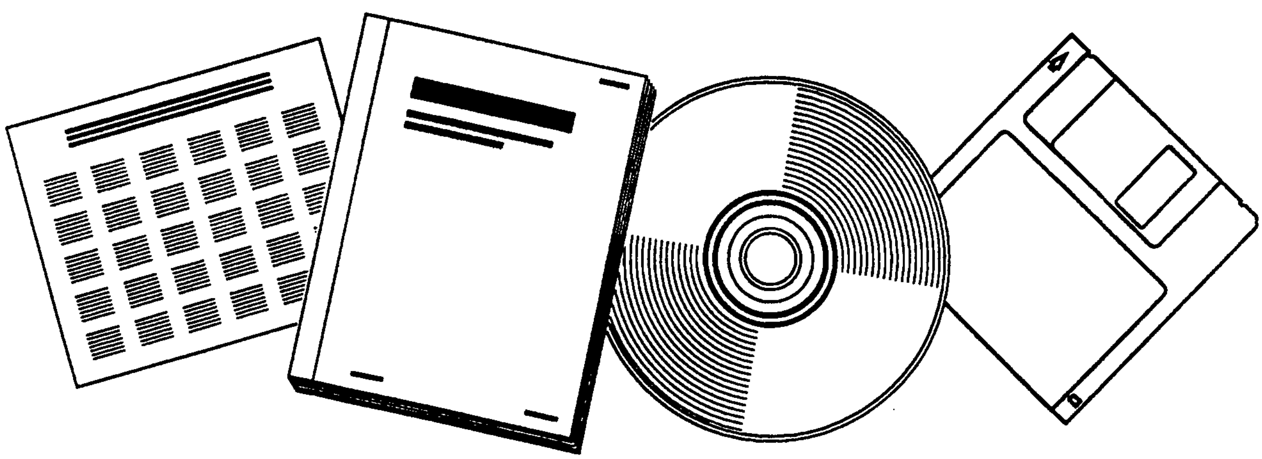
PB98-109812

PLANNING AND IMPLEMENTATION OF AUTOMATIC VEHICLE LOCATION SYSTEMS FOR PUBLIC TRANSIT

JUN 97



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

CUTR

Planning and Implementation of Automatic Vehicle Location Systems for Public Transit

National Urban Transit Institute

at the University of South Florida's Center for Urban Transportation Research

A consortium with · Florida State University · Florida A & M University · Florida International University

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. NUTI95FIU1.2	PB98-109812	3. Recipient's Catalog No.
4. Title and Subtitle Planning and Implementation of Automatic Vehicle Location Systems for Public Transit		5. Report Date June 1997
		6. Performing Organization Code
7. Author(s) Fang Zhao and L. David Shen		8. Performing Organization Report No.
9. Performing Organization Name and Address National Urban Transit Institute Lehman Center for Transportation Research, Florida International University University Park, Miami, FL 33199		10. Work Unit No.
		11. Contract or Grant No. DTRS 95-G-0019
12. Sponsoring Agency Name and Address Office of Research and Special Programs U.S. Department of Transportation, Washington, D.C. 20690		13. Type of Report and Period Covered Sept. 1995 through March 1997
		14. Sponsoring Agency Code

15. Supplementary Notes

Supported by a grant from the U.S. Department of Transportation, University Research Institute Program

16. Abstract

At present, over sixty transit authorities throughout the nation are at various stages of considering or installing AVL systems on their buses to improve fleet management and transit services. Many transit agencies are studying the feasibility of an AVL system, while others have had an operational system for some time now or are in the installation process. While the benefits of AVL systems seem to be evident, their applications are also impeded by the considerable costs associated with them, especially when transit funding faces serious cuts. Additionally, due to the limited operating and maintenance history of AVL systems, particularly of those employing newer technologies, there is a lack of information about AVL performance, benefits, planning practices, implementation processes, operating and maintenance experiences, and operating costs.

The current state-of-the-art AVL technologies, applications, and potential benefits are described in this report. Results from a survey conducted among 135 transit properties are summarized. The survey results show that smaller agencies are less likely to implement AVL since there are less incentives as congestion and crime problems are far less serious than in larger urbanized areas. The perception of AVL only benefiting larger agencies with congestion and crime problems may be a barrier that prevents smaller transit agencies from exploring possible new ways of serving their customers. Other survey results include the commonly used technologies, some of the planning practices, the implementation experiences, etc. Documents related to system specifications and bidding were obtained from a number of transit properties, and are summarized to provide information on some of the technical requirements of AVL systems.

17. Key Words automatic vehicle location system, public transit, planning, implementation	18. Distribution Statement Available to the public through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22181, ph (703) 487-4650		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages	22. Price

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENT

We would like to express our sincere thanks to the following individuals:

Adriana Gomez, a graduate research assistant, provided critical assistance in researching the literature on AVL and in the drafting of the final report.

Muhammed A. Izar, a graduate research assistant, Candace Scott and Raymond Attah, both undergraduate research assistants, also contributed to the project by providing technical assistance.

Mr. Hugh Chen, Metro-Dade Transit Agency (MDTA), provided information about MDTA AVL project and arrange a tour to the new bus control center.

We would like to extend our special thanks to Mr. David Fialkoff, chief, Metro-Dade Transit Agency Service Planning and Scheduling Division, Mr. Ronald J. Baker, General Manager, Communications Implementation and Control Center, Chicago Transit Authority, and Ms. Suzanne B. Tellechea, Transit Planner, City of Winston-Salem for reviewing this report and for their constructive comments.

In the course of this project, we have received kind assistance from many people at different transit agencies by participating in the survey and providing information, which is greatly appreciated. A list of the survey participants is given in APPENDIX D.

This project is made possible through a grant from the U.S. Department of Transportation, Research and Special Programs Administration. Their support is gratefully acknowledged. The views expressed here are those of the authors' and do not reflect the opinions or policies of the U.S. Department of Transportation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

An AVL system is a computer based vehicle tracking system capable of determining a vehicle's location in real time. It allows a dispatcher from a control center to track vehicle movements and communicate with the vehicle's operator. The major benefits for public transit include improved schedule adherence, better emergency responses and passenger security, availability of real time travel information, and the ability to collect more accurate data for planning and operation purposes. However, AVL may also have extended benefits when combined with other technologies to provide, for instance, signal priority for public transit vehicles, and Advanced Traffic Information System (ATIS).

At present, over sixty transit properties throughout the nation are at various stages of considering or installing AVL systems on their buses to improve fleet management and transit services. Many transit agencies are studying the feasibility of an AVL system, while others have had an operational system for some time now or are in the installation process. While the benefits of AVL systems seem to be evident, their applications are also impeded by the considerable costs associated with them, especially when transit funding faces serious cuts. Additionally, due to the limited operating and maintenance history of AVL systems, particularly of those employing newer technologies, there is a lack of information about AVL performance, benefits, planning practices, implementation processes, operating and maintenance experiences, and operating costs.

The current state-of-the-art AVL technologies, applications, and potential benefits are described in this report. Results from a survey conducted among 135 transit properties are summarized. The survey results show that smaller agencies are less likely to implement AVL since there is less incentive as congestion and crime problems are far less serious than in larger urbanized areas. The perception of AVL only benefiting larger agencies with congestion and crime problems may be a barrier that prevents smaller transit agencies from exploring possible new ways of serving their customers. Other survey results include the commonly used technologies, some of the planning practices, the implementation experiences, etc. Documents related to system specifications and bidding were obtained from a number of transit properties, and are summarized to provide information on some of the technical requirements of AVL systems.

EXECUTIVE SUMMARY

Introduction

In the U.S. cities, buses on average carry over 90 percent of the passengers and are an important component of the transportation system. Not only bus services provide mobility to the public, but they also help reduce urban congestions. Providing good bus services, however, has been a challenge to transit properties. Due to continued suburbanization and urban sprawl resulting in decreasing population density, transit properties' ability to provide frequent bus services is limited. Aggravating the problem is the fact that because buses share roadways with general traffic, their operation is very much affected by traffic conditions, and sometimes the schedule becomes unreliable. To improve service quality, transit properties have always been look for solutions. In recent years, innovative technologies have been developed under the umbrella of Advanced Public Transportation Systems (APTS), which is a part of the Intelligent Transportation System (ITS) initiative (referred to as Intelligent Vehicle Highway Systems (IVHS) previously). These technologies have made it possible to significantly improve bus transit performance. One such technology is the automatic vehicle location (AVL) system.

An AVL system is a computer based vehicle tracking system that is capable of determining vehicle locations in real time. It allows a dispatcher from a control center to track vehicle movements and communicate with the vehicle's operator. The major benefits for public transit include improved schedule adherence, better emergency responses and passenger security, availability of real time travel information, and the ability to collect more accurate data for planning and operation purposes.

At present, over sixty transit properties throughout the nation are at various stages of considering or installing AVL systems on their buses to improve fleet management and transit services. Many transit agencies are studying the feasibility of an AVL system, while others have had an operational system for some time now or are installing a system. While the benefits of AVL systems seem to be evident, their applications are also impeded by the considerable costs associated with them, especially when transit funding faces serious cuts. Additionally, due to the limited operating and maintenance history of AVL systems, particularly of those employing newer technologies, there is a lack of information about AVL performance, benefits, planning practices, implementation processes, operating and maintenance experiences, and operating costs.

The goal of this research is to gather useful information about AVL technologies and provide transit agencies with assistance in determining their needs. While a complete guide for planning and implementation will be of great value, the scarce resources and project time table somewhat limited the scope of the work. The objectives are accordingly defined as follows:

1. To identify the existing and potential AVL technologies;

2. To identify the potential applications and benefits of AVL to public transportation;

3. To examine the demand for AVL from transit agencies and the factors that underlie this demand; and

4. To study various aspects of AVL planning and implementation processes.

AVL Applications and Benefits

AVL has been widely accepted as being a useful technology that will help public transit agencies to improve their services and attract ridership. Besides permitting significant improvements in schedule adherence, emergency response, and data collection for service planning purposes, AVL may also be combined with other technologies or ITS components to bring extended benefits. For instance, combined with APC, better data of vehicle loading and loading patterns may be obtained, which will be useful in service planning and adjustments. AVL allows electronic fare boxes to automatically determine the fare based on zonal information. Fare box data such as types of fare, date and time of travel, and volume of passengers traveling between zones are also useful for market analysis and demand modeling. The vehicle's location information may be used to adjust the traffic signal system, allowing signal priority to be provided for public transit vehicles. AVL is also a critical element in automatic annunciation systems, which are capable of determining and announcing the name of the next stop(s), and ATIS, which provides real-time travel information to users via various communication channels. AVL helps to integrate different transit modes by allowing better coordination of modes at transfer points. AVL has also been useful to serve as an effective traffic probe to detect roadway congestion levels, which may be used by transportation agencies for planning, or by automobile drivers to make trip decisions. While these benefits are somewhat evident, AVL is also believed by some to hold the key to the development of new transit paradigms for rural and small urban areas with low density and dispersed activity centers. More studies are needed to investigate such possibilities.

AVL Implementations at Transit Agencies

In recent years, more and more agencies are moving towards adopting one or several components of APTS including AVL. Among the 135 transit agencies that responded to the survey conducted for this project, 69 reported to be considering installing an AVL system, in the process of implementing one, or already have had an operational system, while 65 agencies indicated that they were not considering or had no plans to install an AVL.

In the context of fixed route services, survey results show that larger agencies are more likely to adopt AVL than smaller agencies, which are less burdened with congestion and crime problems. This perception of AVL only benefiting larger agencies with congestion and crime problems may be a barrier that prevents smaller transit agencies from exploring possible new ways of serving their customers.

The top priorities of the majority of the agencies are to improve schedule adherence, emergency responses, and provide real-time travel information. Better data collection for transit planning purposes is also considered important. In comparison, less attention is paid to modal integration and personnel management. This may be a result of many agencies having only one or two modes, which may be verified with more detailed analysis. Some agencies also indicated that their AVL project is part of a large project involving the upgrading of communication systems or ITS.

The response indicated a wide range of technologies being used or considered as the basic locational technology. However, it is clear that global positioning system (GPS) or differential GPS (DGPS), or a combination of GPS/DGPS with another locational technology are the dominant choice today. Many agencies combine GPS or DGPS with another locational technology to compensate for loss of satellite coverage from "urban canyons" and other barriers. Because of the low infrastructure requirements for dead-reckoning, combination of GPS or DGPS may become more popular over other alternatives.

Most AVL funding comes from the federal government, the Federal Transit Administration (FTA). There are also cases where the state contributes up to 20 percent of the funds, in addition to significant local funding sources. For smaller transit properties, funding is a major concern and federal assistance is expected.

Many transit properties that have installed AVL experienced difficulties during the installation process. The leading problems are the reliability of hardware and software, and sometimes limited functionality of software. More than half of the agencies are not satisfied with the obtainable accuracy of the system. A smaller percentage of the survey respondents also indicated problems with cost overrun and contract disputes due to ambiguity in the contract regarding the agency's and contractor's responsibilities.

AVL evaluations that determine the improvement in productivity and benefits to passengers have been limited. A follow-up survey of 13 transit properties that have an operational AVL system, only four have conducted any kind of analysis of AVL benefits. However, information on AVL benefits is valuable to help transit properties improve their systems and develop strategies to take full advantage of the technology. This information will also be invaluable to other agencies considering or implementing an AVL system.

Conclusions and Recommendations

System implementation is not always an easy process due in part to the novelty of the transit applications of the AVL technology. All of the agencies interviewed in the follow-up survey strongly believed that the success of the implementation procedure depends on a series of key elements that are very easy to incorporate in the development process:

- Utilize an outside consultant if the agency lacks the technical personnel necessary to develop the technical specifications. This is very important to ensure that the technology being adopted will provide the necessary capabilities to evolve in a relatively new and constantly changing field, such as AVL systems. With the proper guidance and planning, provisions can be made to ensure that the technology adopted will interface with future systems without becoming obsolete in a short period of time. Small agencies specifically, might not have the trained personnel capable of making appropriate decisions due mainly to lack of training or exposure to the new developing technologies, and might require the expertise of a consultant/vendor in developing a request for proposal or technical specification.

- Choose a vendor that will adhere to the standards published by the Society of Automotive Engineers (SAE). At the present time more than 30 vendors offer technologies that adhere to these standards. Many of the vendors will offer the same or similar features, therefore place emphasis on experience, company stability and recommendations from other agencies.

- Define objectives. It is very important to define, early in the process, the objectives behind the AVL implementation, including future expectations for the system. This important step will allow the agency to review all available technologies and focus on those systems that offer the capabilities needed to perform as desired. These objectives will become the guiding factors for decisions made during the installation process as well as measuring the success of the entire project. It is advisable at this stage of the process to consider a joint effort with other public services such as police, fire and emergency/rescue.

- Involve all concerned parties in the planning process. Wide involvement will ensure that the system is designed to satisfy current and future needs of different transit divisions and local agencies, eliminating conflicts that may arise from incompatibility between the AVL system and different equipment or procedures used by different entities. The benefits of AVL may also be maximized. In addition, as many AVL implementations are a part of a communication system upgrade or of an ITS project, opportunity exists to share the project costs among the involved agencies to reduce the cost burden on transit agencies.

- Prepare detailed specifications incorporating a phased acceptance testing program. This testing program should include the staged installation of the AVL equipment in a few vehicles prior to a full fleet installation. Staged implementation will allow the agency to test the system and work out conflicts as they arise before a full installation. It will also permit the personnel to become familiar with the daily operation of the system prior to a full installation.

- Develop realistic goals for project completion and expect delays. All of the agencies that participated in this study were faced with delays during the implementation process. Technologies are usually tailored to the agency's needs and that generally results in an implementation process that requires testing and developing until the completion and final installation of the system.

- Maintain a positive working relationship with the vendor. The cooperation of agency and vendor will be an invaluable tool for a successful system implementation from the beginning. The AVL system implementation is a long process that by virtue of its novelty, lends itself to changes and upgrades even before the system is completely functional. These changes might not be stipulated in the technical specification or request for proposal issued by the agency and will depend on the good will of the vendor for their inclusion in the implementation process. A vendor will be able to offer suggestions based on their experience with past implementations, resulting in savings (time and money) and a successful implementation process for the agency.

- Break down process into several different tasks. For example, evaluating and determine the agency's needs, gathering documentation of available technology and experience of AVL implementations, choosing the most appropriate technology, developing technical and contractual documents, evaluating proposals by each vendor using the same criteria for all, develop implementation plan, cost estimates, identifying operating costs savings and identify the benefits which will occur with the implementation of the system.

Based on the survey, the average length of time for AVL implementation is 8.25 years. Most of the time was spent on initial acceptance of the concept within an agency, actual installation, and testing. With more information on AVL becoming available and AVL implementation experience accumulating, it is expected that it will take less time for transit properties to learn about AVL and determine it's benefits, develop an RFP or bidding document, and fully test the system and begin regular operations. To assist transit agencies in this task, technical help needs to be provided to them. This may include literature, training workshops, demonstrations, guidelines to help transit agencies to develop project objectives, technical specifications, and contract documents. As indicated by the survey results, most respondents are interested in an AVL planning document that serves as an information source.

Finally, AVL should be viewed as a means to improve transit services and serve the customers, therefore, all the AVL related activities should also be guided with customers' needs in mind. Project goals and evaluation criteria should be established early on in a project to address customer needs and benefits specifically.

Extensive evaluation of AVL benefits, not only to the agencies but also to the passengers, is also urgently needed. Such evaluations will not only benefit other agencies that have not implemented AVL or are in the early stages of AVL planning, but will also benefit the agencies operating AVL to maximize the benefits of AVL.

1. INTRODUCTION

Public transit is facing greater challenges today due to the increased uncertainty in future funding and the continued trend of suburbanization. Suburbanization results in reduced residential density and dispersed employment locations, making it more difficult to provide frequent public transit services with limited resources to those areas. Except in specific heavily traveled corridors and near city centers, fixed guideway systems are often not cost effective due to their low demand, leaving bus transit as the major form of public transit. In fact, bus transit carries approximately 80 percent of all the passengers using public transit and is an important component of the transportation system. Not only bus services provide mobility to the public, but they also help reduce urban congestions.

Providing good bus services, however, has been a challenge to transit properties. Besides transit properties' limited ability to provide frequent bus services, the fact that buses share roadways with general traffic makes their operation susceptible to traffic conditions, and sometimes the schedule becomes unreliable. To improve service quality, transit properties have always been look for solutions. In recent years, innovative technologies have been developed under the umbrella of Advanced Public Transportation Systems (APTS), which is a part of the Intelligent Transportation System (ITS) initiative (referred to as Intelligent Highway Systems (IVHS) previously). These technologies have made it possible to significantly improve bus transit performance. One such technology is the automatic vehicle location (AVL) system.

An AVL system is a computer based vehicle tracking system capable of determining a vehicle's location in real time. It allows a dispatcher from a control center to track vehicle movements and communicate with the vehicle operators. The major benefits for public transit include improved schedule adherence, emergency responses and passenger security, availability of real time travel information, and the ability to collect more accurate data for planning and operational purposes.

At present, over sixty transit authorities throughout the nation are at various stages of considering or installing AVL systems on their buses to improve fleet management and transit services. Many transit agencies are studying the feasibility of an AVL system, while others have had an operational system for some time now or are installing a system. While the benefits of AVL systems seem to be evident, their applications are also impeded by the considerable costs associated with them, especially when transit funding faces serious cuts. Additionally, due to the limited operating and maintenance history of AVL systems, particularly of those employing newer technologies, there is a lack of information about AVL performance, benefits, planning practices, implementation processes, operating and maintenance experiences, and operating costs.

The goal of this research is to gather useful information about AVL technologies and provide transit agencies with assistance in determining their needs. While a complete guide for planning and implementation will be of great value, the limited resources and project time table somewhat limit the scope of the work. The objectives have been accordingly defined as follows:

1. To identify the existing and potential AVL technologies;

2. To identify the potential applications and benefits of AVL to public transportation;

3. To examine the demand for AVL from transit agencies and the factors underlying the demand; and

4. To study various aspects of AVL planning and implementation processes.

In this report, the results of the research are presented. Relevant literature is reviewed in **Section 2**. **Section 3** provides a description of the various vehicle location technologies and their advantages and disadvantages. The major benefits and extended benefits of AVL in conjunction with other advanced technologies are discussed in **Section 4**. **Section 5** provides the results of a survey on the current status of AVL implementation in transit agencies. A number of documents related to system procurement are examined in **Section 6**. Finally **Section 7** provides conclusions and recommendations which address the challenges faced and the needs for technical assistance by transit agencies.

2. RELATED WORK

With the rapid development and deployment of Intelligent Transportation Systems (ITS), public transit has found many new, advanced technologies that allow it to improve services. Automatic Vehicle Location (AVL) systems, which are computer-based vehicle tracking systems capable of determining vehicle locations in real time, have been recognized as having significant impact on improving transit performance. The development of AVL technologies for transit applications began more than two decades ago. Some of the highlights of the developmental history (1970-1992) of automatic vehicle location and control systems for the North America public transit environment are presented in (Cain and Pekilis 1993). The capability of the technologies has progressed from providing crude approximations of vehicular positions with accuracies in terms of miles, to the refined systems of today, which are able to pinpoint vehicles within several meters of its true position. In this section, a summary of the literature on AVL installations, experiences, potential benefits and implementation issues is presented.

One major information source of AVL implementations at public transit agencies is the Federal Transit Administration's document series *Advanced Public Transit Systems - State-of-the Art* (Casey *et al.* 1991, Labell *et al.* 1992, Schweiger *et al.* 1994, Casey *et al.* 1996). APTS was designed to assist the development and evaluation of innovative applications of advanced navigation, information and communication technologies that benefit public transportation the most. As part of this report, an overview of AVL installations at different transit agencies, including the fleet size, technologies, additional equipment included in the project, costs, and operational status is provided. In the 1996 update (Casey *et al.* 1996), 28 agencies are identified as currently operating an AVL system and 36 in the process of installing one, bringing the total of transit agencies installing AVL systems to 64 (see **Table 2.1**). The report also lists expected benefits of AVL systems as follows:

1. Increased overall dispatching and operating efficiency;
2. More reliable service, promoting increased ridership;
3. Quicker response to service disruptions;
4. Inputs to passenger information systems;
5. Increased driver and passenger safety and security;
6. Quicker notice of mechanical problems with the vehicles, reducing maintenance costs;
7. Inputs to traffic signal preferential treatment actuators; and
8. More extensive planning information collected at a lower cost than manual methods.

Table 2.1 North American AVL Systems - Location Technology Summary

	Operating	Installation/ Plan	Total
Signpost and Odometer	14	3	17
Global Positioning	10	30	40
Other	4	3	7
Total	28	36	64

Notes: "Other" refers to dead-reckoning, ground-based radio, or one of these supplemented by signposts or GPS.

Source: (Casey et al. 1996).

The APTS program is divided into six components: assessments of APTS technologies, research of technology adaptations, field operational tests (FOTs), evaluations, technology sharing, and development of user requirements and equipment standards. In (Baker *et al.* 1994), a plan for 16 APTS project sites, including four AVL project sites (each with different characteristics, goals and to some extent, different AVL implementations) is described. The four cities included in the AVL evaluations are Baltimore, Dallas, Denver, and Milwaukee. The AVL systems for these cities are briefly described below (VNTSC 1996).

Baltimore: A test of the AVL system acquired from Westinghouse Electric Corporation in fifty out of MTA's nine hundred fixed route buses was completed. Location referencing was by LORAN-C, supplemented by bus odometer readings and map matching, with the data transmitted over dedicated radio frequencies at a polling rate of twenty seconds. Although the test was performed utilizing LORAN-C technology, it was likely that the final implementation would include GPS, a passenger information system, and a traffic signal preferential treatment technology.

Dallas: The Dallas Area Rapid Transit System purchased a system from ElectroCom Automation L.P. The systems would be GPS-based, supplemented by odometer readings. Data would be transmitted to the center over two dedicated radio frequencies. The system included an emergency alarm and bus component monitoring.

Denver: Westinghouse Electric Corporation would supply Regional Transportation District (RTD) with a GPS-based AVL system, supplemented by odometer readings in areas where satellite signals were not available. Some additional features would be an alarm system, real time vehicle position information to the existing passenger information systems, a farebox alarm, and a possible traffic signal preferential treatment for buses.

Milwaukee: An AVL system, which would operate in much the same way as in Denver, was just purchased from Westinghouse. The initial system did not include vehicle condition monitoring, automatic passenger counting, or automated passenger information, but might be upgraded to include them in the future.

The measures of effectiveness (MOE) used in the evaluation consider nine different areas:

Service to Passengers	actual measures of service quality as well as passenger perceptions.
System Characteristics	operating efficiency, effectiveness as a transportation mode, and the functionality of the system.
Hardware Characteristics	operational performance of the system's equipment.
Software Characteristics	software quality, including expandability and reliability of the system.
Cost Savings	costs of six types: capital, installation, maintenance and repair, operating, labor and fuel.
External Impacts	external impacts including reduction in air pollution, increased accessibility for the disabled, increased security of the system and reduction in number of accidents.
Human Factors	training programs, reassessment of responsibilities of workers in the system and creation of new positions.
Institutional Issues	e.g., overall coordination, interaction between various organizations involved in the implementation, liability issues arising from the mixing of transit control strategies with highway and traffic management, and increased private sector involvement in transit.
Other Issues	e.g., level of disruption during implementation and advertisement to the public.

Three categories of data sources for AVL evaluations are identified in (VNTSC 1996). These are on-going recording activities (including previous years Section 15 Reports, maintenance records, accident reports and security/police records), direct measurements (such as ride checks, point checks and control center observations), and surveys/interviews (passenger, public dispatcher and driver).

Watje *et al.* (1994) presented an overview of the AVL technologies and their potential for improving fleet efficiency and providing better route planning and scheduling. AVL technologies are divided into three main categories: Dead Reckoning, Proximity Signposts and Ranging (tri-lateration, LORAN and GPS). AVL is considered to be primarily used for improving efficiency, service reliability and increasing safety for riders as well as personnel. The authors also pointed out that the most important use of AVL might be in the data collected from the various AVL devices. AVL is more than just a means for locating vehicles, it is a system of technologies. The authors envisioned future uses of AVL as providing a link between real-time vehicle location and geographical and spatial databases for timely and efficient transportation systems, especially demand response, such as paratransit and private transit systems.

The Ministry of Transportation of Ontario (1991) provided an overview of the communications, location and control technologies being employed in transportation, including mobile communications, automatic vehicle identification, automatic vehicle location and navigation (signpost system, dead reckoning, radio location, and application software). At the time the report was published, Ministry of Transportation projects in the areas of automatic vehicle location and control (AVLC) and intelligent vehicle/highways systems included AVLC standards for smaller properties, wide area vehicle monitoring (WAVM), taxi emergency location system, real-time dispatching for paratransit operations, commercial vehicle operations and automatic vehicle identification (AVI), real-time traffic data collection, and real-time route guidance.

In (Perkinson 1994), the feasibility of using a fuzzy-set theory, based on the recognition that most things occur in degrees (set membership on a continuous rather than a dichotomy), and AVL-generated data to monitor congestion was discussed. The case study was performed in the San Antonio, Texas, system, which is based on an electronic signpost and odometer system to determine and report vehicle location. AVL systems provide a fairly economic way for data collection on a continual basis. However, the importance of a substantial inspection of the data is stressed by the authors to eliminate gross data collection errors, as well as to interpret the results.

Baker *et al.* (1994) described the reasons behind the implementation of an AVL/MMS by Seattle Metro (signpost system), Chicago Transit Authority (undecided) and Denver Regional Transportation District (GPS based AVL). A review of the manner in which the systems will operate, as well as the experiences and lessons learned in the process by the different transit agencies, are given. The project objectives for the four transit agencies are summarized in **Table 2.2**. The authors note that all transit authorities have experienced significant delays or problems in the implementation process and have included a list of recommendations to help other transit agencies avoid some of the unanticipated difficulties (or at least place the burden of financial responsibility on the contractor if delays arise).

Table 2.2 Objectives for Four Transit Agencies' AVL Projects

	Seattle Metro	**Denver Regional Transportation District**	**Chicago Transit Authority**
Fleet management	improve radio coverage and call management capabilities	improve ability of dispatchers to adjust on-street operations	provide faster trip time
Safety	assistance in critical situations	increase safety	
Schedule Adherence			provide consistent and reliable service
Improve Schedules	improve service analysis and schedule modifications	develop more efficient schedules	
Provide Travel Information	make on time performance data readily available to users	provide accurate and real-time information to the public	improve passenger information

Overgaard (1993) reported on Seattle Metro's final acceptance of a signpost-based AVL system. A quick overview of the operational aspects of this particular system is given, including a brief explanation on how the coordinators can use the system to monitor service, manage timed transfers, and respond to operator requests for assistance. While Metro's main focus is on deriving the greatest possible benefits from the current signpost-based system, current developments in the area of GPS were still under study at the time of the report for possible consideration. Besides the fixed route system, Seattle Metro has also dial-a-ride and other flexible transit products. Future areas of interest include the integration of the numerous data collection systems on-board transit vehicles, automatic passenger counters (APC), electronic fareboxes, traffic signal prioritazation, automatic annunciators, and participation with Washington State DOT and other transportation agencies in a regional

IVHS data-fusion network.

Jacobson (1993) documented work that had been done in the Puget Sound Region towards developing a region wide signal priority treatment. The focus of this study was to provide priority to buses at signalized intersections by changing the timing of traffic signals to minimize total person delay as opposed to total vehicle delay. Two signal priority control strategies are described: the HOV-Weighted OPAC strategy and the ALift@ control strategy. Results of computer simulation (12 hours of simulation for 16 cases) using the ALift@ strategy showed a reduction of about one third of the delay experienced by buses in the base case. The results achieved were consistent over the confines of volumes analyzed. Consecutive intersections simulating a network were also tested using the ALift@ control strategy, but resulted in inconsistent benefits to buses and negative impacts on general purpose traffic on side streets.

