location, vehicle maintenance needs, and emergencies were displayed graphically on one screen. The other screen provided a variety of information for operations management. The system also had recording and printing capabilities.

The next phase of the project will include equipping the remaining 850 MTA buses, 34 light rail vehicles, and commuter rail vehicles into an integrated CAD/AVL system. A GPS-based AVL system will be used in this phase to increase the accuracy of the vehicle location component (1, 14). It is anticipated that the system will also include automatic passenger counting capabilities and scheduling software. In a related project, Westinghouse also worked with the MTA to install a customer information kiosk at the bus, LRT, and commuter rail stop at the new Camden Yards Ballpark in Baltimore. This kiosk provides transit and tourist information through a touch screen device (1).

Dallas Area Rapid Transit — Dallas, Texas

Dallas Area Rapid Transit (DART) initiated the development of an AVL system in 1992. A GPS-based AVL system using technology from ElectroCom Automation L.P. is currently being implemented. The system includes display units inside the transit vehicles and a central control facility. Two dedicated radio frequencies are used to transmit the information from the vehicles to the central control facility. Ultimately, all buses, over-the-road coaches, supervisor vehicles, and transit police cars will be equipped (1).

Milwaukee County Transit System — Milwaukee, Wisconsin

The Milwaukee County Transit System is in the process of implementing a GPS-based AVL system. The system is being developed and implemented by a consortium that includes Westinghouse Electric Corporation, Trimble Navigation, and Motorola. The system components include 800 megahertz trunk radios, computer aided dispatchers (CAD), and a GPS based AVL system. The main objectives of the system are to enhance safety and schedule adherence of bus service in the Milwaukee area. Additionally, the information generated by the system will be used to enhance the overall management of the transit operations and to provide improved information to riders (14).

The AVL software and hardware are being developed so they can be integrated with many other systems in the future to greatly improve the overall efficiency of the Milwaukee transit service. For example, planned future enhancements focus on monitoring bus engines, wheelchair lift use, and passenger levels. Combining the system with enhanced vehicle scheduling software is also being explored. Further, the system can be coordinated with 3M opticon traffic signal units to provide bus priority treatments at busy intersections (14, 15).

The first implementation phase for the Milwaukee system started in late 1993. The first phase includes testing of the hardware and software on 15 buses. Based on the results of this test the system will be expanded to the full fleet in 1994, with further enhancements occurring over the next few years (14, 15).

Regional Transit District — Denver, Colorado

The Regional Transit District (RTD) in Denver is in the process of implementing a combined computer-aided dispatching (CAD) and AVL system. The RTD is using an innovative approach involving a private sector consortium to develop and implement the CAD/AVL system. The RTD's major objectives for the system include improving dispatching capabilities, improving scheduling, enhancing driver and passenger safety, and providing real-time information to transit riders (14, 15).

The development of the RTD's CAD/AVL system was initiated a few years ago in response to the need to upgrade the existing radio communication system. The RTD utilized a consultant to help examine the issues associated with the existing radio system and to identify the requirements for a new system. A request for proposal (RFP) was issued based on these requirements, soliciting innovative approaches to the development and implementation of a new system. Westinghouse Electric Corporation was selected by the RTD to provide the new CAD/AVL system (15).

The Westinghouse system includes a GPS-based communications and information package that performs a variety of functions. An operations center provides the focal point for the overall system. Other system components include an integrated CAD/AVL software package, the dispatcher and computer work stations, and the on-vehicle elements. Equipment on the RTD buses includes a mobile radio, an on-board processor, a driver console, handset, public address system, external microphone, and a GPS antenna. A vehicle odometer, which is connected to the on-board processor, provides a dead-reckoning feature to support the GPS in areas where satellite signals cannot be picked up (14).

The system polls the location of buses every two minutes on a normal basis, but more frequent communication can be made in response to incidents or emergencies. The system tracks the location of vehicles and compares the actual position with schedule information. In addition, the system allows the dispatchers to talk directly with the operators and to send text messages. A silent alarm switch can also be activated by the driver in the case of an emergency. This alerts the central dispatchers that a problem exists. Dispatchers can respond by monitoring the location of the vehicle more frequently and activating a microphone on the vehicle to monitor the situation (14, 15).

Analysis capabilities are also being established to provide for the development of multiple databases and the ongoing use of information generated by the CAD/AVL system. It is anticipated that regular reports will be prepared to improve overall system management and evaluation. In addition, the RTD plans to provide real-time information on the status of vehicles to the public through electronic screens in two downtown transit stations and through the telephone information system (14, 15).

Currently, the CAD/AVL equipment has been installed on 30 buses, which are operating in revenue service. Ultimately, all 832 buses in the RTD fleet, as well as some 30 supervisory vehicles, will be equipped. At present, the information generated by the CAD/AVL systems is being used only by RTD staff. The connection to the real-time passenger information screens and telephone system will occur over the next year (14).

Municipality of Metropolitan Seattle — Seattle, Washington

The Municipality of Metropolitan Seattle (Metro) is in the process of implementing both a new data radio and an AVL system. The AVL system uses a signpost-based technology. Metro's main objectives in designing the system were to improve bus communications, reduce emergency response time, and improve bus scheduling capabilities. The AVL system includes signpost transmitters, mobile odometers, and a central process unit. The radio system includes four 450-MHz channels for bus voice communication, two 450-MHz channels for supervisory vehicles, and two 800-MHz channels for maintenance vehicles (16).

Vehicle polling occurs every 30 to 90 seconds, depending on the number of buses in operation. The system also has an emergency alarm that can be activated by the driver. Vehicles are automatically polled more frequently — between 5 and 15 seconds — when the emergency alarm is activated. Control center personnel can also request more frequent polling at any time if they feel the need is warranted. Metro is examining possible enhancements to the system and is coordinating the development of the CAD/AVL system with other activities. These include enhancing customer information through the provision of real-time bus status data and improving bus travel times through the use of priority treatments for buses at traffic signals (16).

Metropolitan Transit Authority of Harris County — Houston, Texas

The Metropolitan Transit Authority of Harris County (METRO) has conducted a number of demonstrations and tests of different AVL technologies over the past few years. These have included tests of both ground-based and satellite-based technologies.

