TCRP Synthesis 24

AVL Systems for Bus Transit

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TRANSIT COOPERATIVE RESEARCH PROGRAM

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The Federal Transit Administration

TCRP Synthesis 24

AVL Systems for Bus Transit

A Synthesis of Transit Practice

Transportation Research Board
National Research Council

TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental. and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in TRB ***Special Report 213-Research for Public Transit: New Directions,*** published in 1987 and based on a study sponsored by the Federal Transit Administration (FTA). A report by the American Public Transit Association (APTA), ***Transportation 2000,*** also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program. undertakes research and other technical activities in response to the needs of transit service providers. The scope of vice configuration, equipment. facilities, operations, human resources. maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academy of Sciences, acting through the Transportation Research Board (TRB), and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at anytime. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected. each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end-users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. TCRP results support and complement other ongoing transit research and training programs.

TCRP SYNTHESIS 24

Project J-7, Topic SA-04
ISSN 1073-4880
ISBN O-309-06018-4
Library of Congress Catalog Card No. 97-67059

Price $16.00

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The project that is the subject of this report was a part of the Transit Cooperative Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the project concerned is appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the Transit Development Corporation, the National Research Council, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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TRANSIT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

and can be ordered through the Internet at:

http://www.nas.edu/trb/index.html

Printed in the United States of America

PREFACE

A vast storehouse of information exists on many subjects of concern to the transit industry. This information has resulted from research and from the successful application of solutions to problems by individuals or organizations. There is a continuing need to provide a systematic means for compiling this information and making it available to the entire transit community in a usable format. The Transit Cooperative Research Program includes a synthesis series designed to search for and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in subject areas of concern to the transit industry.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By *Staff Transportation Research Board*

This synthesis will be of interest to transit agency general managers, bus operations, planning, scheduling, safety, and procurement staffs, as well as agency communications and engineering staffs. It addresses various aspects of developing and deploying automated vehicle location (AVL) systems over the last 20 years. Current practice; AVL architecture and technologies; and the institutional context of AVL defined in terms of funding, justification, staffing, and procurement are discussed.

Administrators, practitioners, and researchers are continualIy faced with issues or problems on which there is much information, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered or not readily available in the literature, and, as a consequence, in seeking solutions, full information on what has been learned about an issue or problem is not assembled. Costly research findings may go unused valuable experience may be overlooked and full consideration may not be given to the available methods of solving or alleviating the issue or problem. In an effort to correct this situation, the Transit Cooperative Research Program (TCRP) Synthesis Project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common transit issues and problems and synthesizing available information. The synthesis reports from this endeavor constitute a TCRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to a specific problem or closely related issues.

This report of the Transportation Research Board reports on the different approaches to AVL deployment used at selected transit agencies. It attempts to define the role of AVL for bus transit by examining objectives of implementation and both technological and operational frameworks.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, available information was assembled from numerous sources, including a number of public transportation agencies. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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ACKNOWLEDGMENTS

Paula E. Okunieff, Senior Associate. Cambridge Systematics,Inc.. Cambridge, Massachusetts, was responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Bruce W. Ahem, General Manager, Beaver County Transit Authority, Rochester, Pennsylvania; D.W. (Bill) Dearasaugh Engineer of Design, Transportation Research Board; William D. Evans, Director, Evaluation and Development, Rochester-Genesee Regional Transportation Authority, Rochester, New York; Harold Ewen, Ph.D., Vice President, Special Projects, Millitech Corporation, South Deerfield. Massachusetts; William Hiller, Manager, Information Systems, Ann Arbor Transportation Authority; Bill J. Kronenberger Manager, Advanced Technology Program, Metropolitan Transit Authority of Harris County, Texas; Maurice J. Moroney, Chief, Center for Navigation, Volpe National Transportation Center: David Olson, Director of Transportation, Kansas City Area Transportation Authority; and Denis J. Stymes, Transportation Management Specialist, Federal Transit Administration.

This study was managed by Donna L. Vlasak, Senior Program Officer, who worked with the consultants, the topic panel, and the J-7 project committee in the development and review of the report. Assistance in topic panel selection and project scope development was provided by Sally D. Liff, Senior Program Officer, Linda S. Mason was responsible for editing and production. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

Information on current practice was provided by many transit agencies. Their cooperation and assistance were most helpful.

AVL SYSTEMS FOR BUS TRANSIT

SUMMARY

In response to the need to enhance public transportation, transit agencies are turning to advanced technologies to improve the safety, efficiency, and quality of their services. One such technology is an automated vehicle monitoring (AVM) system that tracks transit vehicles against their designated route schedule. The core technology of this system is the automated vehicle location (AVL) system, which is an automated means of tracking vehicle location.

AVL is contained in broader topics when integrated with systems such as

- Automatic vehicle monitoring/control (AVM/C),
- Emergency location of vehicles,
- Fleet management, including vehicle performance monitoring and service control,
- Data collection,
- Customer information activities including compliance with the Americans with Disabilities Act (ADA) and general passenger information,
- Fare collection, and
- Traffic signal priority.

This synthesis focuses on AVL issues related to the workhorse of the transit fleet, the bus, and examines the range of implementations, benefits, and institutional issues associated with planning, designing, implementing, operating, and maintaining AVL systems for fixed-route bus transit.

Since 1969, more than 20 U.S. transit agencies have implemented AVL systems for fixed-route bus transit, and many more agencies are investigating the possibility of bringing in AVL to assist in managing their fleets. Interest in AVL for fixed-route bus transit is not limited by transit agency size or community type, although a majority of respondents to a survey of transit agencies in the United States and Canada conducted for this project operate in an urban environment.

Most of the early deployments used a combination of signpost and dead-reckoning navigational technologies, although many of these early systems were beset with procurement and technology problems. In the 1990s radio-navigation methods such as Loran-C and global positioning system (GPS) satellites looked promising. As costs for GPS receivers declined, GPS has become the most popular technology for AVL applications. GPS may be augmented with dead-reckoning sensors such as a compass and odometers and/or differential GPS. During the last 2 years, all but three survey respondents procured systems with GPS as part of their on-board navigation sensor suite.

Today, most systems requiring on-board transmission of location data demand specialized interfaces and customized software. Standards mitigate the need for these customized interfaces and software. To this end, many of the most recent requests for proposals require inclusion of industry standards such as the Society of Automotive Engineers standard "Serial Data Communications Between Microcomputer Systems in Heavy-Duty Vehicle Applications" (SAE J1708) and data integration connections (Open Data Base Connectivity).

Data issues emerged as a common, significant obstacle faced by most of the survey respondents, These problems involved most phases of deployment including design,

implementation, training, and maintenance. Two major issues related to data have been identified. The first includes the periodic update of the AVL control software with schedule dam (time points). Metropolitan Council Transit Operations of Minneapolis found that when they changed their scheduling software midway through an operational test, they could no longer input schedule data. An additional three months were added to the schedule to address the interface mismatch. This reflects the dependence of AVL systems on the scheduling software at the time of design and implementation, The Transit Communication Interface Protocol (TCIP) effort just underway as part of a Federal Highway Administration procurement will attempt to build consensus among transit professionals, transit application vendors, and Intelligent Transportation System (ITS) integrators around standard data definitions, interfaces, and communications protocols.

The second data issue includes maintaining the digital map database. Two areas of concern are map data accuracy, and integration of routes, bus stops, and map data. Not every transit organization has a Geographic Information System group that can handle updating of digital map databases. Moreover, these skills are not necessarily acquired by a novice in a few months. In fact, the specialized expertise for collecting, updating, and maintaining AVL data and the private industry demand make it difficult for agencies to find, hire, and keep skilled staff. Some agencies, for example, King County Metro in Seattle, have a well-established GIS and Information Systems staff, others train internal staff, hire consultants who command private sector wages, or contract out these services.

Installation of an AVL system represents a significant investment for a transit agency. Most AVL systems procured and installed prior to 1995 received special funds from demonstration or ITS operational test sources. Many of those sources are no longer available, and transit agencies are applying for grants from traditional sources (e.g., Section 9). Many agencies indicated that the main issue faced during their planning stage was finding a funding source.

Many of the early problems with acquiring new AVL systems may be attributed to the procurement process. Because of the lag between issuing the request for proposals and implementation, many agencies were limited by their initial technical specifications, such as personal computer class (e.g., x 386). Many recent procurements have adopted a two-step process that includes: (Step 1) develop performance specification, and (Step 2) design and build system. In particular, Beaver County Transit Authority hired a consultant to develop a concept plan and performance specifications for their Mobility Manager, the next phase includes hiring contractors to do the design and construction; Houston Metro required a partial design as part of their vendor proposals, the chosen vendor will complete the design and begin implementation.

Training is critical to efficient operation and it requires a significant amount of time and interest, particularly when training non-technical staff to use technical equipment. The most widely cited training issue is the delay between training and on-line operations.

Many systems have not yet accumulated enough years experience to quantify the costs related to annual maintenance. A majority of respondents to the survey for this project report that they include warranty periods and attach multiple-year maintenance contracts to their procurements. In some cases, agencies contract out the periodic updates (run/schedule changes) to their control software and require 24-hour replacement/repair from their software vendor.

Respondents indicated that the primary objective for procuring AVL was to improve customer service. Through increased service reliability, improved safety and security, and use of bus status information, agencies are using AVL to attract new riders, disseminate real-time information to their customers, improve their operations, and maximize use of performance data throughout their organizations. To achieve these goals, and to ensure continued cooperation from departments that affect or rely on the AVL, most agencies indicated that they attempted to involve the major departments in AVL procurement or development phases. The groups most often included in development are operations, maintenance, dispatchers, service planners, and administration.

Implementing an AVL system takes more than a few years from initial planning stages to final operation. With this degree of commitment, the benefits should be clearly distinguishable. Yet, only a few agencies performed an evaluation to measure benefits. Even agencies with systems in operation for more than 3 years have not quantified their efficiencies. Nevertheless, the survey responses indicate profound changes in transit operational strategies and highlight the interdependency of their data needs.

The major obstacles to performing benefits studies for AVL installations are (1) the lack of comparable cost information and (2) the lack of empirical evidence. First, in most cases, AVL systems cannot be readily compared. Although surveys included cost information, itemized data were not always available; various systems, even those installed by the same contractor, were costed differently. Second, empirical evidence can be derived from a variety of measures of effectiveness (MOE). Yet, a research and literature search produced no generic set of MOEs for AVL implementations, Because AVL systems have the ability to improve productivity throughout an organization, traditional categories to measure safety, security, customer satisfaction, or improved quality may not be sufficient for AVL.

Nevertheless, respondents described many anecdotal benefits of AVL. The most significant improvements result from having a more "complete picture." In particular among the operational benefits, respondents cited increased flexibility of assignments, faster response to emergency situations, improved efficiency in tracking on-time performance, and increased capability in handling grievances.

Many transit professionals, also proponents of integrating advanced technologies into transit operations, have cautioned against installing technologies in search of applications. The opportunities and efficiencies provided by AVL systems are not automatic. As noted by W. Jones in *ITS Technologies in Public Transit: Deployment & Benefits.* (ITS America, February 27, 1995) "The agency must effectively utilize this new tool to realize the efficiencies inherent in the technology." Although some AVL systems have been in operation for more than 10 years, transit agencies are still challenged by collecting and using AVL data, and by integrating this technology with other systems such as passenger counters, traffic signal systems, and customer information systems.

INTRODUCTION

The AVL component complements systems that: (1) measure system performance, ridership, and schedule adherence: (2) provide estimated time of arrival: (3) announce next stop information; and (4) display vehicles on an electronic map. As an automated technology, AVL collects, processes, and communicates location information to other applications that need accurate and timely location data. By associating time and location attributes, AVL technology enables the collection of disaggregated data by other on-board systems without the expense of assigning a person to the task.

The AVL component is integrated with or contributes to systems such as

- Emergency location of vehicles,
- Fleet management including vehicle performance monitoring and service control,
- Data collection,
- Customer information activities including Americans with Disabilities Act (ADA) compliance and general passenger information,
- Fare collection, and
- Traffic signal priority.

This synthesis examines the range of implementations, benefits, and institutional issues associated with operating AVL systems for fixed-route bus transit. AVL as an enabling technology and its effect on operational and supervisory procedures are also discussed. Although initial implementation of AVL for bus transit began in 1969, transit agencies still struggle with implementing the system and using the data for areas other than performance monitoring.

Agencies are gradually taking advantage of these technologies to automate systems in other areas of their organizations. This synthesis chronicles the critical success factors, key strategic issues, and lessons learned by many of the agencies that have deployed systems, are implementing systems, or that are in the planning stage of implementation.

SYNTHESIS OBJECTIVES

The area of AVL is contained in broader topics such as automated vehicle monitoring (AVM), computer-aided dispatch (CAD), and fleet management for commercial, emergency, paratransit, bus, and rail. This project focuses on issues related to the work horse of the transit fleet. the bus in fixed-route service.

The AVL system is a complement of technologies that track vehicle locations in an accurate and timely manner. It may be narrowly defied as the navigation suite: sensors and tracking software. The broader description includes the communication link, data channel controller, and central control system. Although industry justifications for AVL systems are combined with the need to purchase new communication systems, and real-time performance monitoring requires the coupling of the two systems. the narrower definition of AVL is applied here.

However, many technologies are required to enable vehicle monitoring: digital maps, analysis software, and communication linkages. Other technologies are required to expand the use of AVL to data collection and real-time traveler information services. This report identifies these technologies relative to their support and extension of AVL.

Within the past year, more than 20 agencies have received funds to procure AVL for fixed-route bus transit; and more agencies are investigating the possibility of bringing in AVL to help manage their fleets. Moreover, as more systems come online, the benefits-no matter how anecdotal-are emerging.

The synthesis identifies applications and practices associated with planning, design, implementation, and AVL interfaces with other AVM components. Additionally, this synthesis identifies field practice and experience in each of these areas.

BRIEF HISTORY OF AUTOMATIC VEHICLE LOCATION IN THE UNITED STATES

Since 1969, with the advent of the first demonstration projects, transit professionals, consultants, and operators have lauded the benefits of AVL, while remonstrating the expensive infrastructure costs. In a TCRP synthesis on bus communications systems, the author commented

> More sophisticated functions such as automatic vehicle location (AVL) will remain relatively expensive because of the labor-intensive cost of installing and maintaining signposts. Larger transit systems will install AVL systems to improve schedule performance and will gradually install passenger counter systems over the next 10 years. (1)

Indeed, 10 years have past since this statement, and most large transit agencies still do not operate AVL systems. Systems are still expensive, but not because of the cost of installing and maintaining signposts, since only a few of the newer systems rely on proximity technologies Yet, in the last few years many transit agencies have invested in the system concept. More than 70 agencies in North America are implementing or have procured funding to deploy or operate AVL for their bus fleet, and many more are planning to acquire the financing to invest in this technology.

The use of AVL in public transit has been slower in the United States than in Canada and Europe. AVL systems were proposed in both Europe and the United States in the 1960s. The U.S. Department of Housing and Urban Development

(HUD) first proposed AVL use in its 1968 Report to Congress, *Tomorrow's Transportation*. The first demonstration of AVL in Europe was in Hamburg, Germany in 1964. The first major development in the United States occurred in 1968, when HUD initiated a program with the Chicago Transit Authority (CTA) to improve public transportation. During that same period, the Public Urban Locator Service (PULSE) held a conference in October to discuss AVM applications and technologies. These activities encouraged widespread interest in this area. Chicago became me site of the first AVM deployment in the United States using a signpost location technology developed by Motorola. The demonstration began with 500 buses on the night runs of the CTA service area, and operated for the next 5 years (2).

The next major effort was not until 1974, when the Urban Mass Transportation Administration (now the Federal Transit Administration) initiated a program "to refine, demonstrate, and evaluate" AVM in an urban environment. The first demonstration field tested four distinct location technologies in Philadelphia between 1975 and 1977. The second phase demonstrated and evaluated a complete AVM for "fixed- and random-route operations" in Los Angeles (2). Two hundred buses on four routes tested real-time schedule adherence, passenger information, and passenger counters.

Since these demonstrations, many other agencies have developed and deployed AVM systems. During this early deployment period, the second major test was developed by the Urban Transportation Laboratory (UTL) of General Motors which demonstrated a Transit Information System (TIS) in Cincinnati, Ohio. The TIS provided current information on passenger loads, run times, and systemwide schedule adherence. The TIS consisted of wayside bus locators, on-board passenger counting devices, and a central computer. Though widely praised for its data collection capabilities, the General Motors demonstration did not seek to increase operational productivity. Other demonstrations were spun off from this test in Columbus, Ohio; Jacksonville, Florida: and Kalamazoo, Michigan without the AVL technologies. Table 1 summarizes AVL use by transit agencies in North America.

Experimentation with AVM systems and components marked the period prior to major budget cuts at UMTA in the early 1980s. In 1977, the Southern California Rapid Transit District (SCRTD) was selected by UMTA as a demonstration site to highlight AVM benefits. This was to be accomplished by measuring the benefits of deploying Automatic Vehicle Monitoring/Control (AVM/C) equipped routes. In 1979, the New York City Transit Authority, using wayside bus locators by Motorola, was the first system to transmit mechanical sensor information related to fare boxes and drive train performance. The test was set up so that digital messages reduced the need for audio communications.