A study by Kihl and Shinn (1993) reports on the first year progress of a two-year project addressing the problems involved with interbus transfer using AVL. This study reports on the difficulties associated with inter-connecting fixed route and demand response vehicles, due in part because of the two very different types of systems. The authors report on the schedule reliability problems associated with a fixed route system, which are the result of the operating environment (e.g. traffic congestion, road construction and weather related factors), driver performance, and vehicular malfunctions. In addition to these operational problems, paratransit must also struggle with trip patterning that is inconsistent and/or unpredictable. This study focuses exclusively on position determination, communication and central processor for Des Moines MTA. The AVL system components for Des Moines are reviewed, including software (tracking, dispatching, scheduling and relational database management system), as well as the GPS receivers, logic boards, radios, on board computers, dispatch, and displays. Year two of this project would be refine a number of issues developed in this paper and would include a real time test of GPS in the Des Moines test site.

Wright, Nookala and Robinson (1994) reported on the Minnesota Department of Transportation's program for IVHS, Minnesota Guidestar. Minnesota Guidestar's project Travlink is an operational test of an integrated AVL/ATIS on a major corridor in the Minneapolis-St. Paul urban area, I-394. The objective of this project is to provide commuters with more timely and accurate information for their travel decisions. Travlink will use a number of devices and systems to provide real time and static multi-modal information to travelers to determine the extent to which the provided information will influence travel behavior. This paper describes project objectives (customer, operations and technology-oriented objectives), the system definition, market research activities, project schedule and public-private partnerships in Travlink.

The Ministry of Transportation of Ontario (1991), in conjunction with several Ontario Transit Properties and the Canadian Urban Transit Association (CUTA) conducted a study on automatic vehicle location and control (AVLC) systems, and their associated technologies. The objective of the study is to provide the information necessary for a series of AVLC demonstration projects at several Ontario Transit Properties. The goal is to lower overall system development and implementation costs, gain experience and knowledge of the benefits of the system, and attempt to advance Canadian AVLC system equipment and software suppliers. The report includes an overview of the AVLC system and a review of the AVLC technology, system impact, and system requirements. A sample of some of North American transit properties that have implemented, are in the process of implementing, or are considering implementing AVLC systems is provided. These transit properties include Hull, Quebec (signpost system); Champaign-Urbana, Illinois (Loran-C based AVL system); Ann Arbor, Michigan (dead-reckoning system in conjunction with a map matching system); Baltimore, Maryland (Loran-C/odometer based AVL system); Hannover, Germany (AVL system is used by light rail, streetcar, and fixed route and demand bus transit for the purpose of eliminating schedule deviations); Strasbourg/Angouleme, France (dead reckoning system); Zurich Switzerland (signpost-based AVL system); and Dublin, Ireland (signpost/odometer system).

The Ministry of Transportation of Ontario also conducted a study to provide a province-wide standard to meet the needs of the majority of properties in Ontario(Cain and Robinson 1993). An overview of the available technologies, their application to the Ontario AVL/C initiative, expected costs, and the potential benefits is presented. The findings and recommendations of this report may be applied to other small and medium Ontario transit properties, therefore some areas relating to property specific applications have been left intentionally vague.

Requirements for an AVL system vary depending on the type of operation (e.g., demand responsive, fixed-route). It is extremely important to define what the true information output requirement is to avoid producing an avalanche of information that would unnecessarily overwhelm dispatch and be detrimental to the operation. A review of AVLC systems' general requirements is provided, along with required accuracies, data considerations and a description of available technologies and their commercial applicability and cost. The different technologies included in the report are buried magnetic strips, multi-lateration, Loran-C, odometer, signposts/beacons, dedicated signpost receiver, capture effect signpost, frequency hopping, synchronized signpost, tag transponders, signpost/odometer, bus stop matching, dead reckoning, GPS, and differential odometer. Recommendations are made for fixed-route and demand responsive systems, respectively, to meet the requirements with the most satisfactory and economical answers available. The authors also included a summary of bid prices on transit data acquisition systems over the previous five years in the appendix of the report. The report was written in conjunction with the Generic Bid Document Package (Cain and Robinson 1993).

Kalaputapu and Demetsky (1995) report on the testing and implementation of automatic vehicle location (AVL) systems for real time monitoring and supervision operations. Implementation of AVL technology needs to be completed by the development of advanced performance analysis and evaluation procedures for assisting in operational planning, management, and real time service control tasks. One potential approach is system behavior modeling. The objective of this study is to investigate the application of artificial neural networks for developing schedule behavior models using schedule-deviation information obtained from Tidewater Regional Transit automatic vehicle location system. The time-series analysis approach is adopted for the development of schedule behavior models at the route level. The outcome of the case study is promising and demonstrates the usefulness of artificial neural networks techniques for modeling schedule deviations of vehicles on a route.

3. TECHNOLOGY REVIEW

A review of various AVL technologies is provided in this section. There is a large volume of literature on various AVL technologies (see, e.g., Ministry of Transportation of Ontario 1991, Gray 1993, Kihl and Shinn 1993, Casey *et al.* 1996, Cain and Robinson 1993, Center for Urban Transportation Research 1994). The degree of sophistication and maturity of different technologies vary. These technologies also have their own distinct operational, performance and cost characteristics. Although global positioning system (GPS) has become the dominant AVL technology for transit applications in recent years, other technologies have been or are still being used. The following review of the technologies will include a description of the basic principles, their applications in public transit, their costs if available, and the advantages and disadvantages.

An AVL system consists of three main components: a method for determining the vehicle position, a communication link between the vehicle (vehicle driver) and the dispatcher, and a control center. The communication is typically achieved via a radio system with both an analog channel for transmitting voice messages and a digital channel for transmitting data. In the control center, where the dispatchers monitor and manage the vehicle operations, there are the central computers for storing and processing transmitted information, visual displays of vehicle locations that are continually updated, and radio equipment. Because of its capability to store, display, and analyze geographic information, geographic information system (GIS) is often used to display the service coverage area and the vehicle locations.

3.1 Odometer System

This technology consists of a stand-alone system that counts wheel revolutions. Odometer systems use flying magnets attached to the front wheels of the vehicle to calculate the distance traveled. This information is then transferred to the control center. The starting point and the final destination must be known for this system to work, since the location of the vehicle is known by measuring the distance traveled along a predefined route.

Typical accuracy of odometer systems are in the order of +/-2 percent of the distance traveled. Odometers may be reset at predetermined points along the route to offset the inaccuracies that build as distance traveled increases, which may be accomplished with signposts (see next section), manual resetting by the driver at known locations, or resetting with door openings.

The main advantage of this system is cost, since it is fairly inexpensive. Odometer monitoring connection costs are approximately $100 (1993 Canadian dollars) per unit (Cain and Robinson 1993). The main disadvantage is the inaccuracy that builds as the distance traveled increases.

3.2 Signpost System

This system relies on short-distance low-powered radio transmitters, referred to as beacons or signposts, mounted 11 to 16 feet above the street on utility poles, which transmit their identification to passing vehicles fitted with a proper receiver (See **Figure 3.1**). A typical signpost has a transmission radius of about 200 feet (60 meters). The vehicle receives the signpost's ID and relays this information to the control center, where the vehicle location is determined based on the particular signpost location identified by the signpost's ID. Each signpost has a unique ID, which, for example, may be equal to the coordinate indices of a Cartesian coordinate system. Assigning a unique ID to each signpost is a convenient way of increasing the number of signposts for the coverage area.

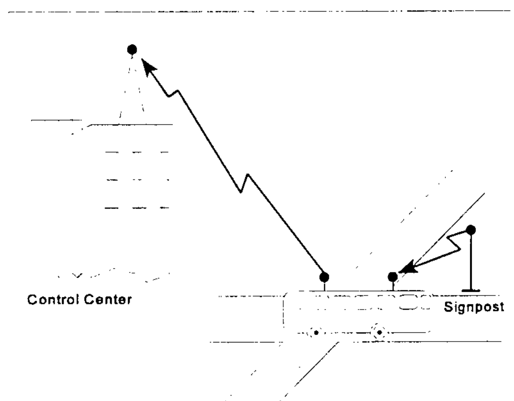


Figure 3.1 A Signpost System

There are two different types of signposts available, narrow focus and wide focus beacons. Narrow focus beacons have a transmission radius of 50 feet (15 meters) and provide a moderately accurate position within the coverage area. Wide focus beams transmit over a radius of 200 feet (60 meters) or more but are not as accurate as narrow focus beacons. One advantage of wide focus over narrow focus beacons is that they may provide coverage for several routes within its vicinity (Pekilis and Heti 1991). Signpost spacing adjustment is the principal method that is employed to assure continuity of coverage. In suburban areas, the spacing between signposts may be increased beyond the distances that are acceptable in more densely developed urban zones.

Each vehicle is equipped with a radio receiver tuned to the frequency of the signpost transmitter, antenna, data processor, narrowband fm transceiver, and a detector circuit that senses the intensity of the emitted signal. A land mobile transceiver, antenna, and remote control terminal link the control center to the vehicles. The ID of the vehicle and the time of passage are stored on board the vehicle until transmitted to the control center through an independent, land mobile radio channel. The dispatcher can then plot the exact location of the vehicle in relation to the signpost and the time of passage.

Approximate costs for a signpost based system is $450 per vehicle for the on-board equipment and $1,000 per location for the wayside proximity signposts transmitter (Pekilis and Heti 1991). **Table 3.1** shows a comparison of the costs of two different transit agencies that employ signpost technology for their transit vehicles. Costs fall within the range of $6,300 - $8,500 per vehicle, as reported in (Federal Transit Administration 1993).

Table 3.1 Cost Comparison for Signpost Technology

Feature		**Cost per Bus**	
		Tampa (190 vehicles)	**Kansas City (284 vehicles)**
Equipment and Maintenance	Communications System	$3,680	$5,970
	Location System	$950	$550
	Central Processing Station	$2,100	$1,020
Software		$1,110	$100
Training		$180	*
Miscellaneous		$280	*
TOTAL		**$8,300**	**$7,640**

*Software costs include training and miscellaneous costs.
Source: (Ball 1994).

Some systems work in reverse by having the signpost equipped with wayside readers which read the vehicle's passive transponder tags as they pass by, and relay the information to the control center (see **Figure 3.2**). Each vehicle transmits a unique ID on a radio channel designated for automatic vehicle location use. This transmission is continuous and low-powered. Signposts equipped with receivers tuned to the designated radio channel relay the vehicle ID to the control center, by means of telephone lines or a wireless channel, where the time of receipt is recorded and the symbol is associated with a specific signpost whose location is known.

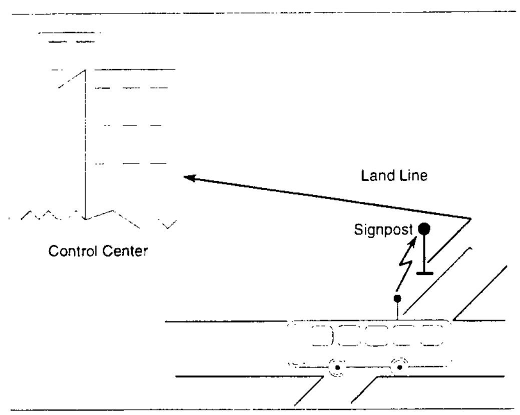


Figure 3.2 A Reverse Signpost System

Approximate costs for a reverse signpost-based system are $50 for the transponder and $14,500 for the wayside equipment, including wayside reader, RF modulator, and wayside antenna (Pekilis and Heti 1991).

Advantages of the signpost system include:

- reasonable costs;
- established consultant experience; and
- reliability and proven effectiveness of the system.

Disadvantages of the signpost system include:

- a large number of signposts required to closely monitor a fleet of vehicles;
- relatively high maintenance costs of the signposts and the receiver on the vehicles, which can be easily dislodged during regular vehicle maintenance;
- radio transmitters subject to vandalism;
- weatherproof cabinets required in cold climates
- being able only to monitor fixed-route buses locked into a particular route. A signpost is required in virtually every corner to be effective in more general applications; and
- inability to provide any other vehicle location information while a vehicle is between signposts.

3.3 Signpost - Odometer System

This system is similar to the signpost only system, but in addition to signposts, each vehicle is fitted with a mobile data unit that monitors the vehicle functions and distance traveled and reports this information to the control center over the radio system. The bus operator enters the route information into the mobile data unit when the vehicle is ready to enter service. Vehicles receive low power signals transmitted from signposts located along the route. . This signal can be detected by receivers on board the vehicle. The signposts constantly transmit their ID number over a small area. The vehicle receives and stores the signpost ID number until the central computer requests the information. In between signposts, the odometer calculates the distance traveled from the last signpost. The vehicle transmits the last signpost it has just passed, along with the distance it has traveled since passing the last signpost when interrogated by the control center. The exact location of the vehicle is known based on the route the vehicle is assigned, the signpost ID number, and the distance traveled since the last signpost. The amount of time the bus is ahead or behind schedule can be estimated by comparing the actual location of the vehicle with computer files containing the information about where each vehicle should be at a given time (Mason 1993).

A reverse alternative of this system reduces radio traffic and the need for reserved radio frequencies, since stationary signposts may be wired into the communication system. With this alternative, each bus has a unique ID, and signals the signpost (equipped with a proper receiver) at the time of passage. The signpost then relays the buses' location to the control center.

The approximate cost of the on-board equipment per bus is $3,200, including electronic compass, wheel monitoring equipment and data monitoring equipment (Pekilis and Heti 1991).

The advantages of employing the traditional method versus the reverse method is that buses may report its location at any point, and not just when a signpost is passed, offering a greater range of positions from which the buses may be located. In general, a signpost-odometer system has improved performance over signpost only systems since a vehicle's position may be determined continuously between signposts.

3.4 Capture Effect Signpost System

In the Capture Effect Signpost system, the in-vehicle receiver receives both the central voice and data signals and the signpost signal, since the control center and the signposts transmit on the same frequency. The signpost signal becomes stronger in the immediate area of the signpost, capturing the receiver. Once the vehicle leaves the signpost coverage area, it notifies the control center of the signpost ID and location. This type of technology relies on the stronger of two signals capturing the receiver, resulting in a very noisy changeover in the proximity of a signpost and a period of blackout communications from the control center. If a vehicle is passing the signpost coverage area at a reasonable speed, this problem may not be serious enough to cause concerns. However, in cases where the vehicle is stationary, moving too slowly or stopped near a signpost, the length of the blackout period from the control center might be unacceptable. While signpost signals tend to be more stable due to their short range, switch-overs tend to be unstable due to variations in fading, multipath, and other factors that produce a constant change in the level of the control center's signal. This instability will result in random variations at the point of capture due to weather, atmospherics and local traffic conditions. Since accuracy depends on where the signpost ID is first received, variations in the RF field strength from the control center will render this system inaccurate and ineffective. As a result, each signpost would require unique adjustments due to the variability of the RF field strength from the control center (Cain and Robinson 1993).

3.5 Frequency Hopping Systems

This system is similar to the capture effect signpost system. The radio signposts are operated on a separate frequency within 1 MHz of the vehicle receiver frequency. The vehicle constantly switches the receiver over to the signpost frequency, in search for a signal from the signpost. If no signal is received, the process continues as before. If a signpost signal is received, information on the signpost ID, and therefore the vehicle's location, is transmitted to the control center on the next poll (Cain and Robinson 1993).

Advantages

- vehicles do not require a separate signpost receiver; and
- all signposts can have the same frequency and are free from interference from the base.

Disadvantages

- possible loss of data while on the signpost search, resulting in inaccuracies due to the hopping time; and
- signpost field may not be detected for some distance while intersecting the signpost radiating area.

3.6 Synchronized Signposts System

In this system, the base transmitter and signposts are on the same channel, but are time multiplexed. *Multiplex* is a technique used to transmit multiple signals or messages simultaneously on the same channel. The synchronization of all signposts permits the base station to shut down while all signposts switch on and vice versa. Vehicle receivers are always on the same channel, and the system remains always under the control of the base transmitter. The signpost requires a receiver for instructions from the base system as to the time of the ID transmittal. These receivers are inexpensive, approximately $150 (1993 Canadian dollars) (Cain and Robinson 1993).

A major problem with this system is the inaccuracies caused by vehicle entering the signpost field when the signpost is not on. The solution requires expensive, high speed switching from the control center.

3.7 Buried Magnetic Strips System

Although this technology has been available for a number of years, it is not anticipated to progress any further due to its inherent drawbacks. Vehicle location is attained by the detection of a binary coded pattern (1-0-1-0) through a pick-up coil on a vehicle traveling over magnetic strips buried in the roadway. The disadvantages of the system include the high cost of the in-vehicle detection system that can reach $5,000 per vehicle (1993 Canadian dollars) (Cain and Robinson 1993), the expenses of burying and maintaining the strips in the roadway, the fact that exact location of the vehicle is known only at the locations fitted with strips, and that changes in routes require extensive modifications of the roadbed.

3.8 Tag Transponder System

This system operates by having a roadside signpost irradiate a vehicle equipped with a transponder. The transponder then sends the ID information to the roadside unit, which then sends it to the dispatch via land lines. This system locates the presence of a vehicle at the roadside signpost, and cannot provide any more than location confirmation at each physical location. Tags are inexpensive, approximately $100, but the cost of the roadside units installed can reach up to $20,000 (1993 Canadian dollars) (Cain and Robinson 1993).

3.9 Dead Reckoning System

The dead reckoning navigation principle is implemented by employing two instruments: one measuring distance traveled and the other the direction of movements. Most often, devices used in dead reckoning are odometer wheel rotation sensors (attached to the unpowered front wheels of the vehicle to avoid errors caused by slippage) and compasses. Using this technology, the position of a vehicle may be continuously determined by measuring the distances and directions from a known point, normally the origination. This data is transmitted by radio to the control center, where the location is computed and displayed (See **Figure 3.3**).

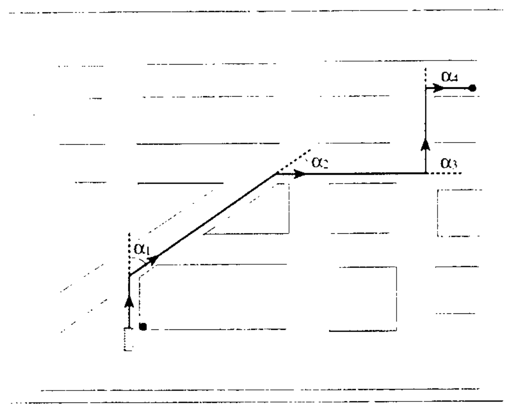


Figure 3.3 Vehicle Location Determination by Dead-Reckoning

The Control Center includes a data processing computer, visual displays, control console, and radio equipment. The computations and data processing performed by the computer include time-ordering the receipt of data from the vehicle sensors, computation, correction, initialization of vehicle position estimates, vehicle status monitoring, vehicle assignment queue maintenance, area map graphical storage, visual display and a radio communications control necessary for effective fleet monitoring.

As the vehicle moves away from the starting point, errors in measuring distance and angular direction accumulate. This forces dead reckoning systems to make provisions for reinitializing each vehicle's position at regular intervals or at designated locations. Whenever a vehicle passes a reinitialization point, both the distance and the angle measuring instruments are adjusted to a predetermined setting and a new track is initiated.

Dead Reckoning systems will periodically position a vehicle off the road or on an adjacent road, a mistake that is easily corrected by the vehicle operator with manual intervention. Another source of errors arise from the use of magnetic compasses, which require calibration to remove the effects of local magnetic disturbances. Some units perform this calibration autonomously, but are still sensitive to transient effects, such as passing under a steel structure, or by other metallic structures in, under or near the road.

Auxiliary correction techniques are frequently used to improve longer term accuracy. This may be accomplished through map matching, where the calculated position of the vehicle is compared to the road network in the vicinity of the calculated position. The basic principle is that if a vehicle is traveling a given distance at a given speed, it must be on a road. Additionally, if the vehicle is turning, it must be doing so from one road onto another. Errors can be corrected based on known road positions and road headings. The distance traveled can be corrected when the vehicle goes around a curve or turns a corner onto a known street (Sweeney and Loughmiller 1993).

The advantage of dead-reckoning systems is the low cost since no installation of extensive wayside equipment or supporting infrastructure is required. The disadvantages of the system include the inaccuracy that builds up in the vehicle's relative position as it travels long distances, and measurement errors caused by vehicles traveling on incline surfaces, in which the compass measures a portion of the vertical component of the earth's magnetic field as well as the desired horizontal component. These errors, however, may be removed by the use of an inclinometer to measure compass tilt, and a calibration procedure to compensate for tilt effects in the compass measurements.

3.10 Multi-Lateration Systems

There are two types of multi-lateration systems, tri-lateration and tri-angulations. *Tri-lateration* systems consist of fixed receiver stations and a transmitter that powers up at a predetermined time and transmits a pulse or radio frequency signal (usually in the 902-928 MHz range). A vehicle's location is based on the difference of time between the arrival of the signals at each location (Cain and Pekilis 1993). The positions of the fixed receiver stations are mapped to a grid and serve as reference points. If three or more receivers receive a signal, a unique location for the vehicle is obtained with an accuracy of +/- 50 feet. The number of receivers depends on the area and the terrain, and the distance between them can be 10 miles or more. Receivers are extremely expensive due to the accurate clocks that are required to measure the signal arrival time. Approximate cost of the system is $7,000 (1993 Canadian dollars) per vehicle, while fixed sites runs into the six figure range (Cain and Robinson 1993). Because of the large number of fixed sites requiring atomic clocks for stability that need to be installed, the cost of the system is high.

Tri-angulation systems require only two fixed sites as opposed to three or more in tri-lateration systems. The antenna sites are mapped onto a grid, and each antenna measures the angle or direction at which a signal arrives. Location accuracy increases with increasing number of antennae that acquire a bearing. This system is cost-effective for transit agencies that have a large fleet, and in locations where radio signal towers have already been installed. This is typical of large metropolitan areas with a high population density.

3.11 Loran-C Systems

Loran-C (Long Range Aid to Navigation) is a land-based radio navigation system which uses low-frequency radio waves to provide signal coverage on land for up to 1500 kilometers (see **Figure 3.4**). This communications system was instituted by the Federal Government to aid the U.S. Geological Survey in mapping. The federal government provides the infrastructure free of charge, covering most of the United States and Southern Canada. It is widely used for air and marine navigation in North America, and consists of a series of synchronized transmitting stations covering most of the continent independent of any line of sight. Stations are typically 1,100 kilometers apart (684 miles).

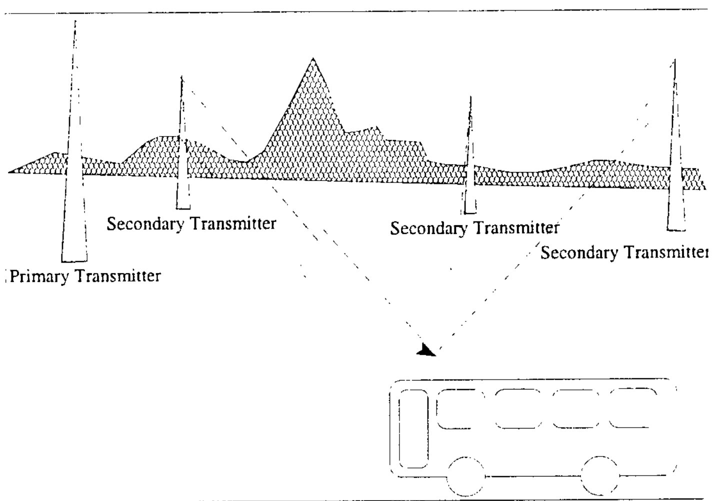


Figure 3.4 AVL Technology Based on Loran-C

Signals are transmitted from sets of chains of three to five Loran Stations. Each chain consists of one master station, with the remaining 2 to 4 stations selected as secondaries. The transmittal sequence follows the following pattern: master station broadcasts first, followed by the secondary transmitters. Loran-C receivers are able to measure the time between the reception of the master signal and the reception of each one of the secondary signals, information that is used to obtain an absolute position accuracy in the range of 165 to 655 feet (50 to 200 meters) (Pekilis and Heti, 1991). The repeatable and relative accuracy depends upon the chain geometry and is usually between 20 and 90 meters with 95 percent of confidence and 99.7 percent availability.

Loran-C systems are being replaced by other positioning technologies due to problems with interference as well as the cost of the vehicular receivers, which are approximately $2,200 each (Ball 1994). Another reason for the decline in use of the Loran-C system is the anticipated replacement of Loran-C by the GPS technology, of which the user equipment price continues to drop. According to the 1994 Federal Radionavigation Plan, the use of Loran-C will remain constant with little or no growth. It is expected, however, that users will switch to GPS as their Loran-C equipment becomes out-dated.

Differential Loran-C, a variation of the basic Loran-C system, provides location accuracies of approximately 50 feet (15 meters). A Loran receiver placed at a known location provides dependable correction data for remote receivers located within a 30 to 50 kilometer radius. Errors can be corrected on the central computer as remote units transmit their time difference information back to central site, or a reference signal can be transmitted to the remote vehicle receivers and applied in their position calculations (Pekilis and Heti 1991).

The most significant advantage of Loran-C is that no infrastructure is required since the system uses an existing network that provides national coverage. However, Loran-C also has several shortcomings, including susceptibility to radio-frequency and electromagnetic interference, such as close proximity to overhead power lines and substations (120 meters or less), reported problems with signal reception in urban canyons, and interference from florescent lights on buses with the ground-based radio signals.

3.12 Reverse Approach System

Newer systems based on radio signal triangulation are being developed, such as "reverse Loran". In these reverse systems, it is the vehicle that transmits a signal to receiving stations, which calculate the location of the source of the signal, allowing a dispatcher to know the location without the need for further communication from the vehicle. Vehicles are polled individually prompting the on-board equipment to transmit a beacon signal which is detectable by the system's receiver stations. The location of the vehicle is calculated by comparing the time difference of the reception of the vehicle's beacon at each one of the receiving stations. This information is then distributed to the various fleet operators over land lines.

Reverse approach system infrastructure is privately owned and operated, therefore the infrastructure for a national system is not in place. The initial infrastructure is very expensive and requires extensive time for set up, increasing the operating costs. Polling and receiving systems are expensive and require multiple receiving towers. Some transit agencies in large urban areas may take advantage of an already installed system and pay a monthly service fee in return for the right to use the system.

3.13 Omega Systems

The Omega system is a low frequency land-based radio navigation system operating in the 10 to 13 kilohertz range, providing an accuracy of 2.3 to 4.6 miles (3.7 to 7.4 kilometers). Up to 90% worldwide coverage is provided through eight stationary transmitting stations located 4,970 miles (8,000 kilometers) apart provided free by the national government. Location accuracy depends on geographic location, time of day, number of stations used in calculating the location, and whether propagation corrections are employed (Pekilis and Heti 1991).

Differential Omega systems provide better location accuracy through the use of fixed reference stations. These stations can identify errors and calculate differential corrections, which in turn are transmitted to users in the surrounding area.

Omega systems have a frequency of polling of 10 seconds. An additional dead-reckoning system is necessary if location information is required more often. The accuracy of the system is influenced by the height and behavior of the ionosphere.

3.14 Cellular Phone System

In cellular technology, a large area is divided into small cells, and groups of cells are usually clustered into sets of seven, although clusters of 4 or 12 cells are also possible. Low-power transmitters are used to transmit signals over short distances to cover a cluster of cells, thus allowing the same frequencies to be reused in nearby cell clusters. This technology is, therefore, able to accommodate a large number of mobile subscribers without requiring a large number of different radio frequencies. Each cell supports a varying number of channels; cells in urban areas may be allocated more channels than nearby cells in rural environments. The more channels a cell has, the more subscribers it can support. This channel-subscriber relationship is, however, not linear. Doubling the number of channels more than doubles the number of subscribers. When a mobile user approaches a cell boundary, the strength of the signal will weaken. This change in signal strength prompt the system to switch the radio link to an adjacent cell.

Cells can be divided into smaller cells when no more subscribers can be accommodated. The new smaller cell can support the same number of channels as the original large cell, however, more stations will be required. Co-channel interference can be minimized with the use of directional antennas at the base station (3 to 6 antennas are used, each covering an angle of 120º to 60º), and by reducing the power output of the base station. The cell splitting process can continue, however, there are some economic and practical constraints, since system cost increases as cell size decreases. Additionally, cells abut or overlap so that there are no gaps in coverage area, which increases the difficulty to minimize interference (Walker 1990).

Cellular coverage in the U.S. has reached 90% of its population and 60% of its geographic regions (Krakiwsky 1996), therefore infrastructure needed is minimum. Cellular phones also do not require "line-of-sight" to be maintained, an advantage over the GPS technology. However, positional accuracy for this technology has yet to be determined [Ball 94]. A test for cellular phone technology is currently being conducted in the Washington D.C. metropolitan area. In the project, cellular telephone users will be tracked by using passive RF signals emitted from cellular phones and special purpose receiving antennas to locate a vehicle.

3.15 Global Positioning System

Global Positioning System (GPS) is a U.S. military positioning and navigational system that uses satellite based transmitters for its radio signal sources. The system consists of 24 satellites revolving at an altitude of 36,000 kilometers in synchronization with the earth's rotation, therefore remaining over the same location above the Earth's surface, and providing coverage world wide. At any time and any location on the earth surface, there will be at least four visible satellites, from which the signals containing positioning and timing information may be received. A GPS receiver mounted on the top of a vehicle may be used to receive these signals and, based on the travel time of the signals and satellite locations, compute the receiver's positions relative to the satellites, from which the position of the receiver on the Earth's surface is derived (see **Figure 3.5**). The vehicle location information may then be transmitted to a central control.