METRO is currently conducting a one-year demonstration project utilizing an AVL system with the METROLift paratransit service. During the summer of 1993, METRO negotiated and executed a contract with PacTel Teletrak, which is owned by PacTel Corporation; a part of the Pacific Telesis Group. Teletrak is a land-based, beacon AVL system. The subscriber-based radiolocation system, which was previously illustrated in Figure 2, provides both vehicle location and the transmission medium for end users. It is the only radio location technology that does not require a user to dedicate a radio frequency (5).

The Teletrac system is comprised of a network of radio towers and a central operations facility and a central computer. The radio tower network provides for the system to locate a vehicle within 45 meters and to display its location graphically. Equipment on the vehicle consists of a vehicle location unit (VLU), which are digital transceivers operating in the 900 Hz frequency band. The VLUs, which can receive and transit data, are the size of a VHS cassette and can be installed anywhere in a vehicle. A standard antenna is also used with the VLU (5).

The central control center uses computers to send and receive vehicle location requests and responses. The system "pages" vehicles using high-power simulcast transmitters. This page is received by the VLU and a digital code is transmitted from the unit. The message is received by multiple towers and the arrival time of the message is measured at each tower. This information is sent to the control center, where the responses from at least three receivers are used to calculate the location of a vehicle. The result is transmitted to the dispatcher's computer using telephone lines and the information is provided both graphically and in tabular form. The process takes approximately 3 seconds and the location of vehicles is accurate to within approximately 45 meters (5).

The Teletrak AVL system is being implemented with 120 vehicle METROLift fleet. The system is being tested over a one-year period. This demonstration is being conducted to both examine the use of AVL systems to enhance the delivery of the METROLift specialized transportation services and to examine the potential expansion of this technology to other METRO vehicles. An evaluation of the one-year test, along with an analysis of the use of other IVHS technologies to improve the delivery of specialized paratransit-services, is being conducted by the Texas Transportation Institute (TTI) for METRO.

Chapter Four

Uses and Benefits of Transit AVL Systems

The information generated from transit AVL systems is currently being used for a number of different purposes. Present applications focus on both improving the overall management and operation of the systems and enhancing the quality and timeliness of customer information. More specifically, current uses can be categorized into the five general areas of real-time corrections to improve on-time performance, safety and security, short-term schedule adjustments, long-term route and schedule planning, and enhanced customer services. Additional benefits of AVL systems include addressing requirements of the Americans with Disabilities Act (ADA), energy savings, and improving energy efficiency. Existing applications of AVL information within each of these categories are discussed in this section.

Real-Time Corrections to Improve On-Time Performance

Enhancing the ability to monitor the actual movement of buses and respond as appropriate to any problems that may be encountered is one of the most common applications of transit AVL systems. Without an AVL system, transit operators must rely on drivers and on-street supervisors to notify the central dispatchers of any problems, incidents, or late buses. Even with radio systems, this approach often results in information reaching the central dispatchers in an untimely fashion. In many cases, the information is provided to the central dispatchers too late to take corrective action or to alert other drivers to the problem. The provision of real-time information on the status of transit vehicles allows dispatchers and other transit personnel to take corrective action immediately.

Most AVL systems are used to enhance the on-time performance and operations of the transit fleet. Depending on the nature, extent, and severity of a problem, dispatchers may maintain a vehicle on its existing route, reroute a vehicle, dispatch another vehicle, or take other actions. In addition, the dispatcher may notify other bus operators of the problem and take action to prevent additional vehicles from experiencing the same difficulty. Thus, the information obtained from the AVL system allows the dispatchers to be pro-active in avoiding major problems rather than just reacting after they have occurred. Further, information on accidents and problems may be provided to other transit personnel, the police, and other agencies.

The information on the status and location of buses is also commonly used to determine the availability of vehicles for special jobs. For example, AVL systems may be used to identify the location of buses returning to the garage at the end of the day. These vehicles may then be assigned to last minute work, such as special events, or reassigned to cover missed trips or other changes. Thus, the information generated by AVL systems greatly enhances the ability of dispatchers to respond to incidents, special events, schedule changes, and other needs.

Safety and Security

Information provided from AVL systems can be used to improve the safety and security of passengers, transit operators, the transit system, and areas along routes. In general, AVL systems provide enhanced communications between the vehicle operator and the central dispatch center. This often involves the use of both radio communication and message capabilities. In some cases this represents a significant improvement over previous communication methods. Prior to the implementation of the VIA AVL system, for example, the only way operators could communicate with the central facility was by using the direct line telephones located at the end of routes. Most AVL systems include some type of security alarm that an operator can activate in case of an emergency. In addition, some systems provide more than one type of emergency alarm.

For example, the Toronto system has a yellow alarm button for incidents that do not represent a direct threat to the driver or passengers. When this button is pushed, an alarm is activated in the dispatch center and information on the status of the vehicle is highlighted on the console. The dispatcher can talk directly to the driver, overriding the normal communication routine. The dispatcher can also make direct contact with emergency services or other help. The silent alarm, which can be activated without the knowledge of anyone on the vehicle, is used when a driver or passenger is in danger. The silent alarm opens a voice channel immediately, even overriding a yellow alarm. The system also includes listening microphones on the buses, allowing the dispatcher to hear what is happening on the vehicle (10, 17).

In addition to emergency alarms, some AVL systems provide other safety enhancements. For example, the Toronto system also includes boom microphones inside and outside the transit vehicle. This allows personnel in the control center to talk directly to passengers. The boom microphones are used when a fare dispute cannot be settled by the driver. In this case, the dispatcher can directly address the passenger in question, with the full bus listening. Toronto has found this form of peer pressure to be effective in handling fare disputes (10, 14). The AVL system used by the RTD in Denver also has an internal public address system (16).

In this regard, AVL systems greatly improve the safety and security of the operator and transit passengers on the vehicle. Since many transit buses are in operation throughout the day and night, the systems can be used to provide information on traffic accidents or other incidents. This information can be quickly transmitted from the central dispatch center to the appropriate authorities and agencies. Thus, AVL systems may enhance the ability to monitor and respond to incidents along bus routes.

The improved security offered by the AVL systems appears to be viewed positively by operators and transit management. Seattle Metro indicated that drivers and coordinators note that the emergency alarm has improved response time to incidents (16). Further, representatives from the TTC in Toronto reported an improved sense of security among drivers and passengers as a result of the system (17).