These early tests used proximity or signpost technologies de veloped during World War II. Yet, with a sufficiently dense infrastructure, many transit agencies still operate AVL equipped buses. In fact the Ministry of Transportation/Ontario, as early as 1991, assessed AVL requirements and technologies for small and medium-sized transit agencies recommending hybrid solutions; chief among them was a signpost-based system integrated with

TABLE 1

BRIEF HISTORY OF AVL FOR BUS TRANSIT IN NORTH AMERICA (2,3,4)

City/Agency	Year Initiated	No. of Vehicles	Primary Sensor	status
Chicago/CTA	1969	500	Signpost	Used for emergency response. (Replacement in progress 1996)
Toronto Transit Commission (TTC)	1972	full fleet	Signpost (microwave)	Operational First Trial (100 Buses 1976-1981) Second (262 Buses)
Cincinnati (QCM)	1975	30	Signpost	Prototype completed (6/77-3/78)
LA/SCRTD	1977	200	Signpost	Premature Termination after 2 years of operation (9/81)
NY/MTA	1979	241	Signpost	Prototype (Non-Operational)
White Plains, NY/Bee-Line	1983	332	Signpost	Operational
Hull, Quebec (STO)	1984	183	Signpost	Operational
San Francisco/Mum	1985	1000	Signpost	Operational (Used For Emergency Response)
Halifax, Nova Scotia/MTD	1987	168	Signpost	Operational (replacement in progress)
San Antonio/VIA	1987	531	Signpost	Operational
Baltimore/MTA	1989-1995	900	Loran-C	Operational (changing to GPS, 1996)
Kansas City/KCATA	1990		Signpost	Non-Operational (replacement in progress)
Hamilton, Ont/HSR	1991	240	Dead Reckoning	Operational
Rochester, PA/BCTA	1991	13	Loran-C	Operational
Sheboygen, WI/STS	1991	20	Loran-C	Operational
Norfolk, VA/TRT	1991	151	Signpost	Operational
Santa Monica/SMMBL	1992	135	Simulcast Paging (radio triangulation)	Operational
Tampa/Hartline	1993	17.5	Signpost	Operational
Seattle/KCMetro	1993 (1980)	1250	Signpost	Operational

odometer/door-opening sensors (5). To this day most Canadian transit agencies operate signpost-based AVL systems. Showing their maturity, MTD and KCATA are installing their second generation signpost systems.

In the 1990s radio-navigation methods such as Loran-C and GPS looked promising, and as costs declined, the technologies became more attractive. In the early 1990s, a few transit agencies deployed Loran-C aided with dead-reckoning sensors. Loran-C was not quite accurate enough and was soon abandoned as au alternative to proximity sensors. As the 24-satellite constellation became operational and Global Positioning System (GPS) receivers were miniaturized and decreased in price, it became the sensor of choice. Today, most new systems use differential GPS technology.

SYNTHESIS ORGANIZATION

This synthesis addresses various aspects of developing and deploying AVL systems during the last 20 years. Chapter 2 discusses the results of a survey of selected transit agencies, summarizing AVL operational characteristics. Chapter 3 reports on AVL technological capabilities and effectiveness in the context of field practices and experiences. The technologies and services provided by AVL can affect traditional institutional and operational paradigms. Institutional issues such as funding, justification, staffing, procurement, and successful strategies to approach them are discussed in chapter 4. Chapter 5 identifies issues related to AVL development stages and operation. Chapter 6 summarizes key success factors and discusses future trends in the industry.

CHAPTER TWO

CURRENT PRACTICE OF AVL FOR BUS TRANSIT

Several methods were used to gather information on AVL systems for bus transit. The primary data collection tool was a survey mailed to transit agencies actively planning, designing, implementing, or operating AVL for fixed-route bus transit in the United States and Canada. The survey queried users on their existing services, equipment, operational practices, interfaces, benefits, milestones, procurement practices, and changes related to this new technology. Respondents were contacted to provide additional data or clarify answers. Visits to transit agencies provided additional insights into the procurement and operation of their AVL systems.

Published materials including articles, studies on technology solutions, issues, and "lessons learned" provided supplementary information. In particular, the FTA through the Volpe National Transportation Systems Center collects and publishes in the *APTS State of the Art (4)* and the *APTS Deployment in the U.S. (6)* data related to planned and implemented AVL systems, including information such as status, location technologies, communication polling method, and vendor.

A third source of information was vendors and system integrators who work in this area. They provided information on critical factors related to deploying and pricing AVL systems.

SURVEY SUMMARY

Survey instruments were mailed to transit agencies in the United States and Canada that had operating systems or had secured federal funds to procure AVL. The 29 agencies that responded (see listing in Appendix B) are in different stages of the procurement/operational process. The survey results are presented in chapters 3, 4 and 5; this chapter summarizes general service characteristics, total cost, status, location technologies, and communication methods employed in AVL implementations in North America in Table 2. Where available, information was supplemented by other sources.

Interest in AVL for fixed-route bus transit is not limited by transit size or community type. Small, medium, and large transit agencies are integrating AVL into their fixed-route operations. Small agencies can deploy a system within a few months: for example, COLTS installed their system (32 vehicles, 500 runs, and 29 routes) in 9 months. Many of the larger systems integrate AVL in stages; MTA-Baltimore, CTA, NYCT, and others plan to test the system on selected runs or routes prior to complete installation. The staged approach may be reflected in Tables 2 and 3 by the number of buses: the

TABLE 2

SUMMARY OF SERVICE LEVELS PROVIDED BY RESPONDENTS OPERATING, IMPLEMENTING, OR PLANNING AVL SYSTEMS

Short Name	Size (sq miles)	Community Type	Number of Buses	Number of Buses Peak Period (PP)	Average Headway PP (min)	Closest Headways (min)	Annual Ridership	Number of Runs	Number of Routes
AATA	75	U	76	64	30	15	4,000,000	80	26
AC Transit		U	717				57,000,000		
BCTA	468	U, S, R	36	12	30	30	598,000	13	5
CDTA		U, S, R	250	190	15	10	10,000,000	2500	60
COLTS	164	U	32	26	30	20	1,899,690	500+	29
CTA	260	U	2064	1631	5	1.4	331,500,000	2511/971/ 3482	138
KC Metro	2100	U, S, R	1148	900	24.9	5.6	77,366,682	1580	240
KCATA	762	U, S	245	199	0	9	14,573,000	215	36
Laketran	232	S		55	15	15	520,000	79	7
LTC			160	126	20	10	12,800,000	196	30
MCTO	2500	U, S	971	797	10	2	65,400,000	766	130
MCTS	250	U	541	425	12	4	48,000,000	847	63
MDTA	200	U	614	479	20	7.5	63,800,000	827	72
MTA—Baltimore	1800	U, S	844	642			105,598,341	6054	74
Muni	49	U	950	700	3.5	1.5	190,000,000		79
NFTA	1500	U, S, R	322	275		10	21,400,000		62
NJ Transit	5325	U, S, R	1990	1800	5	1	166,000,000	8000	152
NYCT	321.8	U, S	3751	3554	5	1	1,500,000	4975	231
PACE	3500	S	550	504	15	8	38,000,000	664	235
RTA	72	U	476	373	10	3	54,467,481	485	60
RTD–Denver	2300	U	905	675	5	5	68,000,000	1475 blocks/ 7500 trips	155
Sioux City	56	U	28	21			1,400,000	21	11
SMART	2000	S	400	346	30	20	8,600,000		59 fixed, connector
SMMBL	51.4	U	135	98	10	10	17,900,000	77 coach/ 62 tripper	12
STO	583 km	U, S	186	152	30	6	10,772,536	350	49
Sun Tran	155	U, S	200	150	8	5	16,000,000		35
Sun Van	165	U	120	106	20	15	5,700,000		
The Vine		U, R	18	13	30	30	720,000	210	6
Tri-Met	592	U	630	513	16	7	56,154,535	807	91

U = urban; S = suburban; R = rural.

TABLE 3

STATUS OF AVL DEVELOPMENTS

Name	Primary Technology	Number of Buses	Status	Years of Operation
RTA (New Orleans)	GPS	500	Feasibility	
CAT	GPS	40	Planning	
Sun Van	NA	120	Planning	
NYCT	GPS	170	Plating	
PACE	GPS	600	Procurement	
AATA	GPS	76	Procurement	
Laketran	GPS	15	Procurement	
CTA	GPS	2064	Design	
AC Transit	GPS	717	Design	
LTC	Signpost	160	Design	
NFTA	GPS	322	Design	
Sun Tran	GPS	200	Design	
SMART	GPS	250	Implementation	
Tri-Met	GPS	630	Implementation	
MDTA	GPS	614	Implementation	
MTA-Baltimore	GPS	844	Implementation	2[#]
NJ Transit	Signpost	800	Implementation	
BCTA	Loran-C	13	Operational	2
STO	Signpost	186	Operational	10
RTD	GPS	900	Operational	1
Muni	Signpost	950	Operational	10
COLTS	GPS	32	Operational	1
MTD	Signpost	170	Operational	10
CDTA	Signpost	232	Operational	0
MCTO	GPS	80	Operational Test	1
KCATA [*]	Signpost	245	Operational	4
KC Metro	Signpost	1148	Operational	2
SMMBL	Simulcast	135	Operational	5
MCTS	GPS	541	Operational	1
The Vine	GPS	18	Operational	0

[*] Off-line until November 1996.

[#] MTA operated a Loran-C-based AVL before this recent procurement.

number in the column entitled 'Number of Buses" signifies the number of buses under consideration for AVL, installation.

The majority of respondents operate in an urban environment-almost 90 percent of the responses came from systems operating in an urban environment with 46 percent operating only in an urban environment. Suburban-only operators accounted for 11 percent of the respondents, and no response came from an operator in a rural-only community. Thirty-nine percent of the responses came from suburban/urban operators, 18 percent came from suburban/urban/rural operators, and less than 4 percent from a rural/urban operator.

The survey included a question on average and closest headways to investigate the use of AVL for managing bus bunching [for close headways) and monitoring service reliability (for long headways). As expected, longer headways are typically associated with agencies operating fewer buses (with one exception: SMART), and closer headways are associated with large and urban operators.

Forty-eight percent of the respondants operate or have operated an AVL system for fixed-route operation. The remainder are in various stages of implementation. Agencies with more than one year experience operate systems that do not use GPS sensor technology. Also, since the collection of these data, many of the systems undergoing implementation are now operational.

The current, clear choice for sensor technology is GPS. Only agencies who procured their system in the 1980s or early 1990s or who are upgrading their existing signpost system are choosing signpost technology. The majority of new projects are GPS- or differential GPS (DGPS)-based, as demonstrated by 88 percent of respondents who are in the feasibility, planning, design, or implementation stages.

Although experience with signpost technology covers more than 10 years, few operators relate more than anecdotal institutional and operational practices and benefits. The next three chapters describe those experiences in more detail. Because the majority of operational systems (50 percent) use signpost technologies, much of the discussion on practices in the field reflect a signpost architecture (though the functionality of AVL systems is similar). Much of the discussion on planning, design, and implementation is from respondents implementing GPS-based systems. Generally, responses reflected similar concerns related to the institutional context and role of AVL regardless of AVL architecture and technology.

CHAPTER THREE

AVL ARCHITECTURE AND TECHNOLOGIES

AVL is an enabling technology for many operational tasks but only a few benefits can be derived from AVL alone. Additional software, hardware, and communications components need to be in place to measure performance, quality of service, and effectiveness of schedules and routes, to ensure safety of operators and passengers, and to provide current service status information to travelers. Different benefits may require different technologies, interface devices, software functionality, and may affect the cost of the system.

This section describes the various technologies and devices that compose the AVL system. It addresses performance issues, operational strategies, and anecdotal experiences related to these technologies.

Many vendors break down AVL systems into their functional subsystems: on-board, communications, and central control system, but this division, although it makes sense conceptually and is easier to cost, hides the differences between AVL and AVM, and obscures some key engineering and data integration issues. Another way to structure AVL systems, used in this synthesis, is to divide AVL into three functional units: navigation, communications, and interface integration.

The navigation and communication systems are composed of both on-board and infrastructure devices. Most navigation systems use radio frequency (RF) to communicate. These units, located on-board a vehicle, receive and send signals from/to infrastructure devices such as roadway beacons, radio towers, and satellites. In turn, communications devices transmit signals from on-board equipment via relay stations to radio tower(s).

Navigation and communication systems performance and technical requirements are driven by the integration of AVL with AVM and other related automated systems. The central control system software is an AVM component that monitors real-time schedule adherence, silent alarms, and other data required by the agency. Accuracy, update frequency, update timeliness, and other critical factors determine the need for specialized interfaces and consequently, the amount of engineering required to integrate the multiple devices. AVM may have additional systems that interface with AVL technology. These are:

- Control software (e.g., data channel controller, computer-aided dispatch terminal, vehicle display software), and
- On-board external interfaces (e.g., control head, automated passenger counters (APC), annunciators, in-vehicle signage).

Other systems or centers may use the data produced by the AVL system. A traffic control center can use real-time travel times as probe data, while other transit centers may use the information for connection protection or to disseminate schedule status information to its customers. (The interfaces are discussed in the section on Interface Components later in this chapter.)

AVL SYSTEM CONFIGURATION

The number of specialized interfaces and the customized software required to integrate the components of an AVL system define the degree of coupling. In explaining "coupling," the ITS community uses the example of stereo equipment. Industry standard physical and signal interfaces permit the consumer to mix and match controllers, CD players, turntables, and cassette decks. This interface configuration defines a low degree of coupling and a high degree of modularity. The AVL system configuration is affected by the interconnection among its various subsystems. For example, a high degree of coupling occurs when vehicle location data are derived in and transmitted by the vehicle logic unit using proprietary protocols (see Figure 1). Each interface is customized, data must be filtered, transformed, and repackaged. Today, most systems requiring on-board transmission of location data demand a high degree of coupling between the navigation and communication units.

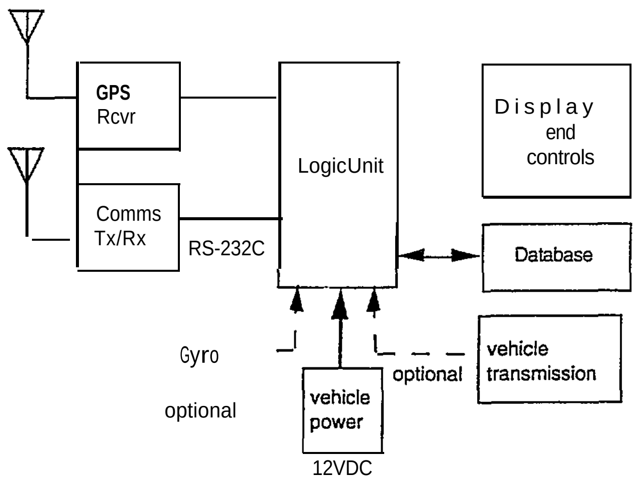

FIGURE 1 AVL configuration with a high degree of coupling. Source: Beaver County Transit Authority Mobility Manager Concept of Operations

Standards mitigate the need for customized interfaces and software. Although the navigation unit still sends data through the on-board communications unit, each component receives and sends information in standard formats. The SAE J1708 family of standards (7-10) provide for decoupling the AVL

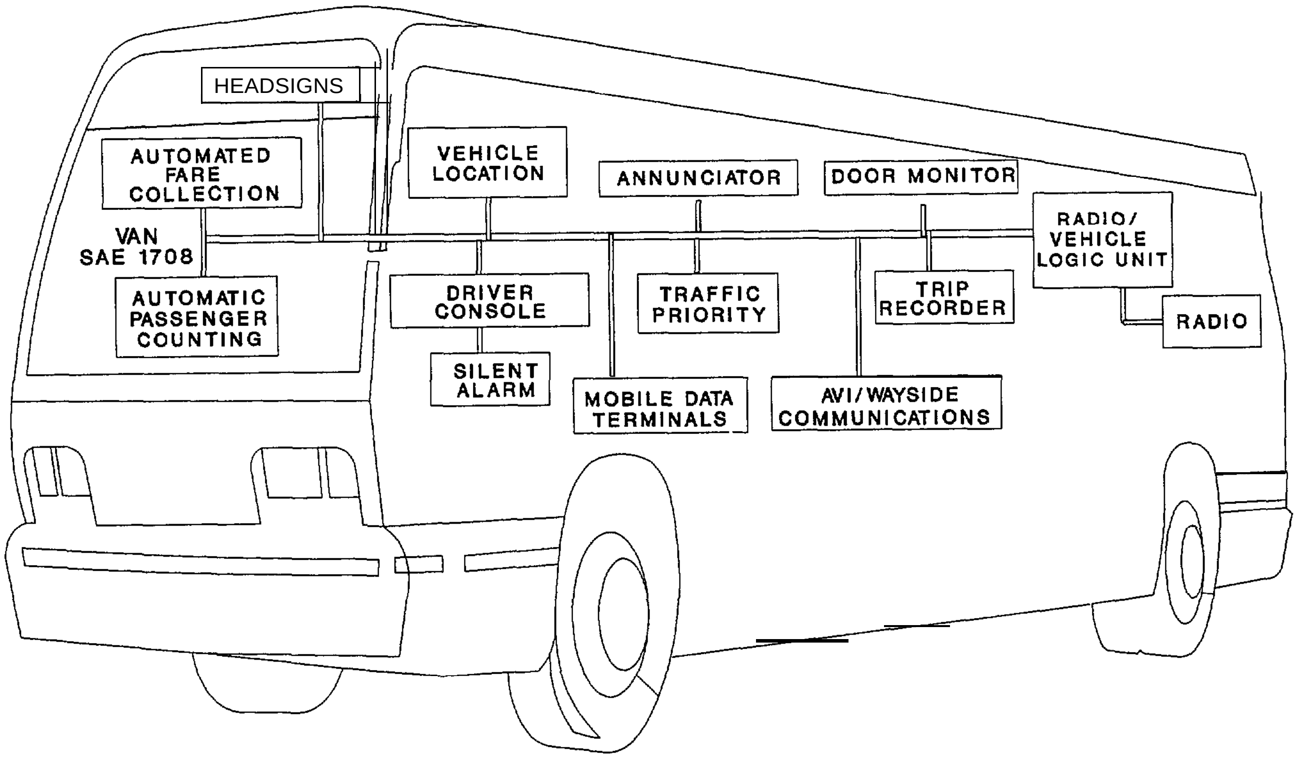

FIGURE 2 AVL configuration with a low degree of coupling. Source: Houston Metro

system by implementing standard protocols for exchanging information (see Figure 2). Also, position determination-for the wayside automatic vehicle identification (AVI)/reverse signpost in use at Ottawa-Carleton Regional Transit Commission and simulcast paging/radio triangulation in use at Santa Monica Municipal Bus Lines (SMMBL)-is performed external to the transit vehicle. In these two cases, the system cost related to the coupling is borne by the service provider or by wireline standards that already exist between the location and communications units.