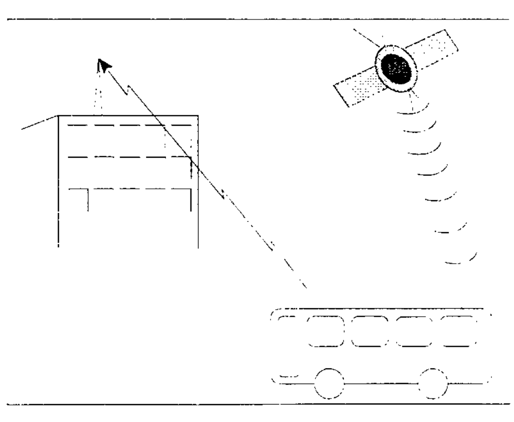


Figure 3.5 GPS-Based AVL

Although this system is now available for civilian use, the US military still retains control of the satellites (21 are now available for civilian use and 3 reserved for military use). This service is provided free of charge, however a license must be obtained. Selective availability is intentional errors introduced by the U.S. military, which are random and tend to slowly drift within a 100 meters (330 feet) radius circular area centered on the true GPS receiver position. These errors may report a vehicle on the wrong road in areas where there is a dense street network or where roads run adjacent to highways (Sweeney and Loughmiller, 1993). The accuracy may be improved by employing differential GPS, which is described in **Section 3.16**.

Another problem experienced with GPS systems are their susceptibility to interference from sources such as buildings, trees, tunnels or subways, which can introduce errors. Since GPS satellites broadcast on microwave frequencies, GPS receivers have to be in the "line of sight". Any interruptions to the "line of sight" transmission from a GPS satellite transmitter will prevent the receiver from locking on to the transmission beam, resulting in signal gaps or blind spots. To deal with this problem, GPS may be combined with dead-reckoning and map matching (Watje *et al.* 1994).

Future developments of GPS include the deployment of the low elevation orbit (LEO) satellites (data only), as opposed to the Geo satellites (voice and data) currently being used by GPS systems. LEO constellations will provide global, low-powered handheld communications at a much lower cost. This newer generation of satellites will require smaller antennas and receivers, since the satellites will remain in a geosynchronous orbit with the earth at a distance of less than 500 miles (800 kilometers).

Table 3.2 shows the approximate costs for three different GPS systems. Fleet management expenses are included in the start-up costs for all three systems. Qualcomm offsets the low positional accuracy by offering extensive fleet management software support. **Table 3.3** is a comparison of the costs for two different transit agencies that have implemented GPS-based AVL systems.

Table 3.2 Approximate Cost for GPS Systems

Vendor	Start-up Cost (per vehicle) (1994 U.S. Dollars)	Monthly Service Charge	Accuracy
Auto-Trac	$7,000	none	+/- 50 feet
Highway Master	$2,000	none	+/- 30 feet
QualComm	$4,500	$170/ per vehicle	+/- 500 feet

Source: (Ball 1994).

Table 3.3 Comparison for GPS-Based AVL Systems: Baltimore and Denver

Feature		Cost per Bus	
		Baltimore	Denver
Equipment	Communications System	$10,320	$11,350
	Location System	$10,500	$1,700
	Central Processing Station	$11,820	$3,140
Software		$620	$480
Training		$280	*
Miscellaneous		$180	*
TOTAL		$33,720	$16,670

*Software costs include training and miscellaneous costs.
Source: (Ball 1994).

Signal outages may be caused by screening of the satellites from a GPS receiver by buildings (10 or more stories), hills and dense foliage, or complete shielding of the satellite by tunnels and subways. Dead reckoning may, however, be used to compensate for signal outages. The system is also affected by ionosphere, and inaccuracies due to ephemeris data, satellite clock data, atmosphere multipath and receiver noise. The system also becomes very expensive for large fleet operations due to the cost of receivers (about $2,000 to $3,000 a piece). The price of receivers may continue to go down as it has in the past.

3.16 Differential Global Positioning System (DGPS)

To improve accuracy, commercial GPS receiver manufacturers are implementing Differential GPS (DGPS). DGPS is capable of attaining accuracies of 3 to 5 feet, by introducing a fixed GPS receiver of known location to measure the errors introduced by selective availability (SA) (Kihl and Shinn 1995). The coordinates at the known location are compared against the location given by the receiver at this site and the differences become the differential corrections. These correction parameters are then conveyed to the in-vehicle navigation system or to the control center to remove the SA errors from GPS positions measured on the vehicles in the surrounding area. According to Sweeney and Laughmiller (1993), these differential corrections require that fixed GPS reference stations be within 62 to 124 miles (100 to 200 kilometers) of the GPS mobile vehicle. Differential correction signals are not universally available. It is more likely that a sufficient number of fixed GPS stations will be provided to cover major metropolitan areas. However, the same will not be true for remote and rural areas. Therefore, map matching may be required in rural areas for reliable navigation.

Table 3.4 provides approximate costs of two DGPS systems. Fleet management expenses are included in the start-up costs for both systems.

Table 3.4 Approximate Cost for DGPS Systems

Vendor	Yearly Service fee	One time	Accuracy
Differential Corrections, Inc	$600	$615/per vehicle	+/- 3.3 feet
Acc-Q-Point	$1,200 per receiver	$519/per vehicle	+/- 3.3 feet

Source: (Ball 1994).

DGPS has the highest obtainable positional accuracy with existing infrastructure. Fixed GPS stations are already established at various locations throughout the country. In **Appendix A**, maps from the U.S. Coast Guard illustrate the locations and radii of coverage of fixed GPS stations.

When an area is not covered by fixed GPS stations, alternative methods may be used to correct for accuracy errors. Studies are being conducted on the possibility of using the same VHF radio system used to communicate with the mobile units for such purposes (Feijóo *et al.* 1993). To do this, there are a number of parameters that must be selected in order to meet the operational requisites. For example, the frequency in the VHF band must be selected in accordance with the type of terrain. A prototype of the system was constructed with a base station transmitted power of 15 w and base station antenna gain of 3dB achieving a typical range of 25 km in rural environment. There exist some coverage problems, and improvements are being considered at the present time.

Another approach for providing DGPS corrections that is cost effective is through the Radio Broadcast Data Standard (RBDS). RBDS is based on the European technology Radio Data System (RDS) and has now been established in the U.S. (Sushko 1993). This concept will provide DGPS correction over existing FM broadcast stations with an accuracy of 2 to 5 meters. In the past, RF subcarrier broadcasting has mostly been used in the U.S. for data paging services. To allow the FM radio receivers to receive DGPS correction data or other data in addition to FM station broadcast, they only need to be equipped to demodulate the data portion of the broadcast.

While DGPS greatly improves the accuracy in a GPS, the system still suffers from the same problems as faced by GPS such as signal outages caused by screening of the satellites from a GPS receiver by buildings, hills or dense foliage or multipath caused by satellite signal reflection from nearby structures and terrain which can produce errors that are not compensated by differential corrections. In addition, DGPS is highly sophisticated and, therefore, very expensive.

3.17 Combination of Location Technologies

GPS information is used to update vehicle position when dead reckoning and map matching show conflicting information which indicates that the present map matching position might be incorrect. The estimated vehicle position is then adjusted to the GPS position, which is usually close enough to the actual vehicle position. Map matching can subsequently acquire the true position. This approach attains much better accuracy and continuity than regular GPS by itself, while it provides self-correction for the dead-reckoning plus map matching errors that occasionally occur (Pacific Rim Conference, July 25, 1993).

One example of a combination of DGPS and dead reckoning system is the Continuous Positioning System (CPS). This system combines the angular measurement made with the gyroscope and the distance traveled measured by the vehicle odometer with the long term accuracy of GPS. It consists of a fiber-optic gyroscope, a GPS receiver, vehicle odometer input and microprocessor, in a compact packaging operating from vehicle power. Additional features offered in this system are communications and data collection interfaces.

4. AVL APPLICATIONS

In this section, the direct and extended benefits of AVL are discussed.

4.1 Direct Benefits of AVL

The goals established for the APTS by the federal Transit Administration include the following:

(1) enhance the quality of on-street service to customers ;
(2) improve system productivity and job satisfaction;
(3) enhance the contribution of public transportation systems to overall community goals; and
(4) expand the knowledge base of professionals concerned with APTS innovations.

AVL is an APTS technology that contributes to the achievement of the above goals. AVL holds the promise of improving transit service and performance by making timely and critical information more readily available to transit management and staff. By itself, AVL allows the location, travel speed (with some of the technologies), and sometimes operating status of buses equipped with AVL and monitoring devices to be displayed on a Geographic Information System (GIS) map in the control center. Dispatchers are always aware of the fleet operational conditions, including bus locations, travel speed, schedule adherence, and any abnormalities such as mechanical or communication problems, deviation of a bus from the assigned route, and emergencies. Deviations from schedule may be detected on-board by comparing the current location of a bus and time against the schedule with the help of a microprocessor. The control center is alerted only when delays exceed a specified tolerance. This may be done also at the control center, where information on schedule adherence may be sent back to the bus. If a schedule deviation is detected, the driver will be alerted and an effort may be made to correct the problem However, the first method, or to determine schedule deviation on-board, is preferred since it conserves the radio space. Improved schedule adherence will increase the satisfaction level of the customer, who will spend less time waiting and worrying about getting on a bus, and will reach his/her destination faster. Passenger security is also improved because of the reduction in the unnecessary time a passenger has to wait for a late transit bus, particularly after dark.

AVL data collected are extremely helpful in developing service plans and schedules. Consistent delays in schedule may signal the need for schedule adjustments to account for increased levels of congestion or other conditions. Reliable schedules may be developed for a different time of the day and different days and seasons, as well as for multiple time points. Collecting detailed running time data is often difficult using the conventional manual methods due to the labor intensive nature of the task. AVL, therefore, promises significant improvements in service planning practices.

Another important benefit directly derived from AVL is improved emergency responses. In case of vehicle breakdown or a medical problem, the control center will be able to determine quickly the precise location of the bus and either dispatch another bus to replace the one that is broken down or send appropriate emergency vehicles. In case of crimes, a silent alarm may be activated by the bus driver and the control center will be able to monitor the bus movement while calling for police help. This feature is an important one as not only it improves response time, but it also help reduce crime rates. AVL as a security measure helps to reduce the crimes on board a bus, and therefore improve security on transit vehicles for bus operators and passengers. Emergency systems are bound to experience a certain number of false alarms. It is therefore desirable for the security computer to have additional capabilities which remove this level of doubt. Presently, this is achieved by dispatchers listening to what is happening through the radio. A radio data network also offers the opportunity to transmit digital reduced-size pictures. Pictures are taken at intervals compatible with the security objectives, and of sufficient quality to be able to analyze the situation. When the emergency situation warrants, pictures of better quality may be transmitted over a longer period of time.

Because of the constant contact and ability to communicate with the control center, and better information on schedule adherence, bus operators will feel more secure, less isolated, and more in control. These will translate into higher job satisfaction and productivity.

It should be pointed out that AVL may potentially impact how public transit services will be provided in small and rural areas. Due to the low densities and dispersed populations, providing services in such areas is difficult. Fixed route services are both expensive and ineffective due to the large coverage area and low ridership. For these areas, public transit services may be provided at a cost comparable to that of low-density urbanized areas by operating a flexible service similar to demand responsive services made possible by utilizing the AVL technology. For instance, Berkshire Regional Transit Authority at Pittsfield, MA, indicated that the agency will shift away from the traditional fixed route service in the more rural portions of the service area to a hybrid of fixed route and demand response services when a GPS-based AVL is implemented in 1998. If proven to be successful, this type of service may be also expanded to low-density urban areas. More studies are needed to determine the potential effects of introducing AVL to small and rural areas.

AVL provides extended benefits when combined with other technologies. Examples of such benefits are briefly described below.

4.2 Automatic Passenger Counters

The most often used automatic passenger counters (APCs) consist of two adjacent and horizontal infrared light beams that span across the door steps of the vehicle, to detect whether a passenger is boarding or alighting. Other motion detection techniques may also be used. Combined with AVL, APCs can provide information on the number of passengers that board and alight a bus at different locations and at different times during the day. This accurate ridership count can then be used in future planning of schedules and routes. APC's are also an effective tool to satisfy the FTA's Section 15 requirements for annual passenger miles.

4.3 Ticket Validators - Electronic Fare Boxes

Bologna Public Transit Authority currently utilizes a ticket validator that is able to perform the following tasks, utilizing traditional paper tickets or smart cards:

- accept ticket, perform required operations and return the ticket quickly, without slowing down the flow of boarding passengers.
- decode/encode all necessary information stored in the ticket
- print on the ticket all validation data to ease the work of ticket inspectors
- prompt passengers for their destination fare zone

Currently, the system is able to process several types of tickets: single-journey tickets for a single ride including a transfer, regular value tickets which can be used on any route and will prompt the passenger for their final destination zone, value cards for season pass holders valid only on a predefined route, and value cards for special user classes valid for one year on a given origin-destination route.

Ticket validators utilize fare structures that are based on the ability of the on-board system to detect the number of fare zones changes or crossings. Fare zones are structured based on passenger flow, public transport usage, and land-use themes, to improve the revenue/cost ratio for the public transit operator. The fare zones map is stored on the on-board computer, so that the computer knows all fare change points. Vehicle position is notified to the on-board computer by the AVL system. When a change of fare zone is imminent, the ticket validator is updated via a serial communication line. In cases where the origin-destination is not predefined, the passenger must key-in his/her own destination directly on the validator, which already has all the information in memory to compute the fare.

This program allows for the implementation of a unified fare system that will ease the integration of different companies operating in the same area, promote the use of public transport through discount policies (e.g. higher discount for more intensive usage), and provide precise knowledge of demand patterns (such as origin-destination matrix, frequency of use of season tickets, vehicle loads). All collected data are automatically transferred to the main computer, ready for management processes and service planning (Brunetti et al, 1995).

4.4 Traffic Signal Priority

Traffic Signal Priority (TSP) has been widely used for transit in Europe since approximately 1968. The following is an overall view of the traffic signal priority as it is implemented in several cities in Europe (CTA 1992).

In many European countries, public transit vehicles are allowed to proceed through signalized intersections without delay. The most important aspect of TSP is to give only the minimum green time, to reduce transit delay and impact on regular traffic, which means giving the signal as late as possible and for the minimum amount of time necessary. The green time is extended up to an usual maximum of 40 seconds or shortened to a minimum of 7 seconds, or the red time is shortened. The cycle of succession of phases itself remains unchanged. An approaching vehicle will usually send three announcements to request priority. The first announcement is usually sent 300 meters in advance to request the central computer to set priority. A second announcement is sent at 100 meters to reconfirm and lock the intersection, and the third provides a log-off point. If a vehicle does not log-off after a predetermined length of time, the vehicle is automatically logged off. A synchronized green wave is automatically activated when a vehicle has crossed several intersections. In situations where a traffic light is located immediately after a stop, the vehicle signals its presence as it approaches the light. The light changes to green after 10 to 15 seconds and remains green until the vehicle signals that it has crossed the intersection. The volume of vehicles that may be accommodated remains unchanged even though priority is given to public transit. Unnecessary green phases are averted to avoid congestion, and traffic is constantly monitored. Some cities have changed from an overall coordinated system to small groups of 3-7 intersections (microsystems). Hannover and Amsterdam report more consistent running times with a 20% cut in total time after the implementation of signal priority (CTA 1992).

There are basically two kinds of priority systems, centralized and decentralized systems, and both are comprised of the same elements: traffic lights, traffic controllers, traffic detectors, transmission system, and a central area computer. Decentralized systems are used mainly for an isolated intersection or intersections which are in a hierarchical Urban Traffic Control

System (UTCS). Traffic lights are controlled by local intersection controllers which are able to work alone or in connection with a central computer, if the city is equipped with a UTCS (Laurens 1995).

A hierarchical UTCS system is compelled to adopt a decentralized approach. The central computer determines the timing of the intersections, delegating the fine tuning of the timings on a second by second basis to the intersection controller. Employing different detection methods, the vehicle is detected at a fixed distance from the intersection and the information is relayed to the intersection controller. The controller can predict the arrival of the vehicle at the intersection using a fixed travel time value. Bernard Laurens (1995) describes the basic process as follows. If the predicted arrival corresponds to a green period, the vehicle can cross the intersection without stopping or any actions on the part of the traffic control system. If the predicted arrival time falls within a yellow or red period but is within the maximum allowed green extension, the green phase will be extended to allow the vehicle to pass through the intersection before the signal changes to the yellow phase. If the vehicle's arrival time is after the maximum green extension but before the minimum red time, then the red time will be shortened to its minimum allowed time. Otherwise, the red time is cut and a green phase begins to coincide with the arrival of the vehicle.

Two detection points are needed for this process. The first detection point is located at a point from the intersection which corresponds to the distance traveled between the decision point at the end of the green phase and the maximum green extension. This detection point may also correspond to the red early cut off time. The second detection point is located after the traffic light to serve as a checkout detection point.

The criteria employed in this process includes the travel time from the first detection point to the intersection, the maximum allowed green extension and the minimum red duration. One additional criteria employed to avoid successive disruptions of the cycle time (which may cause congestion) is a maximum recurrence restriction. These parameters are usually fixed regardless of the traffic situation and, except for some minor adjustments, are basically the same for all the systems (Laurens 1995).

For the centralized system, the central computers for the UTCS and the AVL system are linked to perform direct exchanges between them. This will avoid the necessity of detectors and will optimize the priority process. The central computer controls each phase of each intersection directly, therefore knowing the position of the current cycle to the current coordination plan on a second by second basis.

The centralized process replaces the fixed detection point utilized in the decentralized one by the localization of the vehicle at the last moment when the information is useful. This moment corresponds to the time when the decision to change the intersection traffic lights from green to red needs to be made. Any information before or after this time is useless since the decision has yet to be taken or has already been taken.

The centralized process has been described by Bernard Laurens (1995) as follows:

- Upon crossing a fixed point located before the intersection at a distance sufficient to cover all the maximum timings of the intersection, the vehicle automatically transmits a request for priority to the AVL central computer. The information transferred includes the vehicle's position with regards to the schedule, its identification, and the traffic phase it will use to cross the intersection, which is stored in a table for later use.

- A few seconds before (to allow for the interrogation process) the critical timing of the intersection is at a decision point for a given phase (end of green or end of minimum red), the UTCS computer will search in the table for an indication of an approaching bus. If a bus is approaching, the UTCS computer will transmit to the AVL computer a request for the present location of the vehicle.

- The AVL computer will interrogate instantly the requested vehicle and transmit back to the UTCS computer the vehicle's present position, the latter then computes the arrival time of the bus at the intersection using the mean speed of the vehicle conforming to the present situation.

- From this point on, the process is identical to the decentralized system with respect to the cycle progression and the decisions that need to be made. When the vehicle exits the intersection, it automatically relays a message to the AVL computer, which in turn is transmitted to the UTCS computer to take appropriate action (for example, to terminate the green time).

To avoid congestion, the system manages conflicting priorities by allotting in the next cycle to the modified phase the time lost, or by avoiding successive priorities. The parameters used in the system are minimum red time, maximum green extension, and vehicle speed. These parameters may vary according to the current traffic situation and negotiations with the responsible authorities.

The centralized system has many advantages over the decentralized one:

- the cost is reduced since there will be no need to install a detection system and to link it to the intersection controller as in a decentralized system, and linking UTCS computer with the AVL computer via modems and cables and installing software are less expensive.

- the parameters of the centralized system may be adapted to each traffic situation and adjusted easily.
- the uncertainty of the prediction of the arrival time on the centralized system is minimized resulting in reduced misuse of the green time extension or early red cut-off time.

4.5 Automatic Annunciators

On-board annunciators use a recorded voice to announce stops on a bus route. Combined with AVL, which provides the bus location information, a synthesized voice can indicate in real time street intersection locations in multiple languages. This technology allows transit to accommodate visually-impaired passengers, in compliance with the Americans with Disabilities Act (ADA). At the same time, it removes the burden on the driver who would otherwise have to announce the destinations. Problems associated with unclear announcements may also be eliminated provided the audio system permits clear announcements.

4.6 Advanced Traveler's Information Systems

Advanced traveler's information system is a component of APTS and is intended to provide transit users with accurate, detailed, real-time information through various means. Real-time travel information may include, for instance, the time when next few vehicles will be arriving at a particular bus stop, the time difference between arrivals of two buses at a transfer point, bus arrival time, trip time, and transit fares if fare structure includes time as a factor.

Various methods may be used to disseminate the real-time travel information. Beside traditional telephones, operated either by human operators or computers, many new technologies have emerged, which are described below.

4.7 Passenger Information Displays

Passenger Information Displays (PIDs) can display real-time bus arrival and departure information for transit users. Displays can be passive (TV monitors) or interactive, such as touch-screen kiosks that enable passengers to plan their route by supplying their origin and destination, print out their schedule, check their bus status, check bus fares, learn how to join a carpool, or receive the latest traffic and road information.

Houston is conducting an operational test in which real-time pre-trip information on current traffic conditions and bus schedules is provided to individuals in their homes and places of employment through videotex and telephone technologies (Casey *et al.* 1996).

4.8 Passenger Information at Bus Stops (PIBS)

London Transport provides passenger information at bus stops to improve bus service quality since 1992. Signs for the PIBS system are marketed as "countdown". Estimates are made of the time for vehicles to arrive at bus stops that are equipped with displays. This is accomplished by accessing a database and running a predictive algorithm that utilizes the running time of previous buses within a 20-minute time horizon. Estimates are transmitted over dedicated land-lines to the stops. The displays are 24 character per line, 3 line dot matrix displays, with screens of light emitting diodes (LED) (Smith et al, 1995). Predictions are updated every polling cycle. Between polling cycles, signs perform a countdown in real time. Currently, up to nine buses on different routes can be shown and signs can incorporate 3 or 4 line displays. In addition, a bottom line text message allows to present further information about bus services including regular, specific or timely messages (e.g. traffic congestion is affecting route 77 buses today).

4.9 Passenger Information on the Internet

The Internet is a computer network that interconnects local area and wide area networks (LAN and WAN, respectively) worldwide. The Internet was originally funded by the U.S. Department of Defense in the early 1970's, referred to as ARPAnet at the time. It was designed as a military network, and the early users included the National Aeronautic and Space Administration, universities, and defense contractors. In the mid-'70s, universities began to build their own local networks using ARPAnet protocols, and standard for Ethernet (transport mechanism for local area networks) and TCP/IP (communication protocols between networks) were developed. It was also during this period that the term "Internet" came into use, and the Internet became international. What brought the Internet to include commercial and personal uses was the network built by the National Science Foundation (NSF) in mid-'80s, which included five supercomputers serving numerous local networks. First, all university students were provided access as a condition for universities to use the NSFnet. In 1991, NSF lifted the restrictions on commercial use of the network. Since then, the number of commercial networks and network service providers have grown rapidly, as well as the number of the Internet users.

What has made the Internet accessible to average users without much computer knowledge is web browsers. "World Wide Web" (WWW), which was started by the European Laboratory for Particle Physics (CERN) seeking to build a distributed hypermedia system. In a hypermedia document, documents covering related subjects in the form of text, graphic, images, video, sound, and animations may be linked together and accessed by a click on the highlighted subject, word, or symbol using a browser program. With the development of Java, a language developed by Sun Microsystems that allows WWW pages to contain a code that is executed on the browser, an Internet user not only can request information, but do so interactively.

Because of the easy access to information provided by the Internet technologies and the continual decrease in personal computer prices, a trend expected to continue, more and more people are using the Internet to access transit information. In response, many transit agencies have established their own web sites where transit information including routes, schedules, destinations, and fares is available. With the new Java programming language that allows on-line animation and interactivity, future ATIS will permit users to request real-time travel information, which may be displayed on an interactive map. For instance, a user may request information for a particular trip for a specified time and day and have the route(s), schedule, and fares be displayed on an area map. The map could also show the locations of major activity centers and views of transit stops or stations. A user may also check the expected arrival time of a bus that he or she intends to ride. The availability of real-time information on road congestion level, incidents, and expected delays, will also allow people to give transit more consideration as an alternative by evaluating the various constraints such as costs, trip time, and stress levels.

5. AVL PLANNING, PROCUREMENT, AND IMPLEMENTATION

A survey was conducted to investigate AVL planning, procurement, and implementation at transit agencies. 440 survey forms were sent out, with 135 were returned, representing a 30.7 percent of response rate. The original survey form is included in **Appendix B**. In this section, the survey results are summarized.

5.1 Implementation Status

The first question in the survey was to ask the agencies to identify their progress toward an AVL implementation. Among the 135 transit agencies that responded to the survey, 69 reported to be considering installing an AVL, in the process of implementing one, or already had an operational system, while 65 agencies indicated that they were not considering or had no plan to install an AVL. **Table 5.1** shows in more detail the implementation stages of the 69 transit agencies that were moving towards AVL (which will be referred to as the "yes" agencies). It may be seen that while in this sample only a small number of agencies are actually operating an AVL system, an increasing number of agencies are installing the system. The actual number of agencies involved with AVL is likely to be higher than the 69 obtained from the survey, since the survey results are only a partial representation of the transit properties in the nation and do not include some of the 60 agencies reported in (Casey 1996) that are at different stages ranging from preliminary study to operations did not respond to the survey.

Table 5.1 Transit Agencies Progress Toward AVL Installation

Proposed	Preliminary	RFP	Bidding	Starting	Operational		
					1 year	2 years	2+ years
23	19	3	5	9	2	4	4

For the 62 agencies that had no plan for AVL implementation (which will be subsequently referred to as the "no" agencies), the reasons given were summarized in **Table 5.2**. Difficulty of funding is the possible leading cause that prevents transit agencies from considering AVL. However, it needs to be pointed out that 42.3 percent of the 26 respondents also indicated that they did not see significant benefits that might result from AVL.

A large number of transit professionals (101 out of 125 who answered the question regarding the usefulness of an AVL planning guide) felt that information on AVL for transit was lacking, and indicated that a planning guide providing information on AVL technologies, benefits, costs, and issues related to operating and maintenance would be very helpful. The numbers of positive and negative responses are given in **Table 5.3**. Over half of the respondents from agencies that are at a more advanced state of AVL implementation also indicated that an AVL planning guide would be helpful, emphasizing the current lack of information in the field of AVL. However, some of the respondents did point out that there exists a great variance among different transit agencies when AVL planning is concerned, even if the agencies are similar in terms of characteristics of the service area, service population, fleet size, and types of services provided. Such differences are the results of, for instance, an agency's objectives, the roles to be played by AVL in an agency, the technical characteristics of the bus equipment, and the service planning and operating practices.

Table 5.2 Reasons for Not Considering AVL Installation (26 Respondents)

Reason	Number of	Percent of
too costly	12	46.2
no funding available	17	65.4
extra cost burden	6	23.1
do not have technical capability to operate/maintain	8	30.8
do not see significant benefits	11	42.3
inadequate information to judge	6	23.1

From **Table 5.3**, it is also apparent that more professionals from agencies that have not considered or have decided not to install AVL tend to feel that a planning guide would not be as helpful. It may indicate a lack of understanding of AVL benefits and therefore lack of interest in AVL installations.

Table 5.3 Number of Respondents Desiring a Planning Guide

AVL Status	Useful	Not Useful
Not considering	39	15
Proposed	21	2
Preliminary	19	0
RFP	3	0
Bidding	5	0
Starting	6	3
Operation	8	2
Total	101	24

To further understand the AVL market, the profiles of all the transit agencies participating in the survey were studied. In **Figure 5.1** and **Figure 5.2,** the total population in the urbanized areas served by the "yes" and "no" agencies are shown. **Figure 5.1** shows the number of "yes" and "no" agencies falling into each of the population ranges. Ranges are defined as one tenth of the population difference between the highest and lowest populations. According to the survey results, the majority of transit agencies located in an urban area with a large population size (more then 1.6 million) are at some stage of AVL implementation. In fact, in this population group of 24, 20 are the "yes" agencies and only four are the "no" agencies. There is a large number of agencies that have a population less than 1.6 million (represented by the single tall bar in **Figure 5.1**). The population range for this group is further divided and examined in **Figure 5.2**. It is evident that the likelihood of AVL implementation for transit agencies decreases with decreasing urban population size. Examining the correlation between the service population and the number of "yes" and "no" agencies in **Figure 5.3** and **Figure 5.4** reveals the same trend.