Short-Term Schedule Adjustments

The information generated by AVL systems can be used to make adjustments to transit schedules and vehicle headways. For example, buses continuously behind schedule on a particular route may be an indication of inadequate running time in the current schedule. Short-term adjustments can be made to schedules in response to these types of situations. This can improve both the on-time performance of buses and the potential for operators to maintain schedules. At least one transit system, VIA, has indicated that short-term schedule changes have been made in response to information generated from the AVL system (7).

In order for AVL systems to assist with schedule planning, however, the data generated by the system must be captured and analyzed. As discussed in greater detail in later sections, it appears that this is one area where improvements can be made to enhance the usefulness of information generated by AVL systems. The development of uniform and ongoing monitoring and performance reports for AVL generated data appears to still be in the preliminary stages at many transit systems (12, 17).

Long-Term Route and Schedule Planning

In addition to providing on-time performance data for use in short-term schedule changes, the information generated from AVL systems can be used to enhance longer term route and schedule planning. This is especially true if the AVL system includes or is coordinated with a passenger counting information system. These systems greatly enhance the ability to collect and analyze passenger boarding and deboarding data. This allows adjustments to be made in vehicle assignments, schedule headways, and routes. For example, buses that continuously have standing loads can be replaced with articulated vehicles or headway changes can be made to add more buses to a route.

The development and analysis of control strategies to respond to different incidents or situations represents another longer term planning activity related to the use of AVL-generated data. The Ottawa-Carleton Regional Transit Commission, working with Queens University, is currently developing a model that will be able to simulate different traffic situations and alternative responses by transit vehicles. This model will be used for training purposes to help central control operators identify possible response strategies based on different problems and situations (11, 12).

Enhanced Customer Services

Transit AVL systems are currently enhancing customer information capabilities and customer service functions. At the present time two general applications are used by most transit systems which have AVL systems. These approaches provide a link to customer service personnel and begin to offer enhanced information to transit riders. In addition, most transit agencies are exploring additional applications to provide real-time information on the status of buses to customers.

Information generated from transit AVL systems on late buses and missed trips is usually provided to public information and customer service personnel. This allows customer service representatives to respond to questions and complaints from riders regarding late buses or missed trips. In this way, information from AVL systems can greatly enhance the ability of customer service representatives to respond knowledgeably to questions and complaints from riders. Inquiries can also be made to obtain additional information on reoccurring problems.

The ability to provide information to riders and potential customers on the real-time status of vehicles is also viewed as an important asset of transit AVL systems. Although only limited applications currently exist, most AVL systems are developed and designed to provide enhanced future real-time passenger information capabilities. For example, the Ottawa-Carleton Transit Commission is linking the information obtained from their AVL system into both the *560 Telephone Information System* and transit information monitors located at high volume passenger stops. By connecting the *560* system with the AVL system, callers will be able to obtain information on the real-time status of buses approaching their specific bus stop. Information on the status and sequence of approaching vehicles will also be provided through video monitors and advanced signing at major passenger boarding areas (12, 13). Denver, Baltimore, Seattle, and Milwaukee have also indicated an intent to provide real-time information on the status of buses obtained through the AVL system to passengers (1, 14, 16).

Americans with Disabilities Act

The use of AVL systems may also help transit agencies meet some of the requirements of the 1990 Americans with Disabilities Act (ADA). AVL technology may enhance the accessibility of both regular route services and paratransit services to disabled individuals and may improve the efficiency of specialized services. For example, AVL systems can be used in combination with automatic voice annunciator systems to address the ADA requirement that stops be announced on regular route services. Houston METRO has tested the use of a vehicle annunciator system that utilized AVL technology. Connecting AVL generated real-time data to regular route telephone information systems, maps, and displays can also enhance the ability of disabled individuals to utilize regular route services.

AVL systems can be used with specialized paratransit services to enhance both the efficiency and effectiveness of these services. Rather than operating on a fixed schedule like regular route service, most paratransit systems are demand-responsive. That is, a vehicle is dispatched in response to a specific trip request. By monitoring the location of paratransit vehicles, AVL systems can match trip requests with the closest vehicle, thereby reducing vehicle running time and improving responsiveness to customers. This could allow for more passengers per mile, increasing the efficiency of the system, while at the same time enhancing service.

As noted previously, Houston METRO has recently implemented an AVL system with its specialized METROLift service. This system is being used to help match the location of METROLift vehicles with customers. This approach provides improved service levels and greater efficiencies. In addition, METRO is exploring the potential of linking the AVL system with an advanced paratransit scheduling package that has recently been implemented to further enhance the productivity of the METROLift service.

Energy Savings and Improved Energy Efficiency

The utilization of AVL systems in public transit is expected to increase the energy efficiency of transit operations. Improvements in vehicle scheduling in both the long and short term, made possible by AVL, may result in higher passenger loads which will result in lower fuel consumption per passenger trip. AVL systems also allow transit operational personnel to better respond to incidents and accidents that may delay buses and waste fuel. By taking a pro-active response to incidents buses can be rerouted around major traffic problems, saving fuel and enhancing the fuel efficiency of the overall fleet. Furthermore, the improvements made possible by AVL systems with respect to schedule adherence and on-time performance, safety and security, and customer information enhance the service that can be provided by transit, and thus may be expected to increase the competitiveness of transit as compared to other transportation modes.

If the improvements in transit service can convert single occupancy drivers to transit on even an occasional basis, significant energy benefits can be attained. Estimates indicate that approximately 0.25 gallons of fuel will be conserved for every work trip eliminated; thus, if a single commuter takes transit one day a week, 0.5 gallons of gas will be conserved[1]. Obviously, the energy savings are substantial if even a small percentage of single occupant commuters take transit only one day a week. It has been suggested that transit improvements may result in total direct energy savings as high as 1 to 3 percent (18).

Another area where significant energy gains may be realized is in the adaptation of operating strategies to utilize the real-time data available through AVL systems. This includes the adaptation of transit scheduling and routing to respond to incidents and other non-recurring congestion that may be identified by information provided by AVL systems. By rerouting buses to avoid congestion due to incidents, both time and fuel will be conserved. Adjusting schedules or restricting and rerouting buses to less congested streets may also be possible based on AVL generated data.