The degree of coupling puts the costs in different parts of the AVL system. The more highly coupled the on-board components, the greater the engineering costs associated with their development and deployment. Comparing costs of a recently installed differential GPS (DGPS) system at Tri-Met with SMMBL's simulcast paging system (based on data derived from Table 13), the approximate cost of the DGPS-based system per bus is $10,500, while SMMBL's simulcast paging cost about $1,000 per vehicle. The sophistication and goals of the two systems are very different and are described below in more detail.

LOCATION TECHNOLOGY AND NAVIGATION SYSTEM

The navigation system consists of the equipment and software that identify the location of the vehicle. Navigation technologies may be divided into three general categories: radio navigation, dead reckoning, and other tracking technologies, which include magnetic, optical, and acoustic sensors used to track vehicles. No agencies reported using these technologies, but conceptual application of optical and acoustic sensors will be discussed in the sections on signpost technology.

Radio navigation systems are defined as any location technology that relies on a radio signal to determine position. In most cases these systems require certification of spectrum. Among the technologies in this category are GPS, satellite and radio triangulation, signposts, and wayside transponders.

Dead-reckoning sensors use direction/hearing and distance/speed to determine relative location from a fixed point. Compasses, odometers, and inertial platforms (gyroscopes and accelerometers) are all dead-reckoning sensors.

Dead-reckoning sensors only require on-board equipment. The sensor is calibrated at fixed locations to correct drift. These calibration issues will be discussed in the section below. The frequency of location updates is typically high (as often as every 20 milliseconds).

By comparison, all radio navigation systems require onboard and infrastructure devices, and a wireless communications link to connect them. With a beacon system, the receiver/transmitter location is known, so when the vehicle traverses within its signal coverage the vehicle is made aware of its own location. Signposts and wayside transponders are types of beacon systems. The frequency of location updates depends on the placement of the beacons and how often a vehicle is within beacon range. In a triangulation system, at least three receivers/transmitters of known location and synchronized time are required to solve for a global position (x, y and time). The time component is needed to determine the delay in the signal transmission. These systems include Loran-C, GPS, DGPS, radio triangulation services, and low earth-orbit satellite system services.

According to the 1994 Federal Radio Navigation Plan (FRP) (II), jointly sponsored by the U. S. Department of Defense and U. S. Department of Transportation, a number of technical factors should be considered in evaluating radio navigation systems. Among these are significant factors related to AVL for transit, including:

- Received signal strength-This defines the radio coverage of the broadcasting devices. This measure will determine the coverage of the navigation technology and is particularly important for differential GPS.
- Signal accuracy-Signal accuracy comprises statistical measures of uncertainty in the position. Accuracy may be measured as predictable, repeatable, and relative. Predictable accuracy is the position solution based on the closeness to a geodetic datum. Repeatable accuracy is a measure of how close a series of solutions taken at the same location are to each other. Relative accuracy is the closeness of position solutions taken at the same location by different sets of equipment of the same type.
- Availability-Availability is the percentage of the time or areas in which services are usable. Equipment may be down for servicing or signals may be unavailable in or near obstructing structures or tunnels.
- Signal coverage-A number of factors contribute to evaluating signal coverage, including infrastructure geometry, signal power, receiver sensitivity, atmospheric noise conditions, and signal availability. Some of these will be determined by topography and urban landscape.
- Noise effects-Noise effects may arise from various sources, e.g., equipment, electromagnetic interference, and the atmosphere. The majority of noise comes from atmospheric conditions, particularly during bad weather (e.g., fog, rain, snow). Because these effects are small (centimeter errors), they influence survey quality GPS measurement only. Electromagnetic interference, in particular lightening, can degrade the performance of Loran and DGPS broadcast substantially.
- Signal integrity-Signal integrity refers to the ability of system to provide timely warnings to users when the system should not be used for navigation. These warnings may be needed when signals are degraded or when substation, relay station, tower, or satellite signals are not suitable for use as a navigation aid.
- Multipath effects-A multipath effect occurs when reflected signals interfere with incoming signals or are processed out of order. This is frequently a problem in urban areas with dense concentrations of tall buildings. Frequencies in the microwave band are less likely to be reflected.

Signpost

Most early AVL deployment projects used signpost technology as the location sensor. Signal density and placement are some of the factors that determine system effectiveness. A signpost system may be composed of an on-board short-range communication device and an infrastructure mounted beacon. Existing signpost systems work in two modes:

> *Mode* 1: A vehicle with a transponder continuously sending a signal; within range, the signpost responds with its identification code.
> *Mode* 2: The signpost continually broadcasts its identification number.

Since the location of each signpost and its signal coverage are known, the positional accuracy can be determined.

Signal coverage is determined by a number of factors, including the type of signpost and its signal strength. A signpost may emit a ‘broad” signal that covers an entire intersection, or it may emit a “sharp” signal (12) which is focused in a narrow signal band. (Figure 3 illustrates the different signal coverages and technologies of these two techniques.) The broad signpost technology uses only one signpost to cover an intersection, whereas, the sharp signpost technology may require a signpost for every road or lane.

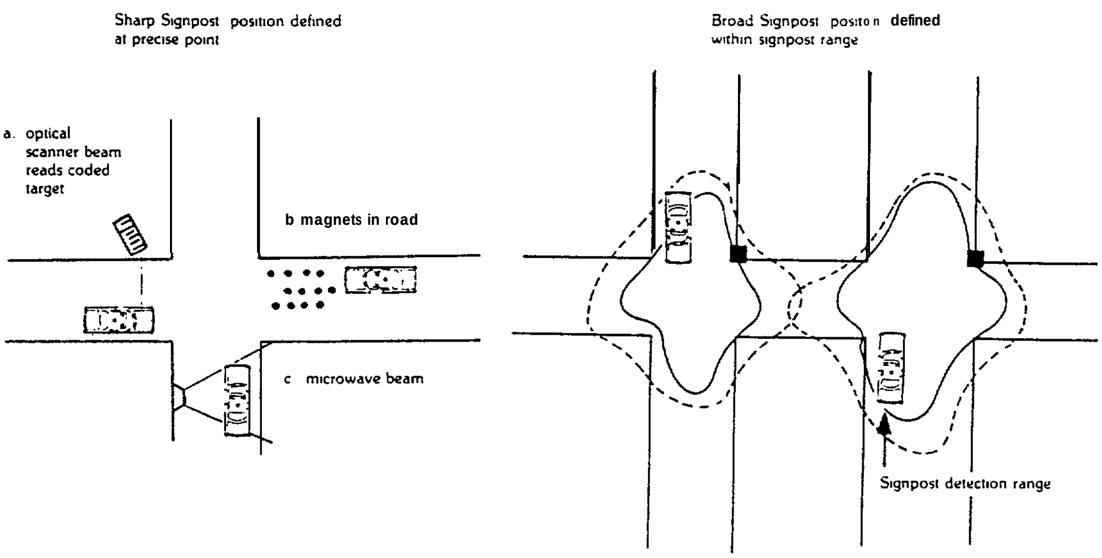

FIGURE 3 Comparison of sharp and broad signpost technologies,

Vehicle Component

The in-vehicle component, which has decreased in size since the early deployments and now may be as small as a credit card, is composed of the antenna and transponder. The antenna is mounted on the vehicle so that it has a clear view of the infrastructure device (i.e., signpost). The vehicle transponder interprets the signal and passes the information to the vehicle logic unit (VLU). The VLU, which directs information to the radio, manages the communications between the vehicle and central dispatch.

Costs vary for the signposts and transponders depending on the frequency and number of units purchased. Most agencies buy units as a package with other devices and software, which makes it difficult to determine the per unit cost.

Infrastructure

The signpost generally is placed on a pole or structure above the height of the bus, since it requires line-of-sight exposure to the receiving antennae. Different manufacturers package the signposts differently. The core technology is a small integrated circuit board and a battery. LACMTA mounts a plastic tube on 20-ft high poles. MTD packages their beacons in aluminum boxes.

The source that powers the signpost is critical for long-term maintenance costs. In the past, MTD mounted units on utility poles from which they derived their power. However, some early battery-based systems were beset with failures 6 to 12 months after the installation. The cost of the batteries, which require changeout every few years, may be significant depending on the number of signposts installed. In the case of one agency with a signpost system with battery lives of 6 months, two staff are employed full time to maintain the system. Newer signposts consume less power and today's more efficient batteries last from 3 to 5 years. KCATA, one of the most recently procured signpost systems, uses batteries that cost about $430.

Placement of signposts is critical to monitoring the fleet in a cost-effective manner. The distance between sensors may be determined by cost, limitation of the secondary sensor, or other factors. Most agencies surveyed responded that the signposts were usually placed at intersections traversed by multiple bus routes. MTD recommends that "city centers require higher densities, while fewer signposts are needed towards the periphery." This statement assumes a higher density of bus stops and time points on the urban roads, King Country Metro uses a software program based on the layout of routes on a map database to optimize signpost placement. Signposts are fairly inexpensive; KCATA purchased their signposts for $275 each, signpost housing for about $85, and on-board receivers for $235 each. The installation fee for each unit (approximately 130 beacons and 254 buses) was $65. Their total cost per sign, including the $430 battery, was $1,025.

The Ministry of Transportation of Ontario, Canada (MT/O) published a report recommending AVL for small and medium-sized transit agencies (5). The hybrid signpost/dead reckoning was among their recommendations, and consequently, most Canadian properties implemented signpost location systems. Certainly for agencies with a small service area, most, if not all, the roads can be instrumented with beacons. San Francisco, with a service area of 49 square miles and 79 bus routes requires only 120 signposts to achieve full coverage. NJ Transit covering Essex county (150 sq. mi) and 35 bus routes installed 118 signposts. The advantages and disadvantages of signpost technology are summarized in Table 4.

TABLE 4

ADVANTAGES AND DISADVANTAGES OF SIGNPOST TECHNOLOGY FOR AVL

Advantages	Disadvantages
- Low in-vehicle cost • No blind spots or interference • Repeatable accuracy (good for measuring time points against performance)	• Requires well-equipped infrastructure • No data outside of deployed infrastructure (can be used reliably only for fiied routes) • Frequency of updates depends on density of signposts

Source: (5) and survey respondents.
Low cost refers to equipment and installation costs under $1,000.

Wayside AVI

Wayside automated vehicle identification (AVI) was once known as "reverse signpost." For wayside AVI, the infrastructure handles communications to central dispatch through a microwave link or landline. Adopted by the Electronic Toll and Traffic Management (ETTM) market, the technology has seen a rapid improvement in performance, reduction in price, and movement toward standards. Some manufacturers sell the vehicle "tags" for as little as $35 (13). Even agencies not installing AVL may install AVI technologies at their maintenance facilities to monitor traffic. For example, Metropolitan Council Transit Operations (MCTO) of Minneapolis/St. Paul, Minnesota has AVI deployed at their garage entrance to aid in electronic check-in and downloading daily maintenance records. Other agencies are working with local, regional, and state transportation agencies to share infrastructure costs by standardizing on a single technology. For example, the four Massachusetts state transportation agencies (i.e., Massachusetts Bay Transit Authority, Massachusetts Turnpike, Massachusetts Port Authority and Massachusetts Highway Department) signed a memorandum of understanding to adhere to a standard interface specification and purchase the same AVI technology.

Vehicle Component

Both the transponder and antenna are packaged into a credit card-sized tag which is mounted on either the inside or outside of the vehicle. The card-sized transponder transmits the vehicle identification to the infrastructure component.

Infrastructure

The infrastructure component must be connected to a communication backbone. Some agencies or states share fiber optic or twisted-pair transmission lines along major rights-of-way, others set up wayside detectors on poles with telephone line access or install microwave link capabilities. These alternatives are very expensive if used solely for monitoring the bus fleet. For example, one leased line (in a city in the northeast) cost about $6 per month, and each wayside device requires a single line.

Because interoperability on the national highway infrastructure is a U.S. DOT priority, states are working together to define a standard or standards for the industry. ITS America released an ETTM standard (14) that reflects the requirements of many state highway and toll facility agencies. The American Society of Testing and Materials (ASTM) (15) and Caltrans also have efforts underway to establish standards. Table 5 shows advantages and disadvantages of wayside AVI technology.

TABLE 5

ADVANTAGES AND DISADVANTAGES OF WAYSIDE AVI TECHNOLOGY FOR AVL

Advantages	Disadvantages
• Low in-vehicle cost • No blind spots or interference • Repeatable accuracy (good for measuring time points against performance) • Shared infrastructure costs with State Transportation agencies	• Requires well-equipped infrastructure • No data outside of deployed infrastructure • Frequency of updates depends on density of signposts • May incur high communications costs

Source: Discussions with industry specialists.
High communications costs refer to costs that may exceed $1,000 per month.

Ground-Based Radio Positioning (GBRP)

GBRP is based on measuring the time difference of signal reception, calibrated against a known position of remote stationary transmitters or receivers. Also known as *radio triangulation,* location is derived by obtaining the bearing of the moving object with reference to two or more fixed radio stations which are a known distance apart: this measurement provides the values of one side and all angles of a triangle from which a position may be computed. (Sometimes people refer to trilateration, which is based on deriving the distances between the moving object and fixed stations, producing the three legs of the triangle. The term trilateration is used primarily in the context of surveying.) Major GBRP systems include Loran-C, a long-range aid to navigation, and simulcast paging services, generally local service providers.

Loran-C, deployed and maintained by the U.S. Coast Guard, now covers the entire United States, The signal emits low-frequency radio waves which provide signal coverage on land and sea up to 1500 km (independent of line of sight), It provides predictable accuracy of better than 150 ft (2 distance root mean squared [drms] or 2 sigma) (II, p.A-6).

The signals are transmitted by three to six stations: one acts as the master, the others as secondaries. The secondary sites are synchronized to the master to transmit their signal at specified intervals. The Loran-C receiver knows the sequence and estimates the time difference of arrival of each signal to estimate its own position. Three transit systems have used Loran-C: MTA-Baltimore, who is transitioning to GPS, Rochester, Pa. and Sheboygen, Wis. Most navigation users are migrating to the more accurate GPS satellite-based system. As a consequence, Loran-C will be decommissioned by the year 2000 (II). No new Loran-C based AVL systems are anticipated in the future.

Simulcast paging services function similarly to Loran-C and commercial paging services. Paging towers are erected to cover a service area. A signal is sent by the tower requesting the attention of a paging device, the paging device responds with its ID. Each tower, synchronized with GPS clocks, de termines the arrival time of the message to a central control unit, which performs a triangulation algorithm to determine the location of the vehicle. The location of the vehicle (using latitude and longitude) is usually transmitted through a modem to the requesting party.

The number of simulcast paging service providers is growing each year. Because the startup costs are low, consumers use them as anti-theft deterrents, and commercial fleets, particularly emergency service fleets, use them for vehicle tracking. For example, the original (1989) cost of SMMBL's turnkey AVL system was $131,779 which included three terminals and modems, software, on-board equipment and installation for 145 vehicles, and training. Today's systems provide remote silent alarm, messaging data terminals for two-way paging, and door sensors mat trigger location queries.

Billings are based on a charge for each request for location. A fixed number of requests are supplied for each unit, each month. SMMBL pays about $24,000 annually for 145 vehicles. Each vehicle is allotted 200 peak and 200 off-peak requests. For excess use, peak requests cost $0.03 and off-peak requests cost $0.02.

Like GPS, many of these systems use spread spectrum modulation techniques for better signal clarity. Engineering costs are much lower than other systems because the unit is independent of the mobile radio units (MRU) and bus communication system eliminating those integration costs. Moreover, the infrastructure costs are born by the service provider, which reduces the maintenance costs of the system.

Vehicle Component

The simulcast paging system is composed of an antenna and a vehicle locator unit inside the vehicle. The vehicle unit is a communications device that contains an identification number and responds to a call from central control; it embodies no other intelligence. The advantages and disadvantages of this technology are summarized in Table 6.

TABLE 6

ADVANTAGES AND DISADVANTAGES OF SIMULCAST PAGING SERVICE FOR AVL

Advantages	Disadvantages
• Low capital cost • Moderate accuracy • Low maintenance costs	• Monthly service fees (relatively high depending on use) • Signal attenuation by foliage and tunnels (inside buildings); blocked bv tall buildings

Source: H. Humes (Teletrac, Inc.) and SMMBL
Low capital costs refer to system procurement costs under $1,000 per bus across all procurement costs except the bus communications system. Moderate accuracy refers to relative accuracy better than 100 ft but not worse than 150 ft. Low maintenance costs refers to total system cost better than $300 per bus averaged across all deployed buses.

Satellite-Based Radio Positioning

There are two types of SBRP systems:

- ***Circular*** orbiting satellites (e.g., GPS and low earth orbit [LEO]) which orbit in a predetermined path, at a set inclination and period around the earth, and
- ***Geostationary*** satellites (e.g., QUALCOMM and INMARSAT) which circle the earth in the same direction with the same period as the earth's rotation, thus providing continuous coverage to the same area on the earth's surface. Geostationary orbiting satellites are a specialized subset of circular orbiting satellites.

Geostationary Satellites

Geostationary satellites provide coverage in a single region. The technology is similar to land-based triangulation except that it has a more limited communications bandwidth and the land-based infrastructure is replaced by one or more satellites.

Circular Orbiting Satellites

Low Earth Orbiting Satellites-within a few years, consortiums of private corporations will be launching low earth orbiting satellites that will provide universal coverage for digital communications (and could track users). These satellite services will function similarly to geostationary satellite and simulcast paging service providers.