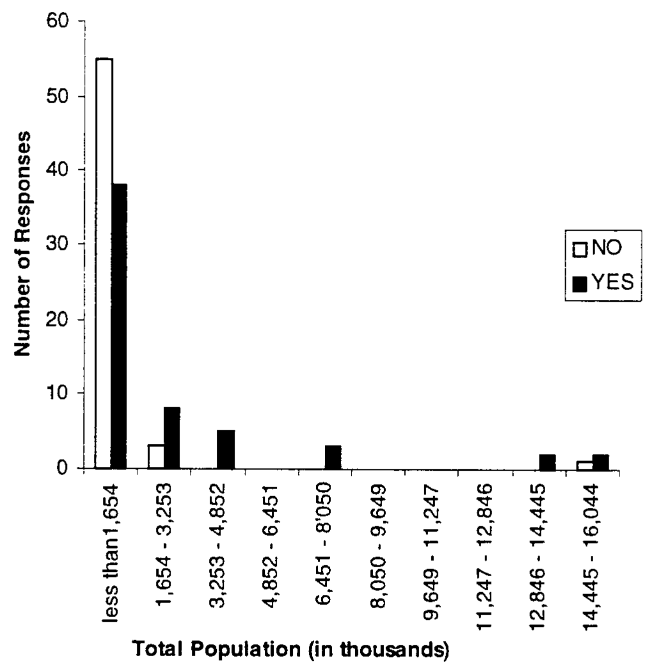


Figure 5.1 Total Populations in Urbanized Areas (117 Respondents)

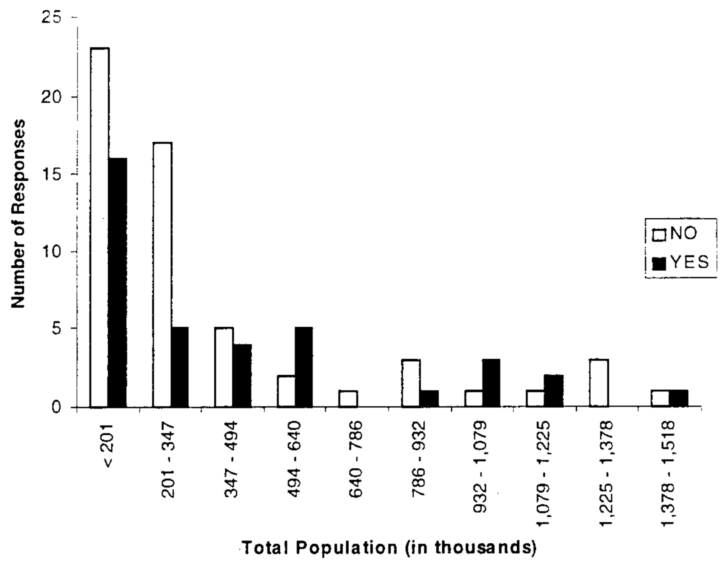


Figure 5.2 Total Populations in Urbanized Areas for Agencies with a Population Less Than 1.65 Million

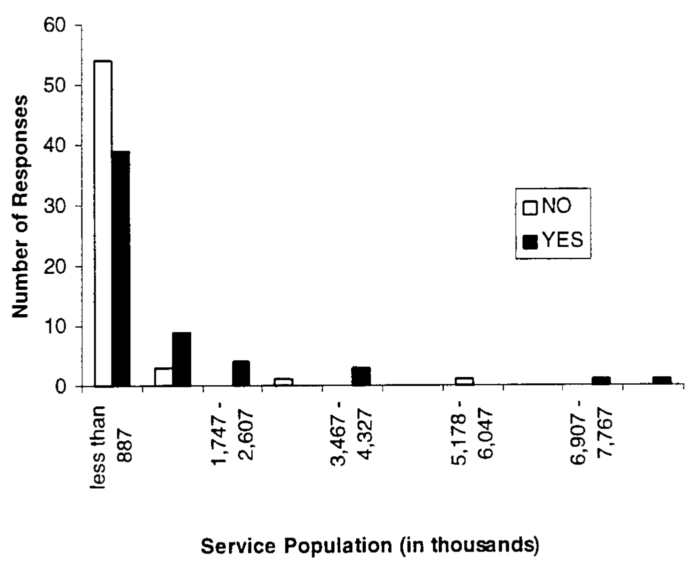


Figure 5.3 Total Populations in Service Areas (All Respondents)

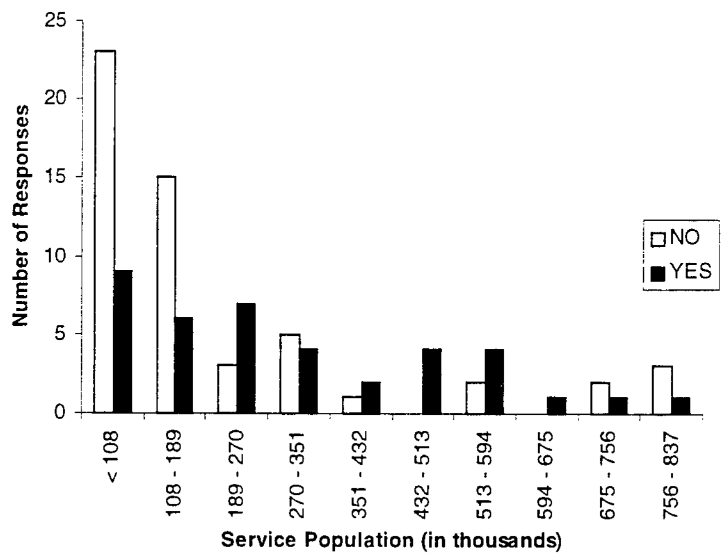


Figure 5.4 Total Populations in Service Areas for Agencies with Service Population Less Than 877,000

The trend of decreased likelihood of a smaller transit agency to implement AVL is again clearly show in **Figure 5.5**. It will be important to investigate the benefits and impact of AVL on the operations of small transit agencies to improve and even sustain services in small urban areas and rural areas. **Figures 5.6** through **5.9** show the correlation between the likelihood of transit agencies implementing AVL and the operation scales expressed in terms of annual passenger miles and annual vehicle revenue hours.

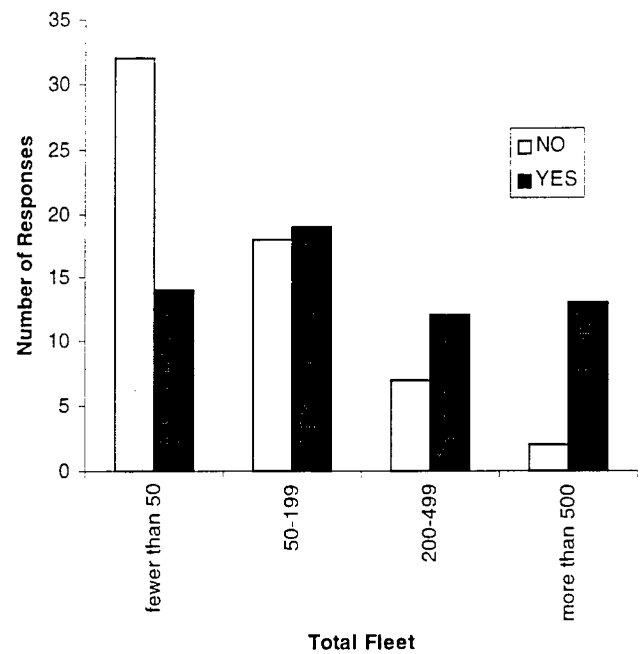


Figure 5.5 Fleet Size Distribution (All Respondents)

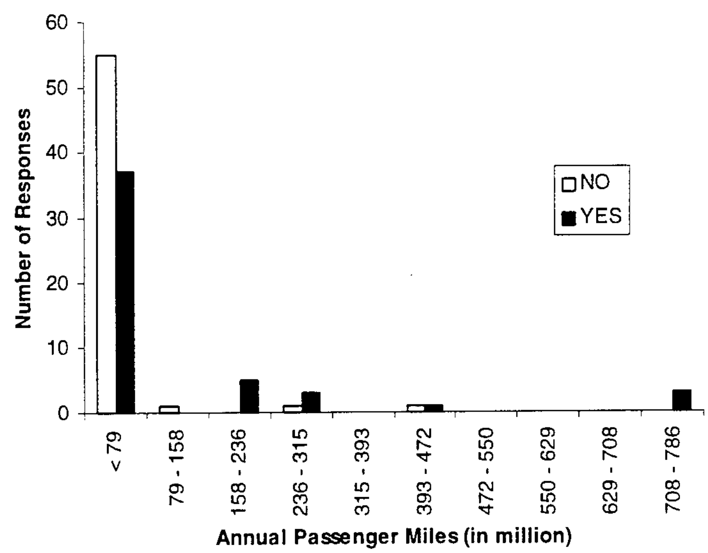


Figure 5.6 Annual Passenger Miles (All Respondents)

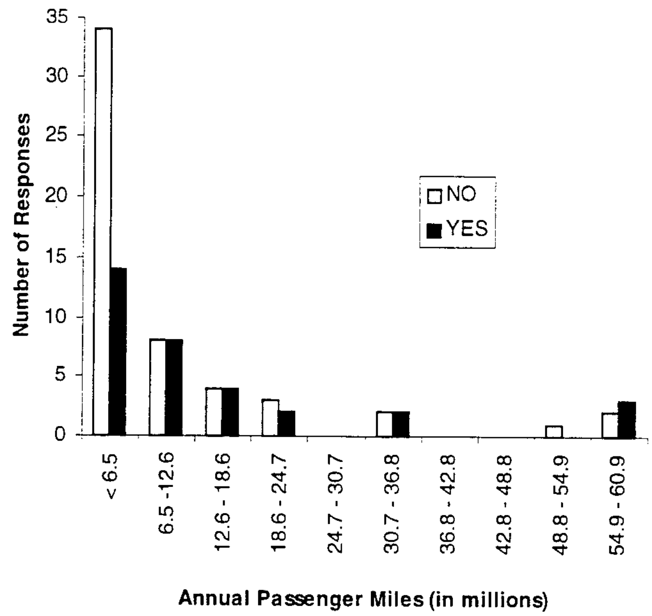


Figure 5.7 Annual Passenger Miles (Less Than 7 million)

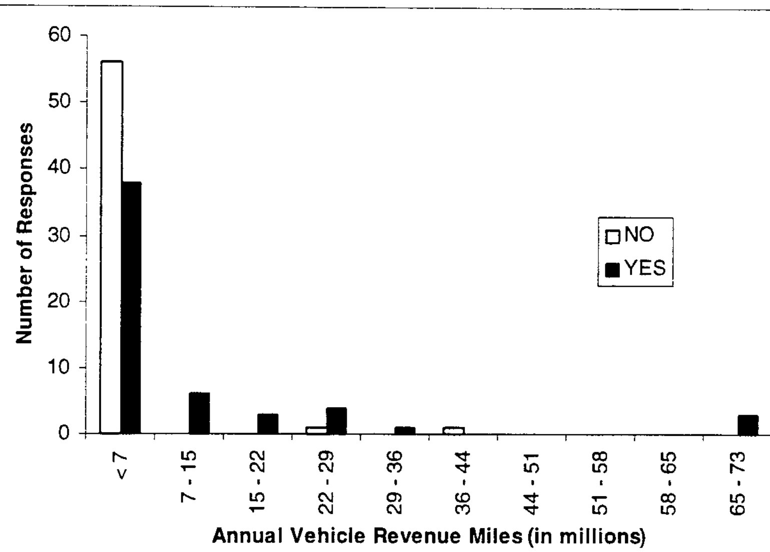


Figure 5.8 Annual Vehicle Revenue Miles (113 Respondents)

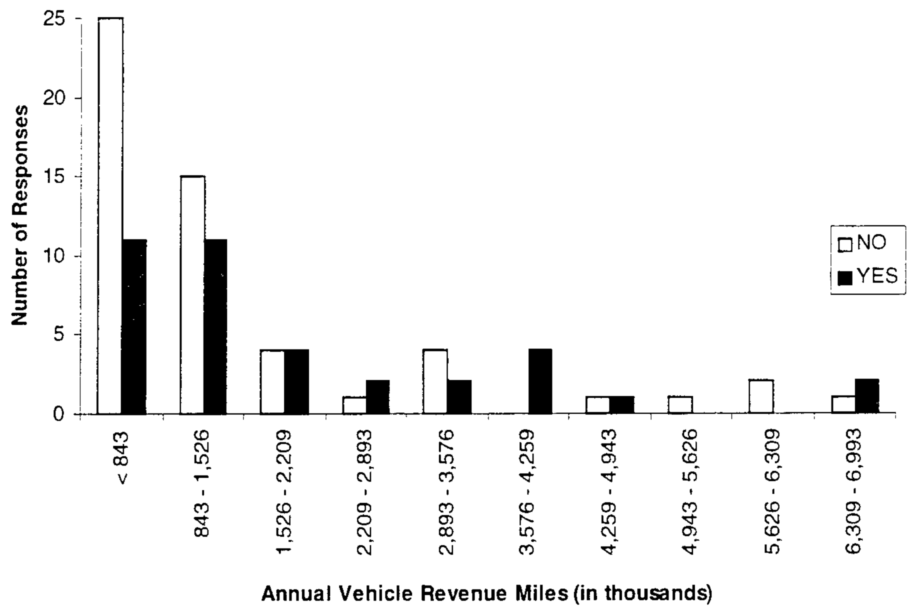


Figure 5.9 Annual Vehicle Miles for Agencies with Vehicle Revenue Miles Less Than 7 million

5.2 AVL Technologies

The responses indicated a wide range of technologies being used or considered as the basic locational technology (see **Table 5.4**). All the signpost systems in this survey have been in operation, indicating that they were installed prior to the achieved maturity of the GPS technology. It is clear that GPS/DGPS or a combination of GPS/DGPS with another locational technology appear to be the dominant choice (16 out of 22) today. Many agencies combine GPS or DGPS with another locational technology to compensate for loss of satellite coverage from "urban canyons" and other barriers. Because of the low infrastructure requirement for dead-reckoning, combination of GPS or DGPS may become more popular over other alternatives.

Positional accuracy reported by four agencies is 25 feet to 50 feet for the first three and 50 feet to 100 feet for the fourth one. The technology used by the first three agencies is GPS or DGPS, while that used by the fourth is also DGPS. It should be noted, however, that AVL accuracy is not absolute, and any stated accuracy is associated with a probability.

Table 5.4 Locational Technologies Being Considered or Used (22 Respondents)

Technology	Number of Responses	
	In Operation	Pending
Signpost	3	0
Signpost+ DR	0	1
DR	1	0
GPS	2	1
GPS+DR+SO	1	0
DGPS	0	3
DGPS+Signpost	0	1
DGPS+DR	1	4
DGPS+GPS	1	1
DGPS+LC	1	0
Radio Telemetric	1	0
Total	**11**	**11**

5.3 AVL Planning

One of the aspects of AVL transit applications is that sometimes transit AVL installation is not a pure transit project. Instead, it may be part of a multi-agency project intended to better integrate communication and coordination of different departments' activities, such as transit, police, public works, fire department, hospitals, etc. In such cases, AVL planning may also be a multi-agency and multi-department activity, as in the case of Tallahassee, FL.

Because an AVL system may benefit many aspects of public transit beyond operations, two questions were asked in the survey regarding the involvement of other departments within a transit agency and outside the agency in both the planning stage and the development of the RFP. According to the 48 surveys that answered the questions, planning activities were completed contained in 26 transit agencies, while 12 others involved at least two other departments of the local government, the most common being 911 emergency center, ambulance services, public works, traffic department, and fire department. The degree of involvement of these various agencies and transit divisions is presented in **Table 5.5**. **Tables 5.6** and **5.7** summarize the involvement of various departments and agencies in AVL planning and specification development, respectively, for all the 48 transit properties.

Table 5.5 Degree of Involvement of Different Transit Divisions/Agencies at 12 AVL Project Locations

Transit Agency	Heavily Involved Transit Divisions/Agencies	Somewhat Involved Transit Divisions/Agencies
King County Metro, Seattle, WA	bus operations	bus maintenance, service planning, long term transit planning, police, fire
Grand Rapids Area Transit Authority, Grand Rapids, MI	bus operations, service planning, long term transit planning	bus maintenance, police, fire, ambulance, 911, public works, traffic
LA County MTA		bus operations, bus maintenance, service planning, long term transit planning, police
New York City Transit	bus operations, bus maintenance, service planning, long term transit planning	police, fire, ambulance, 911, public works, traffic
Connecticut DOT	bus operations, bus maintenance	service planning, police, 911, public works
Laketran, Grand River, Ohio	long term transit planning, 911	bus operations, service planning, police, fire, ambulance
St. Cloud Metropolitan Transit Commission, St. Cloud, MN	service planning, long term transit planning, 911, public works, traffic, MPO, FTA, DOT	bus operations, bus maintenance, police, fire, ambulance
City of Tucson SunTran, Tucson, AZ	bus operations, service planning, long term transit planning, City Comm. Dept.	bus maintenance, public works, traffic
Five Seasons Transportation and Parking, Cedar Rapids, Iowa	bus operations, bus maintenance, service planning, long term transit planning	police, fire, ambulance
Chicago Transit Authority, Chicago, IL	bus operations	bus maintenance service planning, police, fire, public works, traffic, purchasing law
Transit Authority of Lexington, Lexington, KY	service planning, long term transit planning, public works, traffic, KYDOT	bus operations, police, fire, ambulance, 911
City of Napa, Napa, CA	bus operations, service planning, long term transit planning, bus maintenance, public works, traffic	

Table 5.6 Different Parties in a Transit Agency Involved in AVL Planning

Departments/Divisions Involved	Number of Responses (Percent of Responses)	
	Heavily Involved	Somewhat Involved
bus operations	27 (29.3)	13 (10.7)
bus maintenance	14 (15.2)	15 (12.4)
service planning	17 (18.4)	15 (12.4)
long term planning	20 (21.7)	19 (15.7)
police	0 (0.0)	23 (19.0)
fire	0 (0.0)	8 (6.6)
ambulance	1 (1.1)	8 (6.6)
911	2 (2.2)	8 (6.6)
public works	4 (4.3)	8 (6.6)
traffic	3 (3.2)	11 (12.0)
FTA	1 (1.1)	0 (0.0)
state DOT	2 (2.2)	0 (0.0)
others	1 (1.1)	1 (0.8)

Table 5.7 Different Departments/Agencies Involved in Developing Specifications

Different Departments/Divisions Involved	Number of Responses (Percent of Responses)	
	Heavily Involved	Somewhat Involved
bus operations	20 (21.7)	15 (17.4)
bus maintenance	14 (15.2)	14 (16.3)
service planning	13 (14.1)	20 (23.3)
long term planning	15 (16.3)	15 (17.4)
communications	6 (6.5)	3 (3.2)
information system	3 (3.2)	0
police	4 (4.3)	11
fire	0 (0.0)	1
ambulance	1 (1.0)	1
911	0 (0.0)	1
public works	0 (0.0)	1
traffic	0 (0.0)	4
administration	4 (4.3)	0
state DOT	1 (1.0)	0
FTA	1 (1.0)	0
consultant	2 (2.2)	0
other	8 (8.7)	0

The transit agencies were asked to identify the objectives for their AVL implementations. The results are summarized in **Table 5.8**. It may be seen that improving schedule adherence and emergency response, and providing real-time travel information are the three top objectives for AVL implementation. Approximately 86 to 96 percent of respondents rated them as either most important or important. Improving planning and scheduling using AVL data are also considered by most to be important although fewer rated them as the most important objectives. In comparison, even fewer respondents indicated that AVL would be useful for modal integration and improvement of personnel management. From the survey, it is also found that for approximately one third of the agencies, radio system upgrade was either the primary reason or an important factor for the AVL implementation. As transit properties improve their communication capabilities, AVL systems may be installed as part of a communication improvement project.

Table 5.8 Objectives of AVL Projects by Number and Percentile of 50 Responses

Objectives	Most Important	Important	Not Important
improving schedule adherence	28 (56.0)	20 (40.0)	0 (0.0)
improve emergency response	22 (44.0)	24 (48.0)	4 (8.0)
providing real-time travel information	23 (46.0)	22 (44.0)	5 (10.0)
integrating schedule of different modes	13 (26.0)	23 (46.0)	11 (22.0)
obtaining better data for planning	13 (26.0)	33 (66.0)	1 (2.0)
obtaining better data for scheduling	10 (20.0)	35 (70.0)	5 (10.0)
improving personnel management	11 (22.0)	23 (46.0)	14 (28.0)

Among the respondents, 26 developed an RFP. The length of time for the RFP development ranges from two months to 36 months, with an average of 11 months. The majority of the RFPs required five to 12 months for development (see **Table 5.9**).

Table 5.9 Length of Time for RFP Development (26 Responses)

Length of Time (months)	Percent of Responses
0 - 2	7.7
3 - 4	11.5
5 - 6	25.6
7 - 9	15.4
10 - 12	30.8
13 - 24	3.8
25 - 36	3.8

Since the development of an RFP represents a major effort, any reduction in the time needed for its development will reduce the cost and speed up the implementation process. With this in mind, transit agencies were asked in the survey whether they used a generic bid document for medium and small transit agencies developed by the Ministry of Transportation of Ontario, Canada. Only eight agencies (or 18.6 percent) out of the 43 responses to this question, replied that the generic bid document was used, although further questioning on a follow-up telephone interview revealed that even though they referenced the document, it was actually not used as a model. A large percentage of the respondents (31 out of 49 or 63.3 percent), however, indicated that they contacted other transit agencies and used their RFPs or bid documents as references. During the follow-up telephone interview, many expressed the feeling that the differences among transit systems were often enough to prevent the RFP of one system to be used for another, even with significant modifications. Indeed, only 11 out of 49 agencies, or 21.7 percent, said they found the RFPs from other agencies useful. The number of transit agencies contacted by other transit agencies planning or developing bid documents is shown in **Table 5.10**.

Table 5.10 Number of Transit Agencies Contacted for Input (49 Respondents)

Number of Agencies Contacted	Percent of Responses
1 - 5	55.2
6 - 9	10.3
10 - 14	20.7
15 - 19	3.4
20 or more	10.3

The approximate length of time between the proposal of an AVL system to an RFP or Bid Document publication ranges from a few months to over 10 years, with a weighted average of 20 months, according to the 27 responses received for this question. Among these, 18 indicated that the time between the publication of an RFP and contract award ranges between less than six months to more than two years (the weighted average is 10 months). Average actual installation was reported as 22 months, while final system acceptance was reported as 12 months. This long time period for testing and system acceptance may reflect to some degree the lack of experience of both the agencies and the vendors in the early years of AVL projects.

Table 5.11 Weighed Average Time for AVL Implementation

Implementation Stage	Number of Responses	Length of Time (weighted, in months)
Proposal to RFP	27	20
RFP to Contract	18	10
Contract to Start-Up	17	22
Contract to System Acceptance	19	35

5.4 Funding and Costs

The single most important funding source relied on by transit agencies for AVL projects is federal funds. Many agencies expected their AVL projects to be funded by a federal source up to 80 percent of the total cost. **Table 5.12** shows that 80 percent of the U.S. transit agencies received 70 percent (or higher) of the AVL project cost from the federal government. Three California transit agencies were, however, completely funded locally. This may be a result of strong local support to transit and dedicated local transit funding sources.

Table 5.12 Funding Sources (28 Responses)

Funding Sources			Responses		Notes
Federal	State	Local	Number	Percent	
90	5	5	1	3.6	
80	20	0	7	25.0	
80	0	20	7	25.0	
80	16	4	1	3.6	
80	10	10	4	14.4	
80	5	15	1	3.6	
70	20	10	1	3.6	
50	0	50	1	3.6	
30	0	70	1	3.6	
0	100	0	1	3.6	London, Ontario
0	0	100	3	10.8	California

More capital cost information may be found in (Casey *et al.* 1996).

5.5 Implementation

Many of the transit properties surveyed with operating AVL systems reported experiencing various degrees of difficulty during installation, due mainly to the novelty of this technology. The leading problems are the reliability of hardware and software, and sometimes limited functionality of software. For instance, one agency reported that the vendor had difficulty developing transit specific software, and that the development of the computer-aided dispatching system was slow. System reliability is also significant, and more than half of the agencies are not satisfied with the accuracy obtainable by the system. A smaller percentage of the survey respondents also indicated problems with cost overrun and contract disputes due to ambiguity in the contract regarding the agency's and contractor's responsibilities.

Table 5.13 Problems Encountered in AVL Implementation (11 Operational Systems)

Problem Description	Percent
hardware	90.1
software	72.7
system reliability	45.5
position accuracy	54.5
cost overrun	18.2
contract language - agency responsibility	9.1
contract language - contractor responsibility	18.2

Changes are expected to be brought by AVL systems. For instance, PACE reported in the survey that AVL application has resulted in changes in routes, bus stop locations, and scheduling. King County Metro of Seattle, Washington, and City of Napa, California, also indicated changes in routes and scheduling. Personnel change is reported by Denver RTD. It needs to be noted that seven agencies also indicated that the their goals had changed after AVL implementation while seven others indicated that AVL implementation did not result in changes in the agency's goals. This change can be accounted for several reasons. Further investigation of these reasons might be worthwhile, so that other transit agencies may anticipate the impact of AVL and may benefit from the expansion of their systems.

When asked about plans to expand AVL benefits or applications, 11 out of 13 agencies responding to the question said they indeed had such plans. These plans include providing real-time travel information, installing APC for data collection, adjusting schedule to allow timed transfers, improving modal integration, installing electronic fare boxes, and implementing traffic signal preemption. The number of agencies that have a specific plan is provided in Table 5.14. It is evident that providing real-time travel information is the top priority for most of the agencies that have implemented or are implementing AVL systems.

Table 5.14 Immediate Plans for Expanding AVL Applications (28 Agencies)

Applications	Number	Percent
real-time travel information	26	92.9
APC	14	50.0
timed-transfer	13	46.4
electronic fare box	12	42.9
traffic signal preemption	11	39.3
modal integration	7	25.0

In response to the question of whether an agency was an FTA APTS test site or whether it had conducted its own test, the answers obtained revealed that most of the agencies surveyed were not FTA test sites, and only four out of 13 had conducted any kind of analysis of AVL benefits. This may indicate that extensive evaluation of AVL benefits, not only to the agencies but also to the passengers is urgently needed. Such evaluations not only will benefit other agencies that have not implemented AVL or are in the early stages of AVL planning, but will also allow agencies operating AVL to maximize their benefits.

6. CASE STUDIES OF AVL PLANNING

This section includes a summary of several Request for Proposals (RFP), Technical Specifications, and other bid documents provided by different transit agencies.

6.1 Tidewater Regional Transit

The *Technical Specifications* issued by Tidewater Regional Transit is an 158-page document that outlines the functional, operational, and minimum technical parameters of the required AVL system. The document first provides a background of the transit services, including a description of the old system and the new system to be implemented. Technical aspects of the AVL system are then described in detail, organized by vehicular systems, vehicles requiring mobile equipment, portable equipment, base station, satellite receivers and comparators, dispatch console, tape recording equipment, central computer/ data system, computer hardware and software, installation requirements, acceptance, manuals and training, maintenance, and licensing and standards. Selected technical information is summarized in this section.

Background

Tidewater Transportation District Commission (TTDC) provides transit services to the Norfolk general area and Virginia Beach, which include a fixed route system, trolleys, and two demand responsive systems. Tidewater Regional Transit (TRT) operates an extensive fixed route delivery system serving all medium to high demand density portions of the TTDC service area. Schedules are not devised in such a way that all routes arrive and/or depart at a common time with each other. As a result, there are no "peak" periods of required communication to hold buses for late transfers or checks on outstanding transfers prior to departure for outbound trips. TRT operates approximately 22 hours per day, 7 days per week with a non-standard fleet of Transit Coaches and Mini-Buses, including 151 vehicles available for service with approximately 115 actually used during times of peak demand.
Maxi-Ride is the demand responsive system which operates in the low demand density portions of the TTDC service area. Maxi-Ride has a fleet of nine (9) vans and, during periods of higher volume, mini-busses are operated on selected fixed routes. Typically, four to five vans are simultaneously in service during periods of peak demand. The vehicles provide a many-to-many type of demand responsive service available only on the day of request. Major trip generators include shopping malls and TRT transfer points with a private residence almost always being one end of the trip. Handi-Ride is the demand responsive, elderly and handicapped service offered throughout most of the service area.

Virginia Beach is heavily oriented toward tourism and, as a result, TTDC operates a fixed route trolley system specifically designed for that application and has a fleet of 20 trolleys of which none are considered maintenance reserve. All available vehicles are scheduled for service as a result of the overwhelming demand. The service is from 10:00 a.m. until midnight on weekdays, and 8:00 a.m. until 11:30 p.m. on Saturday and Sunday. Scheduled headways are ten to twenty minutes with actual headways being a function of vehicles available for service and traffic congestion on the route in question.

Overview of the Transit Data Communications System

Under a grant program with US DOT, TTDC issued *Technical Specifications* to be used for bid proposals for a Transit Data Communications System for the purpose of improving transit service control and service reliability. The agency also expects the system to become an integral part of its evolving management information system.

The *Technical Specifications* call for the installation of a total fleet management system to provide TTDC with on-line real-time management control of the fleet and a management reporting/information system. The system will provide TTDC management with information on the location, loading, and condition of the fixed route fleet at all times, and communications with the Virginia Beach trolleys and the demand responsive systems. Summarized reports will be provided on the fixed route system to allow management to assess, define, and implement solutions to the problems that may arise regarding mechanical breakdowns and schedule adherence.

The AVL technology was chosen to be dead-reckoning combined with signposts. The AVL system consists of two subsystems: the mobile system and the central dispatch system. Implementation of the mobile system will involve equipping all buses with microprocessor data units, mobile radios, odometer readers, and signpost receivers. Each vehicle will need to be fitted with a microprocessor controlled data unit allowing driver calling, mechanical alarm monitoring, and emergency driver calling. This microprocessor unit will also log the odometer reading and, via a signpost receiver, will provide information on signposts encountered. Each vehicle is to operate in the open speaker mode, loudspeaker and handset equipped.

The central dispatch system will comprise transmitter/receiver combinations, data encoder/decoder equipment, computer, as well as all the dispatch console and control equipment. It will be connected via direct telephone lines with the remote radio sites.

Vehicular Systems

TTDC required all equipment to be able to operate effectively throughout temperature extremes of -30° to +60° C (from -22° to +14°"F), withstand vibrational forces associated with urban transit vehicles, and meet all requirements set forth in the *Technical Specifications* while operating with a mobile power source 15 percent above or below normal design voltage. All components are to be housed in splashproof, tamperproof housings and protected against accidental reversal of polarity.

A coverage map is required to be presented with the bid. This map will show the guaranteed coverage provided by the system design for both portable and mobile units. Voice communications for the mobile system coverage need to be defined as that area whereby communication on 12db SINAD basis is available in 95 percent of locations on a small sector basis, ½ mile by ½ mile. Data communications coverage is to be defined as that area where, in 95 percent of locations on a small sector basis, equipment would successfully and accurately complete a first time data transmission interchange. The contractor is required also to perform a field survey within 60 days of award to determine the actual coverage from the radio transmitter and receiver site locations, including measuring the signal level from a moving test vehicle.