AVL systems may also be used to provide additional data that may be utilized for regional traffic management, including the timing of traffic signals. Currently, few areas provide priority to transit vehicles at signalized intersections. It is reasonable to strive for an intelligent traffic management system that is able to give transit vehicles priority at traffic signals to enhance transit operations and the ability of transit to compete with single-occupant vehicles. Further, when combined with AVL technologies, traffic signals could recognize whether priority is appropriate based on schedule adherence and passenger levels. It would also be possible to use the information provided by AVL in conjunction with information obtained through traditional methods, such as detectors, to optimize the signal network based on either minimum delay or

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[1]Based on average work trip length of 8.5 miles, fuel efficiency of 25 miles/gallon, operating cost per passenger mile for single occupancy auto of 11,000 BTU and operating cost per passenger mile for bus of 3,070 BTU.

minimum fuel consumption. This would be preferable to merely using information from the detectors, because detectors do not differentiate single-occupancy vehicles from high-occupancy vehicles, which implies that they cannot optimize based on person hours of delay.

Energy savings and improved energy efficiency may also be realized by others through the use of information generated by transit AVL systems. Because transit services generally use mixed flow facilities throughout the urban area, the real-time information transit obtains may be useful to a number of other agencies and private sector businesses. Police and incident management personnel may use the information on non-recurrent congestion to identify and respond to incidents quickly, thus reducing congestion and decreasing fuel consumption. Highway advisory services may be linked into the AVL information system and may use the AVL data to determine existing traffic conditions. The information on existing traffic conditions may be used by all commuters in their trip making decisions. Presumably, the real-time information will be used to identify and avoid congestion, resulting in congestion avoidance and reduced fuel consumption. Similarly, real-time traffic information may be used by commercial operators to avoid congestion, and reduce fuel consumption.

Thus, although little documentation is available from transit agencies with operating AVL systems, it appears that AVL technologies can have an important impact on reducing energy consumption and improving energy efficiency. This information may then be used to make intelligent and informed transportation decisions by transit providers, transit users, other agencies, and private businesses. The ability to make more intelligent and informed decisions based on the enhanced information available from AVL systems generally gravitate away from congestion, resulting in reduced trip times, reduced energy consumption, and improved energy efficiency.

Chapter Five

Considerations in AVL System Selection and Implementation

The state-of-the-art literature review and the telephone conversations with representatives from transit systems throughout North America identified a number of factors that should be considered in selecting and implementing an AVL system. These factors are described in this chapter. Elements to be considered in the AVL technology selection process are discussed first. This section is intended to help transit agency personnel who may be considering purchasing an AVL system. This is followed by a summary of the factors that should be included in the implementation and ongoing operation an AVL system. This discussion should be of benefit to representatives with transit agencies interested in developing new AVL systems, as well as those wishing to improve the use of existing systems.

It is important to note that the selection and implementation of an AVL system, or any other major new technology, is not a quick and easy process. The development of an AVL system — starting with the system specifications, through the request for proposal (RFP) and bid process, contract award, to testing and full implementation — often requires at least two years. Although the actual length of time will vary depending on the size of the transit agency and the type of AVL technology, developing a realistic schedule is important to adequately communicate to decision makers and agency staff the level of effort and time involved in the process.

The selection, implementation, and operation of an AVL system will also affect all parts of a transit agency. This includes everyone from the operators, dispatchers, on-street supervisors, and transit police who will be directly operating the system, to the planning and scheduling, maintenance, and administrative personnel who will be utilizing the data generated from the system. Experience from transit agencies with AVL systems indicates that ensuring that all these groups are involved in the selection and implementation process is critical to successful projects. Multi-department teams or planning groups appear to be one of the best techniques for maintaining this involvement. Although all affected groups should be involved, experience also indicates that one department should have the overall responsibility for project development.

AVL System Selection Considerations

Figure 4 summarizes the five key steps in the selection process for an AVL system. These steps reflect the typical factors that would be considered in the decision-making process for any type of capital improvement. The major factors included in Figure 4 are briefly described next. The factors start with the identification of the purpose and use of the system and end with the issuance of a request for proposal and the selection of a vendor. The exact nature and complexity of the issues examined in each step will vary by transit system. The guidelines, however, do provide an indication of the factors all agencies should address in the development and implementation of an AVL system.