GPS

NAVSTAR Joint Program Office of the Department of Defense (DOD) established a program called the Global Positioning System (GPS) in the early 1970s to provide accurate location information (better than 25 meters) for military operations (particularly Trident submarines). As of 1995, the full constellation of 24 satellites was deemed fully operational. The program is divided into space and control components: the user community may be considered a third component.

The space component consists of 24 operational satellites that orbit in a constellation and ensure constant visibility of five to eight satellites from any place on the earth. The satellite or space vehicle (SV) transmits its estimated position and current time every second.

The control component consists of five tracking stations located around the earth. The stations monitor signals from the satellites to model each SV's precise orbital and clock parameters, These parameters, or ephemeris, are uploaded into the satellites for broadcast to GPS receivers.

The user community consists of users of GPS receivers, which convert signals broadcast by SVs into position (pseudorange), velocity (delta-range) and time estimates. Four satellites are required to compute the signals into X, Y, Z (based on the center of a fixed earth or earth centered-earth fixed (ECEF)) and time (weeks and seconds from 24:00:00, January 5, 1980) units. If one or more of the positions or time elements is known, fewer SVs are needed to compute the location solution.

Receivers compute a standard output to the pseudo- and delta-ranges. Location is converted to the World Geodetic Survey datum (WGS-84) and time to Universal Coordinated Time (UTC). Many GPS receivers convert the datum and time to more commonly used parameters such as the North American Datum 1983 (NAD-83) and local time. These reference points can be converted to local position coordinates by maps.

The SV broadcasts position signals worldwide making the information available to anyone, anywhere in the world who possesses a GPS receiver to demodulate the signal. Two bands of signals are broadcast: the Ll frequency (1575.42 Mhz) and the L2 frequency (1227.60 Mhz). Similar navigation data are sent on both frequencies. The Ll frequency is modulated using a spread spectrum technique, which mitigates noise and interference from the atmosphere and other radio frequencies. The Ll frequency carries the navigation messages and Standard Positioning System (SPS) signals; the L2 frequency carries similar information so the receiver may measure the difference between the two signals to detect transmission errors and ionospheric delay. The bundled Ll and L2 modulation signal can be used to calculate more precise positions and is used to determine the Precise Positioning System (PPS) signals. Only DOD authorized and specially equipped GPS units contain the cryptographic keys to decode the PPS information.

The U.S. DOD intentionally degrades the SPS signal to limit the accuracy for non-US. military and government users. The random noise that is added reduces the accuracy of the GPS solution to about 100 meters. According to the FRP: "[a]ny planned disruption of the SPS in peacetime will be subject to a minimum of 48-hour advance notice provided by the DOD to the USCG [U. S. Coast Guard] GPSIC [GPS Information Center] and the FAA Notice to Airman (NOTAM) system" (II). These notices typically are posted on the USCG GPSIC World Wide Web home page (16).

GPS receivers acquire a solution by fixing a line-of-sight on at least four satellites. (When approximating altitude, only three satellites are required.) The relationship of the four satellites determines the optimal geometry for a good solution.

This calculation produces a unitless measurement called the Geometric Dilution of Precision (GDGP). The acceptable range for a GDOP is 6 or less. The measurement can be decomposed into a Position (3 dimensions [3D]), Horizontal (2D), Vertical (height) or Time DOP The GPS receiver calculates the GDOP of all potential groups of four satellites and chooses the best constellation. Also, most GPS receivers output the GDOP measurement. See Table 7.

TABLE 7

ADVANTAGES AND DISADVANTAGES OF GPS

Advantages	Disadvantages
• Moderatelyaccurate • Globalcoverage • Moderate cost per vehicle	• Signal attenuation by foliage and tunnels (inside buildings); blocked by tall buildings • Subject to multipath errors

Source: (13), 1994 Federal Radio-navigation Plan and survey responses. Moderately accurate refers to relative accuracies better than 100 ft. but not worse than 150 ft. Moderate cost per vehicle refers to equipment purchase and installation under $2,000.

Vehicle Component

The vehicle component consists of a GPS receiver and antenna. The price of these units has fallen from over $1,000 just a few years ago to under $300 today. The cost of a unit for an AVL application may vary depending on quantity and functionality.

Infrastructure

The infrastructure consists of 24 satellites maintained and supported by the federal government.

Differential GPS (DGPS)

The majority of errors contributing to an inaccurate GPS solution arise from bias errors. If known, these errors may be taken out. The theory behind finding the error is that if a receiver knows its position, it can calculate the bias contributed by each SV signal. A differential GPS reference receiver observes the bias of each satellite in view based on knowing its own location. Corrections based on the differences between observed signals and predicted signals are transmitted to any remote GPS receiver with a communications link within coverage.

The accuracy of the differential correction depends on a number of factors, including expeditious transmission of differential correction, radio coverage, visibility of the same satellites, and receiver implementation. For the corrections to remove signal biases effectively, differential corrections should be applied to the signal at the remote receiver at an update rate “that is less than the correlation time of SA [selective availability].” (I 7)

Many GPS receivers are “RTCM” ready. That means that they have ports (RS 232) to receive corrections in a standard format specified by the Radio Technical Commission Marine (RTCM) and supported by the U.S. Coast Guard (USCG) (18). The USCG is currently installing a network of base stations that transmit differential corrections by radio beacons for the entire U.S. coastline. Many airports are investigating whether to establish differential monitoring stations to cover approach and landing requirements of their air traffic. The USCG differential signals will provide accuracies better than 10 meters; prototype sites are achieving accuracies on the order of 1 meter at 95 percent (2 sigma) predictable accuracies (19).

The FAA launched a program for a Wide Area Augmentation System (WAAS). This system will provide differential corrections and monitor the integrity of GPS signals. Initial operational capability is expected by 1998, at which time most land-based navigation applications will be capable of navigating with the system. Selective availability will continue to degrade signals, even though the U.S. Government expressed its desire to eliminate selective availability within the next 10 years. Currently, accuracies of 100 ft can be achieved without differential corrections.

Also, some locations have service providers who transmit differential corrections via a paging device using Radio Data Broadcast System (RDBS); the paging device costs about $400 and the service runs between $10 and $30/month depending on the level of accuracy required.

Vehicle Component

The vehicle component consists of a GPS receiver and antenna. The differential unit may also require a radio link that receives corrections from a differential reference station. A real-time radio link will increase the cost of the AVL system considerably.

Infrastructure

Most agencies using DGPS install and support their own differential station. Installation of a differential station requires a site for communication transmission and an all-in-view line of sight to the orbiting satellites on a surveyed location. The communications link may transmit the corrections to the GPS receiver installed in a bus or to the central control software, which computes vehicle location at the central site. Most DGPS base station vendors suggest a maximum coverage of about 200 mi from the reference base station. In cities with diverse terrain. the location of the differential reference tower may be critical for coverage. AATA purchased their differential reference GPS receiver for approximately $70,000 and installed it on an existing radio tower atop a single-story garage. The receiver is connected by landline to their central control facilities. Advantages and disadvantages of DGPS for transit are listed in Table 8.

TABLE 8

ADVANTAGES AND DISADVANTAGES OF DGPS

Advantages	Disadvantages
• Very accurate • Moderate cost per vehicle	• Signal attenuation by foliage and tunnels (inside buildings); blocked by tall buildings • Subject to multipath errors • Must be within range of differential signal • Differential correction must be updated frequently (adds to infrastructure costs)

Source: (13.19) and survey responses.
Very accurate indicates relative and predictable accuracies better than 10 ft.
Moderate cost per vehicle refers to GPS receiver costs between $1,000 and $1,200.

Dead Reckoning

Dead-reckoning sensors, among the oldest navigation technologies, measure distance and direction from a fixed point. From the earliest test and deployment of AVL for bus transit, the wheel odometer or compass provided the backbone or backup system of every navigation suite. These sensors are still found on many fleets as a secondary sensor. Also, unlike other sensor technologies, the dead-reckoning sensor is self-contained within the vehicle, requiring no infrastructure for its operation.

Dead-reckoning sensors are widely used to track and navigate different vehicle types. For example, both commercial and military aircraft still rely on dead-reckoning sensors such as gyros (measures attitude and heading) and accelerometers (measures acceleration) as their primary navigation sensors, and GPS as an "aiding" sensor. Automobile manufacturers use accelerometers to trigger airbags and differential odometers to drive anti-lock braking systems and for intelligent cruise control.

Most AVL systems use a wheel odometer as a backup to GPS or between signposts. The algorithm that interprets the distance does so by counting the number of wheel revolutions between two known points, e.g., signpost to signpost, bus stop to bus stop, or along a surveyed course. These techniques, known as calibration, are accomplished in different ways depending on the primary sensor used. For example, Halifax/MTD counts the number of "clicks" between bus stops, (a click is defined as eight wheel revolutions of the front left wheel). MTD drove a bus along each of its routes and recorded the number of clicks between successive stops along its 40 routes. This information, stored in its fleet management database provides the information to monitor the vehicle position between signposts. In their new system, MTD will count a click after only four revolutions, increasing the accuracy of the system from 250 to 200 ft.

Calibration is needed on a continuous basis because the tire dimensions change over time due to road conditions (e.g., uneven roads, pot holes, hills), tire wear, and tire pressure. The distance measured along a route may not correspond exactly to the path driven on any particular trip, as a consequence, the position will vary depending on distance driven.

Generally, agencies that use signposts calibrate odometers in different ways: NJ Transit, CTA, and LTC drive the bus over a measured course and count the number of wheel rotations per unit distance. Muni, KCATA, and STO apply a general correction factor based on average tire dimensions and wear. KCATA monitors distance traveled as part of their daily maintenance check. If the distance exceeds 5 percent of the expected limit, the odometer is checked and recalibrated. King County Metro estimates a calibration factor for each bus continuously through a trip:

> The calibration process generates a correction factor which is applied to the collected wheel revolutions representing the actual distance traveled between the last two signpost encounters. A major portion of the factor is weighted for all previous encounters by that vehicle. with the remainder representing the most recent encounter. In this way, the effects of tire wear are steadily calculated out of the actual distance traveled by the vehicle.

Another method of calibrating wheel odometers is by matching the distance, or distance and heading to a representation of the route or an actual geometric schematic of the roadway. The "strip chart" method, used in Toronto and Halifax/MTD charts the route as a straight line proportional to the route distance. The distances between bus stops and signposts are measured, so when the vehicle door opens or encounters a signpost, the distance is recalibrated.

The map matching method requires a digital base map that reflects actual distances and geometry of the road network. The heading measurement provides the system with information to determine turns on the network. Since the map matching algorithm knows or interprets the path taken, it recalibrates the position. Direction may be derived from an odometer on both front wheels (called a differential odometer) that detects the difference in wheel revolutions, or compass or gyro which detect heading. Though only a few agencies use map matching, the majority of these use differential odometers to determine direction.

Satellite-based radio positioning systems, due to their global tracking capability, can dynamically calibrate odometer sensors, as is the case with RTD and Tri-Met. (None of the surveyed ground-based radio positioning systems rely on a secondary dead-reckoning system.) Table 9 shows advantages and disadvantages of dead-reckoning sensors.

Hybrid Navigation Systems

Hybrid systems are combinations of multiple location technologies. In some cases, one location technology is used as a backup to another technology (independent hybrid systems); in other configurations, a primary sensor is "'aided" by other sensors. The *1994 Federal Radionavigation Plan* provides an example of a hybrid system combining a system having high accuracy and a low fix rate with a system of lower accuracy and higher fix rate producing a system that "'demonstrates characteristics of a system with both high accuracy and a high fix rate." (II, p. 3-41)

TABLE 9

ADVANTAGES AND DISADVANTAGES OF DEAD-RECKONING SENSORS

Advantages	Disadvantages
• Relatively inexpensive • Self-contained on vehicle (no infrastructure costs) • Only odometer needed (if assume on-route)	• Accuracy degrades with distance traveled (errors can accumulate between known locations) - Requires direction indicator and maybe map matching for off-route use • Corrupted by uneven road surfaces, steep hills or magnetic interference

source: (14,11, p. 3-41)

independent

Most current systems deploy backup sensors to take over when the primary sensor's measurements are degraded, out of range, not within view, or unhealthy. In most cases, the GPS or signpost technology are considered the primary sensors and dead reckoning the backup sensors. In such cases, the accuracy of the navigation suite is determined by the active sensor. As soon as there is a loss of signal for the DGPS estimate, the accuracy of the backup sensor takes over. In a study done by Sandia National Laboratories in conjunction with the Volpe Center and Denver RTD, researchers measured the positional accuracy of the differential and standard GPS position estimates (13). The tests collected data at 22 locations over a 3-day period on three separate occasions within RTD service area. They chose locations they thought were prone to satellite blockage, multipath, or communications interference or coverage problems (for worst case scenarios). The significant aspect of these tests were the sudden differences in positional accuracy when either the communication link was disrupted or one or more satellites were obscured (see Table 10). Sample data results for Point 107 show the sudden jump in positional accuracy that occurs when a satellite drops out of the line of sight or when there is a loss of the communication link to the differential base station. No smoothing occurs as part of the navigation solution.

TABLE 10

DATA RESULTS FROM POSITION ERROR RESULTS FOR TEE DENVER RTD TESTS FOR POINT 107
(at 16th and Curtis/Mall)

Time	Radial Error (ft)	Solution Type
10:36:18	65.58	DGPS 2D
10:37:45	7.98	DGPS 3D
10:38:18	10.49	DGPS 3D
10:39:58	27.11	DGPS 3D
10:40:23	194.16	GPS 3D
10:40:48	23.1	DGPS 3D
10:41:02	3.92	DGPS 3D

source: (14)

Aiding

Aiding systems optimize the strengths of the multiple sensors in a tracking filter by weighting the accuracy of the individual sensor estimates. In aiding systems, the dead reckoning sensor is often the primary sensor and the GPS or signpost is the aiding sensor. A filter estimates and removes the random errors produced by each sensor. KC Metro uses an aiding configuration to continually calibrate the vehicle odometer based on signpost locations. In GPS and odometer systems, a tracking filter estimates the drift and adjusts the measurements produced by me odometer using GPS positional data. Since odometer sensors estimate speed accurately for short periods of time, when the GPS is obscured, the optimization filter continues to estimate the drift based on the last known GPS position. The filter then ensures a slow degradation of the positional accuracy, not a sudden jump as demonstrated in Figure 4. Caskey suggests this solution in his presentation by saying: "there are advantages to using GPS as the back-up, especially in urban areas" where there are disruptions in satellite visibility and communications linkage. No studies have been done to demonstrate the utility of this technique for bus transit, though many studies performed for the DOD demonstrate the advantage of using optimization filters for locating military vehicles (13).

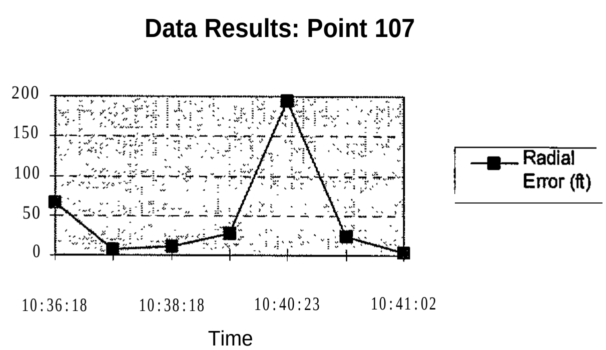

FIGURE 4 Data results of point 107.

COMMUNICATION TECHNOLOGY

Thirty percent of responding transit agencies used the procurement of a new communication system as a justification for purchasing AVL for their bus fleets. Most systems require a link to relay vehicle position to central control. In those systems (e.g., GPS, signpost, dead reckoning), the communication systems cost between 30 and 60 percent of the procurement. The communication system consists of mobile radio units (MRU), base stations, and relay stations. Larger systems include data communications processing capabilities to manage incoming voice and data traffic. These communication systems vary depending on size of transit agency, number of vehicles with MRUs, topography of region (e.g., mountainous or flat), and licensed/unlicensed frequency. With almost equivalent fleet size, Muni maintains nine base stations for complete coverage of 49 sq mi, while MCTO covers 2,500 sq mi with only one base station, According to both SMART and

MTD, a base station costs about $100,000 each to install on their property. Using 18 base stations to cover most of the state increased the proportion of NJ Transit's communications system to almost 67 percent of its AVL procurement.

Agencies whose existing communication systems can accomodate one or more data channels may save significant funds in procuring their system. KCATA's new procurement required replacement of only their signposts and vehicle transponders. The system specifications required that the new on-board location devices package the data according to existing protocols.

AVL systems have been integrated with both analog and digital, conventional and trunked, communication systems. Conventional radio allows for assigning "short slots" for the MRU to transmit location and identification data. A trunked radio system assigns an incoming voice channel to a dedicated pair or group of users. Large system integration of AVL with trunked radio systems requires additional processing to monitor channels for the transmission of short bursts of data, typical of AVL data. Because the data transmission requirements are significant, most AVL systems dedicate a separate channel for data transmission.

Switching systems or data control systems are required to manage incoming data. Many agencies monitor the location of their fleet every 1.5 to 2 minutes; some as frequently as every half minute, and some at 5 minute intervals. Emergency status information may require update rates as frequently as every 10 seconds, according to Denis Symes of FTA's APTS program. Generally, each vehicle is assigned a certain time slot for reporting its data. The data control system decodes, organizes, and transmits the data to the control center processing units.

Some transit agencies expressed frustration at identifying problems between the data control and radio communications. Denver RTD went so far as recommending the purchase of a turnkey system because of difficulties encountered by engaging a vendor for AVL and another for the communication system (20). King County Metro installed a LAN analyzer to capture the movement and timing in order to prevent data loss between subsystems. MTD/Halifax, acting as their own system integrator, required its contractors to build diagnostic tools at all the external interfaces to monitor data movement and timing.