The transmission speed is required to be sufficient to collect 1.5 messages per minute from each bus equipped with passenger counting and 0.5 message per minute from the remainder of the fleet using the data channels outlined. However, it may not be, in any event, less than 1200 BPS.

Vendors are encouraged to select TTDC, state, or municipally owned properties for transmitter and receiver sites. If private properties have to be used, vendors are required to provide information on the property owners and guaranteed least costs, which will be added to the bidder's price.

A schedule adherence display is to be provided on the mobile microprocessor. This display will indicate to the operator, controlled automatically from the central computer, as to whether he/ she is predicted to be ahead or behind schedule at the next time point. This calculation will be based upon the vehicle's progress against a known norm taken from the schedule base. This display shall indicate the time ahead or behind schedule in one minute increments, up to 99 minutes. The display should refresh at least every two minutes and respond to vehicle progress.

The mobile microprocessor will be capable of accepting up to six mechanical alarms indicating vehicle conditions such as "engine hot", "low air", etc. All mechanical alarms will be transmitted directly to dispatch. There will also be a silent emergency alarm switch, to be located under the driver's seat, on the floor or at some convenient location. During and after this alarm sequence there should be no indication that it has been activated. Central dispatch shall not be able to call or in any way contact the operator in this mode. The driver may cancel the alarm by pressing a call request.

The microprocessor shall provide Request to Talk and Priority Request to Talk functions for the driver. It should also provide inputs for automatic functions including the following:

- Odometer Input: odometer reading will be transmitted back to dispatch each time the vehicle is polled, provided mileage has been accumulated since the last poll.
- Signpost Receiver: the receiver shall be able to accept inputs of up to three numeric digits from signposts for identification purposes.

The roadside signposts, in conjunction with the signpost receivers and odometer, will provide an accuracy of " 400 ft downtown", 1000 ft elsewhere, and will be spread throughout the area to serve as a finite location to update/correct odometer readings.

The remote base station site(s) is/are required to provide radio communications between the central dispatch and the vehicular fleet on four channels. Detailed minimum requirements are established for transceivers including primary power, backup power, number of channels, operating frequency, temperature range, protection, and stability; for transmitter including RF power output, output impedance, spurious emission, harmonic emission, modulation, audio response, audio distortion, FM noise, and input level; for receiver including channel spacing, input impedance, sensitivity, selectivity, modulation acceptance, and intermodulation, audio response and audio distortion. Alarms from each remote site will be displayed on the console, including primary power failure, low battery, charger failure and illegal entry.

Under normal circumstances, two-way voice communications are required at all times: between dispatcher and bus, trolley, and van; between supervisor and dispatcher; between maintenance and dispatcher; between portable and dispatcher; between channel 3 dispatcher, remote van dispatcher and van simultaneously; between Virginia Beach dispatcher, dispatcher and trolley, simultaneously.

TTDC requires that this system be geared to a "management by exception" approach to the dispatching function. All schedule adherence and location information be relative to TTDC time points rather than signposts required by the system. At a minimum, system accuracy is to be within +/- 400 feet of actual vehicle location 95 percent of the time. Off-line schedule adherence reports which depend upon the location system shall have an accuracy of +/- 15 seconds for the time of passage at a time point 95 percent of the time. To be able to achieve this, the vendor must either not assume constant speed between polls, must provide very frequent polls for dispatcher screen updates, or must place a signpost at each time point. Schedule adherence parameters are required to be allowed to differ by route, day, and time of day without dispatcher intervention.

All information gathered by the system needs to be reportable via a flexible report generator provided as part of the system. The contractor is required to conduct extensive training in the most effective and efficient use of the report generator.

The system is required to have a reliability or availability of 99 percent. In other words, if the system contains 100 units, one may be expected to be out of service on the average in any given day. The contractor will be given 60 days to rectify any problems if this reliability is not achieved, after a 60 to 120-day testing period. If the contractor fails again, TTDC has the option to instruct the contractor to remove the furnished equipment and be reimbursed by the contractor an amount equal to the total contract price.

Installation of the system is required to be completed within 18 months, be subject to a 30-day acceptance period after the full installation has been completed, and include a one-year full warranty. Maintenance is to be provided by a local service center selected by the successful bidder. Training programs are required to be sufficient in quality and quantity to fully train TTDC in the complete operation of the system. A factory-certified trainer has to be made available to TTDC and will be responsible for training a minimum of 50 drivers and 10 dispatchers in the use of the system.

6.2 Ann Arbor Transit Authority

Ann Arbor Transportation Authority (AATA) issued a Request for Proposal to solicit technical and price proposals from contractors in response to their need for an Intelligent Transportation System. This project is to be funded with a combination of financial assistance received from the state of Michigan DOT, FTA and AATA's locally obtained funds. Ann Arbor has a long tradition of public transit services of over 100 years and has enjoyed local support as illustrated by a 1973 local vote to provide up to 2.5 million dollars to support public transit.

AATA operates 27 fixed routes serving the City of Ann Arbor as well as the remainder of the urbanized area including the City of Ypsilanti and portions of Pittsfield, PA. Services are from 6:00 am to 10:45 pm on weekdays and from 8:15 am to 6:15 pm on weekends. Buses run with 30 minute headway for most part of weekdays, and hourly in evenings and weekends. There are 1,200 bus stops and three park-n-ride lots. The University of Michigan and the Eastern Michigan University campuses are the major trip destinations. Ridership in Fiscal Year 1994 was 3,764,690, which has been increasing steadily since 1979 when the ridership was 1.8 million.

Besides the fixed route services, AATA also operates A-Ride for people with disability, Good as Gold for senior citizens, Night Ride, which is a share-ride tax service for the general public, Senior-Ride, which provides senior citizens group trips to shopping and culture events, Ride-Sharing, which is a free information service, and Art Fair and Football shuttle. Ridership data are given in **Table 6.1**.

Table 6.1 Services Provided by AATA

Service Type	Fare	1994 Ridership
Fixed Route	75 cents, 35 cents special fare, monthly passes $25	3,764,690
A-Ride	$1.50	21,402
Good as Gold	$1.50	102,852
Night Ride	$2.00	34,821
Senior Ride	35 cents	4,944
Art Fair/Football Shuttle	$2.00 Art Fair, $3.00 Football Shuttle, round trip	141,460

AATA has a fleet of 56 large buses (26 are 40 feet buses and 30 are 35 feet buses) and 16 small buses (10 are 25 feet long and six are 21 feet long). All the small buses and 30 of the large buses are low-floor and equipped with ramps. In 1994, AATA operated 170,182 hours of service and 2,628,666 vehicle miles.

Technologies exist for automating many of the functions currently performed by manual operations. Furthermore these technologies also enable additional and more accurate and timely information services than are currently provided. Many of these technologies have not been integrated into a full system operating with one another. The primary goal of this project is to evaluate and hopefully confirm the operation of these technologies integrated together in an operational transit system.

The request for proposal is organized in 5 different sections, instructions to proposers, procurement method, evaluation criteria and award, specifications, and terms and conditions.

General Requirements

The specifications have been prepared to reflect the needs for future expansion utilizing emerging technologies. AATA priorities are to replace current communications equipment and control center, replace the fare collection system with both cash and cashless systems, a single on-board logic unit with a single human interface, interface to existing equipment and to a new peripheral equipment.

Proposals submitted containing "approved equals" or "deviations" from specific requirements of these specifications must include approval confirmed in writing by the AATA. Changes made to the RFP by the AATA shall be put in the form of written amendments and provided to the proposer. Changes that alter substantially the specifications or scope of the RFP will occur no later that 10 days prior to closing date for receipt of proposals. Proposals may be withdrawn prior to the due date upon written request received by the AATA. No proposals may be withdrawn for a period of 90 days after the proposal due date.

Proposals will be evaluated in terms of ability of the ITS to support performance requirements, features of the proposed ITS, performance characteristics and reliability of components, ergonomics and human factors, related experience of firm and staff, schedule, background experience in working with local government, competitiveness, fairness and reasonableness of proposed price for the total system, impact of expected operating cost (up to 3 years) on total cost ownership, and cost effectiveness of use of existing equipment.

Technical requirements will be given greater weight than price. A single entity that will accept full responsibility for completion of this project is preferable, but AATA recognizes that it is unlikely that any single organization is capable of providing all the components specified in the functional description. Some conceptual and management alternatives for proposals include Turnkey Concept and Consortia Joint Venture. The successful bidder will be required to comply with all terms and conditions prescribed for third party contracts in the grant contract between US DOT and AATA.

A contract Change Order shall be used for additions or reduction in work, to modify terms of the contract or whenever an adjustment in the Contract Price and/or Contract Time is required. A claim for acceleration will be considered only if the AATA makes a request in writing to the Contractor to finish the work ahead of schedule, and the contractor agrees to this.

The following schedule should be followed for deliverables:

Phase I: within 360 days after the receipt of the Notice of Award and the confirming purchase order.

Phase II: within 720 days after the receipt of a Notice of Award an the confirming purchase order.

The contractor is responsible to comply with all existing codes including ANSI, EIA, FMVSS, IEEE, FCC, ISA, ISO, NEMA, OSHA, SAE, UL, and VDV. The contractor is also responsible for the correct interfacing of the systems, subsystems, facilities and equipment, including the following: electrical-mechanical interface compatibility, physical interface compatibility, schedule compatibility, and adherence to FCC regulations and licenses. If the system as a whole does not perform in accordance with the agreed-upon specifications, even where AATA has previously paid for deliverables, AATA reserves the right to either reject the whole system and either get a refund from the contractor, and/or accept the system (with its defects) and be reimbursed by the contractor for all costs necessary to bring the system to the level that will meet the AATA's needs. Training of mechanics, technicians and operating personnel to properly operate the ITS equipment also fall within the contractor's responsibility.

The goals of the ITS project include the automation of routine activities to direct human resources to the customer, increase emphasis on data communications for a safer operating environment, implementation of an Operations Control Information System (OCIS) that pre-processes data communications and prompts the Operations Controller (OC) with the appropriate choice of actions, selection of standards and conventions that allow a single Man Machine to interface to the on-board vehicle equipment, and earlier detection of mechanical or service problems to avoid impacts on the service or customers.

Functional Requirements

Vehicle location should be accurate within 10 meters independent of vehicle location and type of route (fixed route, demand response and paratransit). Coverage should include the entire service area during all service hours. Currently, all communications with entities such as police, fire, and emergency personnel are via separate telephone. A reliable point-to-point communications for voice and data transmissions between the Operations Center Information System (OCIS) and other systems is required, as well as two-way communications with the external sources mentioned above.

The System should be capable of processing both real-time and non real-time information as appropriate, and of storing and retrieving such information. Vehicle location and operating/maintenance conditions should be performed on a real-time basis, with updates no less than 30 seconds. A mechanism for non real-time data interchange with outside systems is required, as well as automatic vehicle monitoring of the vehicle's mechanical system.

AATA requires the maintenance of a database of all vehicles with their current operating status, and of information such as digital map data, routes and schedules, etc. The system should support automatic schedule modifications when required, and transfer coordination automatically. Transfer coordination is defined as the holding of one or more vehicles by a late or connecting vehicle to allow passengers to make timely transfers.

Other functional requirements include adaptive signal retiming on a limited basis, automatic processing of passenger capacity performed at each stop with notification when the capacity reaches a pre-determined threshold, automatic internal and external displays on the vehicles and announcement functions, graphic indication of a vehicle in an emergency situation, automatic fare box, and automatic motor couch operator (MCO) check-in and check-out and vehicle position by the use of a smartcard device.

As a limited demonstration, the ITS is required to provide a mechanism at each stop on one route (approximately 20 stops) that will provide information on the amount of time remaining before the arrival of the next vehicle.

6.3 Metro Transit Agency

MTA Long Island Bus (LI Bus) issued Technical Specifications for the services necessary to provide an Automatic Vehicle Location System. The system will be installed for the purpose of improving transit service control, thereby improving on-time performance and service reliability through improved scheduling of vehicle runs. The system will also be utilized to assist LI Bus in the management of emergencies and will eventually provide real-time information to the customers. It is the intent of LI Bus to supplement rather than replace the existing radio and CAD systems. For the new GIS portion of the system new hardware and software will be needed. The following technical specifications outline the functional and operational technical parameters of the required AVL system, are not restrictive and are considered minimum requirements.

Background

LI Bus operates 318 buses over 52 fixed routes linking 96 communities on Nassau County, eastern Queens, and western Suffolk Counties in New York. LI's service area ranges from suburban to rural towns and villages. Transfer hubs are located at shopping malls and LI railroad stations. The major passenger terminal is located in the village of Hempstead. Bus service is provided 7 days a week, 24 hrs. a day with an annual fleet mileage of 10.5 million miles. Paratransit service is also offered (23 vehicles in the present planning to expand to 66). The proposed system should be designed to operate 318 buses and 30 non-revenue vehicles, paratransit will no be included in the AVL system at the present time.

Functional Requirements

The proposed system should integrate with the existing radio communication system. The contractor is required to provide a complete system regardless of any LI bus omissions, and should warrant the system fit for the use intended. Proposals should include all costs to design, provide, install, and maintain the AVL system. System should be design in a manner that allows LI Bus to make future modifications and additions to existing AVL functions. The equipment used should be of current manufacture and is required to be the latest version of all software and hardware. The system should be of open architecture in order for other providers to interface at both the vehicle and all fixed locations.

The contractor is required to survey bus routes and stop locations as necessary, and perform GPS surveys over the bus routes at different times of the day to determine satellite coverage and the effect of satellite constellation drift.

Table 6.2 is a list of the operational data required for the AVL system sizing and data transfer calculations.

Table 6.2 Operational Data for System Sizing and Data Transfer Calculations

Average Speed of Vehicles	13 mph
Number of Bus Stops	4,200 approximately
Number of Vehicles at Peak Time	265
Daily Scheduled Trips	3,925
Daily Scheduled Pull-outs	518
Average Number of Runs	500-525
Number of Timepoints in System	63,000 approximately
Max Number of Timepoints/Run	115-120
Longest Run	150 miles

A Management by exception design approach is strongly recommended. The system should be able to perform on board calculation of schedule and route conformance. In the event of any conflict between the reporting of a system exception and the reporting of less critical information, the exception message is required to take place. An exceptions is defined as a bus running behind schedule or experiencing a route diversion, breakdown or accident. Polling initiated by dispatchers and periodic system status checks will also be required. During unusual circumstances such as severe weather, the system administrator shall have the capability to adjust the update intervals of all exception conditions. If too many exceptions are reported in a short period of time, the system shall sort and prioritize the data. Warning shall be issued before the capacity of the AVL system is overloaded to the extent that the performance might be affected.

The capability to selectively adjust exception thresholds for each route system should be provided. Speed and accuracy of information is crucial, accuracy should be 30 feet or better. DGPS is required, but other technologies such as augmented DGPS will be considered. The preferred method for schedule downloading is via existing 800 MHZ radio system, as an additional option 900 Mhz spread spectrum data radio system may be included as part of the AVL system.

The system should automatically initiate an exception condition when the operator pushes the emergency alarm button, allowing the dispatcher to initiate tracking of the vehicle. A signal will be initiated in the event of on-board methane detection for CNG fueled vehicles. The AVL system should interface with the methane-detection system on-board the vehicle, and should have the capability of future interface with the automatic fare collection system. A base station reference receiver located at LI Bus command center with corrections transmitted over the existing 800 Mhz radio system is required. DGPS service should utilize the existing network of FL radio stations to broadcast the DGPS data corrections in the U.S., and utilization of RTCM 104 broadcast signal from the US Coast Guard DGPS beacons. The system shall be able to determinate if a bus is off-route, defined as 300 feet or more off its scheduled route.

The dispatcher should have the capability of instructing a run to proceed to an "as assigned" insertion point in case of defective equipment, to meet customer demand, etc; instructing a run to hold position pending insertion into service to break a known headway (Bus Insertion in a Known Headway); create a schedule when sending a bus not in service to break up bunching (Sending Bus Dark); and assigning the appropriate schedule when vehicles are sent to predetermined points and swap equipment without triggering messages or reports of non compliance with schedule (Swaps for Road Failure).

The mobile Dispatch requires up to 8 supervisory dispatch vehicles to have limited dispatch capabilities (through a laptop PC) when enabled by the Command Center. MDT shall allow mobile dispatcher to receive calls from the revenue vehicles assigned to his terminal. The Mobile dispatcher shall be able to set up an individual voice call to any vehicle, a group voice call to any group of vehicles, and/or set up voice calls to all vehicles assigned to his supervision

The AVL system should be designed with the capability for future expansion, including the incorporation of AVL data into real time customer information systems, incorporation and integration of paratransit operations, CAD and AVL displays at additional locations, and interface capabilities with General Electric Orion Mobile radios.

Vehicle Logic Units (VLU) shall store route, run, and schedule information and use real time location data from the GPS receiver to determine and transmit exceptions to the command center, and interface with existing radio control unit. At a minimum, the VLU requirements should include the computation and report of accurate vehicle locations, bus schedule and route adherence statistics, detection and transmission to the command center of exception conditions, on-board data processing and control, and at least 2 expansion slots and the capacity for customization.

6.4 Lackawanna Transit System

The County of Lackawanna Transit System (COLTS) issued a request for proposal for the integration and implementation of an AVL system to display position on buses in the Lackawanna-Luzerne County. The specifications call for a GPS based AVL technology to be installed in 36 vehicles.
The objective of the proposed acquisition is to provide better customer service by eliminating buses leaving pickup spots early, arriving late, and improving safety for passengers and driver in the event of an accident or disturbance. The project is being funded with 80% Federal funds and 20% State and Local funds (PaDOT and Lackwanna County).

Background

The County of Lackwanna Transit System serves Lackawanna County and 3 Luzerne County communities, including the city of Scranton and 25 boroughs and townships in Northeastern Pennsylvania. Colts also contracts a private operator to provide service to 6 suburban and rural communities in the Lackawanna County.

Overview of the Proposed System

The GPS vehicle tracking system will consist of an in-vehicle GPS receiver unit, an antenna system interfacing with the already installed two-way radio system, and a tracking and display system located at the dispatch center.

The in-vehicle unit should be capable of tracking and reporting accurate vehicle location using continuous, on request, or by exception modes, providing a digital data communications link between the dispatch center and the vehicle, and providing sensor input for monitoring in-bus functions (electronic farebox, panic switch, etc.). In addition, the system should be capable of future integration to include a mobile data terminal and an auxiliary tracking mechanism, such as a dead-reckoning system.

Table 6.3 shows the operational characteristics of the system.

Table 6.3 Operational Characteristics of the Proposed AVL System

GPS Characteristics	
GPS Receiver	5 discrete channels (4 channel for tracking satellites, 1 channel for acquiring ephemeris)
GPS Antenna	preamplified patch in ruggedized housing
Accuracy	
Position	< 30 meters corrected
Velocity	0.15 knot RMS
Environmental Characteristics	
Operating Temperature	-10 to +70 °C
Humidity	up to 95% non-condensing at 38 °C
Altitude	-400 to +20,000 ft
Package	splash proof

Overview of the Communications System

An UHF half-duplex, two-way radio system is required. The RFP also calls for computers and monitors with mapping software for the dispatch center, using the latest available equipment. The system should be able to receive messages from the vehicles and map their locations simultaneously. It should also be able to receive locations of vehicles at a rate of one per minute for a fleet of 30 to 40 vehicles.

The computer system should be designed using the latest available equipment and processing speed (minimum requirements are 486/33mhz). Detailed specifications of the functions and characteristics of the dispatch center console are provided, including the mapping displays and map ranges.

Documentation and Services to be Provided

Proposers are required to supply technical manuals, warranty information, service contract; unit pricing for spare units, GPS in-vehicle unit swap out procedure in event of unit failure, and technical support. The services to be provided by the contractor include installation, final inspection of bus installations, and training in the use of the new system.

Proposal Requirements

The RFP calls for a fixed fee contract. Proposals should include experience with similar systems in the last five years and a description of the technical approach to the project. The work outlined in the contract should be completed within 90 days upon signing the contract. Penalties will be incurred by the contractor if work is not completed in time, except with prior approval by COLTS.

Contracts will be evaluated based on the technical approach selected, past performance and prior experience, ability to complete the work within the specified time frame, capabilities of all subcontractors involved in the project, responsibilities and commitment of key personnel, and overall cost.

Required contract clauses include delays and damages, termination of agreement, audit and inspection records, conflict of interest, equal employment opportunity, debarred bidders, ownership of documents, and basis of compensation.

6.5 London Transit Commission (Canada)

The London Transit Commission (LTC) Tender ,London, Ontario, issued a request for bids on November, 1993 for a Mobile Data Acquisition System. The Request for Bids is organized in two different sections, containing the instructions for bidders and the technical specifications, respectively. Part one contains contract terms and conditions, such as submission of bids, changes, acceptance period, rejection of bids, and determination of responsibilities, among others. Part two includes the functional and technical specifications of the desired AVL and communications system.

Background

LTC operates an extensive scheduled bus network servicing the London area. While current focus of the routes is on the Central Business District (CBD), immediate future shall see changes to include outlying malls. The current delivery system utilizes approximately 99 base vehicles during weekdays, 63 on Saturdays and 38 on Sundays. Weekday morning and afternoon peak service fleets are 125 and 130 vehicles respectively. Weekday peak headway ranges from a low of 10 minutes to a high of 60 minutes. LTC also provides transportation between the university of Western Ontario and Fanshawe College.

LTC service is provided by different bus groups called "Trippers" (i.e. tripper group x might be scheduled for all service days when all schools are in regular schedule, group Y might be scheduled for those days when only parochial K-12 schools are closed, etc.).

Functional Specifications

LTC is installing the system for the purpose of improving transit service control (particularly improving service reliability). The proposed AVL system should be able to interface with the current radio system, installed in 1990.

Mobile data system hardware should be specifically designed for the transit environment, be able to withstand extreme temperatures, have splash-proof tamper-proof housings, and be protected against accidental reverse of polarity. Mobile data collected from the vehicle will be transmitted to the control center for processing at the rate of 1.5 messages per minute but not less than 2400 BPS. The microprocessor will be capable of accepting a 4-digit ID which will be transmitted with each data exchange.

The system should be able to switch radio dispatch to unattended mode in periods of low activity. A schedule adherence display will be provided on the mobile microprocessor to indicate to the operator whether he/she is predicted to be ahead or behind schedule at the next timepoint. The microprocessor should be capable of receiving up to 6 mechanical alarms, providing certain functions for the driver: Request to Talk (RTT), Priority Request to Talk (PRTT), Transfer Request, Bus to Bus Unattended Mode, and Supplementary Input. Interface with various other devices on the vehicle, such as odometers and location receivers is required. No interface is required at this time for farebox or transfer issuing machine.

Calls to drivers will have an audio alert tone different for group calls and individual calls. Dispatch may also elect to make an individual call to the driver's loudspeaker or PA system. This call will be made with the assumption that the target audience is listening. Calls will not require driver intervention to switch to the voice channel and should be able to be routed to the bus PA system, the driver's loudspeaker or the handset. After a pre-determined period (30-40 seconds) all vehicles shall revert to the data channel. In the event the call was to the handset, the driver will be required to press an ACK button.

Polling should not be performed for vehicles that are out of service automatically. In the event of a system failure, the microprocessor should permit the maintenance of voice communications with all vehicles. Emergency alarms are required to be processed during data system failure. Upon recovery, the control center will re-build it's information. A backup radio unit is required. Two way voice communications will be possible at all times between bus and dispatcher, supervisor and dispatcher, maintenance and dispatcher, and portable and dispatcher.

Bidders are allowed to propose alternatives which, in their experience, are superior to LTC specifications. The system should perform under the management by exception procedure, and must place a premium upon the speed and accuracy of the information through-put on the control center. Screens should take no more than 2 seconds to complete from the appropriate command being given.

The computer system requirements include a 32 bit processor with 8.0 Mbyte main memory expandable to 16, with external vector interrupt capability, two separate fixed disk drives (min 200 Mbytes), with disk shadowing, 4 ports at least 9600 baud. Software should be written on high level language such as C.

The LTC radio system is composed of 3 channel pairs in the UHF spectrum. One channel is used for the fixed route fleet (approximately 180 vehicles are operated by LTC). Three voice channels are divided by function, two channels are assigned to the mobile data system and the fixed route fleet, the other to the supervisory cars. **Table 6.4** shows the data calculations required to meet the information transfer rates.

Table 6.4 LTC Data Requirement for Information Transfer Rate

Average speed of vehicle (mph)	11.97
Number of bus stops in system	2,945
Number of vehicles on road at peak	148
Dispatcher interrogated location/hr (est)	74
Road bed round trip route mileage	422.88
Number of time points in system	311

Minimum requirements for vehicle location are +/- 500/1000 feet , 95% of the time. Schedule adherence reports shall have an accuracy of +/- 30 seconds for the time of passage at a timepoint 95% of the time. These are separate and distinct measurements. If wayside equipment is used, it will operate fully to its specifications (temperature, water and vandal proof). LTC requires capability to compare real vs. published schedules for any vehicle or groups of vehicles, route, timepoint, route/run, and vehicle operator. Schedule adherence parameters are required to be different by route, day and time of day without radio dispatch intervention. Schedule adherence subsystems should be capable of being switched on and off on a route by route basis.

Vehicles outside the window of tolerance should generate an exception message. Multiple messages for a vehicle are not acceptable, the system should automatically update the oldest message for a vehicle upon receipt of a newer message. LTC requires the system to be able to place previously unscheduled and unmanned route/run in front of a regularly scheduled route/run.

LTC requires that the time of passage at a timepoint be within +/- 30 seconds regardless of the speed of the bus and the location system accuracy. Total number of vehicles/timepoints passages will not exceed 400. Timepoint values on the relevant headway may be changed on-line as a result of temporary detours, etc.

Emergency silent alarm should automatically generate a report. Incident reports should include silent alarm, remote disable of mechanical alarms, accident, schedule adherence, passenger problem, re-routings, on road maintenance, service lost, farebox bypass, safety incident, complaint/compliment, generic, and vehicle change.

LTC has multiple routes intersecting other routes other than main transfer points. Because of the lower frequency of such intersections, missing a transfer frequently results in a rather lengthy wait. LTC utilizes the trapeze system to identify all transfers. The proposed system should use this information to alert the vehicle operator to look for the run card notation. The vehicle Request for Transfer Hold shall allow the operator of a vehicle in scheduled service to notify another operator in scheduled service that the former has a transfer for the latter's vehicle. Notification to the originating vehicle should be issued if the message has not been successfully delivered.

6.6 Metro-Dade Transit Agency

Metro-Dade Transit Agency provides transit services to the Metropolitan Dade County, which covers 353 sq-miles and has a population of 1.91 million. The City of Miami is the largest municipality in the county, with Ft. Lauderdale as another major city nearby in the adjacent Broward County. Besides the Everglades, a large swampy area where the Everglades National Park and the Big Cypress National Preserve are located, most of the county is urbanized. The service area of MDTA is 285 sq-miles, with a service population of 1.74 million. MDTA operates a 21.1-mile heavy rail line, a 4.6-mile automated people mover that circulates the downtown area, and 65 bus routes. MDTA's fleet includes 132 heavy rail vehicles, 29 automated people mover vehicles, and 608 buses. MDTA also provides demand response services both in house and through a private contractor.

Transit services are provided seven days a week with reduced services on weekends. Headway for heavy rail is five minutes during the peak hours, 15 minutes during the midday period, and 20 minutes during evenings and weekends. Headway for heavily traveled bus routes is 7.5 minutes and typically 30 minutes in suburban residential areas during the peak hours. During the off-peak and weekends, buses run on 15 to 60 minutes depending on the routes and travel time.

In 1995, MDTA ridership was 80.2 million with 364 million passenger miles and 28.9 million vehicle revenue hours. MDTA faces several challenges in providing quality transit services. The majority of the Dade County is low density suburbs, which makes it difficult to provide frequent services to all service areas. At the same time, Dade County is also ranked as the fourth U.S. city as having the worst traffic congestion. In searching for ways to improve public transit, MDTA introduced an AVL system to its entire fleet including the buses and the rail vehicles.

As part of a county-wide plan to upgrade the radio communication and introducing AVL into the police and fire departments and equipping some county vehciles with AVL, Dade County issued a request for proposal to secure a contract for the implementation of an upgraded communications system. Metro-Dade Transit joined the project and contributed $15 million toward the total project cost. This system should be state-of-the-art in operational techniques and equipment to provide effective communications, minimize maintenance costs, and maximize operational reliability.

System Requirements

All equipment shall be in accordance with the Urban Mass Transit Administration (UMTA) guidelines. Proposed system should include vehicle mounted radio package, AVL/AVM, CAD, consoles, and all necessary fixed site equipment.

The communications system is required to be safety certified by the State of Florida, UMTA, and Florida Department of Transportation Rule 14-55. The purpose of the desired communications system is to allow efficient and reliable control of transit vehicles and supervisory/maintenance operations form a central control point. Radio frequency coverage must meet 95% reliability criteria.

Operational Requirements

A GPS-based AVL system is specified, capable of multi channel approach due to rapid changes in vehicle location technology with Dead Reckoning sensors for backup due to aberrations caused by shadowing by buildings, bridges, foliage, etc. The Dead Reckoning devices shall monitor the vehicle's travel distance (odometer) and direction (compass). The

GPS system should operate in an enhanced Differential mode for maximum accuracy and reliability. The Dade County Geographic Information System (GIS) is the preferred electronic graphic map.

The AVL system should be automatic and independent of any route, have the capability of future expansion, and should interface with TOS Software (MDTA's on-line software that updates and maintains the correlation between vehicles' schedule and operators). The onboard system will know the vehicle location at all times, and the information transmitted to the Operation Center via the radio system. Other requirements include consolidation of the control center with remotes, improved computer response time, redundant equipment and operating modes, increased coach functions, data collection and monitoring, provision of additional input to MIS programs, and incorporation of specialized data channels as required.