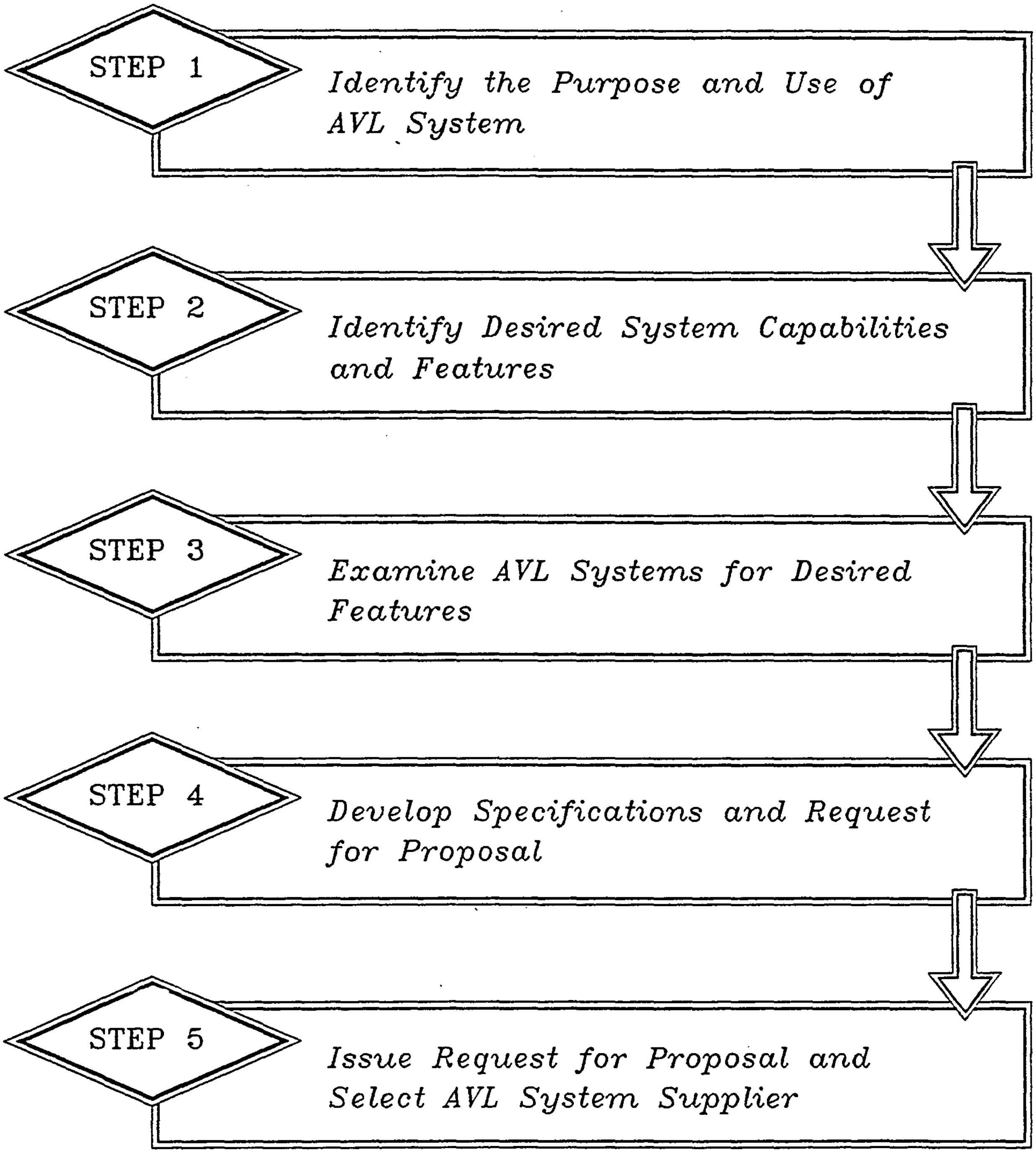

Figure 4. Key Steps in AVL System Selection

Step 1. Identify the Purpose and Use of AVL System

The development of an AVL system is not an end or objective in and of itself. Rather, AVL systems are used for specific purposes and to meet specific goals and objectives. As discussed previously in Chapters III and IV, existing AVL systems are performing a variety of functions and the information is being used in numerous applications. Thus, the reasons for implementing AVL systems and their use varies among different transit agencies.

The first step in the selection process should be a realistic assessment of the need for and use of an AVL system. This assessment should include a clear articulation of the problems or issues the AVL system will address, the purpose and use of the system, and the goals and objectives for its use. Ensuring that there is agreement on these among all departments — and with the policy board — is critical to both developing realistic expectations and to selecting the appropriate system.

Step 2. Identify Desired System Capabilities and Features

Once the purpose and use or goals and objectives of the AVL system have been identified, the next step is to translate these into the specific features and capabilities desired in the technology. These will determine the types of AVL technologies that should be considered which in turn will influence the cost of the system. For example, the need to locate vehicles anywhere within a service area — rather than just along a route — rules out the use of land-based or signpost technologies.

Consideration of the desired system capabilities and features should include those associated directly with the AVL system, as well as additional elements. Examples of both of these are highlighted in Table 1. Elements basic to the AVL system include the desired level of accuracy and reliability, while additional features might include passenger counting, engine monitoring, and emergency notification capabilities.

Table 1. Examples of AVL System Features

	Features
AVL System	• Accuracy Level — Route or Areawide Base • Vehicle Polling and Reporting Frequency • Performance • Reliability and Maintenance
Supporting Components	• Passenger Counting System • Emergency Alarm System • Interior and/or Exterior Microphone and Listening System • Engine and Vehicle Monitoring System • Real-Time Passenger Information Systems • Internal Data Reporting Systems

Step 3. Examine AVL Systems for Desired Features

Once the desired system capabilities and features have been identified, the different types of AVL technologies available to meet these requirements can be examined. This step focuses on evaluating available AVL systems against the desired features. This process will assist in developing a realistic assessment of the types of technologies that may be used and the costs associated with each. The results of this analysis will provide transit management and the decision-making board with an indication of the nature, scope, and cost of the potential system.

It is important to realize, however, that this step is not intended to select the exact AVL technology. That will happen in Step 5. This step is intended to provide an assessment of the type or types of technologies that may be appropriate, the general approach to implementation and operation, and the costs associated with the system. Information can first be used by management to determine the viability of the project. Second, if a decision is made to proceed with the system, this information can be used in the development of the bid specifications and request for proposal (RFP) undertaken in Step 4.

The assessment undertaken in this step should include an examination of the costs and benefits of different technologies and approaches. In general, the costs of implementing AVL systems vary both with the size of the bus fleet and the type of technology. With respect to the size of the fleet, the per vehicle cost of existing AVL equipment tends to decrease as the size of the fleet increases. This trend is less pronounced once the fleet size reaches 100 vehicles, but costs appear to increase for fleets smaller than 80 or 90 vehicles.

The rapid improvements in technology and the reductions in cost that have occurred with AVL systems over the past few years can be expected to continue. Thus, transit agencies should obtain the most recent information on prices as part of this assessment. This analysis should also consider the potential savings that may result from the AVL system. Potential savings may be realized through increased operating efficiency, reductions in fuel consumption, enhanced labor productivity, and increased ridership. For example, the Societe de Transport de L 'Outaouais (STO) in Hull, Quebec estimates that three vehicles from its fleet of 162 were made available due to increased efficiency in the use of vehicles, and a 60 percent redistribution of supervisory staff was realized upon implementation of the AVL system (4). This assessment should include both tangible benefits as well as other benefits that may be harder to quantify.

Step 4. Develop Specifications and Request for Proposal

The detailed bid specifications and the request for proposal (RFP) or request for bid is completed in this step. The information analyzed in the previous step on the desired system features is used here to outline the specific elements vendors will be asked to bid on. Most transit systems have specific procedures, often governed by federal or state laws, for procuring capital equipment and fixed facilities. These procedures usually require that a competitive bidding process be followed, rather than a sole source procurement. A variety of approaches may be used in this process. For example, some transit systems may use a one step process, while others may use a two step request for technical proposals (RFTP) process.