INTERFACE COMPONENTS

An AVL system interfaces to other components of an AVM system that collect and disseminate information to groups both at and external to the transit agency. The data typically are transferred by a direct link to the navigation unit or processor, or the control center software, or via a communications bus, such as a local- or wide-area network (LAN or WAN). Until recently, a standard did not exist to tie in devices through a network configuration, particularly on the vehicle. Now with the promulgation of the SAE J1708 Smart Bus family of standards, most of the recent AVL procurements specify its inclusion. Moreover. with the industry moving toward the Open Data Base Connectivity (ODBC) and Data Communications Environment (DCE) standards, sharing information among multiple platforms in a distributed system is increasingly seamless.

Because of the lengthy development period for a new device, few operating systems have deployed the 51708 "vehicle area network." Most vendors specify a 51708 interface as part of their vehicle logic units (VLUs). The navigation unit and radio interface is typically contained within the VLU. Of the currently operating systems, The Vine, Milwaukee, and MCTO have VLUs with J1708 interfaces, Tri-Met is wiring their buses with a 51708 multiplex communications bus which will enable use of the J1708 interface. The APTS VAN Working Group is compiling a list of vendors who sell devices that are J1708 ready. Undoubtedly, this list will grow as more transit agencies begin wiring their buses with a VAN that is 51708 compliant.

On-Board External Interfaces

The typical interaction between the interface component and on-board AVL system requires the coupling of the device data and the AVL location (and time) stamp. For example, vehicle ID and current location are attached to an emergency alarm message. The list of potential on-board devices was compiled from the module identification descriptions in the draft MID/PID Utilization Guide (21), vendor system capability descriptions and performance and functional specifications developed by transit agencies. These interfaces are contained in Table 11 and Table 12 shows the frequency of on-board interface specifications in AVL procurements.

The devices most frequently procured or interfaced with the AVL system are listed in Table 12 and include the VLU, control head, silent alarm, and drive train sensor links. (Most of the early deployments disconnected the drive train sensors after dealing with too many false alarms.) Some agencies are including an interface to a covert microphone and video camera (e.g., Baltimore MTA), bus traffic signal priority communications device (e.g., CTA), automated passenger counter (e.g., KC Metro, CTA, and Milwaukee), and annunciator (e.g., COLTS).

Interfaces to Central Control Software (also called Computer-Aided Dispatch)

Most existing operational systems use a central processor to monitor their fleet in their dispatch centers. The processing and display capabilities vary. One of the simplest systems is a fleet management software package that enables SMMBL to query the location of a vehicle at a specified time and record its position (latitude and longitude, or nearest intersection). On the other hand, LACTA (in 1987) was one of the first transit agencies to develop a functional and performance specification for their control software. The software includes interfaces to the radio, telephone (automatic dial), and on-board devices, and databases with route/line descriptions, runs and time points, maintenance histories of each bus, operator information, digital

TABLE11

ON-BOARD EXTERNAL INTERFACES DEFINITIONS

Trip Recorder	To provide access to current or historical data obtained from the device's constant monitoring of the drive train and other devices through sensors/device monitoring. This includes accessing information from the electronic transmission (i.e., travel speed), door sensors, and wheel chair lifts.
Control Head	Driver display and keypad (or touch screen).
Vehicle Logic Unit	Primary on-vehicle controller, interface to the vehicle radio and power source for all J-1708 units.
Vehicle Destination Signs	To provide for the control and display of destination and other signage on the vehicle.
Annunciator (directly driven, pointer driven, wayside driven)	To provide audible and visual announcements of next stop, stop requested and other information, both on and off the vehicle from ASCII messages, from points to texts and announcements, or from pointers received from wayside detection devices.
Fare Collection	Point-of-sale interface with bus patrons, driver's fare collection interface, and the source of stop level fare collection detail.
Passenger Counter (post stop and real-time)	Determine the current number of passengers on the bus after pullout from a stop or report the boarding and alighting of passengers as they occur.
Schedule Adherence Unit	Calculate and report the vehicle's failure to maintain the planned schedule. (Some agencies may perform schedule adherence at their Control Center.)
Maintenance Printer	Provide any device on the 51708 bus with access to an on-vehicle printing device.
Vehicle Turntable Position	Report the current turntable angle of an articulated vehicle.
Bus Chassis Identification Unit	On demand, report the unique identity of a vehicle assigned by the local authority.
Smart Card Terminal	Interactive interface to smart card technologies.
Mobile Data Terminals	Processor, paging device, or dedicated display device for supervisors, police. or patron.
Silent Alarm (remote)	Provide for the remote generation of silent alarms on the vehicle.
Surveillance Microphone	Support remote switching of one of several microphones in the vehicle to the radio unit during emergency conditions.
Surveillance Camera	Support remote switching of a video camera in the vehicle during emergency conditions or normal operations.
Collision Avoidance Radar	To assist in the prevention of collision with other vehicles and/or objects through the use of the emerging radar sensor technologies.
Bus Traffic Signal Priority Communications Device	To provide for a generic interface between an intelligent vehicle logic unit and an on-vehicle traffic signal communications device. This device signals the next traffic intersection of a current readiness for priority advancement by the bus through the intersection, with transparency to the actual communications technology used by the local traffic controller (e.g.. radio, optic, inductive, etc.).

TABLE 12

FREQUENCY OF ON-BOARD INTERFACE SPECIFICATION IN AVL PROCUREMENTS

External Interface	Percent of Agencies that Specified Interface in AVL Procurement	Number of Agencies with Operational Interfaces
Control Head	66	10
VLU	100	14
Vehicle Destination Signs	41	3
Annunciator	21	1
Fare Collection	no known	–
APC	17	3
Schedule Adherence	24	7
Maintenance Printer	no known	
Veh Turntable Position	no known	–
Bus Chassis ID Unit	no known	–
Smart Card Terminal	no known	
Mobile Data Terminal	no known	
Silent Alarm	100	13
Surveillance Microphone	exact number is unknown	exact number is unknown
Surveillance Camera	unknown	1
Collision Avoidance Radar	no known	
Bus Traffic Signal priority Communications Device	3	–

maps with various display, level of detail, and analysis functionality. The software analyzes the performance of the fleet or each bus for headways and schedule adherence, sends/responds to messages from the control head, prioritizes all incoming messages from different sources (e.g., telephone, radio, pagers), alerts operators to emergencies, and more.

Of course, the difference in cost among AVL software packages can be significant. Whereas SMMBL purchased their software for $2,000, most control software systems cost on the order of $750,000 to $2.5 million including interfaces to existing scheduling and runcutting software products and map databases. In general, estimates of both vendors and survey data show the approximate cost of the central control software, hardware, and interfaces at just less than one-third of the total procurement cost of an AVL system.

Moreover, development of the central control software was cited most often as the most significant design and implementation problem encountered in new systems. In some places, system integrators could not meet the performance requirements for display and analysis. In other cases, no framework was in place at the transit agency to share, structure, and maintain core transit information such as bus stop locations, route descriptions, schedules and run data, or to maintain standard formats over time.

Interfaces to Other Transit Agency Departments

Similar to the issue of pulling schedule and run information into the central control software is the problem of collecting and disseminating it to other departments. Agencies dealt with sharing AVL data by including this function in the original procurement, specifying use of a database with an open interface standard, or saving it for a future upgrade. Of the respondents, only two did not include data collection as part of their procurement: and one of those two specified a recognized industry standard interface (i.e., ODBC) “so all data is available to all users on the LAN at the end of each day.”

The majority of respondents share AVL information with operations (transportation), scheduling, and service planning groups. Some agencies provide information to fleet. vehicle and equipment maintenance, customer service (transit information services), management, payroll and accounts receivable, safety, ITS, and marketing. Though some agencies still share data by printing out reports, others, such as the MTA and KC Metro have embarked on reconciling their diverse information systems so that they can share data electronically. Organizations such as Tri-Met that have developed agency-wide information systems, specify full data integration.

Transit Agencies, Traffic Management Centers, and Other information or Control Centers

With U.S. DOT promotion of integrated transportation infrastructure (ITI), many transit agencies are developing strategies for sharing AVL information with other control systems and information providers. KC Metro developed a World Wide Web site that displays real-time bus status information. Halifax/MTD interfaces their control system with GoTime, a customer information system that provides on-time departure information on a stop-by-stop basis. MCTO, in cooperation with Minnesota Guidestar project (Mn/DOT) and the FHWA, implemented a demonstration to display real-time bus status information through bus stop signs, kiosks, and on-line computer terminals, exploit bus travel times to validate corridor congestion levels, and provide closed circuit television feeds to the transit operations center. Many other agencies are discussing ways to integrate their real-time data with traffic management centers, information service providers, and other transit agencies.

Functions using AVL data include interfaces with control centers of the types described below.

Transportation information center

- AVL data provide real-time status information on bus arrival/departure times for connection protection with agency vehicles (e.g., paratransit, rail, ferry, subway) or neighboring service providers. The TravInfo Project, sponsored by the Bay Area Metropolitan Transportation Commission (MTC), will soon be online providing scheduled and real-time transit (over 45 providers) and traffic information. This information will become available to TravInfo partners to disseminate to their customers.

Some transit agencies disseminate real-time transit information through a variety of methods. These include audiodial, video monitor, variable message sign, kiosk, and speakerphone. STO and MTD have the most mature and comprehensive systems. Based on bus location, MTD’s GoTime estimates the departure time of each trip for each bus stop along a route. GoTime estimates the departure time if a bus is enroute, otherwise the scheduled departure time is used. The same information is disseminated through four different methods.

GoTime Audio Subsystem-Customers dial an exchange (465) and the 4-digit GoTime code associated with each bus stop (e.g., 465-1234, where 1234 is the GoTime code). The Audiodial system announces the next two departure times for buses servicing that stop. A bus stop may have more than one number if it attends to more than four routes. A switching modem system which handles 24 channels and GoTime software controls the appropriate response from the database. The system currently supports 1,333 bus stop codes though the agency maintains only 2,400 bus stops. System time tables identify bus stop codes for bus stops identified in the system schedule (see Figure 5). Users must be aware of their bus stop code in order to use the system.

- Four *Autodial telephones* placed at two locations in suburban malls automatically dial the GoTime Audio Subsystem and disseminate inbound and outbound information.
- *Speakerphones* are installed at strategic bus stops. The customer pushes a button and the speaker announces the departure times of the next two buses. The speakerphone responds with:

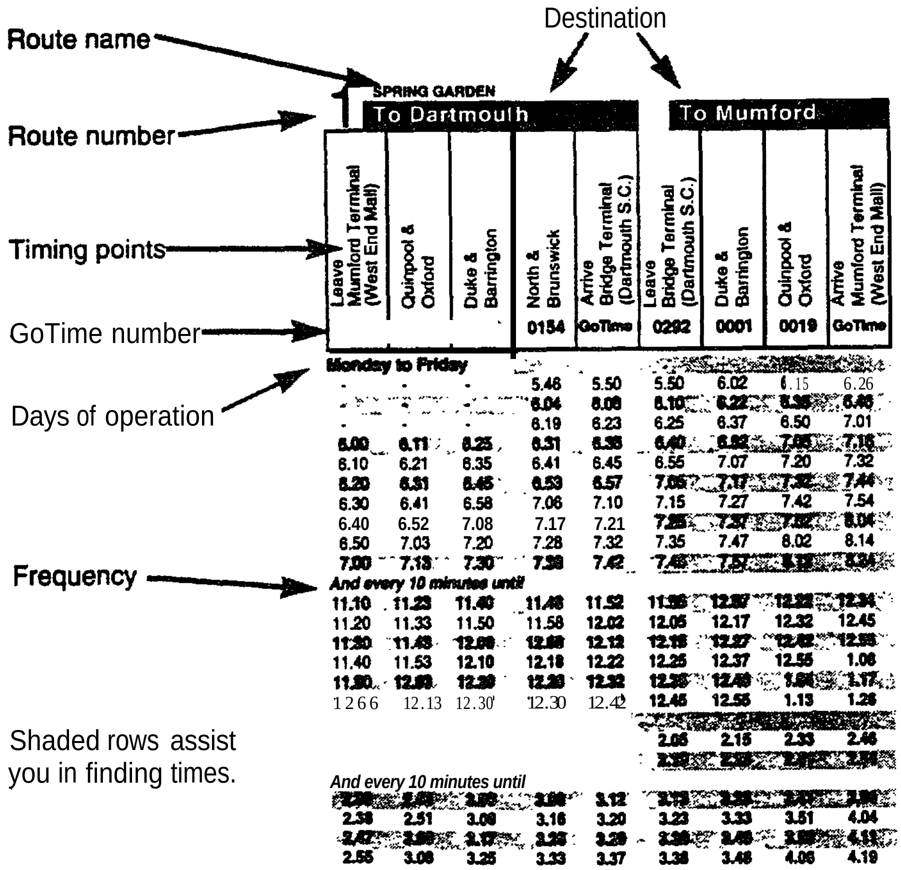

FIGURE 5 MTD time table instructions. Source: Metro Transit Division (MTD)—Metropolitan Authority (Halifax) Time Table

"Hello this is GoTime, the next bus on route xx will depart in 20 minutes." The speakerphones use the Audiodial Telephone system. Phones are preprogrammed with the bus stop exchange and code. MTD purchased, installed, and maintains the hardware on the telephone poles. The hookup was performed by the local phone company.

- Video displays (like airline displays) are located at 14 terminals throughout the metropolitan area in shopping malls and terminals. These monitors are located near shopping malls within transit terminals.

Traffic management center

A. Freeway management center

- AVL data provide congestion level information to transit software control system. Currently, no system integrates real-time travel times with dispatch software to predict actual bus travel times.
- AVL data provide travel times based on bus speed to freeway management centers (i.e., using buses as probes). The TRAVLINK (MCTO) program tested this concept using way-side AVI devices.

B. Local and regional management center

- AVL data provide congestion level information to transit control system. Currently, no system integrates real-time travel times with dispatch software to predict actual bus travel time.
- AVL data provide travel times based on bus speed to local/regional traffic management centers.
- AVL data enable the use of traffic signal prioritization for buses running late on congested arterials. Tri-Met performed tests to estimate the effect on the signal control system. The study did not produce any conclusive results. CTA is discussing operation with local traffic engineers to determine feasibility on long runs along major arterials.

Independent service provider

- AVL data provide real-time information on bus service to private enterprise to disseminate information for profit. Although the Metropolitan Boston Transportation Authority (MBTA) does not currently support AVL for buses, Smart Route Systems monitors dispatchers to provide exception status information to its audio-text SmartTraveler program.

Bus, subway, train, or light rail operations center (otherproviders or within an organization)

- AVL data provide real-time schedule adherence information to other transit operations centers for connection protection or to coordinate emergencies. Some agencies are discussing the exchange of real-time information once their AVL is fully deployed.

Maintenance and emergency operations

- AVL data provide information on incidents and emergencies occurring on or near a transit vehicle, including transit police, local police, state patrols, supervisors, and maintenance dispatch operations. Some agencies provide their transit police and/or maintenance departments with a software control terminal to monitor emergency messages. In most cases, the control software includes an autodial function and maintains phone numbers for emergency operations including transit police, local police, fire, and EMT.

CHAPTER FOUR

INSTITUTIONAL CONTEXT OF AVL

Institutional issues related to AVL development and operations include bringing AVL into an organization and changes affected by its deployment. These issues include the how and why of funding, the procurement process, changes to the organization that affect staff, and reengineering transit roles and responsibilities. No formal studies were found that addressed these issues. The information contained in this section is based on responses to the survey and conversations with transit professionals and consultants involved in AVL for bus transit.

FUNDING ISSUES (COSTS)

An AVL system is a significant investment. A few years ago, a number of agencies issued requests for proposals, thinking that system costs would be on the order of a few million dollars. They withdrew their procurements after receiving cost proposals from vendors that in many cases were three to five times the original estimates.

System Funding

Many AVL systems procured and installed prior to 1995 received limited funds from various federal programs for transit demonstration or lTS operational tests that permitted small-scale AVL installations. Because many of those sources are no longer available, transit agencies are applying for grants from traditional sources (e.g., Section 9).

Many agencies with deployed systems cited the need to require itemized costs from contractors, though few possess this information. Table 13 lists the transit agency, number of vehicles with installed or procured systems, total cost, additional components integrated with the AVL, and approximate cost of AVL system per bus (if provided by the agency). Respondents were asked to itemize the AVL component costs in addition to other components, map database, control software, radio, and VLU. These costs are listed in Table 14. Although respondents itemized their costs, specific delineation of the particulars was not always included in survey responses. Some elements include more value than others, for example, equipment costs may or may not include installation, mobile and fixed devices were combined or separated into two categories, control software may connote only fleet management display capability or complete computer-aided dispatch/schedule adherence functionality.

Training

Significant amounts of time and interest are devoted to training. A respondent identified training as "critical to efficient operation," particularly training nontechnical staff to use technical equipment, an issue mentioned several times in the survey responses. One respondent identified the need to provide "lots" of training to dispatchers, since the software is usually very complicated, having multiple display capabilities, information resources, and processes.

Few agencies referenced their training costs in their responses to the survey (see Table 15); many do not know. The most widely cited issue related to training was the delay between training and on-line operations. Most respondents and operators needed to retrain their operators and dispatchers prior to acceptance testing. Generally, staff are trained as the equipment is installed on the vehicles so they are prepared as soon as the system is operational. (Table 16 provides the training schedules of responding agencies.) KC Metro described the paradox of this situation:

> All operators had to be trained before any equipment was installed . . . so that they would know what to expect when assigned a bus with the new equipment. On the other hand, it was quite a while after installation before the central computing functions of the data radio/AVL system were ready for testing.

Many agencies encountered delays due to software changes or other technical glitches prior to deployment. As a consequence, their operators did not use the equipment in the buses for months, and their dispatchers could only practice if fleet management software (connected to the AVL equipment) was made available to them. LACTA dealt with maintaining dispatcher skill levels by keeping a few software control systems on-line for dispatchers to rotate through. MCTO stationed a trainer with a portable control head in the operators' meeting/lunch room to review procedures and answer questions with the operators prior to their shift.