Vehicle location accuracy as required at the operations center is shown in **Table 6.5.**

Table 6.5. MDTA Vehicle Location Accuracy

Outside Central Business District (CBD)	+/-50'
In Central Business District (CBD)	+/-100
Supervisory Vehicles and Maintenance	+/-50'

Polling time for vehicles is at least once every 2 minutes. If bunching is detected in the Central Business District (2 or more buses on the same street, going the same direction, and within 1,000' of each other), the polling sequence should be adjusted to display vehicles in their actual order of travel.

The vehicle's position shall be available whether the vehicle is on or off route or off the roadway anywhere within the coverage area. The system should be able to compare the location of the vehicle with the scheduled position of the vehicle. Vehicles either running ahead of schedule or running behind schedule will be identified for management attention.

The vehicle location screen will have a base display map, the largest area to be displayed on a screen is MDTA Regional Transit Area, while the smallest area would be approximately 1/4 mile square with several intermediate steps required to be available. Overlaying the Base Display Map will be the vehicle Route Display, capable of displaying a minimum of 200 routes. Overlaying the Route Display (which is overlaying the Base Display Map) shall be the display of vehicles and their location. The 1/4 mile screen should be able to show all vehicles is the selected area, their route and block numbers, the individual vehicle numbers, direction of travel, and schedule adherence. The regional screen should be able to show all vehicles on at least two routes, travel direction, schedule adherence, route and block number, and the individual vehicle number.

Vehicles running out of schedule tolerance will be identified for action by the dispatcher through visual identification of the vehicle and a text display of pertinent information. In order of seriousness, situations to be addressed by the system are missed trip delay causing passenger delays in excess of 30 minutes, vehicle running more than 2 minutes ahead of schedule, and missed trip/delays where passengers will be delayed 10-30 minutes. A dispatcher should automatically log on to his/her assigned geographic area and/or specific routes to monitor. When faced with a missed trip/delay over selected value, the dispatcher would get a screen which shows the location of other vehicles on the route, the location of vehicles not in service which could be inserted into this service, and the location of vehicles on another route which could be diverted to fill this gap.

Upon receipt of a silent alarm, the screen would zoom to a scale which shows the location of the vehicles emitting the silent alarm, the location of the nearest supervisor vehicle, and the location of other MDTA vehicles near the vehicle in alarm.

The on-board message display of schedule adherence (such as "you are on schedule") could be activated by depressing a function key, by automatically generating the message if immediate operation action is required (for example "the bus is 6 minutes ahead of schedule"), or if Central Dispatch wants the operator to be aware of his schedule adherence (for example, "you are 10 minutes behind schedule").

When the vehicle is stored, the on-board equipment should go into a low power mode with all the displays off. However, the unit should still monitor certain inputs and response as required. For example, it should respond to periodic polls from the Control Center (once per hour) report certain items such as alarms (in case when a farebox is entered), and awaken and report "in operation" upon an input on the operator's control panel or if the vehicle is started. The mobile unit should have sufficient backup power to maintain any volatile memory for a minimum of 48 hours.

As a separate option, a method for counting exiting and entering passengers is required. The system may include sensors which count in both directions, or sensors for exiting and farebox data for entry (it is assumed that the electronic farebox interface can provide the count of boarding passengers). Information should be available down to the individual stop level, to be used by schedulers to alter route and run cutting based on ridership requirements which may change over the course of scheduled runs.

An interface to an existing Public Announcement (PA) system is required with each vehicle mobile radio that can be activated from either the operator's position or from the dispatcher.

6.7 Alameda Contra Costa Transit

Alameda Contra Costa Transit District (AC Transit) released the Technical Specifications for the procurement of the SATCOM 2000 system in June, 1996. The objective was to release information on AC Transit in order to purchase a SATCOM 2000 to support a GPS-based AVL, as well as increase data transmission to and from a variety of devices to be installed on on-board vehicles (vehicle control heads, AVL equipment, fareboxes, APC, overhead signs, odometer inputs, passenger information devices, traffic signal controllers, engine and transmission monitoring equipment, status points, and alarm points). There are currently no plans to expand to paratransit service.

Background

AC transit provides fixed-route services to the western parts of Alameda and Contra Costa Counties, extending from San Pablo Bay in the north to the southern city limits of Fremont in the south. The service area encompasses 400 square miles and includes 13 cities plus adjacent unincorporated communities, serving approximately 1.3 million people. AC transit has a fleet of 700 buses on 124 fixed routes, 571 on peak periods. Service is expected to increase on the next 10-15 yrs to 800 vehicles. Buses are scheduled daily from 5 AM to 10 PM. **Table 6.6** shows the service characteristics of AC transit.

Table 6.6 AC Transit Service Characteristics

Number of Routes	124
Number of Stops	8000
Maximum Time of Bus Service/day	16 hours
Maximum Layover on a Run	1/2 hour
Maximum Number of Stops in a Run	325
Total Fleet	700 vehicles
Number of vehicles in peak periods	571

Functional Requirements

The SATCOM 2000 bus dispatch system should be capable of interfacing up to 900 transit vehicles on 8 communications channels. The system is required to display and use the scheduled trips that apply to the particular service day (weekday, school day, non-school day, holidays, weekends).

The use of "smart polling" strategies to provide most frequent polling where it is needed the most (i.e. off-route buses) and less frequent polling of buses in the yard or at the end of the route is encouraged. The vehicle should initiate "health check" transmissions whenever no exception report transmissions have been made for a period of 5 minutes. Emergency alarms an Priority Request to Talk (PRTT) shall be displayed within 5 seconds. Redundant alarms will be eliminated.

Central Dispatch (CD) should receive and process all data from vehicles even if the vehicles are not logged on, and should be able to disable individual vehicle radios if they are degrading the communications with other vehicles. All communications with the vehicle in the fallback mode will be made via the bus operator's handset or speaker. **Table 6.7** shows a summary of AC existing and future Transit Fleet.

Table 6.7 AC Transit Fleet

Vehicle Type	Initial Fleet		Future Fleet	
	Total Fleet	Peak Periods	Total Fleet	Peak Periods
Bus	700	571	800	700
Supervisory	15	15	100	15
Totals	715	586	900	715

AC Transit future development plans require the following data and control features for the SATCOM 2000: traffic signal preemption, and automatic on-board visual display of information to passenger, such as next stop, major intersections, key transfer points, promotional information, public service information, and advertising.

The system should be able to collect both historical and operational data for retrieving, displaying and printing, including incident report handling, and relational database server connected to AC transit ethernet WAN. It should also provide an efficient procedure for data exchange for Network file server data exchanges, Automatic Passenger Counter (APC), Transportation Information System (TIS), Public Information system (PIS), including real time schedule information, headway, schedule adherence, road conditions, and accidents. The system should also be capable of manipulating geographic map information, including but not limited to, importing base regional maps and the necessary tools for map manipulation such as creating map overlays to be used as the basis of the CAD/AVL user interface. AC Transit plans to purchase periodic updates to the base map from a third party source. Optical Character Recognition software is required to be provided as part of the system.

AVL System General Requirements

The system shall include a GPS based AVL capable of on-board calculation and display of schedule and route adherence with only schedule and route deviation and occasional on-demand schedule/route reporting to central dispatch, while minimizing the radio communications for the transmission of vehicle location data. Schedule/route adherence of vehicle location should be displayed in a graphical and tabular manner.

Vehicles will be considered off schedule if over 1 minute early or over five minutes late or more than 250 ft from scheduled route. Vehicle schedule and route adherence shall be calculated on board and reported whenever the schedule or route adherence threshold are exceeded, and at least every five minutes. Consideration for backup equipment such as dead reckoning to use when the GPS has lost line of sight is encouraged.

The functional requirements of the AVL system include reporting of true mileage traveled, transmittal to the farebox equipment upon fare entry, reporting actual time of vehicle leaving the yard, and compliance with ADA act to trigger next stop announcements on board the bus.

The automatic passenger counting equipment should be able to track passengers boarding and alighting at each stop, utilizing infrared light beam technology. Information that is not needed in real time should be stored on the buses until off-loaded at the end of the run. Schedule adherence should be calculated for each defined timepoint and accurately estimated between timepoints. System accuracy should be +/- 30 seconds.

Passenger information kiosks will support the display of passenger information on interactive kiosks located through the AC transit service area, and allow the public to request information on current transit system operations such as schedule adherence, route/run schedules, etc.

The system's user interface should allow for display of 6 windows simultaneously, including scrolling, display types, event queue, incident report, and geographic map display, among others The maps should include streets, highways, prominent geographic areas, rivers, lakes, bays, oceans, important landmark ,bridges, airports, important buildings, jurisdictional boundaries, ADA service boundaries, bus routes, rail lines and stations, and real time location of buses. Location of vehicles will be displayed by symbols overlaid in the geographic map display. These symbols will indicate schedule status, silent alarm, route status, type of vehicle, direction of travel, and non-schedule logged on and not logged on.

The system will support the selection of individual and multiple routes, location and centering of the display on selected vehicle, definition of landmarks, centering the display at selected landmark or any selected point, automatically centering map display on vehicle with emergency alarm, calculation of distance between two points on the map, display of individual vehicle identities of overlapped vehicles, and display of major bodies of water. Additional requirements include the display of the following functions: actual versus scheduled headway, early and late buses, off-route and pull-in, status information, lost service, extra service, missed pull-out, report scheduling, and scheduled relief display. Procedures display required include emergency alarms, road call, relays, out late, cancellations, turnbacks, extra-service, late service, lost time, accidents/incidents, bomb threats, enforcement incidents, illness, crimes, re-routes, and hazardous materials. The user interface is required to support the generation of reports such as incident, daily log activity, dispatch activity, lost service, extra service, bus pullout, missed pullout, bus radio malfunctions, emergency vehicle, weather, schedule deviation, and passenger lift log.

DPGS reference receiver and antenna should be provided to supply DGPS corrections to each GPS-equipped vehicle. The pseudo range and range-rate correction for each GPS satellite in view of the reference receiver will be calculated by the DGPS reference receiver and transmitted to each GPS-equipped vehicle at least every 30 seconds. Parallel (dedicated channel) tracking receivers will be capable of tracking simultaneously 8 GPS satellites in the best geometry for a position fix and provide time signals to the contractor-provided on-board equipment. GPS receivers will report latitude, longitude, speed, time, and direction of travel, and support all BLOCK I, II and IIR GPS satellites that are operational at the time the GPS is delivered. Minimum differentially-corrected positional accuracy is 10 meters (2 Drms). This applies to both the positions used on-board and the positions used by the CD equipment. Cold start time to first fix (TTFF) of 2 minutes or less with a signal reacquisition time of 15 seconds or less, following the loss of signal for at least one minute, is required. Velocity measurements provided will be accurate to 0.1 meters/second. GPS time signals to other on-board equipment will be accurate to +/- 1 ms. GPS backup (dead reckoning) equipment will be accurate to +/- 3% of the distance traveled.

Overhead Sign Interface will update the sign messages with the proper route messages at bus operator login and at predefine points along the route. The Automatic Passenger Counter system will interface with the rest of the on-board equipment to allow passenger count to be correctly associated with the GPS based location and bus stop.

6.8 Ontario, Canada

The Ministry of Transportation of Ontario (MTO) has developed a generic bid document package, containing both contract terms and conditions, and functional system specifications, for the procurement of transit-oriented mobile data acquisition systems, AVL systems, or Automatic Vehicle Location and Control (AVLC) systems (Cain and Robinson 1993). This document may be reproduced for non-commercial purposes only with attribution to the ministry. The objectives of this document are to standardize AVL/C system functionality and specifications, to lower overall implementation costs, to gain insight into AVL/C's benefits, to gain experience in the deployment of new-transit related technologies, and to assist local industry to offer a better service.

This report was intended for small and medium size properties planning to procure and implement either a mobile data radio system for voice and data, an AVL system for tracking and locating vehicles, or an AVLC system for monitoring and predicting fleet schedule adherence. It provides an outline of essential contract terms, conditions and technical specifications for procuring transit agencies. This document package has been divided into 5 sections: Information For Bid terms and conditions, Request For Proposal terms and conditions, Systems Options Selection List, Generic Technical Specifications, and Property Specific Technical Specifications. Appendix A provides the Transit Authority of River City Interface File Specifications. The non-technical section of this package provides both, Request for Proposal (RFP) and Information for Bid (IFB) material to allow transit properties the use of the Generic Bid Document in either process. Step by step instructions on how to adapt the generic bid document to a particular situation are offered by Barry Pekilis, PE, Project Manager of the Ontario AVL/C Initiative. The Ontario AVL/C Initiative, Small and Medium Properties Recommendations: Phase II Report was written as a companion document to the generic bid package.

Section 1, Information for Bids, is divided into 4 chapters

Chapter 1: Instructions for Bidders. This section includes information on Definition of Terms, Changes, Bid Acceptance Period,, Determination of Responsibility, Submission, Modification and Withdrawal, Opening, Rejection, Alternative and Single Bids, etc.

Chapter 2: Standard Equipment and Supply Contract Conditions. This section includes information on Patents, Brand Names, General Warranty, Inspection and Testing of Materials, Contractor's Obligations, Payment, Subcontracting, Conflicting Conditions, Interpretation of Specifications, etc.

Chapter 3 : Property Specific Terms and Conditions. This section is reserved for the inclusion of any required property specific terms and conditions.

Chapter 4: Contract Forms. The following forms are provided in this section: Acknowledgment of Addenda, Bid Form, and Bidder Information.

Section 2, Request for Proposal, is divided into 4 chapters.

Chapter 1 : Instructions to Proposers. This chapter included information on Definition of Terms, Submission, Acceptance Period, Rejection, Modification or Withdrawal, Guarantee, Determination of Responsibility, Qualifications for Award, Documents to be submitted, Form of Proposal and Signature, Alteration/Calculation Errors, Delivery Chargers, Time for Execution of Contract, Performance Bond, Waiver, Non-Collusive affidavit, Penalty for Collusion, Postponement, Request and Appeals, Equal Employment Opportunity, and Representation.

Chapter 2: Standard Equipment and Supply Contract Conditions. This section includes information on Patents, Genera and Product/Service Warranty, Contractor's Obligations, Payment, Interpretation of Specifications, Documents Deemed Part of Contract, Order of Precedence, Changes by Contractor and Contracting Officer, Extension of Time, Contractors Indemnity, Approval, Defective or Damaged Work, Failure to Complete Contract, Compliance with Laws and Regulations, Warranty of Title, Non-Waiver of Warranties, Prohibited Interests, and Acceptance and Termination of Contract.

Chapter 3: Property Specific Terms and Conditions: This section is reserved for the inclusion of any required property specific terms and conditions.

Chapter 4: Contract Forms. The following forms are provided in this section: Acknowledgment of Addenda, Proposal Form, and Bidder Information.

Section 3: System Options Selections List. This Section allows the transit property to adapt the generic specification for property-specific use. This is accomplished by selecting the desired systems from a checklist. As the selection is performed, specific sections of the technical specification are confirmed of deleted. The items included in the checklist are radio equipment, schedule adherence system, AVL system, data system, dispatch console, tape recording equipment, public information systems and scheduling system.

Section 4: Generic Technical Specifications. The following topics are covered in this section: Introduction and scope, Mobile radio units, Mobile data system, Maintenance and supervisory vehicles, Portable equipment, Central Base Station, Fixed site links, Satellite receivers and comparators, Dispatch Consoles, Tape recording equipment, Public information systems, Functional specifications overview, Software design specifications, Computer system requirements, Scheduling system, Installation requirements, Acceptance, Manual and training, Maintenance, and Licensing and Standards.

Section 5: Property Specific Technical Specifications. The contents of this section are as follows: Existing system overview, Data Calculations, Vehicular channelization and coverage requirements, Vehicle Details, Dispatch center, Dispatch center displays, Reports, Other system interfaces, Public information applications, and Checklist of technical specifications.

Sections 4 and 5 were designed to be combined into a single, two part technical specification.

The Generic Bid Document Package is an ever evolving document that will continue to develop over time, as recommendations from transit properties and the transit industry on the contents and applicability of the document are incorporated.

7. CONCLUSIONS AND RECOMMENDATIONS

AVL has been widely accepted as a useful technology that will help public transit agencies improve their services and attract ridership. Besides permitting significant improvements in schedule adherence, emergency response, and data collection for service planning purposes, AVL may also be combined with other technologies or ITS components to bring extended benefits. For instance, combined with APC, better data of vehicle loading and loading patterns may be obtained, which will be useful in service planning and adjustments. AVL systems allow electronic fare boxes to automatically determine the fare based on zonal information. Fare box data such as type of fare, date and time of travel, and origin-destination are also useful for market analysis and demand modeling. The vehicle's location information may be used to adjust the traffic signal system, allowing signal priority to be provided for public transit vehicles. AVL is also a critical element in automatic annunciation systems, which are capable of determining and announcing the name of the next stop(s), and in ATIS, which provides real-time travel information to users via various communication media. AVL helps to integrate different transit modes by allowing better coordination of modes at transfer points. It has also been used as an effective traffic probe to determine roadway congestion levels, which may be used by transportation agencies for planning, or by automobile drivers to make trip decisions. While these benefits are somewhat evident, AVL is also believed by some to hold the key to the development of new transit paradigms for rural and small urban areas with low density and dispersed activity centers. More studies are needed to investigate such possibilities.

In recent years, a greater number of agencies are moving towards adopting one or more components of APTS, including AVL. However, in the context of fixed route services, survey results show that larger agencies are more likely to adopt AVL than smaller agencies, which are less burdened with problems of congestion and crimes. This perception of AVL only benefiting larger agencies with congestion and crime problems may be a barrier that prevents smaller transit agencies from exploring possible new ways of serving their customers. Other barriers faced by smaller transit agencies include lack of technical personnel and lack of information on AVL technology, which likely also contributed to the fact that smaller agencies tend to be less enthusiastic toward AVL implementation.

Currently, the top priorities of the majority of the agencies that are planning, implementing, or operating AVL systems are to improve schedule adherence, emergency responses, and provide real-time travel information. Better data collection for transit planning purposes is also considered important. In comparison, less attention is paid to modal integration and personnel management. This may be a result of many agencies having only one or two modes, which may be verified with more detailed analysis.

System implementation is not always an easy process due in part to the novelty of the AVL technology. All the agencies interviewed strongly believed that the success of the implementation procedure depends on a series of key elements that are very easy to incorporate in the development process:

- Utilize an outside consultant if the agency lacks the technical personnel necessary to develop the technical specifications. This is very important to ensure that the technology being adopted will provide the necessary capabilities to evolve in a relatively new and constantly changing field, such as AVL systems. With the proper guidance and planning, provisions can be made to ensure that the technology adopted will interface with future systems without becoming obsolete in a short period of time. Small agencies, in particular, might not have the technical personnel capable of making appropriate decisions due mainly to lack of training or exposure to the new developing technologies, and might require the expertise of a consultant/vendor in developing a request for proposal or technical specifications.

- Choose a vendor that will adhere to the standards published by the Society of Automotive Engineers (SAE). At the present time more than 30 vendors offer technologies that adhere to these standards. Many of the vendors will offer the same or similar features, therefore emphasis may be placed on experience, company stability, and recommendations from other agencies. The SAE standards are available for a modest cost[1]. These include J1708 ($25), J1455 ($45), J1587 ($45), and J1922 ($35) as of December, 1996. Some of the goals of the subcommittee in developing these documents are reproduced in verbatim below from the standards (SAE 1989):

  a) minimize hardware cost and overhead;

  b) provide flexibility for expansion and technology advancements with minimum hardware and software impact on in-place assemblies;

  c) utilize widely accepted electronics industry standard hardware and protocol to give designers flexibility in parts selection;

  d) provide a high degree of electromagnetic compatibility; and

  e) provide original equipment manufacturers, suppliers, and after market suppliers the

[1] To obtain a copy, contact SAE at (412) 776-4841 located at 400 Commonwealth Drive, Warrendale, PA 15098-001.

flexibility to customize for product individuality and for proprietary considerations.

- Define objectives. It is very important to define early in the process, the objectives to be achieved through the AVL implementation, including future expectations for the system. This important step will allow the agency to review all available technologies and focus on those systems that offer the capabilities needed to perform as desired and are compatible with other APTS components. These objectives will become the guiding factors for decisions made during the installation process as well as measuring the success of the entire project. It is advisable at this stage of the process to consider a joint effort with other county services such as police, fire and emergency/rescue, and public works.

- Involve all concerned parties in the planning process. Wide involvement will ensure that the system is designed to satisfy current and future needs of different transit divisions and local agencies, eliminating conflicts that may arise from incompatibility between equipment or procedures used by different entities and maximizing the benefits of AVL. For instance, by identifying various parties' needs for information derived from AVL data, detailed and clear specifications may be developed for AVL software. Not only is this important to ensure that the system serves the needs of the concerned parties, it also prevents project cost escalation by avoiding having to reengineer the AVL software that proves inadequate in its functionality. In addition, as many AVL implementations are a part of a communication system upgrade or of an ITS project, opportunities exist to share the project costs among the involved agencies to reduce the cost burden on the transit property.

- Prepare detailed specifications incorporating a phased acceptance testing program. This testing program should include the staged installation of the AVL equipment in a few vehicles prior to a full fleet installation. Staged implementation will allow the agency to test the system and work out conflicts as they arise before a full installation. It will also permit the personnel to become familiar with the daily operation of the system prior to a full installation.

- Develop realistic goals for project completion and expect delays. All of the agencies that participated in this study were faced with delays during the implementation process. Technologies are usually tailored to the agency's needs and that generally results in an implementation process that requires testing and developing until the completion and final installation of the system.

- Maintain a positive working relationship with the vendor. The cooperation of agency and vendor will be and invaluable tool for a successful system implementation from the beginning. The AVL system implementation is a long process that, by virtue of its novelty, lends itself to changes and upgrades even before the system is completely functional. These changes might not be stipulated in the technical specifications or request for proposal issued by the agency and will depend on the good will of the vendor for their inclusion in the implementation process. A vendor will be able to offer suggestions based on their experience with past implementations, resulting in savings (time and money) and a successful implementation process for the agency.

The planning process may be broken down into several different tasks. For example, RTA (Greater Cleveland Regional Transit Authority) defined the following list of tasks reproduced below for their AVL implementation:

Task 1: Determine the agency's needs. This is a very important step that will guide the rest of the process, and it may be accomplished by selecting a committee of individuals from different departments directly affected by the implementation of the AVL System.

Task 2: Perform an in-depth research to gather information on available technology, for example try to obtain information and questionnaires mailed to other transit agencies with similar characteristics.

Task 3: Visit transit properties which have implemented the systems identified in task 2. This will allow your agency to see first hand how the AVL system performs, and how to avoid mistakes based on the experiences of the toured facilty.

Task 4: Choose most appropriate technology and conduct a system evaluation. Utilize the same criteria for all prospective vendors.

Task 5: Develop an implementation plan. Allow extra time for the fine tunning of the system, since AVL system are a fairly new technology that still needs to be perfected.

Task 6: Develop specific capital and operating costs estimates. Have all prospective vendors supply a cost estimate for chosen system. This estimate should include consideration of all expenses that might be incurred through the implementation process, including future operating and maintenance costs associated with the system, and all operating costs savings. Compared this estimate with other transit properties that have installed a similar system.

Task 7: Identify costs savings that will occur with the system implementation.

Task 8: Prepare Final Report. Present in a concise manner the findings of the research performed. Include all necessary refinements and work to be carried out in the implementation phase.

Based on the survey, the average length of time for AVL implementation is 8.25 years. Most of the time was spent on initial acceptance of the concept within an agency, actual installation, and testing. With more information on AVL becoming available and AVL implementation experience accumulating, it is expected that it will take less time for transit properties to learn about AVL and determine its benefits, develop an RFP or bidding document, and fully test the system and begin regular operations. Technical information needs to be provided to assist transit agencies in this task. This may include literature, training workshops, demonstrations, and guidelines to help transit agencies to develop project objectives, technical specifications, and contract documents. Such assistance is especially important considering the complexity of AVL and other APTS technologies and the lack of information on transit applications of these technologies.

Finally, AVL should be viewed as a means to improve transit services and serve the customers, therefore, all the AVL related activities should also be guided with customers' needs in mind. Project goals and evaluation criteria should be established early on in a project to specifically address customer needs and benefits. Customer input and feedback are important before, during, and after AVL installation in helping a transit agency to ensure that the project will bring significant improvements to transit services from users' perspective. After all, it is the ridership that is the ultimate test for a successful transit project.

REFERENCES

Ann Arbor Transportation Authority (1995). *Request for proposal #328 - Intelligent Transportation System*, Ann Arbor, Michigan.

Ball, W. (1994), *Economic and Policy Considerations of Advanced Public Transportation Systems (APTS)*, Center for Urban Transportation Research, University of South Florida.

Baker, R., Casey, R.F., Ha, L. and Overgaard, D. (1994). "Lessons Learned in Procurement and Implementation of Transit Automatic Vehicle Location Management and Monitoring Systems," *Proceedings of the 1994 Annual Meeting of IVHS America*, Vol 2, Atlanta Georgia.

Behnke, R. (1992). *California Smart Traveler System*, technical Report DOT-T-92-16. Office of Technical Assistance, Federal Transit Administration, U.S. Department of Transportation, 400 7th Street SW, Washington, D.C.

Body, C. (1996). *"The Evolution of ITS: Intermodal Transportation Systems", Passenger Transport*, September 2, 1996, pp. 1-11.

Brunetti, R., Claroni, C. and Gazzotti, F. (1995). "Distance Related Fares System Based Upon GPS Location," *Towards an Intelligent Transport System - Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, ERTICO, Paris, France, p2872-2879.

Burgener, E.C. (1993). "Personal Transit Arrival Time Receiver," *Proceedings of the IEEE-IEE Vehicle Navigation and Informations Systems Conference*, IEEE, Piscataway, NJ.

Cain, D. and Pekilis, B. (1993). "AVLC Technology Today: A Developmental History of Automatic Vehicle Location and Control Systems for the Transit Environment," *Proceedings of the IEEE-IEE Vehicle Navigation and Information Systems Conference*, Parviainen, J. (editor), Ottawa, Ontario, October 12-15, 1993.

Cain, D. and Robinson, J. (1993). *Ontario AVL/C Initiative, Small and Medium Properties Recommendations: Phase II Report,* Ministry of Transportation of Ontario Transportation Technology and Energy Branch, 1201 Wilson Avenue, Downsview, Ontario, Canada.

Cain, D. and Robinson, J. (1993). *Ontario AVL/C Initiative, Small and Medium Properties: Generic Bid Document Package.* Technical Publications, Ministry of Transportation of Ontario, 1201 Wilson Ave., Downsview, Ontario Canada.

Casey, R.F. and Labell, L.N. (1992). "Evaluation Plan for AVL Implementation in Four U.S. Cities," *Surface Transportation and the Information Age," Proceedings of IVHS American Annual Meeting*, pp. 426-434.

Casey, R.F., Labell, L.N., Prensky, S.P., and Schweiger, C.L. (1991). *Advanced Public Transportation Systems: The State of the Art*, Technical Report DOT-VNTSC-UMTA-91-2, U.S. Department of Transportation, Urban Mass Transportation Administration, Washington, D.C.

Casey, R.F., Labell, L.N., Holmstrom, R., LoVecchio, J.A., Schweiger, C.L. and Sheehan, T. (1996). *Advanced Public Transportation Systems: The State of the Art Update '96*, Technical Report FTA-MA-26-7007-96-1, U.S. Department of Transportation, Federal Transit Administration, Washington, D.C.

Center for Urban Transportation Research (1994). *Automatic Vehicle Location for Measurement of Corridor Level-of-Service: Statewide Feasibility Analysis,* Final Report, University of South Florida, Tampa, FL.

Chesnoy, A. and Bense, D. (1995). "Radiopositioning of Mobiles in a Densely Built Up Urban Area and Applications to RATP Bus Fleet Management and Passenger Information, Towards an Intelligent Transport System," *Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, ERTICO, Paris, France, pp. 2952-2958.

Chicago Transit Authority (1992). *Automatic Vehicle Location/Control and Traffic Signal Preemption: Lessons From Europe*, U.S. Department of Congress, National Technical Information Service.

Claroni, C., Gazzotti, F., Armandi, M. ,and Falconieri, L. (1993). "Public Transport Fleet Locations System Based on DGPS Integrated with Dead Reckoning," *Road Vehicle Automation - Proceedings of the 1st International Conference on Road Vehicle Automation*, Bolton, UK, pp. 259-269.

Daily, D. and Haselkorn, M. (1995). "Demonstration of an Advanced Public Transportation System in the Context of an IVHS Regional Architecture," *Towards an Intelligent Transport System - Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, ERTICO, Paris, France, pp. 3024-3032.

Federal Transit Administration (1993). *Analysis of IVHS Benefits/Costs Studies Project*

Memorandum, U.S. Department of Transportation, Washington, D.C.

Feijóo, C., Ramos, J. and Perez, F. (1993). "A system for Fleet Management Using Differential GPS and VHF Data Transmission Mobile Networks," *Proceedings of the IEEE-IEE Vehicle Navigation and Information Systems Conference*, Parviainen, J. (editor), Ottawa, Ontario, October 12-15, 1993.

Foy, R. (1992), "Automated Bus Diagnostic System," *National Conference on Advanced Technologies in Public Transportation*, Transportation Research Board, National Research Council.

Gault, H. (1993). "Automatic Vehicle Location Control at OC Transpo," *Proceedings of the IEEE-IEE Vehicle Navigation and Information Systems Conference*, Parviainen, J. (ed.).

Giugno, M. (1996). "Milwaukee Turns 'SmartTrack' Concept into Reality," *Passenger Transport*, September 2, 1996, pp. 8-9.