A number of sources of information are available for assisting transit agencies in the development of bid specifications and RFPs or RFTPs. For example, the Ontario Ministry of Transportation is developing a generic AVL/C system bid document package for use by small and medium transit properties (4). This document should be of benefit to systems in the United States as well. Transit agencies may also wish to obtain copies of the specifications and bid requests used by other transit properties in the procurement of AVL systems. This would be especially beneficial if the planned technology and application matches that of an existing system.

Step 5. Issue Request for Proposal and Select AVL System Supplier

The last step in the AVL selection process includes issuing the RFP, evaluating the responses, and selecting the supplier or vendor. As in Step 4, this process is usually governed by specific requirements and procedures established by individual transit agencies. These procedures address requirements related to notification and advertising, pre-proposal meetings, vendor contacts, schedule, and content of the response. The procedures may also address requirements to select the low bidder or may provide cost flexibility based on system specifications.

The RFP will include the factors and process that will be used in evaluating the proposals. Depending on the type of procurement, vendors may be qualified in the first step and asked to submit cost proposals for the second step. Internal selection committees, comprised of representatives from all the affected departments, are often used by transit systems in the proposal review and selection process. In addition, it is important that legal council participates to ensure compliance with all appropriate rules and regulations.

The outcome of this five step process is the selection of an AVL technology supplier or vendor. As outlined in the next section, the selection process is then followed by the actual implementation of the AVL system.

AVL System Implementation and Operation Considerations

The implementation and operation of any new technology is often accompanied by problems. These may include issues related to the technology, human behavior, and organizational changes. Examples of potential problems and issues that may be encountered in the development and implementation of an AVL system are highlighted in Table 2 and briefly summarized next. These are presented along with approaches to address them to assist transit agencies in developing implementation and operational plans to avoid major problems.

Table 2. Examples of Potential Implementation and Operation Problems

General Category	Potential Problems	Potential Solutions
Technology	• Unrealistic expectations of system capabilities	• Present realistic assessment of technology and use
	• Implementation schedule longer than planned	• Develop realistic schedule and build in extra time for testing and addressing problems
Human Behavior	• System not working as planned	• Anticipate that problems will arise, but build vendor responsibility to contract
		• Build in specific milestones with ongoing, open, and specific review at each point
Organizational	• Operators and dispatchers not comfortable with system	• Develop and implement training and outreach program for operators, dispatchers, and other personnel
	• Dispatchers unhappy with changing nature of job	• Present realistic expectations of job changes, rotate jobs, and provide outlet for employee concerns
	• Turf issues among divisions	• Use multi-department committee to encourage ownership by all groups
	• Information not being collection, analyzed, and used	• Design system to meet needs of all key functions and assign responsibility for ongoing maintenance of system

The first general area where problems are likely to occur is with the AVL technology itself. Problems that may arise include schedule delays, malfunctioning system components, and unrealistic expectations concerning the capability of the technology. These issues are not unique to AVL systems, but represent issues often associated with the development of any new system or the construction of a new facility. A variety of techniques can be used to minimize the potential of these from becoming major problems and for addressing them if they do.

Developing realistic expectations of the technology and not overselling the potential benefits is critical. It is often easy for agency staff to paint too glowing a picture of the capabilities and benefits of a technology or project in their attempt to obtain management and board approval. Guarding against this, and presenting an accurate assessment of the system, is important.

Also important is the development of a realistic schedule for the implementation of the AVL system. The schedule should be designed with adequate time for installation, testing, and full deployment. The potential for delays should be anticipated, and a plan should be developed to address these if they arise. Keeping all departments, management, and policy groups apprised of the status — including any problems — is a critical part of this process.

Finally, although problems may be expected to arise with the implementation of new technologies, transit systems should protect themselves by ensuring that the supplier is responsible for correcting major problems and malfunctions. This should be included in the contract, along with specific milestones, reviews, and deadlines.

The implementation and operation of an AVL system directly changes the job responsibilities and functions of operators, dispatchers, on-street supervisors, and managers, and indirectly influences many other areas within a transit agency. For example, with AVL systems, dispatchers spend most of their time watching video screens. The responsibilities of dispatchers are also greatly enhanced. Dispatchers become the focal point for information concerning the status of the system and provide the direct communication link to vehicle operators. Further, they are responsible for making decisions, such as rerouting vehicles, dispatching additional buses, or summoning help, in response to the information coming through the system.

Ensuring that all personnel affected by the AVL system have the proper training and an understanding of the technology and system is a critical first step in addressing these human resource issues. Staff should also be provided with realistic assessments of the changing nature of jobs and should be provided with other opportunities if the new requirements do not match their skills and abilities. Rotating jobs, so that an individual does not spend all day at a computer terminal for example, represents another potential approach. The FTA is including a human factors assessment as part of the national evaluations being conducted on the Baltimore, Denver, and Milwaukee AVL systems. The results of this assessment should provide additional insight into the human factors issues associated with the development and operation of AVL systems, as well as approaches to addressing major problems.

Organizational issues represent a third major area where problems may emerge with the implementation and operation of AVL systems. Problems that may be encountered include turf issues, lack of communication among different departments, and AVL-generated data not being collected, analyzed, disseminated, and used. One good approach for addressing these issues is the use of a multi-department committee throughout the planning, implementation, and operation phases. Other possible techniques include designing the system to meet the needs of all user groups, assigning responsibility for the ongoing maintenance of the information system, and promoting greater interaction among all departments.

Chapter Six

Future Applications of Transit AVL Systems

The examination of transit AVL systems conducted in the study provides an assessment of the current status of different AVL technologies and the uses of information generated from existing systems. The results of this analysis indicate that the potential exists to expand the use of AVL systems to a wider range of transit services and to enhance the use of information generated from AVL systems. Additional applications in both of these areas are discussed in this chapter, along with potential demonstration projects and other tests.

Implementation of AVL Systems with Additional Transit Services

To date, the vast majority of AVL systems in North America have been implemented by relatively large transit agencies in major metropolitan areas. Only a few examples exist of AVL systems in operation at smaller transit properties. Further, no rural systems were identified as currently using AVL. This is not surprising given the cost and complexity of AVL technology and the financial and staff resources needed to develop, implement, and operate these systems. Based on the continuing improvements in technology and the reductions in cost, however, it appears that AVL systems may be more readily available to other sizes and types of transit services in the future. These include systems in smaller communities, rural providers, and paratransit and specialized transit services. Potential demonstration projects in Texas to advance the state-of-the-practice with a wide range of transit services are presented next.