Annual Maintenance

Many systems have not yet accumulated enough years experience to quantify the costs related to annual maintenance. Those who responded to the survey reported the obvious maintenance costs-software updates, map updates, signpost batteries, and parts replacement (see Table 17.) New systems are usually procured with warranties and maintenance contracts. Respondents reported that warranties began after a subsystem was installed, followed by maintenance contracts. Delays in implementing the system may create different views of when the maintenance contract/warranty begins. For example, communications problems that arise after the communications subsystem warranty has expired may fall into other subsystem warranties or into the communications maintenance contract.

TABLE 13

TOTAL SYSTEM COSTS FOR AVL

Short Name	No. Vehicle	Total Cost ($)	Radio System	Control Head/VLU	Schedule Adherence	CAD	Public Information	Enroute*	Phone*
Arc Transit*	14	440,000	N/A			x			
AC Transit	717	11,200,000	N/A						
BCTA	36	201,151	x				x		
CAT	52	600,000	x	x		x	x		x
COLTS	32	357,935	x	x	x		x		
DART*	1200	16,400,000	N/A			x	x	x	
Houston Metro*	1750	22,000,000	N/A			x	x	x	
HSR*	240	6,000,000	N/A			x			
KC Metro	1148	15,200,000	x	x	x	x	x		
KCATA	245	2,172,264	x	x	x	x			
Kitsap Transit*	155	600,000	N/A			x	x	x	
LACTA*	2085	12,000,000	x			x			
LTC	160	2,000,000	N/A			x			
MARTA*	250	7,000,000	N/A			x			
MCTS	541	7,800,000	x	x	x	x			
MDTA	614	14,000,000	x			x			
MTA	844	8,100,000	x	x	x	x			
MCTO	80	1,500,000	x			x	x	x	
MTD/Halifax	170	2,400,000	x	x	x	x	x	x	x
Muni	950	3,000,000	N/A						
NFTA	322	10,000,000	x	x	x	x			
NJ Transit	1990	31,000,000	x		x	x	x	x	x
NYCT	170	5,230,000		x	x	x	x	x	
RTD	900	11,000,000	x			x	x	x	
SMART	400	2,700,000	x	x	x	x			
SMMBL	135	131,779							
STO	186	1,500,000	N/A	x	x		x		x
STS*	20	100,000	N/A						
Sun Tran	200	3,500,000	N/A	x	x		x	x	x
TARC*	257	2,500,000	N/A			x			
The Vine	18	130,000	N/A			x	x		x
Tri-Met	630	6,600,000				x			
TRT*	151	2,000,000	N/A						
TTC*	2300	38,000,000	N/A			x	x		
VIA	500	3,266,840	x	x		x	x		

*Information from *APTS State of the Art (4)*.

Respondents question if maintaining these systems will prove to be "overly time-consuming and complex." Advice given by agencies includes involving the mechanic responsible for installation "right from the start" and require self-diagnostic software in major subsystems. This will ensure that the agency mechanic is familiar with the diagnostic tools and can identify the source of the problem before calling in the warranty. Computer system problems and data integration have also been identified as requiring maintenance. MTD has trained, on-call staff who handle all failures, and 24-hour service contracts with their vendors. In addition, they contracted the software vendor to input service changes into their control software when necessary.

Examples of specific maintenance issues reported in survey responses relate to odometer calibration and battery replacement schedules. Because early signpost/odometer systems experienced significant problems, many agencies, such as KCATA and KC Metro, included odometers on their preventive maintenance schedules. Odometers were checked on a daily basis at KCATA to ensure correct calibration. Also endemic with the early signpost systems was the short battery life and the need for frequent replacement. The 3- to 5-year life span for newer battery-based systems has eased the maintenance costs.

For agencies providing real-time travel information or connecting systems by landlines, telecommunications charges may become significant on-going maintenance costs. MTD pays out $65,000 (Canadian dollars) per year to maintain GoTime, a real-time bus information system; SMMBL pays for telephone lines to connect to their service provider.

JUSTIFICATION ISSUES

The survey solicited input on the factors and benefits that convinced the agency to procure AVL. The primary reason was customer service: AVL improves service quality and provides real-time information to increase ridership. MTD justified a second generation AVL procurement as "being able to provide an AVL/C System at the same cost as a . . . public information

Cable*	Bus Stop Display	On-Board Display	Annunciator	In-Vehicle*	Smart Card*	APC	Engine Probe*	Silent Alarm*	Signal Prioritization	Fare Collection
					x					
	x	x	x							
								x		
x										
	x	x	x					x		
							x	x		
				x			x	x		x
						x		x		
						x		x	x	
								x		
								x	x	
							x	x	x	
							x			
				x		x		x		
						x		x		
							x	x		
								x		
						x				
	x							x		
								x		
x	x	x								
								x		
	x	x				x	x	x		
								x		
							x	x	x	
								x		
		x			x		x	x	x	
		x	x			x	x	x		
						x	x	x		
								x	x	
						x		x	x	
							x	x		
				x				x	x	
	x									

system." They supported this justification with a 2 percent increase in ridership, and a ridership survey that showed a high approval rating for their current AVL based public information system. Other factors, ranked in order, include:

- need for a new communication system,
- schedule adherence,
- availability of funds,
- safety,
- efficiency (potential savings),
- perceived value,
- increased data collection (e.g., engine monitoring).

Perceived value refers to the value for the dollar. Closely related to efficiency, this term reflects the desire to apply advanced techniques to transit services.

STAFFING ISSUES

Introduction of advanced technologies creates changes in the work place; AVL is no exception. Since the major focus of agencies is to provide bus service, AVL can enhance the effective use of resources, collection of data, and dissemination of information. In theory, AVL deployment changes staff skill requirements and reengineers the processes supported by existing systems. These changes affect those who run the services or make use of the data collected by the operations, and issues such as privacy, user acceptance, and adaptability emerge. Respondents indicated that key issues (e.g., work load, work rule, supervisor, staff buy-in, training, organzation, and skill set) were different based on how the technology was introduced to the organization. These are discussed in the following paragraphs.

Work Load Issues

In addition to training requirements, dispatchers' work loads increase if they are not expert in schedule adherence software. MCTO personnel commented that during the first few months, dispatchers were overwhelmed with not only

TABLE 14

ITEMIZED COSTS FOR AVL COMPONENTS

Short Name	Bus Location Tech	Bus Location Tech and VLU	Other Bus Comp	MRU and VLU	Control Center	Equipment and SW	Roadside Components
AC Transit	42,595						
BCTA			500/bus	5500/bus	31,000		
CAT							
COLTS	122,610		23,000	127,634			
KC Metro							
KCATA			1,694,480		289,990		
MCTS		2,600,000	400,000	2,500,000[*1]	400,000		
MDTA						12,000,000	
MTA	3,000,000		1,000,000	2,100,000	1,000,000		
MCTD				280,000		711,000	140,000
MTD/Halifax						750,000	1,500,000
Muni				3000/bus			
NYCT	12,188/bus		2,302/bus[*2]	1,354/bus[*3]	758,412		54,172
RTD			617/bus				
SMART				5400/bus	262,000		300,000[*4]
SMMBL	450/bus						

Short Name	Map Database	SW Support & Licensing	External Funding	Installation	Planning	Design	Implementation	Acceptance Testing
BCTA				10,605				
CAT			350,000					
COLTS	2,000		76%–FTA	16,000	7,500			
KC Metro			500,000					
KCATA		29,980	80%–FTA	156,800[*5]				
MCTS				1,900,000	370,000	See plan		344,500
MDTA			80%–Sect 9		1.5 M (all phases)			
MTA	20,000[*6]							
MCTO	72,000	100,000	100% MNDOT[*7]					
MTD/Halifax			50% Prov					
Muni			2,400,000					
NFTA			85%–FTA/ NYDOT		10,000	163,000		
NYTA		67,715				135,431		135,431
SMART		3600	100%–FTA	600/bus				
SMMBL		24,000						
SunTran					20,000	30,000	100,000	
The Vine			Vendor Prototype					
Tri-Met			80%–Sect 9		150,000	6,300,000		

[*1]mobile and fixed.[*2]APC, [*3]interface existing MRU with AVL,[*4] 3 base stations,[*5]includes radio and AVL devices,[*6] includes 25 licenses, and [*7] ITS Operational Test funding for Public-Pvt Partnership.

TABLE 15

EXAMPLES OF REPORTED TRAINING COSTS

Short Name	Total Cost ($)	Training Cost
MCTS	7,800,000	301,000
MTD/Halifax	2,400,000	40,200
Muni	3,000,000	28,800

managing the radios as they had before AVL deployment, but now assuming additional display windows, messages, and instructions. During the transition at the MTA, dispatchers had to work with two systems. Yet, those dispatchers who have used AVL control center software do not willingly relinquish it. Only at one site did an agency use the fleet software as an auxiliary tool for dispatchers.

In general, an AVL system reduces the amount of paperwork for dispatchers and service planning personnel who collect data, and monitor schedule adherence and performance. Supervisors make better use of their time because they are no longer required to perform on-time performance checks. Moreover, call prioritization allows dispatchers to handle calls at their own speed, which results in reduced stress and an improved quality of communications.

TABLE 16

TRAINING SCHEDULES

Transit Agency	Training	Communications	Component Maintenance	Customer Service	Daily Maintenance
BCTA				20 hours	
COLTS					
KC Metro			correspond. course		6 months (ojt)
MCTS	thru installation				
MDTA					
MTA		40 hours	48 hours		48 hours
MCTO					
MTD					
NFTA			6 weeks		6 weeks
NJ Transit			4 hours		
RTD			8–10 weeks		8–10 weeks
SMART			2 days		
SMMBL					

Transit Agency	Dispatchers	Field Super	Mgmt	MIS	Operators
BCTA			40 hours		
COLTS	5 days				2 hours
KC Metro	24 hours	2 hours	8 hours	6 months	2 hours
MCTS	30 hours				
MDTA					
MTA	48 hours		3 months		48 hours
MCTO	8 hours				2 hours
MTD	2 weeks	2 weeks			4 hours
NFTA	2 weeks	1 week	1 week	1 week	1 week
NJ Transit	4 hours	0			1 hours
RTD	4-5 weeks	1-2 days	1 week	3-4 weeks	2 hours+
SMART	10 days			5 days	

TABLE 17

EXAMPLES OF AVL ANNUAL MAINTENANCE COSTS

Short Name	Annual Maint	Annual Maint (HW)	Annual Maint (Map)	Annual Maint (SW)	Annual Maint (Roadside)	Maint (average cost/parts/yr)	Other
BCTA	250*1						
COLTS					2,500–3,000		
KC Metro	885,000	775,000	10,000	100,000			
MCTS	306,000						
MDTA	500,000						
MTA	138,000						
MTD/Halifax				36,00*2			78,000*3
Muni					11,000		
NYCT				270,862			
SMMBL	31,375					7,000	24,000*4

*1average cost/vehicle/year, *2year 1; 32k Yr 2; 28k Yr3; 24k Yr 4+, *3annual costs include: 12k raido licenses; 1.1k batteries; 65 k telecommunications, and *4annual service fee.

Work Rule Issues

The control software permits supervisory staff to closely monitor operator behavior. This includes checking for late/early departures from scheduled locations, traveling off route, speeding, indication of drive train alarms, and other work rule violations. Most respondents have dealt with this issue through education and training, emphasizing the security aspects of the technology. Only in one case did a respondent report that the union requested a Memorandum of Understanding so that the information "could not be used for disciplinary purposes." In fact, much of the information is used to benefit the driver, such as proactively alerting the driver to early/late departures and documenting actual departure times, which can then be compared against customer complaints.

Supervisor Issues

Supervisor issues reflected the relationships between field supervisors and control staff. A number of respondents mentioned the shift of overall responsibility from the field to the control center, which now had a systemwide view of the fleet (see Effect on Operational Strategies section). In certain agencies, this shift caused work rule changes because field supervisors had seniority over dispatchers. Another respondent acknowledged that union regulations prevented them from eliminating positions or shifting field supervisors to the control center.

StuffInvolvement

Most agencies attempted to involve the major departments in the development of the AVL system. Respondents agreed that involvement led to "buy-in." Table 18 lists the groups that survey respondents indicated were engaged as part of an AVL procurement. Generally, *Operations* (also known as Transportation) took the lead in planning, procuring, implementing, testing, accepting, and operating the system. *Maintenance* was a key player in the process; most respondents identified maintenance personnel as installing or overseeing installation of the on-board equipment. One respondent recommended that the "installer" be included in discussions from the earliest planning phase. *The dispatchers* were involved in identifying the control software interface and functionality. They also participated in testing the software. *Service planners* participated in developing performance metrics for the control software during the needs assessment. The control software measures schedule adherence based on time points for scheduled trips or runs.

To this end, scheduler data are key to meeting operational objectives. Cooperation from Scheduling was identified by respondents as well as vendors as critical to ensuring the continued success of the AVL. The interface between the scheduling software and AVL is affected every time the schedule is changed. One agency changed their scheduling software midway through the implementation phase leading to a significant delay in deployment. Other information such as bus stop, layover. dead head, and comfort station locations, operator assignments. and blocks need to be included in many of the currently deployed control center software systems. Much of this information is managed or created by service planning or by the garage. As in the case with the scheduling software, once the AVL system is deployed. changes in file structures affect automated input procedures and may cause delays or require manual processing to ensure up-to-date information.

Administration participated in the need? assessment and procurement process. One respondent exclaimed that AVL "really is their program." The other participants listed in Table 18 participated primarily in the needs assessment/requirements analysis phase.

Skill issues

The skills required for developing and maintaining an AVL system cannot always be acquired by personnel on staff. Supervisors and dispatchers may be trained in using decision sup port tools designed to perform specific functions maintenance staff learn on the job, through correspondence classes, or in short courses. Yet respondents agreed that the AVL system, because of its reliance on communications and computer technologies, data processing, programming, and spatial data collection and analysis requires specialized skills that are highly competitive in the marketplace. These responsibilities may be spread among different individuals in various departments in an organization. The CTA centralized these responsibilities into a single group, included expertise in AVL, software engineering, geographic information systems, communications, maintenance and more, and formed strong alliances with staff from other departments who may affect the data or operations of the AVL system.

Data integration expertise is cited by many respondents as key to deploying and maintaining an AVL system. The AVL requires planned and unplanned updates of the map database, runs, route schedules, bus stops, and personnel. The update is usually instigated by the software engineer or an information systems staff person. Yet, the utility of the system is based not only on data entering the system, but also, in using the data to monitor performance, fine-tune service planning models, and identify marketing opportunities. Although much of this information is accessible with management reporting tools, the data integration specialist ensures the quality, timeliness, and accessibility of enormous volumes of data output by the AVL system in addition to the accurate correlation of AVL with other advanced technology systems (e.g., passenger counters, customer information). Thus, the expertise is needed over the long-run, not just during implementation. For example, even after a year of assessing the system's feasibility, designing a plan, and beginning implementation, KC Metro's designated "data integration specialist" is still working on maximizing the widespread use and integration of their AVL data.

This specialized expertise and high demand sets up a dilemma for the transit agency. Staff turnover often occurs when a junior level person trained to perform these duties is enticed to a private sector position where salaries are generally higher than transit can offer. Some agencies are contracting out or hiring "permanent" consultant staff to bypass a salary cap. MTD set up a contract with their software vendor that included loading,

TABLE 18

INVOLVEMENT OF STAFF IN AVL DEVELOPMENT

Staff Buy-In	Involved in Process (%)
Operations	93
Maintenance	83
Dispatchers	80
Service Planning/Scheduling	70
Administration	63
Consultants	60
Field Supervisors	57
Operators	53
Customer Information	47
UnionRepresentatives	33
FTA Technical Support	23
Marketing	23
MIS	3

collecting, and reporting all necessary data. The CTA established a position for a permanent consultant to lead their software engineering responsibilities, including building and maintaining their database management system and their geographic information system, and updating and verifying their data.

PROCUREMENT ISSUES

Many of the early problems with acquiring new AVL systems may be attributed to the procurement process. Many procurements were released, later to be retracted: some procurements encountered major litigation. One respondent summed up the situation:

> With few exceptions, companies are offering new technologies/second generation equipment that has not been integrated and installed yet. This requires contractual language to protect the property that scares away all but the largest companies, and makes integration/acceptance testing very crucial.

From the vendor viewpoint, transit agencies are unrealistic about cost, schedules, capabilities and technical issues. For many transit agencies, this may be their first large advanced technology purchase. Previous contracting selection criteria for some procurements may not be appropriate for AVL. As an example, a few respondents cited the change from the two-step process: prequalifying and accepting low bid (the method used by six responding agencies) to a competitive bidding or negotiating practice (used by 10 responding agencies).

In many cases, AVL systems cannot be readily compared. The software functionality differs, the number and types of interfaced components differ. This makes comparing the quality among systems difficult. Baker et al. (20) recommend a number of methods to address these concerns:

- Require unit pricing and separate start-up costs. This strategy will allow reasonable estimation of downsizing or expanding the scope of the project.
- Establish clear, detailed proposal evaluation criteria and include the definition of numerical values that have potential for assignment to each quantity so evaluators have a well defined standard for assigning such point values. Put evaluation criteria consideration points in the specification.
- Prepare a manual that details how each step in the procurement process will be conducted.
- Require a noncompliance table in the proposal. This permits a starting point for rapid identification of those features that will not be supplied.
- Consider using a competitive negotiation contractor selection process. Competitive negotiation will permit bid revision; avoid low bid requirement: allow re-scoping or re-sizing to fit the budget; permit clear understanding of terms and deliverables; allow adjustment of specification to gain greater functionality and/or lower cost: and permit discussion of legal concerns, possibly reducing the often lengthy, post contract approval signing process.

Though no respondent specifically addressed changing from the traditional procurement process of contracting the design and build phases separately, many studies and articles have been published in ITS related compediums and journals that recommend a design/build process for procurement to reduce the deployment schedule and mitigate the risk of deployment. Specifically, in a study prepared for the Maryland State Highway Administration and subsequently presented as an unpublished paper, Brian Cronin (22) cites six concerns addressed by a design/build approach:

1. A project has to be done in a limited time frame.
2. The owner lacks expertise in the subject area.
3. The owner wants to shift liability to the contractor.
4. The owner wants to lessen the administrative burden.
5. A fixed cost can be assessed in the project development stage.
6. The owner hopes for innovative solutions to the problem.