Gray, T. (1993). "Automatic Vehicle Location: the current state of the art," *Road Vehicle Automation; Proceedings of the 1st International Conference on Road Vehicle Automation*, Bolton, U.K. Nwagboso, C. (editor), pp. 24-26.

Haccoun, D., Rosenberg, C., Caron, M. (1993). "Radiopositioning by Satellite," *Proceedings of the IEEE-IEE Vehicle Navigation and Information Systems Conference*, Ottawa, Ontario, Parviainen, J. (Editor).

Heti, G. (1991). *Informatics - Vehicle Location, Communications, Control and Monitoring Systems Under Development in Ontario*, Technical Report TCT-91-01, Transportation Technology and Energy Branch, Ministry of Transportation of Ontario.

Jacobson, K. (1993). "Transit Signal Priority Treatments in the Pudget Sound Region," *Proceedings of the Pacific Rim Conference*, Seattle Washington, July 25-28, pp. 272-277.

Jones, J. (1994). "AVL and More", *Mass Transit*, November-December 1994, p38-49.

Kalaputapu, R. and Demetsky, M.J. (1995). "Modeling Schedule Deviations of Buses Using Automatic Vehicle Location Data and Artificial Neural Networks", *Transportation Research Record*, Vol. 1497, pp. 44-52.

Krakiwsky, E. (1996). "Navigation and Tracking Systems," *ITS World*, 1(1), pp 32-36, Johnson, N.S. (editor), Philip Arndt Publisher.

Kihl, M. (1993). "Advanced Vehicle Location System for Paratransit in Iowa," *Proceedings of the IEEE-IEE Vehicle Navigation and Informations Systems Conference*, IEEE, Piscataway, NJ.

Kihl, Mary and Shinn, Duane, August 1993, *Improving Interbus Transfer with Automatic Vehicle Location. Year One Report*, Midwest Transportation Center, Iowa State University (515) 294-8103.

Kihl, Mary and Shinn, Duane, June 1995, *Improving Interbus Transfer with Automatic Vehicle Location. Year 2-Final Report*, Midwest Transportation Center, Iowa State University (515) 294-8103.

Labell, L.N., Schweiger, C.L., and Kihl, M. (1992*). Advanced Public Transportation Systems: The State of the Art Update '92*, Technical Report DOT-VNTSC-FTA-92-3, U.S. Department of Transportation, Federal Transit Administration, Washington, D.C.

Lachapelle, G., Townsend, B., Gehue, H., and Cannon, M.E. (1993). "GPS versus Loran-C for Vehicular Navigation in Urban and Mountainous Areas," *Proceedings of the IEEE-IEE Vehicle Navigation and Information Systems Conference*, Parviainen, J. (editor), Ottawa, Ontario, October 12-15, 1993.

Laurens, B. (1995). "Experiences in Public Transport Priority at Intersection Centralized Versus Decentralized Approach," *Towards an Intelligent Transport System - Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, ERTICO, Paris, France, pp. 3072-3077.

Mansfield, R.S. and Bannister, D. (1995), "The Use of ATT Applications for Public Transport in Scope Cities," *Towards an Intelligent Transport System - Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, ERTICO, Paris, France, pp. 2920-2927.

Mason, W. (1993). "The Implementation of an AVL/M System - River City, KY: One Transit Property's Actual Experience," *Proceedings of the IEEE-IEE Vehicle Navigation and Information Systems Conference*, Parviainen, J. (editor).

Ministry of Transportation of Ontario (1991). *Automatic Vehicle Location and Control*

Systems for Small and Medium Ontario Transit Properties: Phase 1 Report. Technical Report TCT-91-02, Transportation Technology and Energy Branch.

Overgaard, D. (1993). "Automatic Vehicle Location at Seattle Metro," *Proceedings of the Pacific Rim Conference*, July 25-28, 1993, Seattle, Washington. (date 7)

Pekilis, P. and Heti, G. (1991). *Automatic Vehicle Location and Control Systems for Small and Medium Ontario Transit Properties: Phase 1 Report*, Technical Report TCT-91-02, Ministry of Transportation of Ontario Transportation Technology and Energy Branch.

Perkinson, D.G. (1994). "Using Automatic Vehicle Location Data to Monitor Congestion: Fuzzy Set theory," *ITE Journal*, February 1994, pp. 35-40.

Polk, A. (1994). *Automatic Vehicle Location for Measurement of Corridor Level-of-Service: Statewide Feasibility Analysis,* Final Report, Center for Urban Transportation Research, University of South Florida, Tampa, FL.

Schweiger, C.L., Kihl, M., and Labell, L.N. (1994). *Advanced Public Transportation Systems: The State of the Art Update '94*, Technical Report FTA-MA-26-007-94-1 or DOT-VNTSC-FTA-93-8, U.S. Department of Transportation, Federal Transit Administration, Washington, D.C.

Smith, R., Atkins, S. and Sheldon, R. (1995). "London Transport Buses: ATT in Action and the London Countdown Route 18 Project," *Towards an Intelligent Transport System - Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, ERTICO, Paris, France, pp. 3048-3055.

Smith, W., Nelson, J.D. and Bell, M. (1995). "Buses as Probes: The Use of AVL Information for Improved Traffic Control," *Towards an Intelligent Transport System - Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, ERTICO, Paris, France, pp. 3063-3073.

Sushko, M. (1993). "DGPS Broadcasts using the Radio Broadcast System (RBDS) for IVHS," *Proceedings of the IEEE-IEE Vehicle Navigation and Information Systems Conference,* Parviainen, J. (editor), Ottawa, Ontario, October 12-15, 1993.

Sweeney, L. and Loughmiller, G. (1993). "Comparative Accuracies of Technologies for Vehicle Location and Navigation," *Proceedings of the ASCE Third International Conference on Applications of Advanced Technologies in Transportation Engineering*, Pacific Rim

Transtech Conference, Hendrickson, C. and Sinha, K. (editors), American Society of Civil Engineers.

Sweeney, L., Zavoli, W. and Loughmiller, G. (1993). "Comparative Performance of Various Automotive Navigation Technologies," *Proceedings of the IEEE-IEE Vehicle Navigation and Information Systems Conference*, Parviainen, J. (editor), Ottawa, Ontario, October 12-15, 1993.

Tidewater Transportation District Commision (199?). *Automatic Vehicle Location System (AVL), Part IV: Technical Specifications*, Norfolk, Virginia.

Vicek, C., McLain, P. and Murphy, M. (1993). "GPS/Dead Reckoning for Vehicle Tracking in the 'Urban Canyon' Environment," *Proceedings of the IEEE-IEE Vehicle Navigation and Information Systems Conference*, Parviainen, J. (editor), Ottawa, Ontario, October 12-15, 1993.

Walker, J. (1990). *Mobile Information Systems*, Artech House, pp. 50-100.

Watje, J., Symes, D. and Ow, R.S. (1994). "Vehicle Location Technologies in Automatic Vehicle Monitoring and Management System," *IVHS Journal*, 1(3), pp.295-303.

Wright,J., Nookala, M., and Robinson, F., (1994). "Minnesota Guidestar Project Travlink," *Proceedings of the 1994 Annual Meeting of IVHS America*, Vol 2, Atlanta, Georgia, April 17-20, 1994.

APPENDIX A. LOCATION AND COVERAGE OF GPS FIXED STATIONS

The DGPS coverages in the U.S. are obtained through the web site (www.navcen.uscg.mil/dgps/coverage/) of the National Coast Guards. It should be noted that the displayed DGPS coverages are unvalidated estimates developed using a modeling tool.

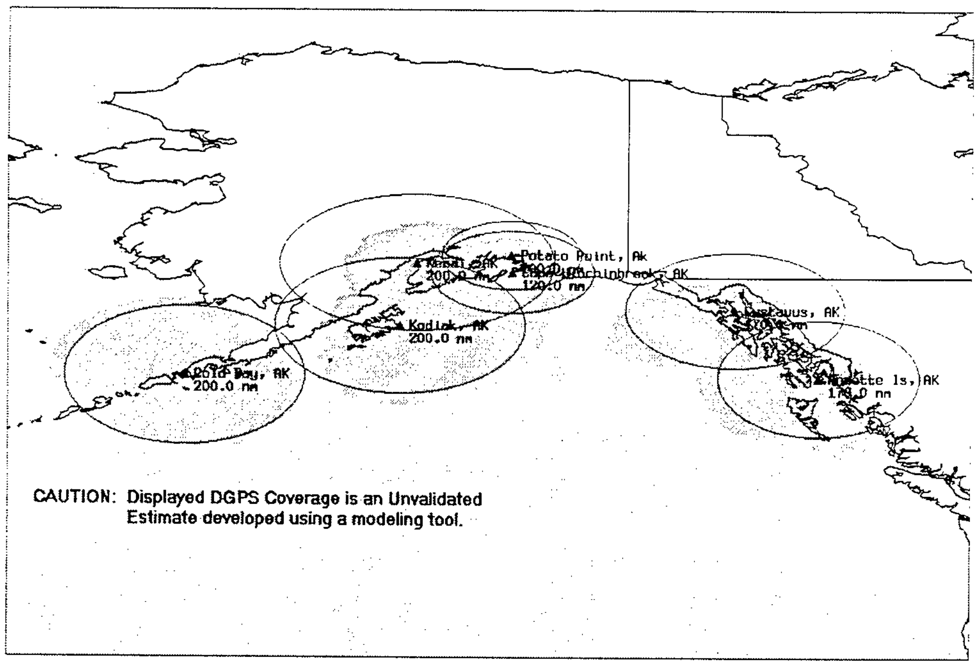


Figure A.1 Alaska Area DGPS Coverage

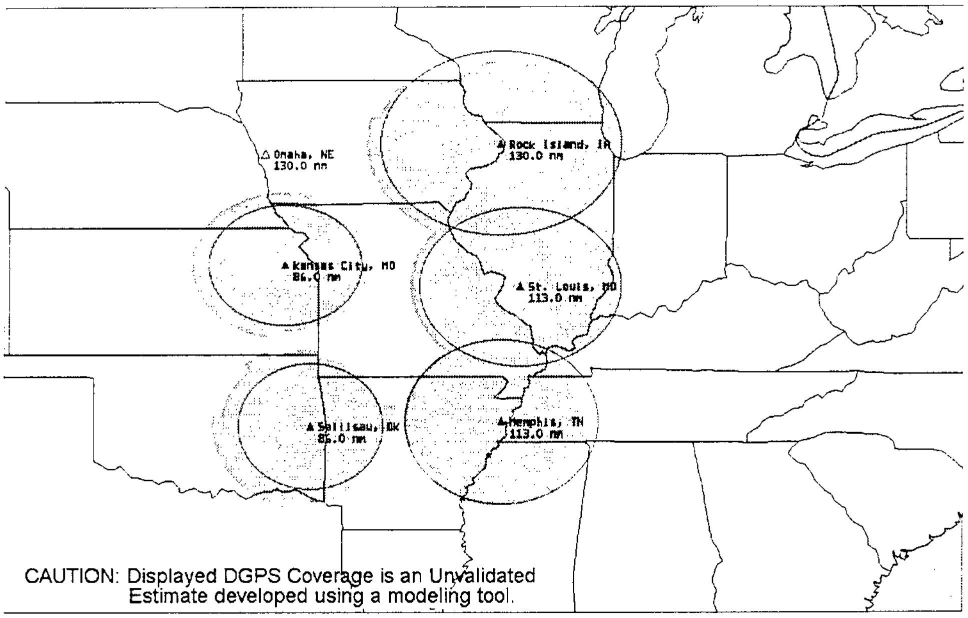


Figure A.2 Central States Area DGPS Coverage

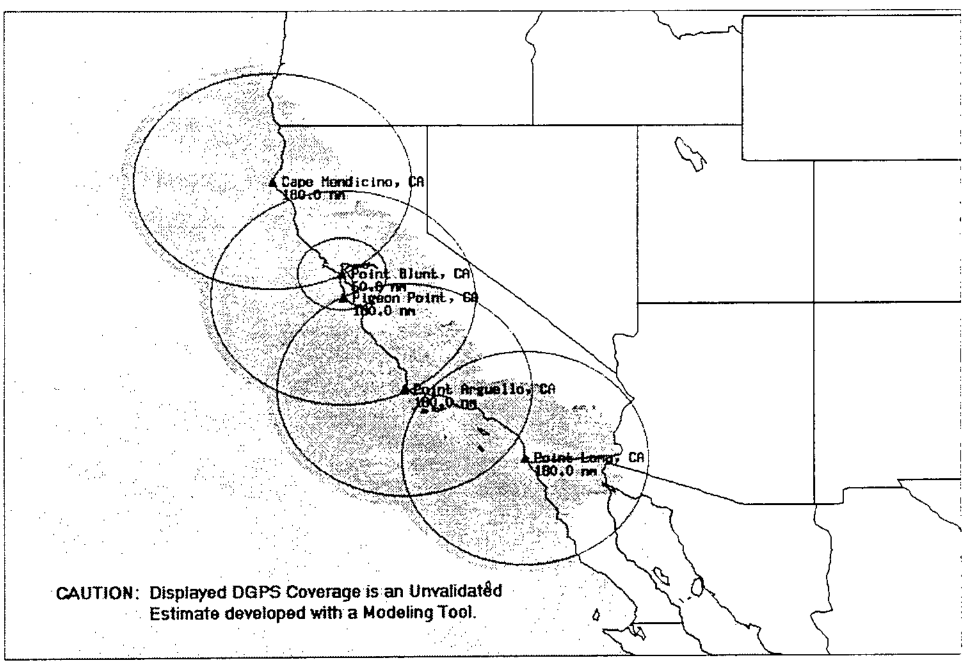


Figure A.3 California Area DGPS Coverage

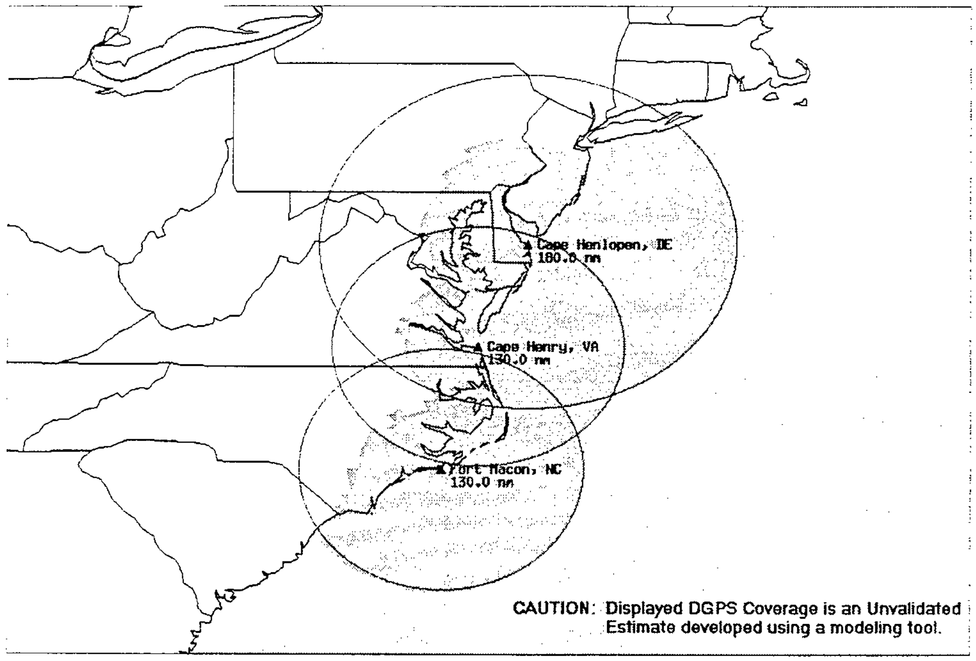


Figure A.4 East Coast Area DGPS Coverage

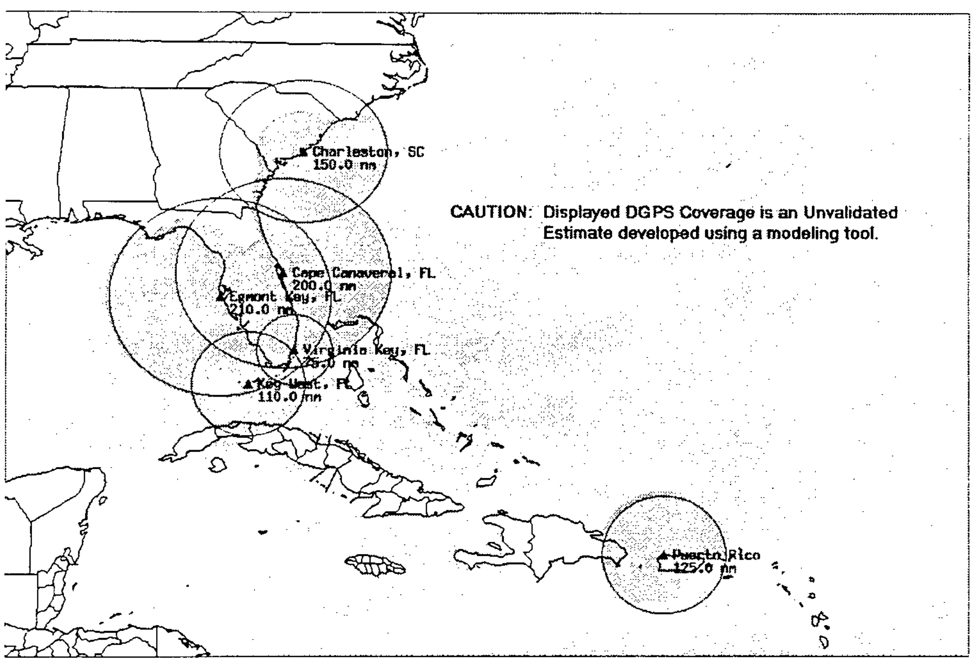


Figure A.5 Florida, South Carolina, and Puerto Rico Area DGPS Coverage

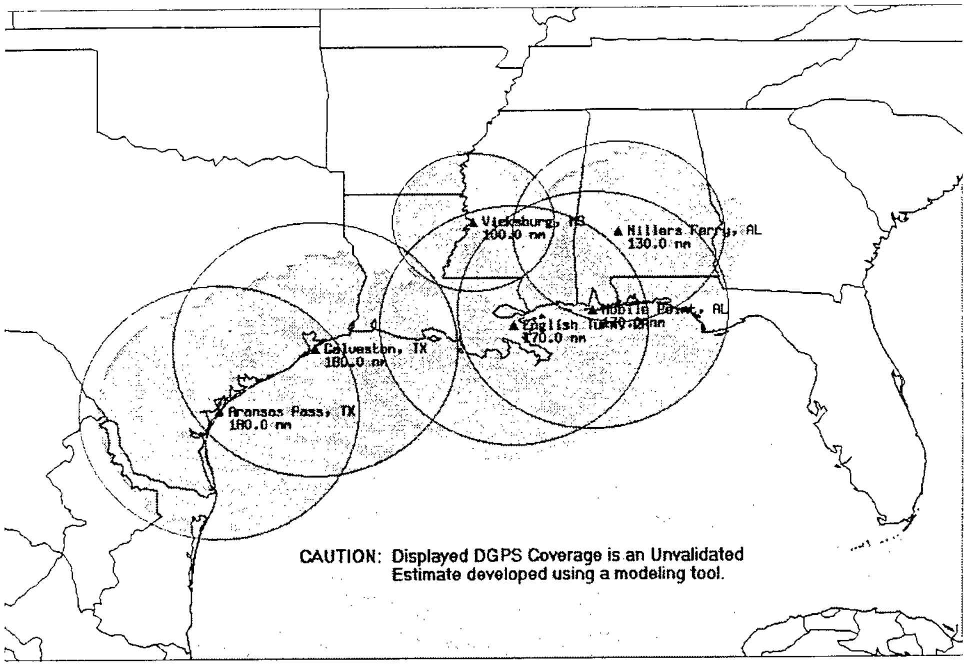


Figure A.6 Gulf Coast Area DGPS Coverage

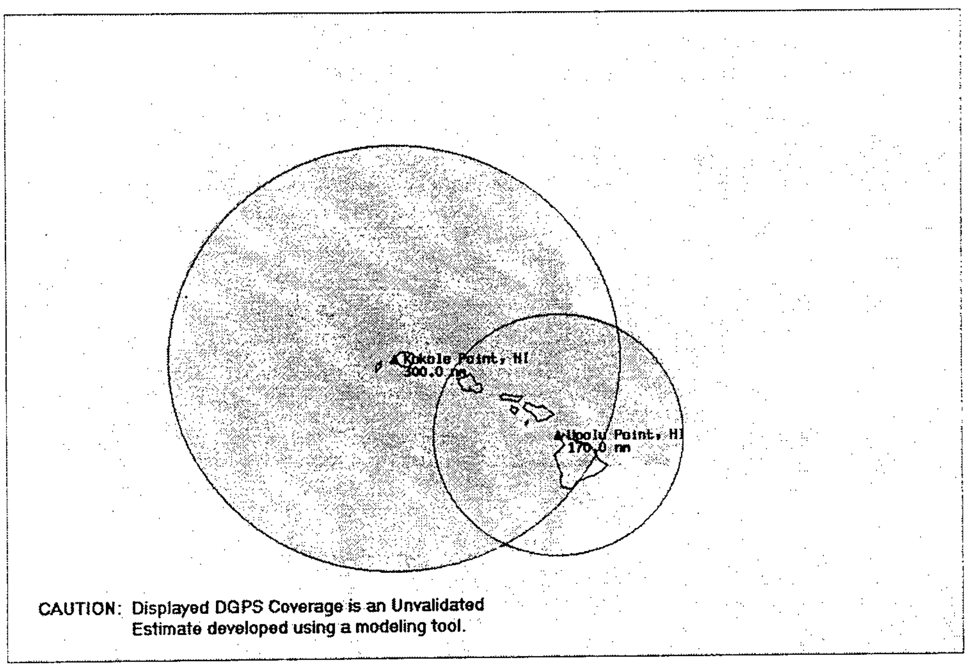


Figure A.7 Hawaii Area DPGS Coverage

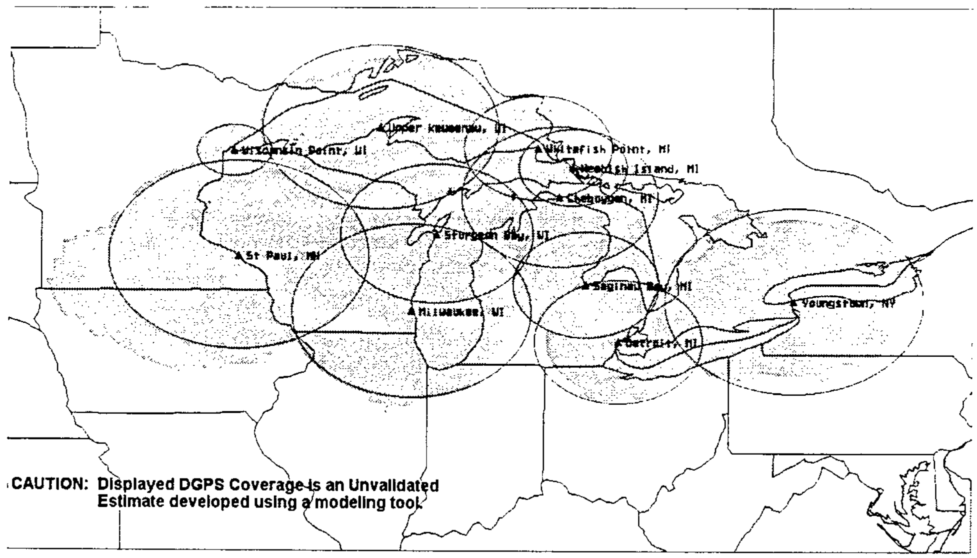


Figure A.8 New York, Midwest Area DPGS Coverage

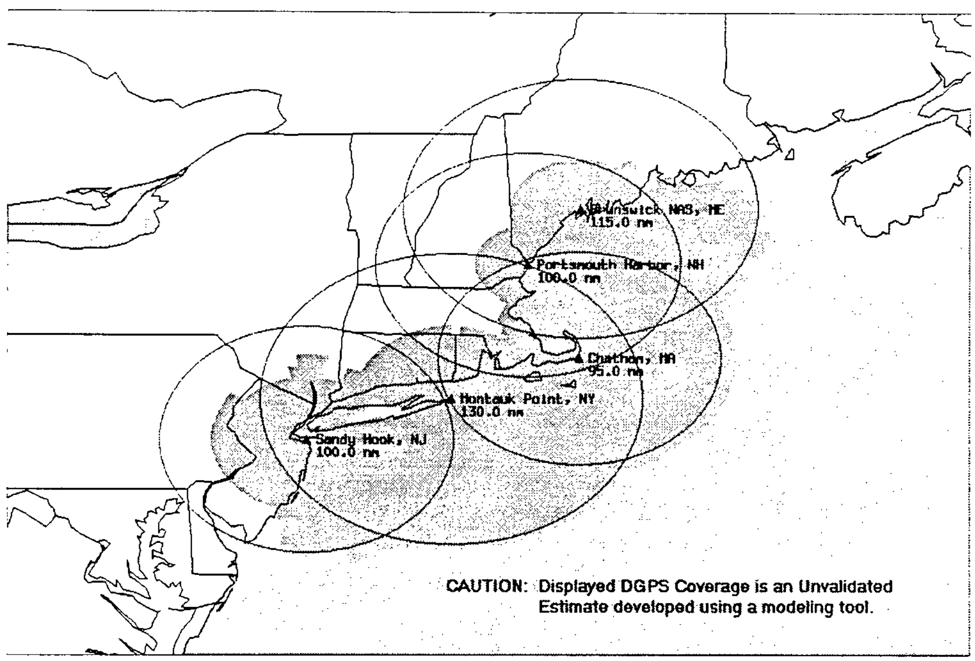


Figure A.9 Northeast Coast Area DPGS Coverage

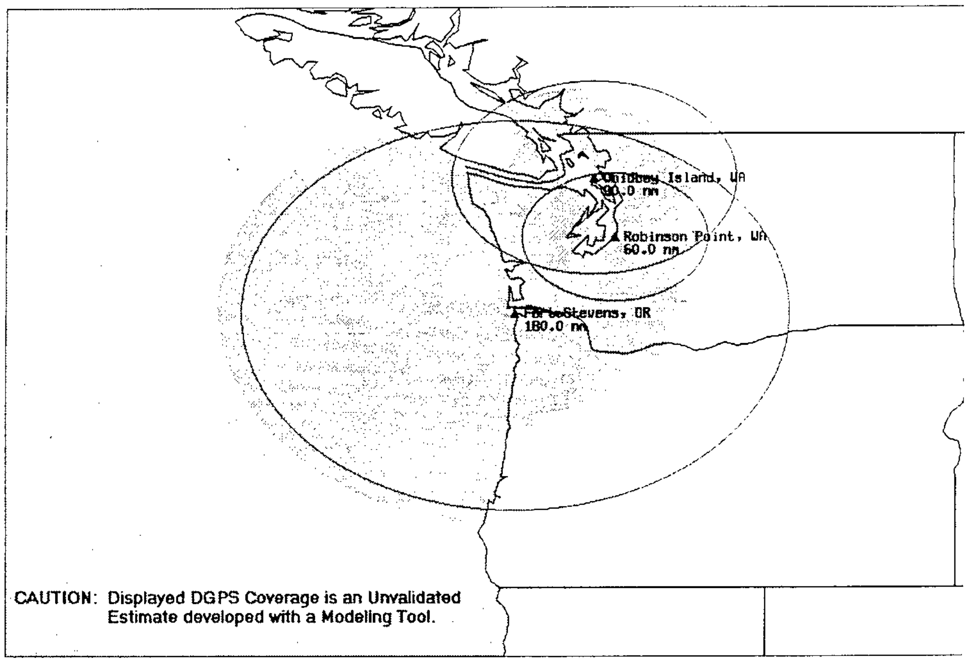


Figure A.10 Northwest Coast Area DGPS Coverage

APPENDIX B. SURVEY FORM

Planning for Advanced Vehicle Location System Implementation
Questionnaire

Agency ____________________
Department/Division ____________________
Name ____________________ Title ____________________
Phone ____________________ Fax ____________________
E-mail ____________________

Please send us your business card when returning the survey. Otherwise, please give your address: ____________________

1. Which of the following best describes the AVL implementation stage in your agency?
   - not being considered _____
   - proposed within the agency _____
   - preliminary study in progress _____
   - Request for Proposal in progress _____
   - in bidding process _____
   - operation to begin soon _____
   - in operation for less than 1 year _____
     - less than 2 years _____
     - 2 years or more _____

2. If your agency is not planning an AVL implementation, please specify the reason(s) (check all that apply):
   We have not considered it _____
   We may consider it in the future _____
   We have considered it but decided not to implement it because
   - it is too costly _____
   - there is no funding for such a project _____
   - it will bring extra cost burden _____
   - we do not have the necessary technical personnel to operate/maintain it _____
   - we do not see significant benefits for us _____
   - we do not have enough information to judge at this time _____
   - other (please specify) ____________________

3. Do you feel a document such as "AVL Planning Guide" would be (or would have been) helpful to your agency? Yes________ No___________

If your agency is not currently considering an AVL implementation, STOP here and return the survey. Thank you. Otherwise, please continue.