Texas has the largest number of rural transit providers and the largest rural service area of any state in the country. These services, which are operated by a diverse group of providers, may serve a single community or a multi-county area. Further, the 23 municipal systems and 7 large transit agencies make Texas one of the states with the largest number of public transit systems. This wide range of transit services makes Texas an ideal test bed for AVL technologies.

Based on the analysis in this report, it appears that rural and small city transit operators could benefit from AVL systems. For example, knowing the location of vehicles operating in rural areas could provide benefits greater than those realized in major metropolitan areas. These include greatly enhanced safety and security, improved efficiency, and greater responsiveness to riders needs. Rural transit systems should benefit from improvements in non-signpost AVL technologies and lowering costs.

Developing a series of demonstration projects focusing on the use of AVL systems with rural and small city systems in Texas would provide numerous benefits to these systems and would help advance the deployment of AVL technologies. Such a program should include testing different types of technologies in different geographical locations and with different types of transit services. For example, CARTS, which provides service in the 9 counties around Austin would be a natural candidate for a demonstration. Such a test could be coordinated with a similar demonstration at Capital METRO in Austin.

The use of an AVL system with the METROLift service operated by Houston METRO represents one of the few applications of AVL technologies with specialized paratransit services. Like rural and small city systems, it appears that specialized paratransit systems could benefit from the greater operating efficiencies and enhanced service productivity that may be afforded through the use of AVL technologies. Further, AVL technologies could help transit systems address some of the requirements of the ADA and enhance services to special client groups. Individuals using specialized transportation services should also benefit from these systems through improved scheduling, enhanced responsiveness, and greater flexibility.

Conducting further tests of AVL technologies with paratransit and specialized transportation services would assist both providers and users of these services. These demonstrations should include the use of different AVL technologies with different types of specialized service providers. These demonstrations would also be of interest to transit systems, user groups, and others throughout the country. Thus, the demonstrations suggested for all types of transit systems would continue to establish Texas as a leader in the innovative application of advanced technologies to enhance all types of public transit services.

Additional Uses of AVL-Generated Data

The current uses of AVL-generated information described in Chapter V are just beginning to tap the extensive capabilities offered by these systems. A number of additional applications are being planned or considered by transit agencies with operating AVL systems. Further, AVL systems currently under development are being designed with enhanced capabilities. Many of the planned improvements focus on real-time customer information services, but enhancements are also being examined in other areas as well. In many cases, these applications are being coordinated with the use of other advanced technologies to maximize the benefits from all systems. This section examines additional applications currently being pursued by transit systems and enhancements for further consideration. Table 3 provides a summary of these applications.

Providing real-time information on the status of buses to customers and potential customers is one of the main applications being pursued by many transit systems (1, 11, 12, 17). Approaches being considered include linking the AVL-generated information on vehicle status with telephone information systems, video kiosks at major passenger waiting areas, cable television, and videotex units in individual homes and places of work. Before these systems are widely used, however, transit personnel must be comfortable that accurate information is being provided through the AVL systems. Some concerns have been raised in this regard, primarily with ground-based systems that rely on odometer readings. Ensuring that the information being provided to customers is correct is critical to the success of this approach.

Table 3. Examples of Additional Applications of AVL-Generated Information

- Real-time information to customers on the status of buses through telephone information systems, video kiosks, cable television, and videotex units in homes and places of work.
- Coordinate with advanced traffic management systems (ATMS) to provide real-time traffic information on routes regularly travelled by buses.
- Enhanced maintenance through coordination with bus condition monitoring systems.
- Enhanced management information systems to include automated passenger counting capabilities, cross-based bus reference systems, expanded databases for route and schedule planning, developing dispatcher responses to specific conditions, and establishing closer ties between dispatchers and operators.
- Monitor fuel consumption and energy use.
- Enhanced safety and security of operators, passengers, and areas along routes.
- Coordinate with voice annunciator systems to address ADA requirements.
- Expand use with specialized paratransit systems to address ADA requirements and enhance service delivery and operating efficiencies.

The potential for using AVL systems to generate information on real-time traffic conditions is also being examined. For example, VIA in San Antonio has conducted a few preliminary tests focusing on the use of AVL-generated information to monitor freeway congestion levels. These experiments indicate that a methodology can be developed to monitor congestion using AVL, although it is somewhat labor intensive and limited to the location of sign posts. Further, linking AVL systems into advanced traffic management systems (ATMS) has been identified as a long-range goal in some areas (19).

Expanding the use of AVL-generated data to other maintenance and management areas is also being considered by some transit systems. Maintenance applications being examined focus on enhancing bus condition monitoring systems. This may include monitoring brake air pressure, engine temperature, oil pressure, fuel use, miles between service calls, and other maintenance items. This approach provides transit maintenance personnel with the ability to track buses with problems and to take a pro-active approach to maintaining vehicles, rather than waiting for break-downs to occur. Management applications being pursued including improving management information systems, adding automated passenger counting capabilities, developing bus cross-based reference systems, expanding databases for route and schedule planning, establishing closer ties between dispatchers and operators, and developing scenarios to respond to different types of incidents and accidents. Adding and enhancing security and warning systems are also being explored to further improve the safety and security of operators, passengers, and areas along bus routes.

Finally, AVL-generated information can enhance the delivery of specialized paratransit services and assist transit-systems in meeting the requirements of the ADA. The testing of an AVL system with a bus stop annunciator system by Houston METRO provides one example of this. The use of the METROLift AVL system provides one example of the use of AVL technologies to enhance the delivery of specialized paratransit services. The information generated from paratransit AVL systems could be used in the same type of applications described previously for regular route transit services. In addition, integrating AVL systems with other advanced technologies — such as paratransit scheduling packages — could enhance the overall management and efficiency of specialized paratransit services.