Though no “design/build” model has been accepted as the industry standard, Cronin presents general steps derived from a few DOT procurement processes. The process may be condensed into two major steps: (1) develop project concept, and (2) design and construction. Many transit agencies procuring AVL have already adopted this paradigm, for example, BCTA hired a consultant to develop a concept plan and performance specifications for their Mobility Manager: the next phase includes hiring the contractors to do the design and construction. Houston Metro required a partial design as part of their vendor proposals, the chosen vendor will complete the design and begin implementation.

CHAPTER FIVE

ROLE OF AVL FOR BUS TRANSIT

Objectives for AVL systems emphasize improving bus transit operations and include improved reliability, increased safety, and better performance. Yet, the means of achieving those objectives through AVL are not well documented. The discussion in the previous section on procurement and staffing reflected changes to staff responsibilities and organizational issues. Key success factors related to both implementation and operational strategies are discussed in this section.

OBJECTIVES OF AVL IMPLEMENTATION

The lists of objectives and justification factors are closely related. Of agencies responding to the survey, the majority identified schedule adherence as their number one objective for implementing AVL. Safety and security, performance monitoring, public information, improved communications, improved fleet management, and improved management system were other objectives.

Schedule Adherence (56 percent)

Agency staff tend to link improved service reliability with increased ridership. One respondent stated as an objective: ‘More reliable service, faster service, better passenger information and ultimately, more riders.” Another related aspect of schedule adherence is protecting connections and guaranteeing timed transfers, particularly “between regular and feeder services” and “linehaul and paratransit” services.

Safety and Security (48 percent)

Generally, respondents stated that they felt secure in knowing the location of the buses to ensure the safety and security of operators and customers. Specifically, this objective relates to improving “emergency response time” when an accident or incident is reported. This objective refers to the operator alerting the central dispatch of an emergency either directly through a permission-to-talk feature on the control head or a “silent alarm.”

Performance Monitoring (40 percent)

The difference between performance monitoring and schedule adherence is timing and scope. Generally, performance monitoring, tasked to Service Planning or Scheduling, seeks to “improve . . . [the] accuracy of schedules,” “reduce fleet requirements in peak,” “improve safe increase in speeds,” and ultimately to “reduce operating costs” and “introduce more efficient systems.”

Public Information (40 percent)

Though many respondents cited public information, this objective is scheduled for phase two of many AVL procurements. Many transit agencies see real-time schedule information as a means of “improving public communications and marketing” and addressing ADA requirements with in-vehicle annunciators and displays. Only two respondents (MTD and STO) cited public information as their sole objective. Both operate the most advanced real-time bus status systems in North America.

Improved Communications (20 percent)

Many transit agencies procure AVL in conjunction with a new communication system. One respondent cited that “the radio system was in need of replacement and it was the relatively low cost of adding on an AVL system to the radio procurement making a more modem communications system.” Specific concerns relate to decreasing the voice traffic on the radio, sometimes decreasing the volume by as much as 50 percent.

Improved Fleet Management (20 percent)

This objective is broader than schedule adherence, because it includes the entire fleet, but is related to more immediate operational concerns than performance monitoring. Improving fleet management is concerned with better utilization of field supervisors, improved ability to adjust on-street operations, and the ability to create “electronic HOV lanes” through signal prioritization.

Improve Management Systems (8 percent)

This objective identified the ability to collect and share better quality data for improved decision making. The few respondents who identified this objective were those with operational systems.

AVL PROJECT FRAMEWORK

Respondents were asked to describe the major issues faced during the various phases of AVL development and deployment.

TABLE 19

DURATION OF PROJECT PHASES

	Total System	Bus Location Tech	Other Bus Component	MRU and VLU	Control Center	Planning	Design	Installation
COLTS	9 months							3.5 weeks
MCTS	4 years+					1 year	1 year	
MTA	2.5 years	21 months	6 months	18 months	6 months	8 months	12 months	18 months
MTD	3 years							
Muni	2-3 years							
NFTA	2 years	2 months	2 months	2 months	3 months	6 months	6 months	6 months
NYCT	1 years							
SMART	13 months						3 months	9 months
STO	l-2 years							
Tri-Met						2 years	12 months	26 months

These phases included planning, design, integration, implementation, acceptance testing, training, and evaluation. Deployment schedules varied depending on the organization size, number of buses deployed, and complexity of the software. For example, COLTS deployed 32 vehicles with a GPS system in 9 months, whereas MTA's development of a DGPS system for 844 vehicles was scheduled to last 2.5 years. Technical issues effect the duration of each project. The earliest GPS-based AVL systems encountered many unforeseen problems; schedules suffered as a result. Table 19 lists examples of project duration.

Planning

The planning phase included concept development, understanding the various technologies, developing specifications, estimating the budget, acquiring financing, and procuring a system.

Understanding the Technologies

More than 62 percent of the respondents indicated that they hired consultants to help them understand the various alternatives and to develop performance or technical specifications. Many survey responses suggested that the technology was very new, and continuing to emerge. In particular, one respondent wrote that "the rate at which technology changes and the resultant paradigm shifts required changes in the midst of the planning phase." This sentiment reappears in responses related to all the phases.

Closely related to this view, respondents who deploy new technologies, such as KCATA and Muni in the 1980s, and RTD most recently, expressed frustration about the lack of "technical and operational information" available on the technology.

Specifications

Baker et al. (20) emphasized the importance of the contract specification. Based on delays resulting from legal issues, KC Metro was constrained to use a dated contract specification that identified specific technologies for their system. By the time of award, the older technologies "did not adequately refleet Metro's current thinking on operational needs, software requirements, system integration issues, and new technological capabilities." The agency and contractor needed to resolve those issues during later stages of system testing and implementation. Both RTD and CTA recommend detailed, nonambiguous specifications and requirements that describe equipment, geographical data, user interfaces, fleet size and spare requirements, and compatibility with in-house information. Separately, BCTA emphasized the development of performance specifications that define the performance and functional requirements of the system (personal communication, B. Ahem, 1996).

Survey respondents agreed on the importance of preparing specifications, although they were divided on whether technical or performance-based specifications were more critical. Fifty-five percent of the respondents prepared performance specifications, 45 percent prepared technical specifications, and 34 percent developed both. Tri-Met indicated that industry review of their draft performance specification increased vendor participation in the process.

Estimating Budget

The most often cited issue during the planning process is the lack of good information on "accurate, reliable cost estimates for budget development." More often than not, agencies release a Request for Proposal and receive bids that exceed their funding levels. Many agencies get cost estimates from other agencies who undergo the process, yet few of them have precise data on the various costs comprising equipment, software, and integration.

Acquiring Financing

A major concern during the planning phase was identifying funding sources. Most agencies indicated that they received a federal matching grant to procure the system. Most systems procured between 1991 and 1995 received funding grants from the Federal Highway Administration's ITS Operational Test program Within the past year, agencies have secured funding from traditional granting sources such as Section 9 monies.

Design

The major design challenge involves data issues: schedule data formats, map data set accuracy, and integration of routes, bus stops, and map database. Particularly for DGPS, system performance depends on an accurate geographic representation of the road network. MTD considered deploying a GPS-based system, but could not procure a map for the province that provided the necessary accuracy requirements because it was considered cost-prohibitive. Initially, RTD used the Denver TIGER/Line File, a map database developed by the U.S. Bureau of Census. This data set was not complete nor uniformly accurate for all roads overlaid with transit routes. Map updating to the required quality level, though not as costly as the development of a new one, was expensive and time consuming, according to RTD's contractor .

A second data issue concerns transferring scheduling data into the fleet management/schedule adherence software. Initially, the vendor developing KC Metro's management software planned to "deliver, additional hardware and software tools to support [manual] data entry of the scheduling information. However, this decision was later reversed when it became clear that the volume of scheduling changes and the timing of their availability before the service change would present an overwhelming data entry task." An automated software solution is necessary because of the periodic updates of schedules. Customized interfaces are developed to transfer scheduling/runcutting data to AVL management software packages. In one case, the transit agency changed commercial scheduling packages during the test phase, requiring their vendor to rewrite the interface.

The third data issue concerns geocoding time points and route alignments into the map database. Some agencies, such as Tri-Met, LACMTA and KC Metro, use their own digital base maps with the AVL management software. These maps are maintained and verified as part of their daily responsibilities As data sets are updated with new and altered bus routes, streets, and bus stops, they are input into the system. Other agencies rely on the vendor to supply commercially available maps. The agency pays for the automation of transit features-bus stops, time points. and transit routes-into the map both for display and analysis. Because many transit agencies do not maintain a complete set of time points with precise location information (e.g., latitude/longitude or address) or transit routes with all the street designations, the geocoding becomes a costly and time consuming effort. Some vendors install a DGPS unit and data recording device in a vehicle to register time points and map routes.

Integration

Two types of issues were identified by respondents during the integration phase: transferring data from other sources such as scheduling software and map databases; and interfacing with other devices such as silent alarm and annunciator. Most respondents implementing DGPS solutions cited "quality of GIS data . . . [and] difficulty of integrating GIS, scheduling and bus stop data" and "reliability of data transfer" as significant issues. One respondent elaborated on his response, saying:

> Proper AVL system operation is contingent on having a complete and accurate 'picture' of what the bus service [should do] . . in the form of schedules and spatial route patterns.

Data collection and integration are significant sources of hidden costs in the AVL procurement, yet, in only 3 percent of the responses were staff from Management Information Systems (MIS) included on the project teams, and only one agency identified the AVL project as an opportunity to build an agencywide data infrastructure.

Implementation

The principle issue related to implementation is adherence to the critical path. Three issues surfaced in this phase: delays due to software development and performance, impact of system during regular operations. and installation schedules.

Many respondents who procured first generation AVL software encountered delays in implementation. One respondent alluded to the need to "separate operational functions from 'vaporware' " early in the planning process.

Most system integrators simulate the operational environment to test and load the software during implementation. Many respondents recommended implementing the fleet in stages; initially, deploy a small number of vehicles to identify integration issues, then, a larger number to load the system Yet, respondents recognized that "there is no way to test the system under full load without involving the entire revenue fleet."

The final issue involved installing the AVL equipment onboard the vehicle. Generally, most respondents acknowledged that after the first installations, the rest were standard and the schedules predictable. A certain number of bus installations were done at night. At MCTO, three types of vehicles were used. Each type of vehicle required different installation procedures, slowing the installation schedule slightly. The placement of the control head became an issue in one bus type because it could only be placed in a position that slightly obscured the operator's view of the door.

Acceptance Testing

Acceptance testing is the final set of tests prior to completion of a project. The testing usually involves flawless or near flawless system and vehicle operations under a full load for a specified number of days. This may entail verification of a vehicle on/off route displayed within 95 percent accuracy of its true position. Acceptance testing criteria are usually specified in the performance requirements, and acceptance test measures and methods are clearly stated.

Acceptance testing is usually preceded by subsystem testing and interim milestone testing. Subsystem testing includes vehicle inspections following installation, and testing the communications and software control systems. MCTA, MTD, and MTA reported that they required interim prototype testing of a few installations (between 10 and 45 vehicles), inspection and testing after complete installation of all the vehicles, subsystem testing of communications and CAD/AVL, and final acceptance testing (for MCTA this required 30 days of flawless operations).

Training

Training was conducted primarily for dispatchers, field supervisors, operators, administrative, and management staff. The duration and method varied depending on the staff trained and technology implemented. Respondents with signpost technologies reported fewer days (e.g., 4 hours) devoted to maintenance training than respondents with GPS technologies (e.g., 1 to 8 weeks). Moreover, many agencies involved key staff in the design and development of the system. These teams became the experts charged with training their peers.

Dispatcher-s were trained in operating the console, which in most cases involved monitoring the fleet and handling communications with drivers. The console training included training operators in using the mapping stations and database functions, and the communications capabilities integrated into me console. Most respondents reported that dispatchers were trained either by their peers or by vendors for 8 to 48 hours, followed by hands-on/on-the-job training during operations. Respondents beset by delays identified the delay between training and on-line operations as a major obstacle to effective training.

Field supervisors were given a system overview of the AVL system. They trained to use the transit control head or message data terminals and new radio procedures. Those who had access to dispatch screens were trained to send messages to drivers. Some installations effected field supervisor's roles. In those cases, supervisors were given instruction in their new responsibilities and procedures. In agencies in which supervisors did not perform dispatcher duty, instruction was minimal, between 1 and 2 hours.

Most *operators* received 1 to 4 hours of training. Trainers taught the mechanics of the MDT in a classroom setting. This training also included orientation on the AVL system, particularly the benefits of the silent alarm and emergency communications features. KC Metro developed a video on the security features. Because of delays between installation and deployment, most respondents cited the need to retrain operators on the vehicle prior to operation.

Maintenance and MIS training differed in duration and type for software and hardware skills. Some transit agencies contract hardware and software maintenance to outside vendors, so there is a need for staff to recognize problems and troubleshoot easily replaceable units such as the MDTs. In other transit agencies, hardware and software skills needed to maintain these systems require weeks of correspondence courses, on-the-job training, or other forms of classroom training. In a few cases, transit agencies have bought or developed the skills required to maintain their systems. KC Metro and LACMTA use existing staff, who honed their skills through developing their information system, to maintain map and schedule databases. An issue raised by respondents regarding training these technical staff included poor documentation Specifically, this comment was leveled at system integration training materials primarily used by Information Systems professionals.

System management staff are trained in extracting information from the AVL databases to evaluate performance and generate reports. Some agencies are implementing report writers for decision makers to generate reports quickly. Other agencies maintain a list of generic reports that management can produce on a periodic basis. Management is trained in the use of these tools in about a week of instruction.

Another group targeted for training is customer *service.* As transit agencies make real-time information available, customer service personnel will need to be trained in providing real-time locations to check customer complaints.

Evaluation

The Federal Transit Administration issued evaluation guidelines to promote a "consistent and carefully structured approach for operational test evaluation" (23). This evaluation framework is based on using a statistical methodology to quantify the success of a well defined set of project, APTS program, and U.S. DOT objectives. The Volpe Center, which is coordinating evaluations for AVL deployments funded with ITS operational test grants, is currently evaluating three sites including MCTS, RTD, and SMART. The CTA is sponsoring its own evaluation based on the framework defined in the evaluation guidelines. As is the case with benefits studies (see below), few organizations performed evaluations of their AVL projects.

OPERATIONAL FRAMEWORK

Implementing AVL takes more than a few years from initial planning stages to final operation. With this degree of commitment the benefits should be clearly distinguishable. Yet, only a few agencies performed an evaluation that measured benefits. Even agencies with systems in operation for more than 3 years have not quantified their efficiencies. Nevertheless, the survey responses indicate profound changes in transit operational strategies and highlight the interdependency of their data needs.

Benefit Studies

In the 20 years since the first demonstration tests, few studies have addressed the costs and benefits of installing AVL. Moreover, successes related to nontangible benefits, such as faster emergency response times, increased integration of management information systems, improved internal communications, and better complaint handling procedures that affect staff and customer relationships, are not easily quantified. Until safety considerations, better information, and improved productivity are quantifiable, most studies rely on traditional cost/benefit models based on reducing fleet size or revenue miles.

A study conducted by Morlock, Bruun, and Blackman for UMTA investigated benefits and economic feasibility of AVL and communications systems for bus transit (24). The study examined whether AVL was practicable for transit by assessing both economic and intangible benefits. Based on AVL installations in the late 1980s Morlock conducted a break-even analysis that determined the feasibility of cost recovery for expenditure outlays versus cost reductions for AVL deployment. Cost reductions were defined as reducing slack time in schedules, thereby reducing fleet size, operator hours, and revenue miles, Though controversial particularly as deployment costs have increased and scheduling software models are better at reducing slack times, the analysis concluded that AVM/C systems have the potential to recover much of the purchase costs within the first 3 years of operation based only on reducing fleet size or revenue miles. With the inclusion of nontangible benefits such as improvement of service quality and safety considerations, the authors conclude that AVM/C is "one of the most important and potentially effective ways to improve the attractiveness of bus transit services" (25).

In 1994, the National Urban Transit Institute (25) reviewed and updated the model using 1992 national transit statistics and extended the model to incorporate an increase in revenues from increased ridership. Their analysis identified that a representative transit agency break-even point on its investment must reduce its fleet size by 2.30 percent or reduce its revenue miles by 0.93 percent. The same savings could be realized with a 2.30 percent increase in revenues or a 2.30 percent increase in ridership.

The NUT1 analysis was confirmed by a similar analysis performed by KCATA (personal communication, D. Brehm, February 1995). Faced with funding reductions, KCATA embarked on a comprehensive rescheduling effort to find cost savings in levels of service frequency reductions. Scheduling assessed the feasibility of reducing the fleet size, platform hours, operator pay hours, and miles based on operational statistics collected by KCATA's signpost AVLS. By using segment running times collected during the previous 6 months, slack time was eliminated from the schedules. The new schedules resulted in a level of service gain which furthered a reduction of three base buses and an additional four pm-peak vehicles. The value, accounting for vehicle maintenance and related operator wages, totals an annual savings of $404,670, not including accrued savings over the vehicle lifecycle. The reductions in fleet size totals about 1.5 percent of the base fleet and an additional 2 percent for the pm-peak period.

Superintendent Brehm identified the opportunities for savings:

- *Efficiency of the initial schedule.* The greater the difference between scheduled and actual running times, the greater the opportunity for savings.
- *Level of service or "headway."* The vehicle requirement on routes with frequent service can be reduced with relatively small reductions in running time. Routes with wider headways, for example 15 minutes or more, are unlikely to achieve a vehicle reduction with the level of running time reduction available through AVLS measurements (personal communication, D. Brehm, February 1995).