4. What AVL technology is being considered/used?
   - signpost _____ GPS ____
   - LORAN/C _____ Differential GPS ____
   - dead-reckoning _____ other (please specify) ______________________
   - combination of technologies (please specify) ___________________________

5. Please answer the following questions regarding some important dates:

   5a) When was AVL first considered within the agency? Year 19__ Month ______

   5b) Approximate date of RFP publication: Year 19____ Month _____

   5c) Approximate date of contract(s) award: Year 19____ Month _____

   5d) Approximate acceptance date for the AVL system: Year 19____ Month _____

   5e) Approximate start-up date for the AVL system: Year 19____ Month_____

6. Was the *Generic Bid Document Package* (published by the Ministry of Transportation of Ontario, Canada) used as a model or reference when developing your own RFP?
   Yes _____ No _____

7. Did you gather or are you gathering other transit agencies' experiences in AVL implementation? Yes ______ No ______

   7a) If yes, approximately how many transit agencies did you contact? __________

   7b) If yes, did you use their RFPs as the basis for developing your own?
   Yes ______ No _______

8. Please identify the major reasons why your agency implemented/is implementing AVL. Please rate their importance:

	most important	important	not important	not considered
Improving schedule adherence	____	____	____	____
Improving emergency responses	____	____	____	____
Providing real-time travel information	____	____	____	____
Integrating schedules of different modes	____	____	____	____
Obtaining better data for scheduling	____	____	____	____
Obtaining better data for service planning	____	____	____	____
Improve personnel management	____	____	____	____
As part of radio system upgrade	____	____	____	____
Other (please specify) ____________	____	____	____	____
____________________	____	____	____	____
____________________	____	____	____	____

9. Which of the following departments/divisions within your agency were/are involved in the process of developing the plans and specifications? Please characterize their involvement:

	heavily involved	somewhat involved	not involved	not sure
transit long term planning	____	____	____	____
service planning and scheduling	____	____	____	____
bus operations	____	____	____	____
bus maintenance	____	____	____	____
transit police	____	____	____	____
city/county police	____	____	____	____
city/county fire department	____	____	____	____
ambulance service	____	____	____	____
911	____	____	____	____
public works department	____	____	____	____
city traffic department	____	____	____	____
other (please specify)				
____________________	____	____	____	____
____________________	____	____	____	____

10. Identify the department/division responsible for developing the Request For Proposal (RFP):

	heavily involved	somewhat involved	not involved	not sure
transit long term planning	____	____	____	____
service planning and scheduling	____	____	____	____

bus operations	____	____	____	____
bus maintenance	____	____	____	____
communications	____	____	____	____
transit police	____	____	____	____
city/county police	____	____	____	____
city/county fire department	____	____	____	____
911	____	____	____	____
ambulance	____	____	____	____
public works department	____	____	____	____
outside consultant(s)	____	____	____	____
other	____	____	____	____
____________	____	____	____	____

12. Are you the person that we should contact if we have a question on the RFP?
    Yes ______ No ______

    12a) If the answer is No, please provide the name and phone number of a contact person:
    Name ______________________ Phone ______________

13. How many vendors responded to the RFP? ___________

14. Indicate duration of contract execution, from contract award to system acceptance:
    _______ months

15. Will employee's performance be evaluated using AVL-collected data?
    Yes_____ No_____ Plan to use in the future______

    15a) If yes, have there been objections from the union? Yes______ No______

16. Total cost of the AVL installation:
    estimated cost $__________ final cost $______________

17. Funding sources (please indicate amount or percentage):
    federal _________ state _________ local __________

18. Have your transit agency goals in regards to the AVL implementation changed after the use of AVL technology?
    Yes__________ No__________

19. Training of personnel as required by AVL

	Control Center	Supervisor	Bus Operator
length of time required for training	______	______	______
methods (individual, group, etc)	______	______	______
length of time required to become proficient in their tasks	______	______	______

20. What are your immediate plans for expanding AVL benefits (things you are committed to in the near future)?

automatic passenger counting ______ real-time travel information ______
modal integration ______ timed-transfer ______
signal preemption ______ electronic fare box ______

21. Has the use of AVL resulted in changes in services and operations such as (check all that apply):

routes ______ scheduling ______
bus stops ______ worker schedules ______
personnel ______ other (please specify) ______

22. The radio tower(s)

exist before AVL implementation ______ none existed ______
More needed to be added ______ needed to be upgraded ______

22a) If not, what was (will be) the cost of a new tower?
Total cost $ ______ Number of towers ______

23. What is the estimated annual maintenance cost of the AVL system? $ ______

24. If AVL has been in operation in your agency, has there been an operational test conducted under the FTA's guidelines? Yes ______ No ______

25. If AVL has been in operation in your agency, but you are not an FTA operations test site, did you conduct your own analysis of the benefits generated from the AVL implementation?

Yes ______ No ______

26. What problems have you encountered? (check all that apply. Please explain if you like.)

hardware problems ______
software problems ______

position accuracy ____________________
AVL system reliability ____________________
cost overrun ____________________
not all of agency's responsibilities clearly defined in the contract ____________
not all of contractors responsibilities clearly defined in the contract ____________
too many change orders ____________________
other (please specify) ____________________

____

____

____

____

____

Thank you very much. Please return the survey to

Dr. Fang Zhao, Deputy Director
Lehman Center for Transportation Research
Department of Civil and Environmental Engineering
Florida International University
Miami, FL 33199

APPENDIX C. AVL VENDORS

Vendor	Location	Phone Fax e-mail Web site	Products	Transit Clients
II Morrow		(503) 391-3684 (503) 581-7205 Fax	LC	STS
3M Corp			GPS	The Vine Kitsap Transit
Acc-Q-Point	Torrance, CA	(310) 618-7076 (310) 618-7001 Fax	DGPS	
Andrew Corp	10500 W 153rd St. Orland Park, IL	800 255-1479 www.andrew.com	CPS	
Amtech			SO	OC Transpo
Auto Trac	Dallas, TX	(214) 480-8145 (214) 907-2292 Fax	GPS	COLTS
Bell Radio			SO	TTC
Differential Corrections	Cupertino, CA	(408) 446-8350 (408) 446-8383 Fax		
ElectroCom			GPS	DART
Etak		(415) 328-3825 Fax	Mapping DR	
F&M Global			SO	TRT
Gandalf		800-Gandalf www.gandalf.ca	GPS	PRTC STO
Gen. R'way Signal			SO	LAMTA, VIA
Glenayre		704-553-0038 704-553-0524 Fax imoore@atlanta.glenayre.com www.glenayre.com		
GMSI			GPS	WSTA
Harris Corp			GPS, SO	Metro KC Metro

Vendor	Location	Phone Fax e-mail Web site	Products	Clients
Highway Masters	Dallas, Tx	(214) 732-2500 (214) 250-0182 Fax		
LocUs		(608) 244-0500 Fax	Loran-C GPS	
Magnavox		(213) 618-7319	GPS, DR	
Marcor		(202) 408-0080	GPS	
Mets		(317) 573-2200 Fax	Mapping Loran-C GPS	
Motorolla		fleet@harris.com	SO	Muni, CoTran, Hartline, NJT, CDTA,BeeLine, Beever Cty TA
NDS		(504) 734-5566 Fax	Loran-C GPS	
Orbital Science			GPS	CTA, NYCTA, Tri-Met
QualComm	San Diego, CA	(619) 587 1121 (619) 587-8276 Fax		
Rockwell Int'l		800-854-8099 baudman@nb.rock well.com www.rockwell.com:80	GPS	SunTran
Siemens			SO	LTC
Teletrac	Fort Lauderdale, Fl	(305) 484-1300 (305) 486-2799 Fax		
Trimble		(408) 481-8000 (408)730-2997 Fax www.trimble.com	GPS	Ourtreach, MCTS
TMS			GPS	SMART, MTC, MCTS, METRO (Houston)
UMA			GPS	Outreach

Source: (Casey et al. 1996), miscellaneous. Notes: SO=Signpost-Odometer, LC=Loran-C, GPS=Global Positioning System, DR=Dead Reckoning, CPS=Continuous Positioning System

Automatic Passenger Counter Vendors:

- Crayfield Digital
- Microtronics
- Red Pine
- Pachena
- Urban Transportation Associates
- Wardrup

APPENDIX D. AVL SURVEY PARTICIPANTS

Transit Agency	Contact Person	Title	Phone Fax
City of Amarillo	Jeff Jenkins	Senior Trans. Director	(806) 378-9382 (806) 378-9388
Altoona Metro Transit, 3301 Fifth Avenue, Altoona, PA 16602	Philip L. Fry	General Manager	(814) 944-4074 (814) 941-2733
Antelope Valley Transit Authority, 1031 West Avenue L-12, Lancaster, CA	Bill Budlung	Executive Director	(805) 726-2616 (805) 726-2615
City of Arlington, P.O. Box 231, Arlington, TX 76004-0231	Wilma J. Smith	Assistant Director	(817) 459-6350 (817) 459-6379
Eua Claire Transit System (ECT), 910 Forest Street, Eua Calire, WI 54703	An Gullickson	Transit Manager	(305) 348-2802 (715) 839-1693
CT Transit, 100 Leibert Road / P.O. Box 66, Hartford, CT 06141-0066	David Lee	General Manager	
City of Greeley, Colorado 1200 A Street, Greeley, Co 80631	William A. Stetzling	Director of Public Works	(970)350-9795 (970)350-9736
Regional Transportation Commission, P.O. Box 30002, 2050 Villanova Drive Reno, Nevada 89520	Celia G. Kupersmith	Executive Director	(702)348-0400 (702)324-3503
Eric Metropolitan Transit Authority, P.O. Box 2057, 127 East Fourteen St., Eric, PA 16512	Donald R. Harmon	General Manager	(814) 459-4287 (814) 456-9032
Santa Cruz Metro. Transit District, 230 Walnut Ave., Santa Cruz, CA 95060	Sandi Evans	Administration Coordinator	(408) 426-6080 (408) 426-6117
Battle Creek Transit, 339 West Michigan Ave., Battle Creek, MI 49017	Jim Walker	Transit Manager	(616) 966-3588 (616) 966-3652
Waco Transit System, 421 Columbus Ave., Waco, TX 76701	Kirk Scott	General Manager	(817) 753-0113 (817) 753-8878
City of Rochester, Dept. of Public Works, 201 4th St. S.E., Rm. 108, Rochester, MN 55904-3740	Anthony J. Knauer	Transportation Planner	(507) 287-1976 (507) 281-6216
Knoxville Area Transit, 1135 Magnolia Ave., Knoxville, Tennessee 37917	George H. Chauvin	Director of Operations	(423) 546-3752 (423) 525-5240
Greater Portland Transit District, 114 Valley St., P.O. Box 1097, Portland, Maine 04104-1097	Sarah P. deDose	General Manager	(207) 774-0351

Transit Agency	Contact Person	Title	Phone Fax
Indianapolis Public Trans. Corporation, P.O. Box 2383, Indianapolis, IN 46206	Ted Rieck	General Manager	(317) 635-2100
Town of Chapel Hill, 306 North Columbia St., Chapel Hill, NC 27516	Robert J. Godding	Director of Transportation	(919) 968-2755 (919) 968-2840
Okaloosa Coordinated Trans., 207 Hospital Drive, Fort Walton Beach, FL 32548-5066	Kimberly A. Wesley	Executive Director	(904) 833-9165 (904) 833-9174
City of Petersburg, City Wally Annex, W. Tabb Street, Petersburgh, VA 23803	M. Guthrie Smith	Director	(804) 733-2353 (804) 732-2030
Saginaw Transit System Authority, 615 Johnson St., Saginaw, MI 48607	Sylvester Payne	Executive Director	
City of Wichita Falls, Public Works Trans. Dept, 533, 2100 Seymour Hwy, Wichita Falls, TX 76301	Robert E. Parker	Director of Traffic and Transportation	(817) 761-7640 (817) 761-8877
Merrimack Valley Regional Transit Authority, 85 Railroad Ave. Haverhill, MA 01835			
Lakeland Area Mass Transit District, 1212 George Jenkins Blvd., Lakeland, FL 33801	Steve Githens	Transit Director	(941) 688-7433 (941) 683-4132
Escambia County Area Transit, 1515 West Fairfield Drive, Pensacola, FL 32501	Ken Westbrook	Manager	(904) 436-9383 (904) 936-9847
Rockland Coaches Inc., 126 N. Washington Ave., P.O. Box 447, Bergenfield, NJ 07621	Jan M. Dan	Traffic Manager	(201) 384-2400
Mountain Line, 1221 Shakespeare, Missoula, MT 59802-2307	Michael E. Kress, AICP	Assistant General Manager	(406) 543-8386
Brunswick Transit Authority, City Hall, 4093 Center Road, Brunswick, Ohio	Robert A. Trimbler	City Manager	(330) 225-9144 (330) 273-8023
Worcester Regional Transit Authority, 287 Grove St., Worcester, MA 01605	Robert E. Ojala	Administrator	(508) 791-2389 (508) 752-1676

Transit Agency	Contact Person	Title	Phone Fax
Sioux Falls Transit , 500 East Sixth St., Sioux Falls, SD 57102-0404	Bruce Abel	General Manager	(605) 367-7108 (605) 367-4237
Green Bay Transit, 318 South Washington St., Green Bay, Wisconsin 54301	Gary Gretzinger	Transit Director	(414) 448-3451 (414) 448-3461
Lee County, 10715 E. Airport Rd., Fort Myers, FL 33907	Jim Fetzer	Transit Director	(813) 277-5012 (813) 277-5011
City of Moorhead, 500 Center Ave., Box 779, Moorhead, Minnesota 56561	Lori Van Beek	Transit Manager	(218) 299-5370
City of Fairfield, 1000 Webster St., Fairfield, CA 94533	Kevyn S. Daughton	Trans. Manager	(707) 428-7590
PATransit, Port Authority of Alleqhery County, South Hills Village Rail Center, 1000 Village Rail Drive Center, Pittsburgh PA 15241	William A. Wacko	Manager Electronic System	(412) 854-7359 (412) 854-9086
City of Port Arthur, PO Box 1089 Port Arthur, Texas 77641-108	Josephine Harris	Assistant	(409) 983-8767 (409) 983-8609
City of Hickory, PO Box 398, Hickory, NC 28603	Michael Bradshaw	Transit Manager	(704) 464-9444 (704) 323-7550
Chemung County Transit System, 1201 Clemens Center Parkway, Elmira, N.Y. 14901	Tina Carr	Transit Specialist	(607) 734-5212 (607) 734-5207
Albany Transit System, P.O. Box 447, Albany, NY	Kerwin Terry	General Manager	(912) 430-5182 (912) 430-5160
City Transit Management Company, Inc., PO Box 2000, 801 Texas Ave., Lubbock, TX 79457	John L. Wilson	General Manager	(806)767-2380 (806)767-2387
City of Pine Bluff, Office of The Mayor, 200 East 8th Ave, Pine Bluff, Arkansas 71601	Jeff Hawkins	Director of Planning	(501) 543-1890 (501) 543-5198
City of Lincoln, 710 J Street, Lincoln, NE 68508-2938	Dennis H. Johnk	Transit Planner	(402) 441-7673 (402) 441-7055
The City of Wichita, 1825 South McLean Boulevard, Wichita, Kansas 67213-4197	Michael P. Melaniphy	General Manager	(316) 265-1450 (316) 337-9287

Transit Agency	Contact Person	Title	Phone Fax
Palm Tran, Building S. 1440 P.B. I. A., West Palm Beach, FL 33406	Fred Stubbs	Transit Planner	(407) 233-1166 (407) 233-1140
Beloit Transit, 1225 Willowbrook Road, Beloit, Wisconsin 53511	Robert C. Spenle	Transit Manager	(608) 364-2870 (608) 364-2871
City of Lake Charles, Office of the Mayor, P.O. Box 900, Lake Charles, LA 70602-0900	Ernest Broussard	Director of Planning	(318) 491-1440 (318) 491-1437
The City of Kalamazoo, 241 West South Street, Kalamazoo, Michigan 49007-4796	Jeanne A. Doonan	Senior Human Resources Officer	(616) 337-8052
Broome County Department of Public Trans., 413 Old Mill Road, Vestal, New York 13850	Gary J. Crandell	Commissioner	(607) 763-4464 (607) 763-4468
Mid Ohio Valley Transit Authority, 213 First St., Parkersburg, WV 26101	Joe Luckhart	Manager	(304) 422-4100 (304) 422-3200
Memphis Area Transit Authority, 1370 Levee RD, Memphis , TN 38108-1011	Maury Miles	Contracting Officer	(901) 722-7118 (901) 722-7123
City of Santa Maria, 705 W. Cypress Street, Santa Maria, CL 93454-5060	Debra Larson	Associate Civil Engineer	(805) 925-0951 (805) 928-4995
Housatonic Area Regional Transit, 107 Newton Rd, Suite 2e, Danburg, CT 06810	Richard Schreiner	Director Service Deptt.	(203) 744-4070 (203) 744-0764
Metra Columbus Transit System, PO Box 1340, Columbus, GA 31902-1340	Lisa Goodwin	Assistant Director	(706) 571-4883 (706) 571-5866
City of Jackson Transportation Authority, 2350 E. High St., Jackson, MI 49203	Gorden L. Szlachetka	General Manager	(517) 787-8363 (517) 787-6833
Golden Empire Transit District, 1830 Golden State Ave., Bakersfield, CA 93301-1012	Chester C. Moland	Assistant G. Manager	(805) 324-9874 (805) 324-7849
Fairfax County Office of Transportation, 12055 Government Center Parkway, Suite 1034, 10th Floor, Fairfax, Virgina 22035-5511	Andy Szakos	Chief, Transit Operations	(703) 324-1194 (703) 324-1450
Community Transit, York County Transportation Authority, 1230 Roosevelt Ave., York PA 17404	Stephen G. Bland	Executive Director	(717) 846-5562 (717) 848-4853

Transit Agency	Contact Person	Title	Phone Fax
City of Jackson, 200 South President St., Suite 106, P.O. Box 17, Jackson, Mississippi 39205-0017	John W. Cook	City Administrator	(601) 960-2314 (601) 960-2210
City Utilities of Springfields, 301 East Central, P.O. Box 551, Springfield, Missouri 63801-0551	Cliff Groover	Senior Manager Finance	(417) 831-8633 (417) 831-8908
Miami Valley Regional Transit Authority, 600 Longworth St., P.O. Box 1301, Dayton, Ohio 45401	Keith A. Sims	Senior Executive Engineer	(513) 443-3034 (513) 463-5770
Intercity Transit, 526 Pattison, S.E., P.O. Box 659, Olympia, WA 48507	Steean Marks	Planning Manager	(360) 705-5833 (360) 357-6184
Bettendorf Transit System, 4403 Devils Glen Road, Bettendorf, Iowa 52722	Grrald F. Springer	Director of Operations	(319) 344-4088 (319) 344-4101
Delaware Transit Corporation, P.O. Box 1670, 1 South Monroe St., Wilmington, DE 19899	John M. Anderson	Assistant Director of Operations	(302) 658-8960
Washington Metropolatin Area Transit Authority, 600 Fifth Ave, NW Washington, DC 20001	Robert L. Polk	General Manager	(202) 962-1000 (202) 962-1133
Council on Aging of St. Lucie, Inc, 1505 Orange Ave., Fort Pierce, FL 34950	Patricia A. Scarlet	Executive Director	(407) 465-5220
Sarasota County Area Transit, 5303 Pinkney Ave., Sarasota, FL 34233	Bruce McQuade	Transit Planner	(941) 316-1007 (941) 316-1238
City of Winston-Saleem Transportation, P.O. Box 2511, Winston-Saleem, N.C. 27102	Suzanne B. Tellechea	Transit Planner	(910) 727-2648
Louisiana Transit Company Inc., 8265 Jefferson Highway, P.O. Box 23247 Harahan, Louisiana 70183-0247	Michael J. Seither	Operation Manager	(504) 737-9611 (504) 737-4589
Red Rose Transit Authority, 45 Erick Road Lancaster, PA 17601	Scott A. Gibson	Director of Developme	(717) 397-5613 (717) 397-4761
Metro. of Black Hawk County, 1515 Black Hawk Street, Waterloo, Iowa 50702	Walter Stephenson	General Manager	(319) 234-5714

Transit Agency	Contact Person	Title	Phone Fax
Central Area Transportation Authority, 2081 W. Whitehall Road, State College, PA	Hugh A. Mose	General Manager	(814) 238-0625 (814) 238-7643
Votran, 950 Big Tree Road, South Daytona, FL 32119	Becky Weedo	Transit Manager	(904) 756-7496 (904) 756-7487
Cape Cod Regional Transit Authority, 585 Main Street, Old Dennis Court, P.O. Box 2006, Dennis, MA 02638	Joseph G. Pokzta, Jr.	Administrator	(508) 385-8311 (508) 385-1812
Berkshire Regional Transit Authority, 67 Downing Parkway, Downing Industrial Park, Pittsfield, MA 01201	Dianne M. Smith, C.C.T.M	Administrator	(413) 499-2782 (413) 442-2536
Lond Island Bus, 700 Commercial Ave. Garden City, NY 11530-6434	John A. Gariti	Project Coordinator	(516) 542-0100 (516) 542-1428
San Diego Transit, 100 16th Street, P.O. Box 2511, San Diego, CA	Richard A. Murphy	Vice President	(619) 238-0100 (619) 696-8159
Golden Gate Bridge, Highway and Transportation District, San Francisco, CA	Jerome M. Kuykendal	Planning Director	
Ben Franklin Transit, 1000 Columbia Dr. S.E., Richland, Washington 99352	Linda Upton	Procurement Supervis	(509) 735-4131 (509) 735-1800
Mass Transportation Authority, 1401 South Dort Highway, Flint, MI 48503	Robert J. Foy	General Manager	(810) 767-6950 (801) 767-6580
NJ Transit, NJ Transit Headquaters, One Penn Plaza East, Newark, NJ 07105-2246	James W. Kemp	Principal Planner	(201) 491-7861 (201) 491-7837
Beaver County Transit Authority, 200 W. Washington St. Rochester, PA 15074	Bruce W. Ahern	General Manager	(412) 728-4255 (412) 728-8333
Riverside Transit Agency, 1825 Third St. P.O. Box 59968, Riverside, CA 92517-1968	Stephen C. Oiler	Superintendent	(909) 684-0850 (909) 684-1007
City of Napa, Public Works, 1600 first street, P.O. Box 660, Napa, CA 94559-0660	Celinda Dahlgren	Transportation Program Manager	(707) 257-9520 (707) 257-9522

Transit Agency	Contact Person	Title	Phone Fax
Sun Tran, 601 Yale S.E. , Albuquerque, NM 87106	Linda A. Dowling	Manager	(505) 764-6154 (505) 764-6146
Transit Authority of Lexington, Kentucky, 109 West Loudon Ave., Lexington, Kentucky 40508	Stephen D. Rowland	General Manager	(606) 255-7756 (606) 233-9446
Chicago Transit Authority, 120 N. Racine, Chicago, IL 60607	Ronald J. Baker	General Manager	(312) 432-8001 (312) 432-8010
Chattanoga Area Regional Transportation Authority, 1617 Wilcox Boulevard, Chattanooga, Tennessee 37406	Art Barnes	Assistant Executive Director	(423) 629-1411 (423) 698-2749
Spartanburg County Planning Department, 366 North Church St., SC 29303	Gerald Poss	Senior Planner	(864) 596-3570 (864) 596-3018
Access Service Inc., 725 S. Figueroa Street, Los Angeles, CA 90017	Kevin Chen	Planning Manager	(213) 270-6011 (213) 270-6058
The Greater Cleveland Regional Transit Authority, 615 Superior Ave., W. Cleveland, Ohio 44113-1878	Michael C. York	Director of Planning	(216) 586-5101 (216) 781-4726
County of Lackawanna Transit System (COLTS), North South Road, Scranton, PA 18504	Kurt Kempter	Director of Development	(717) 343-1720
Mass Transit Administration, William Donald Schaefer Tower, 6 St. Paul St., Baltimore, Maryland 21202-1614	David L. Hill	Senior Systems Engineer	(410) 767-3316 (410) 333-4810
Pace, 550 West Algonquin Road, Arlington Heigtts, Illinois 60005-4412	William J. Reynolds	Department Manager	(847) 228-4296
Metro/Soiuthwest Ohio Regional Transit Authority (SORTA)	Gregory Lind	Manager	(513) 632-7571 (513) 621-1580
Valley Transit, 801 Whitman Avenue, Appleton, WI 54914	Thad Kluck	Operations Supervisor	(414) 832-6100 (414) 832-1631
Texoma Council of Governments, 3201 Texoma Parkway, Suite 240, Sherman, TX 75090	Robert Wood	Trans. Director	(903) 813-3534 (903) 813-3539

Transit Agency	Contact Person	Title	Phone Fax
Massachusetts Bay Transportation Authority, 10 Park Plaza, Boston, MA 02116	Lasana Kamau	Manager Service Planning	(617) 222-5753 (617) 222-3776
Five Seasons Transportation Parking, 427 8th Street N.W., Ceder Rapids, Iowa 52405	William Hoekstra	Dir. Trans. & Parking	(319) 398-5367 (319) 398-5393
Regional Public Trans. Authority, 302 N. First Ave., Suite 700, Phoenix, AZ 85003	Jim Dickey	Director of Operation	(602) 495-0585 (602) 495-0411
Poineer Valley Transit Authority (PVTA), 2808 Main St. Springfield, MA 01107	Sandra E. Sheehan	Assistant Administrator	(413) 732-6248 (413) 737-2954
Springs Transit Management Inc., 1210 South Hancook Expressway, Colorado Springs, CO 80903	Larry Tenenhoiz	Administrator Analyst	(719) 635-1500 (719) 575-0430
City of Tucson- SunTran, County City Public Works Bldg. 201 N. Stone, 6th Floor, Tucson, AZ 85726-7210	Jill L. Merrick	Principal Planner	(520) 791-4371 (520) 791-4608
Metrobus, St. Cloud Metropolitan Transit Commission, Waite Park, Sauk Rapids, St. Cloud, Minnesota, 665 Franklin Ave. N.E., St, Cloud, MN 56304	Thomas Cruikshank	Transit Planner	(612) 251-1499
Sacramento Regional Transit District, 1400 29th Street, P.O. Box 2110, Sacramentio, CA 95812-2110	Anthoney J. Palmere	Planning Manager	(916) 321-2866 (916) 454-6016
Livermore/Amador Valley Transit Authority, 1362 Rutan Court, Suite 100, Livermore, CA 94550	Austin O' Dell	Planning Manager	(510) 455-7559 (510) 443-1375
Bay Area Rapid Transit District (BART), 800 Madison St. PO Box. 12688, Oakland, CA 94604-2688	Gene Nishinaza	Manager	(510) 869-2415 (510) 289-4751
AC Transit, 10626 E14th Street, Oakland, CA 94603	Patrick J. Cannon	Manager of Maintenance	(510) 577-8871 (510) 577-8859

Transit Agency	Contact Person	Title	Phone Fax
Capital District Transportation Authority, 110 Watervliet Avenue, Albany, NY 12206	Charles Cohen	Director of Transportation	(518) 482-9191 (518) 482-9035
City of Los Angles, Department of Transportation	Colenne Ralph		(213) 580-5437 (213) 580-5458
Central Ohio Transit Authority (COTA), 1600 McKinley Avenue, Columbus, OH 43222	Patrice L. Ware	Senior Director of Operations	(614) 275-5804 (614) 275-5933
Southeastern Pennsylvania Transportation Authority, 1234 Market St., Philadephia, PA 19107-3780	Patrick A. Nowakowski, P.E.	Assistant General Manager	(215) 580-8280 (215) 580-8282
City of Fort Collins, Transportation Planning, 210 E. Olive, Fort Collins, CO 80524	John Daggett	Trans. Planner	(970) 224-6190 (970) 221-6239
Laketran, P.O. Box 158, Grand River, Ohio 44045-0158	Dale Madison	Director of Development	(216) 350-1000 (216) 354-4202
State of Conniecticut Dept., of Transportation, 2800 Berlin Turnpike, Newington, CT 06131-7546	Michael A. Sanders	Transit & Ridehare Administrator	(860) 594-2829 (860) 594-2848
City of Santa Monica, Transportation Department, 1660 Seventh Street, Santa Monica, CA 90401-3324	Robert L. Ayer	Assistant Director of Transportation	(310) 458-1975 (310) 451-3163
Greater Richmond Transit Company, 101 South Davis Ave., Richmond Virginia, P.O. Box 27323. Richmond Virginia 23261	Rollo C. Axton	General Manager	(804) 358-3871 (804) 342-1933
London Transit Commission	Bill Brock	Manager Trans.	(591) 451-1340 (591) 451-4411
City of Santa Maria, 705 West Cypress Street, snata Maria, CA 93454-5060	Debra L. Larson	Associate	(805) 925-0951 (805) 928-4995
LYNX, Central Florida Regional Transportation Authority, 225 E. Robinsons St. Suite 300, Orlando, FL 32801	Ann Joslin	Mobility Assistant Manager	(407) 841-2279 (407) 245-0327

City of Fresno, 2223 "G" Street, Fresno, CA 93706	Seng Tang	Customer Services Clerk II	(209) 498-1419 (305) 348-2802
Massachusetts Bay Transportation Authority, 10 Park Plaza, Boston, MA 02116	Lasana Kamau	Manager, Service Planning	(617) 222-5753 (617) 222-3776
TalTran, 555 Appleyard Drive, Tallahassee Florida 32304	William S. Carter	Administrater	(904) 891-5367 (904) 891-5385
Cooperative Alliance for Seacoast Transportation (COAST), Transp. Bldg. Univ. of New Hampshire, Durham, NH 03824	Joe R. Follansbee	Executive Director	(603) 862-1931
Regional Transportation District, 1900 31st St., Denver, CO 80216-4909	Lou Ha	Manager	(303) 299-6265 (303) 299-6060
Northwest Louisiana Council of Governments, 509 Market St., Suite 1000 Shreveport, LA 71101	Wayne Gaither	Transit Planner	(318) 673-5950 (318) 673-5952
Metropolitan Bus Authority, P.O. Box 195349, San Juan, PR 00919-5349	Hector R. Rivera	President	(809) 767-0115 (809) 751-0527
New Orleans Regional Transit Authority, 6700 Plaza Dr., New Orleans, LA 70127	Valeria Moten	Transit Planner	(504) 248-3723 (504) 248-3872

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161 (703) 487-4650