Chapter Seven

Conclusions

This report has provided an overview of the current use of AVL technologies by transit systems in North America. It has included a discussion of the types of AVL technologies, current applications within the transit industry, existing uses of AVL-generated information, benefits of transit AVL systems, and the identification of further applications within Texas. As discussed, a number of transit agencies in North America, including those in Texas, are presently utilizing AVL systems. These systems currently provide a number of benefits and enhance both the management and operational capabilities of the transit systems. The examination also indicated that AVL systems are still in the development stages at many transit properties, however, and that many agencies are not using the information available through these systems to the full extent. Advancing the deployment of AVL technologies to all types of transit services and maximizing the use of information generated by these systems will require a number of actions. A plan for addressing these needs — utilizing Texas as a test bed — is presented in this conclusion, along with areas for further research.

The suggested program builds on the current use of AVL systems by VIA, DART, and METRO, the extensive opportunities offered by the diverse mix of transit providers in the state, and the numerous advance technology companies in Texas. In combination with the expertise available through TTI and other university research organizations in the state, TxDOT, and other public and private sector groups, Texas provides an ideal location to conduct an ongoing comprehensive transit AVL deployment and research program.

The major elements of the proposed *Texas Transit AVL Deployment and Research Program* are highlighted in Table 4. The comprehensive approach focuses on the three general areas of deployment and evaluation, research to enhance the use of AVL-generated information and expand its use in transit operations and management, and development of innovative public and private sector approaches to advance the state-of-the-art. Each of these elements is briefly described next.

Table 4. Proposed Texas Transit AVL Deployment and Research Program

Major Program Components	Specific Focus Area
Deployment and Evaluation	• Test and evaluate different AVL technologies with - Large transit systems - Small and medium transit systems - Rural providers - Specialized paratransit services
Research to Advance the Applications of AVL-Generated Information	• Develop standardized database for different transit management and operations functions • Develop approaches for combining and coordinating AVL systems with other advanced technologies • Test accuracy and performance of different AVL technologies • Human factors issues • Training needs
Innovative Public and Private Sector Partnerships	• Utilize innovative approaches in testing and evaluation program • Utilize innovative approaches in research activities

The deployment and evaluation component of the proposed program would provide a comprehensive approach to testing and evaluating different AVL technologies with a wide range of transit services under varying conditions. This program would build on the work that has already been done at VIA, DART, and METRO — all of which are utilizing different AVL technologies — and would be coordinated with the activities being conducted through the Texas A&M University IVHS Research Center of Excellence. Structured tests and evaluations would be conducted of AVL technologies with large metropolitan, smaller urban, and rural transit systems and specialized transit services in the state.

Each demonstration would be developed as a comprehensive operational test and evaluation program, following the guidelines developed by FTA. This would include the clear articulation of the goals and purpose of the individual test, the establishment of goals, objectives, and measures of effectiveness, and a comprehensive ongoing data collection, monitoring, and evaluation programs. It is anticipated that each deployment and evaluation project would be undertaken through the cooperative efforts of the transit system, FTA, TxDOT, the private sector system supplier, and TTI.

The second aspect of the proposed program is an ongoing research effort to advance the state-of-the-practice related to the use of AVL-generated information. As noted in this report, current applications are limited by a number of factors. The research undertaken in this portion of the program would focus on developing standardized approaches that could be used by transit agencies. This would avoid duplication of efforts which may currently be occurring and would make it much easier for transit systems to implement various applications. Examples of applications for initial research include the development of standardized data bases, testing the accuracy of different technologies, identifying ways to coordinate with ATMS and other advanced technologies, and monitoring and evaluating actual energy savings resulting from AVL systems.

As noted previously, one of the factors limiting the more extensive use of AVL-generated information is that many systems have not developed standardized and ongoing reporting mechanisms for recording and analyzing the information obtained from the AVL system. Until this is done, data generated from a system cannot be used extensively throughout the agency. Research conducted under the proposed program would develop standardized data bases for collecting, analyzing, and dissemination AVL-generated information for a wide range of transit management and operation functions. In addition, research would be conducted to identify ways of coordinating AVL systems with other advanced technologies to enhance transit and overall transportation management.

Another factor limiting the more extensive use of some AVL systems appears to be uncertainty over the accuracy of the information provided. Most of these concerns focus on the accuracy of real-time information on the status of buses from ground-based AVL systems using odometer readings. Ensuring that the information provided by AVL systems is accurate is critical to their success in attracting new riders to transit and providing transit personnel with data needed to enhance management and operational capabilities. This issue would be addressed in the research program through the evaluation of the accuracy and performance of different technologies.

Additional research would also be conducted to provide a better understanding of other issues related to maximizing the benefits from AVL systems. Further research into the data needs and requirements of transit management, maintenance, planning, scheduling, and finance personnel would enhance the design of standardized reporting formats. This would help ensure that all possible users are involved in designing the system to maximize the benefits to each department. Further, coordinating the development of the different reports with other data needs of the agency is important. The work currently underway by the *IVHS America* APTS Committee Map and Spatial Database Working Group should help in this effort.

The research program would also examine the human factors and training issues associated with the implementation and use of transit AVL systems. The job responsibilities and functions of center control personnel and vehicle operators change with the implementation of AVL systems. Currently, little work has been done to determine the impacts of these changes. Analysis in this area would be of benefit to ensure that the human aspects are being adequately considered in the development and implementation of transit AVL systems. The work in this area would be coordinated with current FTA sponsored activities.

The third area of the proposed program would utilize innovative public and private sector approaches to implement the demonstration projects and to conduct the various research activities. As noted previously, the combination of advanced technology businesses in the state, progressive transit systems, TxDOT, and university-based transportation research institutes provide an ideal setting to foster new and creative approaches to implementing this program. It is anticipated that a variety of techniques would be used with the different tests. The experience with these approaches would be monitored and documented to provide other groups with information on the advantages and limitation of different techniques.

Making the *Texas Transit AVL Deployment and Research Program* a reality will take the concerted and coordinated efforts of numerous groups. The support of FTA, local transit systems, TxDOT, private sector businesses, university transportation research institutes, and other groups will be critical. This report provides the first step towards furthering the use of AVL systems by the transit industry in Texas. Further, it provides the base for the development of an ongoing deployment and research program to expand the benefits of AVL technology to additional transit systems and their passengers.

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The following individuals provided additional information on the status and use of AVL technologies with different transit systems.

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