The major obstacles to performing benefits studies for AVL installations are the lack of good cost information and the lack of empirical evidence. Regarding the former, Morlock stated that the figures used for the cost of installing and operating an AVM/C system were "fragmentary and inconclusive" due to the different pricing and marketing strategies used by the various vendors. Specifically, "there is no standard AVM/C system for bus transit, but rather there are many such systems consisting of different types of hardware elements performing a variety of different functions" (24). In the section on Funding Issues (see above), itemized data were not available: various systems, even those installed by the same contractors, were costed differently.

A recent study (26) sponsored by the Federal Transit Administration and conducted by the Volpe Center provides the most thorough benefits assessment of ARTS systems, using data for ridership, fares, operating costs, and vehicle acquisition costs collected over the last 5 years. Although the study examines a range of services, benefits for two systems-transit management and traveler information systems-are derived from deploying AVL (e.g., current bus location). The study based its approach on benefits accrual over a lo-year horizon. Assumptions based on this approach included calculating savings using 1996 dollars, constant ridership, and increases in operating costs, fares, revenue miles and the total number of vehicles used for maximum service (26). These assumptions are summarized in Table 20.

TABLE 20

SUMMARY OF ANALYSIS ASSUMPTIONS

Analysis Assumptions [Average annual rates]	Motorbus (percent of increase)
OMB recommended discount rate	7.0
Transit ridership	0.0
Transit operating costs	2.5
Transit fares	3.5
Transit vehicle revenue miles	1.0
Transit vehicle fleet	0.5

Source: Goeddel, Dennis. *Benefits Assessment of Advanced Public Transportation* Systems. U.S. DOT, DOT-VNTSC-RA-96-7, July 30, 1996. p., 6.

The benefits were calculated for a total of 145 transit agencies currently operating, implementing, or planning transit management and traveler information systems. Since the results were not compiled into separate categories, the calculation of benefits includes motorbus (fixed route) and demand-responsive vehicles. Some agencies may be identified

TABLE 21

APTS SYSTEM BENEFITS

	Transit Management Systems	Traveler Information Systems	Total
APTS Deployments (considered)	73	72	145
Benefits [(Low Estimate) in millions of discounted, present-valued dollars]			
Total Benefits	1,718.8	796.0	2,514.8
Annualized	244.7	113.3	358.0
Benefits [(High Estimate) in millions of discounted, present-valued dollars]			
Total Benefits	3,204.2	1,592.0	4,796.2
Annualized	456.2	226.1	682.9

Source: Goeddel, Dennis. *Benefits Assessment of Advanced Public Transportation Systems.* U.S. DOT, DOT-VNTSC-WA-96-7, July 30, 1996. p., v.

twice with respect to deploying both transit management and traveler information systems. In addition, the benefits for transit management were based on reduction in transit fleet acquisition and operating costs, and the benefits assumed for traveler information included an increase in transit revenue based on growth in ridership. The result of this analysis identified the total savings due to deploying transit management and traveler information systems to be between $2,514.8 million and $4,796.2 million, and annual savings of between $358.0 million and $682.9 million. These figures are summarized in Table 2 1.

The costs of deployment and maintenance offset the total benefits. According to the figures collected as part of this synthesis, 34 transit agencies have or will have spent more than $241 million deploying the infrastructure to support transit management and traveler information systems. Assuming that these agencies represent a statistical sample of agencies deploying, developing, and planning transit management systems, and normalizing the cost and benefit figures, the projected total savings of implementing AVL for transit management is $960.0 to $2,445.4 million.

These numbers are optimistic because they only reflect the infrastructure procurement costs, and do not include costs incurred by agency staff to implement the AVL or analyze the performance measures to improve operations. Moreover, the Volpe study did not include annual maintenance costs to support the infrastructure (see Annual Maintenance Costs). As described earlier, maintenance costs are not well documented. Many agencies with GPS-based implementations have yet to collect average annual maintenance costs, and agencies sup porting older systems have different maintenance needs, particularly related to staff skills and technology innovations. Yet, according to a few (three) agencies that support maintenance contracts, the cost will average about $472 per vehicle. The Volpe study considered 39,334 motorbuses in their analysis (26). Using these figures, the annual maintenance cost will total approximately $18.6 million.

The Volpe study is the best evidence of the potential cost savings expected after deployment of AVL, although the study only examined a few performance measures to determine the savings. Empirical evidence can be derived from a variety of measures of effectiveness (MOE). Yet, research and a literature search produced no generic set of MOEs for AVL implementation. Morlock reviewed two studies that indicated benefits for a number of areas including bus utilization rates, vehicle traffic volumes, security (emergency response times and reporting statistics) and dispatcher and supervisory staff requirements. Because AVL systems have the ability to improve productivity throughout an organization, traditional categories to measure the benefits and effectiveness of operational strategies may not be sufficient for AVL.

Effect On Operational Strategies

Understanding the effect of AVL on operational strategies requires further research. Although the survey responses sup ply rich anecdotal information on changes or expected changes to roles and responsibilities of supervisors and dispatchers after implementation, only one study quantified the economic benefit. None discussed how AVL affected changes to supervisor strategies, performance measures, route planning, scheduling activities, and customer service.

In an NCTRP synthesis of supervisory strategies (27), the author identified the most significant impediments to improved supervision as: limited resources ("span of control too broad"), diversion of supervisors to other activities, effect of traffic, weather, fire, and disruption of service, inadequate communications, particularly inability to view entire route. According to this synthesis survey, many of these impediments are addressed by AVL. The most significant improvement is a result of acquiring the "complete picture," thereby gaining 'better management/control [over the] fleet and operators." In particular, respondents cited the increased flexibility in assigning field supervisors, changes in dealing with emergency situations, improved efficiency in tracking on-time performance and increased effectiveness in handling grievances.

Increased Flexibility in Assignments

Respondents were almost unanimous in discussing their ability to make more efficient use of their field supervisors. One respondent wrote, "complete AVL is expected to shift service management responsibility from field to control center." Agencies with operational systems acknowledge this shift, though, at least one agency described its struggle to move the responsibility into the control center; work rules may prevent an easy transition. Field supervisors spend less time monitoring buses and more time solving problems, which requires fewer supervisors to manage incidents and respond to emergencies. Moreover, because the control center software contains landmarks, addresses. trips, schedules, driver information and vehicle maintenance logs, supervisors no longer rely solely on dispatch for information.

Faster Response to Emergency Situations

Field supervisors and emergency vehicles are now immediately directed to the bus location, whereas prior to AVL deployment, supervisors had to hunt for a bus based on its expected location. This ability improves response time and enables response vehicles to take more effective action. For example, in Denver, robbery suspects boarded an RTD bus to flee the crime. The driver was alerted and identified the suspects so the police could apprehend them enroute (28).

Improved Efficiency in Tracking On-Time Performance

Another significant change is the shift of on-time performance monitoring from the field to the control center. Service management staff need not send out field supervisors to track performance, the AVL control tools allow them to be proactive in addressing on-time performance and communication issues with operators. One respondent wrote that "problems in operation are noticed almost immediately and correction is more timely."

Increased Capability in Handling Grievances

A respondent wrote that "bus location and timeliness were no longer subjective between the dispatcher, driver, and passenger. These things became objective and are available in a printed form." Documentation on bus location improved the agency's ability to mediate complaints and disputes.

CHAPTER SIX

CONCLUSIONS

Transit agencies are turning to advanced technologies to improve services, increase safety, and attract ridership. Specifically, automatic vehicle monitoring (AVM) systems are being deployed on bus transit to achieve operational and system benefits. Although AVM systems were deployed in the 1970s and 1980s, only recently have transit agencies embraced the concept. The core technology. the automatic vehicle location (AVL) system, offers detailed status information previously absent from the bus operations, customer support, maintenance, and service planning areas. Moreover, synchronization and integration with other transportation agencies, modes, and federal initiatives, such as the Integrated Transportation Infrastructure (ITI), depend on tracking transit assets in a timely manner. To this end, transit professionals are confident that the technology will continue to make advances over the next decade.

The AVL system tracks vehicle movement. This capability, integrated with other functions, enables transit agencies to provide new and improved services, such as reduced emergency response times, real-time bus status information, automated passenger counting information, and improved mobile communications. These services are derived from the AVL's tracking system. Over the years, different technologies have been installed to locate vehicles. Most systems are composed of both on-board and infrastructure devices.

- Most early systems installed proximity systems that detect bus movement only when a vehicle is within range of the signpost. At least 16 properties in North America operate signpost systems, with three systems installing second-generation systems. Proximity systems have significantly improved the signpost and odometer technologies, as well as strategies to place signposts and calibrate odometers, and have improved procedures to maintain the infrastructure and on-board equipment.
- Just as the early technologies were improving, ubiquitous radio navigation location technologies, such as the global positioning system (GPS) with differential augmentation, became viable. GPS systems, providing global coverage, now contribute to all but a few of the systems installed in the past few years. Requiring an accurate digital base map with placement of bus stop, time point and route locations, and supplementary dead-reckoning sensors for urban environments, GPS-based systems account for three operational systems and 15 currently under development.

None of this information could be used in real-time without a communication link to control software. Communications requirements differ among service areas. and among properties. The number of radio towers, relay stations, and frequency spectra depend on the physical terrain, service area, urban environment, and frequency licenses. Respondents reported that on average, one-third to two-thirds of the cost of their AVL systems is spent on procuring the communication systems. Most respondent systems require customized integration software between the AVL and communication systems. Even when agencies use their existing communication system, integrating the radio with the AVL incurs significant costs.

Standards mitigate the need for a high degree of coupling among the AVL components. The SAE J1708 standard provides for the decoupling of on-board interface devices from the AVL and VLU. Most on-board interfaces require a location (and time) stamp from the AVL system. For example, vehicle ID and current location are attached to an emergency alarm message. The emergency alarm function interprets the information and performs the proper activity. That function may be performed on the vehicle or at a control center. To this end, the most useful component of the AVM system is the central control software.

Also known as computer-aided dispatch software, the central control software monitors schedule adherence, prioritizes communications, analyzes on-time performance, collects data and writes reports. Respondents reported that the control center is approximately one-third of the cost of an AVL procurement. This includes development, equipment, data collection, and integration costs. The control software development was reported as the cause for more delays than any other factor. The two major reasons cited for the delays were that the software did not function as specified or that schedule data did not correspond to bus locations.

Although many transit agencies and publications discuss integration with other transportation control centers and information service providers, few provide real-time information to customers. MTD, which does provide uncensored real-time bus status, has shown a 2 percent increase in ridership over the last year, and through a customer survey, has verified a high satisfaction with the GoTime audiodial subsystem; albeit, at a significant communications cost. An issue that may emerge as transit agencies rollout real-time bus status is when to release information.

The institutional context of AVL is defined by the issues of bringing AVL into an organization and the changes effected by its deployment. These issues include the how and why of funding, changes to the procurement process, changes to the organization that affect staff, and reengineering roles and responsibilities.

An AVL system is a significant investment. Signpost and GPS-based systems cost about the same. Survey results indicate that, on average, systems cost about $13,700 per vehicle. Smaller agencies tend to pay more per vehicle because they must spread the cost of the infrastructure and control software over fewer buses. Based on the figures provided by respondents, the minimum cost for even a small AVL system (32 buses) that requires a communications system is about $350,000. These costs will vary depending on the features installed and the sophistication of the control software. Other costs are distributed among training and maintenance activities.

The primary justification for installing an AVL system is customer service-AVL improves service quality and provides real-time information to increase ridership. The need for a new communication system, schedule adherence, availability of funds, and safety are other reasons that support the investment in an AVL system.

AVL systems affect work roles and responsibilities. The most significant affect is on operators whose work load increases as a result of bringing in this technology, and on the people who operate the system, manage the data, and ensure the reliability of the equipment. As an automated electronic system, the skills needed by these staff must be honed on a continuous basis. Furthermore, work loads and work rules change because new procedures are promulgated throughout operations. Better and shared information require closer interaction among different groups within the transit agency, particularly during AVL design and development. This necessitates inclusion of many other groups in the requirements, procurement, and development phases.

In many cases, the procurement process changed from the two-step prequalifying/low-bid method to a competitive negotiation process. Increased technical support was required to ensure proper scoring of the technical proposals. More than 60 percent of respondents hired consultants to support require ments development, procurement, and monitoring functions.

Many of the early deployments encountered the same types of issues during the development lifecycle. The duration of each phase varied depending on the number of buses, complexity of the central control software, and number of features. The planning phase consisted of concept development, developing specifications, estimating budget, finding financing, understanding the various technologies, and procuring the system The most useful activity during this period was developing a clear set of performance or functional specifications.

The major design challenges involved data issues: schedule data formats, map data set accuracy, and integration of routes, bus stops, and the map database. This issue unresolved would continue to disrupt the update of the AVL after every schedule, runcutting, or level of service change. Three types of issues were identified during the integration phase: transferring data from other sources, such as scheduling software and map databases; interfacing with other devices, such as silent alarm, annunciator, and engine monitoring sensors; and timely AVL deployment. Issues related to interfacing with other devices may not be as relevant with today's technologies as they were 5 and 6 years ago. The principle issue related to implementation is adhering to the timetable for AVL deployment. Almost all the respondents reported that they encountered delays due to software development and performance issues. Most operational systems that have successfully passed this stage are first generation, early technology deployments. The latest installations do not appear to encounter the same problems, Finally, major issues with acceptance testing deal with when the testing ends and when the system is fully operational. The starting date effects the warranty and maintenance periods.

Training is normally conducted for all appropriate staff including dispatchers, operators, maintenance, management, and others. Dispatchers receive 1 to 3 weeks of training, while operators received 1 to 4 hours of training. The group who required the most training was the management information systems (MIS) staff, particularly if they are required to maintain the digital base map, update bus stops, time points, and routes on the map database, transfer schedule information from scheduling software to the AVL and maintain the AVL database, produce reports, and operate the computer system.

Objectives for AVL systems include improving bus transit operations: improved reliability, increased safety, and better performance. Yet, the means of achieving those objectives through AVL are not well documented. Measures of effectiveness are not defined; few benefits studies have been performed, and those studies evaluate only a limited number of benefits with "fragmented and inconclusive" cost information,

Yet, anecdotal information about the profound changes to their operational strategies and the interdependency in their data needs validate many of the hypothetical benefits. AVL systems shift the primary responsibility for fleet management to the dispatcher, freeing the field supervisors to handle emergencies and other customer concerns. AVL systems provide exact location information to emergency vehicles for faster response times. Moreover, AVL systems have improved efficiency in tracking on-time performance. Field supervisors need not survey fleet running times, that function is performed by the central control software. Finally, the central control software documents bus location and times; which improves the agency's ability to mediate complaints and disputes.

Though much has been written on AVL, survey data, research study results and discussions with transit professionals developing AVL systems indicate the need for further studies related to AVL in the following areas:

- Measures of effectiveness,
- Methods and models to improve on-time reliability such as signal priority,
- Effect of disseminating real-time information to customers,
- AVL in the 21st century: technological evolution currently underway for the next generation,
- Human factors, and
- Strategies for mitigating data integration costs.

This last research area, strategies for mitigating data integration costs, is soon to be addressed by a recent task order to the Institute of Transportation Engineers by the Federal Highway Administration. The Transit Communication Interface Protocol (TCIP) effort, just underway, will attempt to build a consensus among transit professionals, transit application vendors and ITS system integrators around standard data definitions, interfaces, and communications protocols to address the issue of customized data interface issues. The TCIP effort will attempt to lessen the dependence on the specific vendor scheduling and other system software used at the time of the AVL design and implementation.

AVL systems hold much promise for bus transit. The technologies are maturing and additional technical information is available for agencies that want to deploy systems. The core technologies, location, communications, control software, and standard interfaces permit phasing-in of advanced features that will provide additional benefits. For example, the future will bring wider use of real-time information for travelers information. As real-time traffic information is made available from other control centers, transit agencies may want to incorporate dynamic travel times into their schedule adherence, real-time dispatch, and estimated bus arrival time algorithms. These algorithms will aid flexible routing solutions to estimate how a deviation from the schedule will alter the running time.

Many transit professionals, also proponents of integrating advanced technologies into transit operations, have cautioned against installing technologies in search of applications. AVL may appear and be viewed in that light. The opportunities and efficiencies provided by AVL systems are not automatic. As noted by W. Jones in a paper on APTS benefits: “The agency must effectively utilize this new tool to realize the efficiencies inherent in the technology” (29).

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ACRONYMS

ADA	Americans with Disabilities Act
APC	Automatic Passenger Counter
APTS	Advanced Public Transportation System
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
AVLC	Automatic Vehicle Location and Control
AVM	Automatic Vehicle Monitoring
CAD	Computer-Aided Dispatch
DCE	Digital Communication Environment
DGPS	Differential Global Positioning System (GPS)
DOD	Department of Defense
DOT	Department of Transportation
ECEF	Earth Centered-Earth Fixed
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GIS	Geographic Information Systems
GPS	Global Positioning System
HUD	Department of Housing and Urban Development
ITI	Intelligent Transportation Infrastructure
ITS	Intelligent Transportation Systems
ITS-A	Intelligent Transportation Society of America
LAN	Local Area Network
LEO	Low Earth-Orbiting Satellite
MOE	Measure of Effectiveness
MRU	Mobile Radio Unit
MTO (MT/O)	Ministry of Transportation/Ontario
NAD	North American Datum-1983
ODBC	Object Data Base Connectivity
PPS	Precise Positioning System
RDBS	Relational Data Base System
RF	Radio Frequency
RTCM	Radio Technical Commission Marine
SPS	Standard Position System
TIS	Transit Information System or Traveler Information System
UMTA	Urban Mass Transportation Administration (currently known as the FTA)
USCG	United States Coast Guard
UCT	Universal Coordinated Time
VAN	Vehicle Area Network
VLU	Vehicle Logic Unit
VNTSC	Volpe National Transportation Systems Center
WAAS	Wide Area Augmentation System
WAN	Wide Area Network
WGS-84	World Geodetic System-1984